

The Role of Green Hydrogen in Achieving Sustainable Development

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Abstract:

This research paper explores the contribution of green hydrogen to achieving sustainable development. Produced from renewable energy sources, green hydrogen offers a promising pathway for decarbonizing various sectors. The paper examines its potential to enhance the environmental, economic, and social dimensions of sustainability. It focuses on the production processes of green hydrogen, its applications, and the associated challenges and opportunities for its adoption. Green hydrogen is generated through the electrolysis of water, making it a clean alternative to fossil fuels. This technology converts renewable energy into hydrogen, which can be utilized for energy storage and transportation. Its role in sustainable development is significant as it helps reduce carbon emissions and supports the transition to a low-carbon economy. By integrating green hydrogen into energy systems, countries can effectively address climate change challenges and enhance energy security, aligning with global sustainability goals and contributing to long-term environmental and economic benefits.

Key words: Green; Hydrogen; Green Hydrogen; Sustainable Development; Renewable Energy

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Introduction:

Recent advancements in clean energy technologies have spotlighted green hydrogen as a promising solution for sustainable development. Produced through the electrolysis of water with renewable energy sources such as wind, solar, and hydropower, green hydrogen is an environmentally superior option compared to grey hydrogen, (International Renewable Energy Agency, Hydrogen: A renewable energy perspective, 2021, pp. 23,25) which emits significant carbon dioxide, and blue hydrogen, which involves carbon capture and storage. (International Renewable Energy Agency, 2020, pp. 15,17)

Green hydrogen offers substantial environmental benefits as a zero-emission fuel, reducing carbon footprints in transportation, industry, and power generation. In the transport sector, hydrogen fuel cell vehicles emit only water vapor, contributing to cleaner air and reduced greenhouse gas emission. (International Renewable Energy Agency, 2020, pp. 16,18) It also helps decarbonize heavy industries like steel and cement production and provides a means of storing excess renewable energy, enhancing power grid stability. (International Renewable Energy Agency, 2021, pp. 20,22)

Economically, green hydrogen infrastructure development promises significant investment and job creation, with the potential to generate up to 30 million jobs globally by 2050. (Hydrogen Council, 2020, pp. 3,5) It also enhances energy security by diversifying energy sources and reducing reliance on imported fossil fuels. (International Renewable Energy Agency, 2021, pp. 26,27)

Socially, green hydrogen can bridge energy access gaps in underserved regions, improve quality of life, (United Nations Development Programme, 2020, pp. 6,8) and provide public health benefits through reduced air pollution. (World Health Organization, 2018, pp. 8,10)

Challenges include high production costs and the need for substantial infrastructure investments and supportive policies. However, ongoing advancements and economies of scale are expected to lower costs. (Ibrahim Dincer & Canan Aca, 2015) This paper will explore green hydrogen's production, applications, and emphasizing its role in achieving sustainable development goals, The study seeks to address the following question: How does green hydrogen contribute to achieving sustainable development, and what challenges does it encounter?

I. Concept of Green Hydrogen

Hydrogen was primarily used in industrial applications without focusing on sustainability aspects. In the 19th century, Sir William Grove developed the process of electrolysis of water, which is a fundamental technique for hydrogen production. However,

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this process relied on electricity generated from fossil fuels, making the resulting hydrogen environmentally unfriendly. With the increasing environmental awareness in the second half of the 20th century, research began to focus on improving electrolysis techniques to be more sustainable, leading to the emergence of the concept of green hydrogen, produced using renewable energy sources such as wind and solar power (Kai Zeng and Dongke Zhang, 2010). This makes it a clean product that does not produce carbon emissions (International Renewable Energy Agency, 2020, p. 8).

As interest in clean energy technologies grew, governments and major corporations began investing significant amounts to develop green hydrogen technology. This field has experienced rapid growth thanks to innovations in electrolysis techniques and advancements in hydrogen storage, enhancing the capacity to achieve sustainability goals and reduce carbon emissions (International Energy Agency, 2021, p. 25).

