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The Impact of Green Hydrogen on Environmental Sustainability. (Case Study in Jordan)

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Abstract: - Green hydrogen production is done by using excess renewable energy hence making it a clean electricity option. This process helps in eradicating greenhouse gas emissions and the use of fossil energy products is also minimized. One of the advantages of green hydrogen, and which distinguishes it from other forms of hydrogen, is that it is not a direct source of noxious emissions or gases. However, to fully realize its environmental benefits, the entire supply chain—storage, transport, and usage—must be considered. Hydrogen holds promise as a key clean energy source, supporting global goals for decarbonization and net-zero emissions by 2050. This paper discusses the techniques for producing green hydrogen, provides an overview of the process, and explores its future potential to advance sustainable energy solutions.

Keywords: Green hydrogen, Sustainable, Environmental Sustainability, Hydrogen production**.**

I. INTRODUCTION

Hydrogen generated using processes that align with certain sustainability standards is generically known as green hydrogen [Bassma et al., 2024] At present, renewable energy-driven green hydrogen production is emerging as one of the popular methods to cut down Greenhouse Gases (GHG) emissions and alleviate environmental pollution, thus helping the world achieve de-carbonization. [Meiling et al., 2021] Hydrogen is an affordable and eco-friendly option for energy consumption and storage. In addition, it plays a key role in advancing a low-carbon society and significantly increasing the use of hydrogen [Shigeki & Ko, 2019] Green hydrogen is already economically competitive in regions where optimal conditions are met [IRENA, 2020] Green hydrogen is set to contribute significantly to the realization of the United Nations 2030 Sustainable Development Goals (SDGs) which is on affording sustainable and clean energy to everyone. [A.G. et al., 2023].

Environmental considerations refer to climate change and the overconsumption of fossil fuels to generate power.

Another important objective of this research is to demonstrate and compare various methods for producing green hydrogen and to estimate its potential for hydrogen generation, particularly in Jordan. The concept of a hydrogen farm has also been utilized in order to assess Jordan's hydrogen energy potentials by making use of solar energy. This research paper will serve to enlighten policy makers in particular to consider the use of renewable resources for developing a total hydrogen economy, a development that can yield much employment opportunities. We are also employing the hydrogen farm approach to estimate the capability of Jordan for the hydrogen energy from solar electricity. This study intends to guide policymakers to optimize the opportunities of renewable energy to develop multi-faceted hydrogen economy options that may create employment.

II. SUSTAINABLE AND ENVIRONMENTAL SUSTAINABILITY

The most commonly cited definition of sustainability is the ability to fully provide for today's demands without negatively affecting the ability to do so in the future. It combines ecological, environmental, and social aspects for maintaining sustainability looking into the economic health of the natural world and the welfare of people about resources. Sustainability has more to do with the ability to effect proper utilization of precious resources and the environment to avoid degrading natural resources. [Peterson, 2022].

Environmental sustainability is an important concept that analyzes how ecosystems maintain the species and production continuity. It means an overall approach where it aims at satisfying human requirements while at the same time respecting the reserves of natural resources for the present and future generations. Fundamental to this approach is tackling climate change which forms a significant agenda that has devastating impacts on the environment [Joachim, 2011]

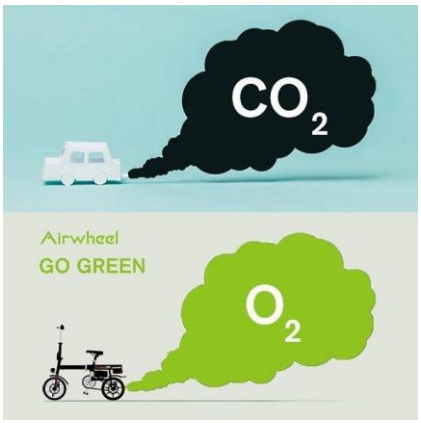

Figure 1: Different Emissions

III. Hydrogen in Energy Transition

The use of fuels was closely linked to the progress made by people in the 20th century. This link grew stronger over time. A major result was the progress that came from the widespread use of fossil fuels. However, this progress came at the cost of higher levels of pollution in the environment. These effects have now shown up in different ways, with global climate change being the most important one.