Green hydrogen is a type of hydrogen produced through the electrolysis of water using renewable energy from sources such as solar, wind, or hydro power, where water is separated into oxygen and hydrogen using electricity generated from renewable sources, ensuring that the process produces no carbon emissions (International Renewable Energy Agency, 2020,p;8)

1. Definition and Concept:

Green hydrogen refers to hydrogen produced through the electrolysis of water using electricity generated from renewable energy sources such as wind, solar, or hydropower. (International Renewable Energy Agency, 2021, p. 23) This production method is deemed green because it does not emit carbon dioxide or other greenhouse gases, making it a clean alternative to hydrogen produced from fossil fuels. (Ahmed Osman, Neha mehta, & other, 2022, p. 155) Unlike grey hydrogen, which is derived from natural gas and emits significant amounts of CO₂, (International Renewable Energy Agency, 2020, p. 15) or blue hydrogen, which involves carbon capture and storage, green hydrogen is created with zero emissions during its production phase. (Suman Dutta, 2014, p. 1150) As a sustainable energy carrier, green hydrogen plays a crucial role in reducing greenhouse gas emissions and supports the transition towards a more sustainable energy system.

The importance of green hydrogen technology globalization cannot be overstated as it is considered the fuel of the future, It directly contributes to addressing climate change and achieving net-zero emissions, This technology reduces pollution and integrates excellently with renewable energy technologies as a very effective solution for energy storage. By doing so, it helps to balance the grid from renewable energy sources. Additionally, the current

applications of green hydrogen provide a sustainable and environmentally friendly alternative to traditional fuels, contributing to the reduction of harmful emissions and the achievement of sustainable development goals. (the Arab Renewable Energy, 2021, p. 10)

2. Electrolysis Technologies:

Proton Exchange Membrane Electrolysis utilizes a proton exchange membrane to separate hydrogen and oxygen, operating efficiently at high current densities with a quick response time. This makes Proton Exchange Membrane technology especially suitable for applications with fluctuating renewable energy sources, providing high-purity hydrogen and the capability to operate at higher pressures compared to alkaline electrolyzers (Ibrahim Dincer & Canan Aca, 2015, p. 10708). Alkaline Electrolysis, a well-established technology, employs an alkaline electrolyte like potassium hydroxide and is favored for large-scale hydrogen production due to its lower cost and robust performance. Despite its reliability and long operational life, alkaline electrolysis operates at lower current densities and slower response times compared to Proton Exchange Membrane systems (Ibrahim Dincer & Canan Aca, 2015, pp. 10709, 10711). Solid Oxide Electrolysis, which uses a solid oxide electrolyte at high temperatures, offers high efficiency and low energy consumption for producing hydrogen with high purity. Although still under development, this method holds promise for future large-scale applications due to its potential for lower operational costs. (International Renewable Energy Agency, 2020, p. 17) Integrating green hydrogen production with renewable energy sources such as wind and solar is essential for sustainability. Given the intermittent nature of these renewable sources, green hydrogen provides a means to store excess energy when production surpasses demand, thus stabilizing energy supply and enhancing the reliability of renewable energy. (International Renewable Energy Agency, 2021, p. 24)

3. Current Applications of Green Hydrogen

Green hydrogen is making significant strides in various sectors, with promising applications both now and in the future. Currently, it is increasingly used in the transport sector, with fuel cell vehicles from major automakers like Toyota and Hyundai offering a zero-emission alternative to fossil fuels, thereby reducing air pollution and greenhouse gas emissions. (International Renewable Energy Agency, 2021, p. 29) In industrial processes, green hydrogen is being explored to replace traditional reducing agents in steel and cement production, aiming to cut CO₂ emissions in these high-temperature processes. (International Renewable Energy Agency, 2020, p. 20) Additionally, green hydrogen plays a key role in power generation and storage by storing excess renewable energy from sources like wind and solar, which can be converted back to electricity, thus aiding in grid stabilization. (International Renewable Energy Agency, 2021, p. 30)

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Looking to the future, green hydrogen is expected to significantly impact grid balancing and energy storage, addressing the intermittent nature of renewable energy sources and improving energy security through large-scale storage solutions. (International Renewable Energy Agency, 2020, p. 22) It also holds potential for heating and cooling applications, with the ability to replace natural gas in heating systems and provide efficient combined heat and power solutions. (International Renewable Energy Agency, 2021, p. 33) The development of a hydrogen economy will create new business opportunities and economic growth, driven by investments in hydrogen infrastructure and technology. (International Renewable Energy Agency, 2020, p. 23) Furthermore, green hydrogen is being explored for aviation and maritime industries, with ongoing research into hydrogen-powered aircraft and ships to reduce emissions in these. (International Renewable Energy Agency, 2021, p. 35)

4. Current Status of Green Hydrogen

Green hydrogen production is rapidly growing but remains in its early stages. As of 2023, green hydrogen accounted for approximately 1% of global hydrogen production, with fossil fuels still dominating. (International Energy Agency, 2024, p. 45) However, there has been a significant increase in green hydrogen projects, with around 450 large-scale projects announced worldwide, aiming to scale up production capacity to over 6 million tons per year by 2030. (International Renewable Energy Agency, 2023, p. 22)

Investment in green hydrogen infrastructure and technology is expanding, reaching approximately \$1.3 billion globally in 2023, reflecting a strong commitment to the sector. (BloombergNEF, 2024, p. 11) The cost of producing green hydrogen has decreased from about \$6.00 per kilogram in 2020 to a projected range of \$3.50 to \$4.00 per kilogram by 2025. The goal is to reduce costs to below \$2.00 per kilogram by 2030, driven by advancements in technology and economies of scale. (International Energy Agency, 2024, p. 48)

Governments worldwide are implementing supportive policies. For example, the European Union aims to produce 10 million tons of green hydrogen annually by 2030. (European Commission, 2023, p. 9) Countries such as Japan, South Korea, and Australia are heavily investing in hydrogen infrastructure and technology to lead in the green hydrogen economy. (International Energy Agency, 2024, p. 50) Green hydrogen is being deployed in various sectors, including transportation, industry, and power generation, with pilot projects demonstrating its potential as a large-scale energy source (International Renewable Energy Agency, 2023, p. 30). Production has grown from 0.03 million tons in 2020 to 0.20 million tons in 2024, with an anticipated increase to 6 million tons by 2030. This reflects a significant scale-up effort and the sector's ambition to integrate into the global energy mix.

(International Renewable Energy Agency, 2023, p. 22) Key developments include advancements from initial pilot projects to large-scale deployments and substantial infrastructure investments. (European Commission, 2023, p. 9) Future projections highlight a robust growth trajectory, with expected cost reductions and increased competitiveness, driven by technological advancements and large-scale deployment. (International Energy Agency, 2024, p. 26).

The potential of green hydrogen in Arab countries is gaining significant attention as nations seek to leverage their renewable energy resources for sustainable development. Egypt leads the Arab world with 24 hydrogen projects, primarily focused on green hydrogen and green ammonia, aiming to capture 5-8% of the global hydrogen market and reduce carbon emissions by 40 million tons annually by 2040. Following Egypt, the United Arab Emirates is investing in 12 diverse hydrogen projects, including green hydrogen and blue hydrogen, targeting the production of 1.4 million metric tons of hydrogen by 2030, increasing to 15 million tons by 2050. Oman ranks third with 11 projects focused on green hydrogen and ammonia, with aspirations to become the sixth-largest hydrogen exporter globally by 2030. Saudi Arabia is also a key player with 10 projects, planning to export 2.9 million tons of hydrogen annually by 2030, rising to between 3.5 million and 4 million tons by 2035. Morocco is advancing with seven hydrogen projects, while Algeria is developing four, and Mauritania has three projects in progress. Additionally, Iraq and Djibouti each have two projects, and Qatar and Jordan have one project each. Overall, the Arab region is poised to become a significant player in the global green hydrogen market, utilizing its abundant renewable energy resources to foster sustainable development and reduce carbon emissions.