People think that climate change is the main reason why we are moving toward renewable energy. This change is seen as both good for the economy and necessary for the health of all people.

Scientists have been warning us for a long time that the world depends too much on fossil fuels. These warnings have definitely sped up the development of renewable energy technologies, even before we saw the real effects of climate change and global warming on our daily lives. Also, the growing importance of environmental issues has led to a lot more research and development of clean and new energy solutions.

The world is currently in a climate crisis. As these problems get worse, people are talking more and more about ways to deal with them and ways to adapt. On the other hand, some people think that global progress is just a natural part of human curiosity and growth, with no connection to climate change [E.L.F et al., 2020; Haotian et al., 2021]

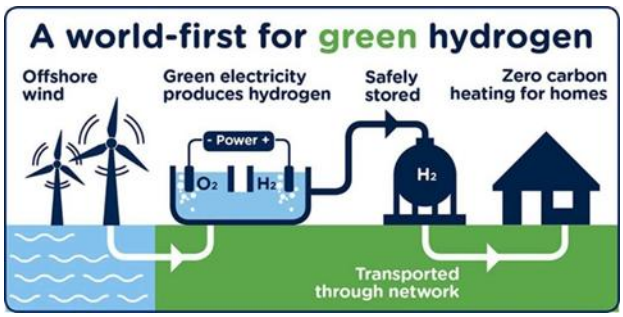

Figure 2: Green Hydrogen explanation graph.

This can be explained by the fact that also demand on energy is increasing alongside renewable. We only use ~10% (current share of energy across the world) to heat in a pleasant temperature range. In the Planned Energy Scenario put forward by IRENA, modern renewable energy in end-use would reach 17% of total final energy supply by 2030 and 25% by 2050. In the same setting, it is predicted that this percentage will rise from 28 to 66 per cent between 2030 and 2050. Meanwhile, CO2 emissions from related to energy production must decline average of 3.8% each year until 2050 – with a target of at least 70% below 2019 level [Singh et al., 2021].

One example is hydrogen, which has become a promising way to store energy without releasing CO_2 or other greenhouse gases. Still, taking a chance on hydrogen was worth intuit was a hard and expensive road to useful and

reliable technology, but the long-term benefits are so great that it is worth continuing to invest [Jens & Grietus, 2007]

The carbon-neutral society will only be attained through strategic planning and having RES. There are numerous obstacles to overcome, but in the future, hydrogen integration will be critical for the advancement of smart grid solutions. [Roughing et al., 2020]

Hydrogen (H2) is a zero-carbon emission source that has an important role to play in the stabilization of the variability of RES production, particularly when combined with long-term electrical energy storage systems. Sources (RES) production, especially when paired with long-term electrical energy storage systems [Chanhee & Jiyong, 2020].

Although it does have certain disadvantages, hydrogen technology is pivotal in the future development roadmap. Long-term carbon-neutral energy storage solutions with hydrogen will supplement the different kinds of renewable energy sources that are being made available. In the face of the economic crisis, the Jordanian government has no option but to come up with new policies, which they can use to their advantage in accelerating the transition toward green energy. [Caroline et al., 2020].

IV. Energy Storage & the Future of Green Hydrogen

Hydrogen storage solutions play a crucial role in hydrogen systems, particularly in the context of large-scale projects and operations. Additionally, the storage methods can be further classified into physical-based and material-based designs, as illustrated in the next Figure.