5. Challenges Green Hydrogen:

Green hydrogen offers significant potential for advancing sustainable development, but it faces several notable challenges. Key obstacles include high production costs, driven by expensive electrolyze technology and the cost of renewable electricity, particularly in resource-limited areas. (International Renewable Energy Agency, 2020, p. 20) Additionally, developing the necessary infrastructure for production, storage, and distribution demands substantial investment and adaptation of existing natural gas infrastructure. (International Renewable Energy Agency, 2021, p. 36) Hydrogen's low energy density further complicates its storage and transportation, requiring advanced technologies and high energy costs for compression or liquefaction. (International Renewable Energy Agency, 2020, p. 25) The sector also competes with other low-carbon technologies and needs supportive policies and incentives to foster growth. (International Renewable Energy Agency, 2020, p. 26) Scaling up production to meet global demand while reducing costs requires ongoing research and development. (Ibrahim Dincer & Canan Aca, 2015, p. 10713)

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Despite these challenges, there are significant opportunities for green hydrogen. Diverse production sources, such as electrolysis using renewable energy, can enhance the sustainability of energy sources. (Haris Ishaq , Ibrahim Dincer , & Curran Crawford, 2022, p. 26240) Technological advancements have the potential to reduce production and storage costs, making hydrogen a more competitive energy source. (Haris Ishaq , Ibrahim Dincer , & Curran Crawford, 2022, p. 26242) Furthermore, hydrogen can be integrated with existing systems to store excess energy from renewable sources, supporting grid stability. (Haris Ishaq , Ibrahim Dincer , & Curran Crawford, 2022, p. 26243) Future advancements, including better catalyst materials, improved electrolyze designs, and hybrid systems, are expected to address current limitations and expand green hydrogen's role in the global energy landscape. (International Renewable Energy Agency, 2020, p. 19) Continued research and innovation will be crucial to making production, storage, and transport technologies more cost-effective and environmentally friendly. (Haris Ishaq , Ibrahim Dincer , & Curran Crawford, 2022, p. 26244).

II. Green Hydrogen and Its Contributions to Sustainable Development

Green hydrogen, produced from renewable energy sources such as solar and wind, offers significant benefits across environmental, social, and economic dimensions of sustainable development. Environmentally, it reduces carbon emissions and enhances air quality by serving as a cleaner alternative to fossil fuels, thus mitigating climate change and decreasing health risks associated with air pollution. (International Renewable Energy Agency, 2021, p. 24) Socially, green hydrogen improves quality of life by reducing pollution-related health issues, generates substantial employment opportunities across various sectors, and promotes social justice by providing affordable energy to underserved communities. (United Nations Development Programme, 2020, p. 15) Economically, it drives job creation and innovation, enhances energy security by diversifying sources, and supports the transition to sustainable industrial practices. (Hydrogen Council, 2020, p. 7) Additionally, advancements in technology and economies of scale are expected to lower production costs, making green hydrogen more competitive and fostering wider adoption. (International Renewable Energy Agency, 2023, p. 26) By contributing to resource conservation and supporting local economic development, green hydrogen plays a pivotal role in advancing sustainable development goals. (International Renewable Energy Agency, 2014, p. 52)