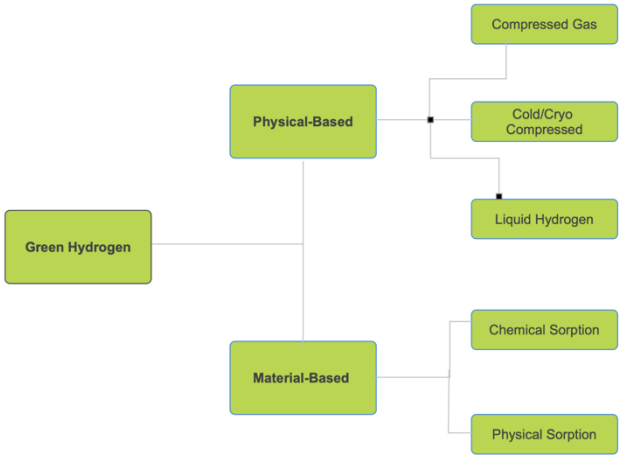

Figure 3: Energy Storage Methods

Green technologies, driven by renewable energy, are reducing greenhouse gas emissions and environmental pollution in the global decarbonization process. Believe it or not, obviously, the basic requirement is to reduce the world's CO2 emissions by more than 90%, and the renewable energy sector must directly contribute 41% of this reduction the world energy system needs to move away from fossil fuels and towards a sustainable and low-carbon system.

Hydrogen (H2) is an economical and environmentally friendly alternative for energy use and storage [IRENA, 2022]. Moreover, this is achieved by significantly less carbon in the distribution of hydrogen.

Hydrogen technology is an option that can support many sectors at different levels. Hydrogen has the potential to make a significant difference in the world thanks to strict climate regulations. In addition, the fact that hydrogen can be used in fuel cells to generate electricity and in many areas such as industry, transportation, and domestic use shows the potential of hydrogen to decarbonize.

The economic support for hydrogen - for zero-carbon fuels based on hydrogen will be clear to anyone who follows this development. This push has led to an increase in the cost of hydrogen produced from renewable energy sources (so-called "green hydrogen") and the need to reduce greenhouse gas emissions. However, green hydrogen will dominate and become highly commercialized in the next decade [Yanfei et al., 2021; IEA, 2019]

Hydrogen can be produced from coal, methane, bioenergy, and even solar energy; however, green hydrogen is one of many methods [Richa et al., 2004]. Many countries believe that the use of hydrogen energy is the best solution for the next generation of energy management, so they are promoting hydrogen energy technology and focusing on creating a carbon-free economy. In this context, many countries have developed a complete strategy and plans for the development and use of this technology [Ankica et al., 2021].

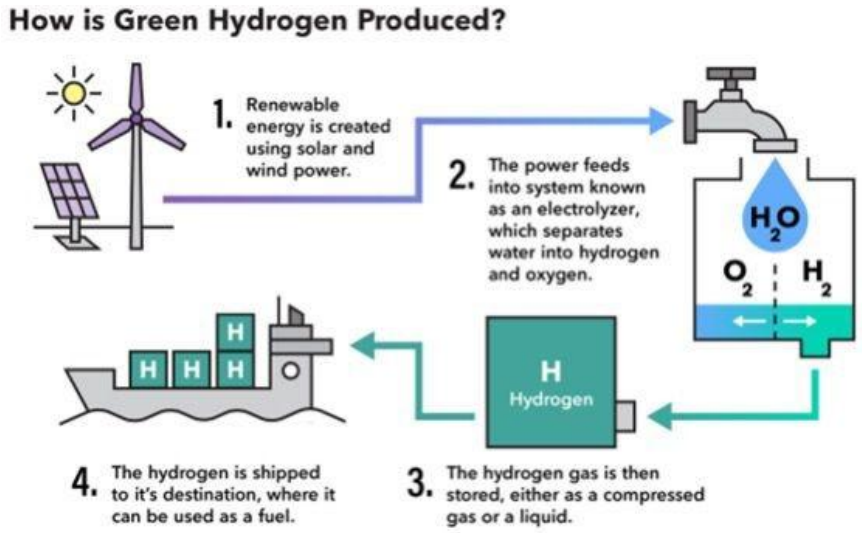

Figure 4: Green Hydrogen Production Process

The global demand for green hydrogen, or hydrogen that emits less CO2, could reach 530 million tonnes (Mt) by 2050. Therefore, it will consume about 10.4 billion barrels of oil, which is about 37% of the world's oil production before the pandemic [Yahya et al., 2020;Imran & Sami, 2023].

It is estimated that the global green hydrogen export market will be worth 300 billion US dollars per year by 2050, creating about 400,000 jobs in hydrogen and renewable energy. Technology, energy use, and environmental impact [Michel et al., 2020].

The cleanest type of hydrogen is currently green hydrogen, which is produced from renewable energy that doesn't harm the environment by producing energy in clean manners, removing carbon dioxide from the production. However, green hydrogen is produced by the electrolysis of water and then powered by renewable energy Shiva & Hankwon, 2022; Batista et al., 2022]

It will play an important role in achieving the United Nations' 2030 Sustainable Development Goals, which include the sustainable development agenda agreed upon by members of the United Nations. The specific guidance for SDG 7 focuses on "clean capacity" [Van & Chen-Kuei, 2023]. For this reason, many international projects have been implemented recently to achieve this goal.

Therefore, this paper examines the issue of establishing a green hydrogen economy (GEE) by examining green hydrogen production projects and conducting detailed research on the topics mentioned in the introduction above.

Hydrogen has many uses, from energy production to industry, from batteries to transportation. Green energy hydrogen production is therefore important to the world's efforts to transition to a low-carbon economy and achieve an energy elimination plan.

Therefore, places where renewable energy is abundant and water is readily available are considered the best places to produce large quantities of green hydrogen. However, it is important to introduce hydrogen as a viable option and to the need for green energy options that can be useful instead of fossil fuels requires the development of technology and the reduction of costs.

In this case, one of the options they have is to use their production capacity to attract investment, on the other hand, to be able to obtain long-term electronic products by signing with electronic equipment manufacturers.

Therefore, the government needs to create a strong framework for the production and use of green hydrogen and its derivatives. It should include hydrogen storage and transportation infrastructure [IRENA, 2021].

V. THE IMPACT OF FUTURE ENERGY DEMAND ON RENEWABLE ENERGY PRODUCTION

The share of renewable energy in the future is a primary target of multiple policies. Understanding the separate evolutions and their implications are fundamental, as it is tied to the energetically uncertain future demand. Forecasts of energy need represent one of the axes that studies and guidelines relate to savings, efficiency, uptake technologies, and the generate renewables. The evolution of energy demand will be one of the defining characteristics of the future energy system. A lot of forecasts come from predictions about GDP and population growth [Richard & Maryse, 2008]

Growing apprehensions regarding climate change, evolving consumer inclinations towards environmentally friendly products, the proliferation of renewable energy, and its subsequent decline in cost have initiated new trends in both the political and industrial spheres.

The Paris Agreement, which aims to restrict global warming to below 2 °C compared to pre-industrial levels, came into effect in 2016. In 2018, the Intergovernmental Panel on Climate Change (IPCC)[UN, 2015; IPCC, 2018]

The Committee on Climate Change, now the United Nations' climate change advisory body, published a major report in 2018 titled "Special Report on the Global Challenge to 1.5°C." it discusses the need to keep global warming to 1.5°C above or below pre-industrial levels and how this can be achieved through greenhouse mitigation strategies. This has led to most governments around the world tackling climate change as a political priority.

However, reducing domestic carbon emissions requires a significant shift from today's fossil fuel-based energy sources to renewables.. Hydrogen is at the heart of the debate because of its versatility, leading to a discussion about the development of a green hydrogen industry.