1. Green Hydrogen and the Sustainable Development Goals

Green hydrogen, produced through the electrolysis of water using renewable energy sources, is pivotal in advancing the Sustainable Development Goals. It can significantly impact **No Poverty** by fostering economic growth and job creation in renewable energy

sectors, particularly in developing regions. (International Renewable Energy Agency, 2020, p. 12) In the realm of **Zero Hunger**, green hydrogen's energy can drive agricultural advancements, improve food storage, and bolster food security (International Renewable Energy Agency, 2021, p. 20) It supports **Good Health and Well-being** by reducing air pollution from fossil fuels, thereby improving public health. (World Health Organization, 2018, p. 15) Educational programs focusing on green hydrogen enhance skills and knowledge, aligning with **Quality Education**. (United Nations Development Programme, 2020, p. 9) Promoting **Gender Equality** within the renewable energy sector, including green hydrogen projects, empowers women and ensures equal job opportunities. (International Renewable Energy Agency, 2020, p. 18) Additionally, green hydrogen can be paired with desalination technology to address **Clean Water and Sanitation** needs in arid areas. (International Renewable Energy Agency, 2021, p. 24) As a sustainable and renewable energy source, it directly supports **Affordable and Clean Energy**. (International Renewable Energy Agency, 2020, p. 21) The sector's growth promises new job opportunities and economic stimulation, contributing to **Decent Work and Economic Growth**. (Hydrogen Council, 2020, p. 30) Investments in green hydrogen drive **Industry, Innovation, and Infrastructure** development, (International Renewable Energy Agency, 2021, p. 24) while improving energy access can reduce **Reduced Inequality**. (International Renewable Energy Agency, 2021, p. 28) Green hydrogen also plays a role in **Sustainable Cities and Communities** by powering public transportation and supporting urban clean energy solutions. (International Renewable Energy Agency, 2021, p. 31) It promotes **Responsible Consumption and Production** by supporting sustainable energy production. (International Renewable Energy Agency, 2020, p. 25) and contributes to **Climate Action** through significant reductions in greenhouse gas emissions. (International Renewable Energy Agency, 2021, p. 35) By mitigating climate change, it also benefits **Life Below Water** by protecting marine ecosystems. (World Health Organization, 2018, p. 17) and **Life on Land** by decreasing land degradation. (International Renewable Energy Agency, 2021, p. 19) Establishing stable regulatory frameworks for green hydrogen fosters **Peace, Justice, and Strong Institutions**, (United Nations Development Programme, 2020, p. 12) while international collaboration on hydrogen projects enhances **Partnerships for the Goals**. (Hydrogen Council, 2020, p. 33)

2. Case Studies of Green Hydrogen Projects

The Hydeal Ambition is a major green hydrogen initiative in Western Europe, aiming to establish a vast green hydrogen production and distribution network. The project envisions generating up to 100 GW of renewable energy capacity, primarily from wind and solar sources, to produce green hydrogen sustainably, Spanning multiple Western European countries, Hydeal Ambition seeks to support regional decarbonization by supplying hydrogen to various industries. The project is planned to be developed in phases, with

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significant advancements expected over the coming decade, For the most accurate and current information, refer to the official Hydeal Ambition website or recent press releases.

The Western Green Energy Hub is situated in the remote outback of Western Australia. This expansive project covers an area of approximately 15,000 square kilometers. It is located in a region characterized by its gently undulating terrain and sparse vegetation, which is ideal for harnessing wind and solar energy. The hub is a collaborative effort involving InterContinental Energy, CWP Global, and the Mirning Traditional Lands Aboriginal Corporation. The facility aims to produce 3.5 million tonnes of green hydrogen annually, with a focus on serving the growing export market for green fuels.

Hydrogen Energy Supply Chain - Australia and Japan: The project is a collaboration between Australia and Japan to produce and export green hydrogen, The project involves producing hydrogen in Australia using renewable energy, liquefying it, and shipping it to Japan, It uses wind and solar energy for hydrogen production in Australia and develops advanced liquefaction and shipping technologies to transport hydrogen to Japan. The HESC project aims to establish a commercial hydrogen supply chain and promote international hydrogen trade. It is expected to start operations with a capacity of around 160,000 tons of hydrogen annually.

Port of Rotterdam Hydrogen Hub in the Netherlands: is developing a large-scale hydrogen hub to support the use of green hydrogen in the maritime and industrial sectors, The hub will integrate hydrogen production, storage, and distribution within the port area. It will establish infrastructure for hydrogen production, storage, and refueling in a major industrial port and aims to use hydrogen to fuel ships and reduce emissions in the maritime sector, The hydrogen hub is expected to play a crucial role in the Netherlands' transition to a hydrogen economy and support large-scale industrial.