This is seen as a significant step towards achieving the climate protection goals of the Paris Agreement, and policymakers in many countries are now developing plans and taking measures to help develop a green hydrogen industry. They are also examining the impact of green hydrogen on their operations and looking at future business opportunities. Such predictions about the future role of hydrogen are often confusing due to the current demand and supply.

Green hydrogen is becoming a more and more crucial energy source globally. The high potential of hydrogen as a renewable energy source makes it an appealing energy carrier. In this article, we talk about the possibility of creating eco-friendly hydrogen in Jordan.

Aqaba, situated in the southern part of Jordan, was chosen to research the possibility of generating environmentally friendly hydrogen, because it is close to a water source (such as the Red Sea) and Jordan's coastline

VI. JORDAN'S NATIONAL SIZE

Jordan's country size as a whole. Numerous less-developed nations lack access to clean energy sources, leading to a heavy reliance on imported fossil fuels to satisfy their needs for energy and freshwater.

Additionally, when designing a 100% renewable energy system (RES) to meet the energy demand on an hourly basis, the RES is often too large. Therefore, significant surplus energy would be produced during times of high production, low demand, and fully charged energy storage systems (ESSs). Therefore, by examining Jordan as an example, this paper suggests a new combined system of wind, solar PV, and lithium-ion ESS to meet all of the country's energy needs and utilize extra power to operate reverse osmosis water desalination plants to meet the need for freshwater as well.

Figure 5: Potential of Producing Green Hydrogen in Jordan

The hybrid system performed the best, especially when compared to the wind-ESS RES. It had a total installed capacity of 33.37 GW, an LCOE of 0.0492 USD/kWh, a specific water cost of 0.3629 USD/m3, and energy and water demand–supply fractions of 99.47% and 96.16%, respectively.

Storing purified water in underground natural wells was found to be a good choice for improving the performance of the three systems, where the amount of water stored at the end of the year was enough to meet the freshwater needs for the next several years. Ultimately, any extra energy is utilized to create environmentally friendly hydrogen, resulting in an annual output of approximately 1.37 million tons and a cost of about 1.08 US dollars per kilogram. [Mustafa et al., 2022; Loiy et al., 2024].

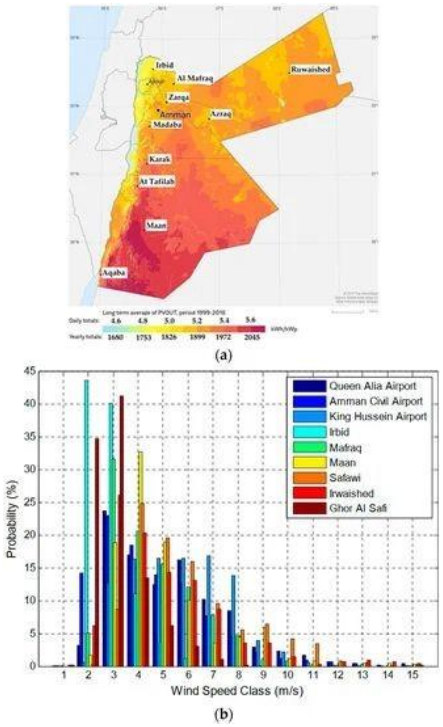

Figure 6: PV power potential and wind speed probability in Jordan.

VII. CONCLUSION

Therefore, as much as capacity and capability, the potential of green hydrogen offers Jordan a unique chance to become the leader in the field and capitalize on its abundant solar and wind resources. Demand for efficient energy keeps increasing across the globe, and green hydrogen is an effective tool for the decarbonization of the economy and less dependence on hydrocarbons. Realizing sustainable investment in green hydrogen technologies and their integration into Jordan's energy system would not only fulfill Jordan's sustainability objectives but also make Jordan a significant player in the progress of the global sustainable energy shift. If the leadership of Jordan has the vision and targets the necessary actions correctly, it can become a pioneer in developing a green hydrogen economy and create numerous new demands in the country.

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