III. The Green Hydrogen in Algeria

Algeria possesses immense potential in renewable energy and seeks to harness its natural resources and develop green hydrogen technologies as part of its energy transition strategy. The country boasts solar fields with approximately 3,000 hours of sunlight annually, making it one of the highest-ranked nations in the world regarding solar energy potential. Additionally, wind energy potential is estimated at around 35,000 megawatts, combined with abundant water resources and proximity to the European market, enhancing opportunities for using renewable energy in green hydrogen production. This forms a robust foundation for producing green hydrogen through electrolysis.

In 2022, Algeria launched its National Hydrogen Strategy aimed at developing a hydrogen economy by 2030, focusing on utilizing renewable energy for hydrogen

production and integrating it into the national energy mix , The government is investing in research and development to enhance hydrogen technologies and the necessary infrastructure.

Several pilot projects are currently being implemented to test the feasibility of green hydrogen production, including the solar hydrogen project in Hassi R'mel, which aims to produce 1.5 million tons of green hydrogen annually by 2030. This project contributes to a reduction of carbon emissions by about 10 million tons per year, equivalent to removing 2.1 million cars from the roads. Furthermore, Algeria plans to export approximately 500,000 tons of green hydrogen annually to European markets by 2035, contributing to the national economy and creating around 100,000 direct and indirect job opportunities in the renewable energy and hydrogen sectors.

Algeria has also initiated several experimental projects to explore green hydrogen production, including collaborations with European companies to develop solar-powered hydrogen production facilities. These projects aim to test technologies and establish a production base for future commercial operations. Algeria seeks to build partnerships with European countries, such as Germany and France, to develop green hydrogen projects. These partnerships include technology transfer, joint ventures, and investment in hydrogen infrastructure.

One of the significant challenges facing Algeria is developing the infrastructure for hydrogen production, storage, and distribution, which requires substantial investments in building facilities. However, this also presents an opportunity for Algeria to diversify its economy away from oil and gas dependence, create new jobs, stimulate technological innovation, and attract foreign investments. Thanks to its renewable resources and strategic location, Algeria is poised to play a significant role in the green hydrogen market. (Algerian Renewable Energy Company, 2021, Ministry of Energy and Mines, Algeria, 2020- 2021, International Renewable Energy Agency, 2023).

Conclusion:

Green hydrogen holds significant promise for advancing sustainable development by addressing environmental, economic, and social challenges. Its integration into the global energy system requires coordinated efforts from governments, industry, and research institutions to fully realize its potential and achieve a sustainable future, Green hydrogen has the ability to reduce carbon emissions, support renewable energy integration, and drive economic growth, underscoring its importance in the transition to a low-carbon future, Addressing the challenges associated with its production and deployment through continued research, investment, and supportive policies is essential for unlocking its full potential. As

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green hydrogen technology advances and becomes more cost-effective, it will play a key role in enabling a cleaner, more equitable, and resilient global energy system.

Green hydrogen is vital for achieving Sustainable Development Goals by reducing carbon emissions and promoting clean energy. Produced through the electrolysis of water using renewable sources, it aligns with Goal 13, focusing on climate action. Additionally, green hydrogen enhances energy security and diversifies energy sources, supporting Goal 7 for affordable and clean energy. Its production creates jobs and stimulates economic growth, contributing to Goal 8. Furthermore, investments in this technology encourage innovation, supporting Goal 9 on industry and infrastructure development, making green hydrogen a key player in sustainable development efforts.

In Algeria, green hydrogen is considered a key element in its strategy to achieve sustainable development by reducing emissions, supporting the energy transition, and fostering innovation. Algeria can play a leading role in the shift toward a low-carbon economy if it continues to invest in this field, collaborating with international partners to develop its local capabilities and effectively strengthen the sector.

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