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Requirements for the Application of Green Hydrogen in the Red Sea Sector by Application to Ras Ghareb City

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Abstract Renewable and new energy sources play a vital role in the development of urban communities, aligning with the seventh goal of the Sustainable Development Goals (SDGs), which focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all, while doubling the global rate of improvement in energy efficiency. Furthermore, this goal complements the eleventh SDG, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable. These objectives are at the core of the New Urban Agenda for achieving spatial sustainability.

The production of green hydrogen from renewable energy sources, such as wind and solar energy, is particularly significant. These sources are inherently intermittent, and their full potential can only be realized if they are converted into more stable energy forms, such as hydrogen. This conversion contributes to environmental sustainability from renewable resources.

This research explores the application of green hydrogen in the city of Ras Ghareb benefits from optimal wind speeds suitable for operating wind turbines to generate electricity, as well as radiation levels that can efficiently power solar panels. That for generating electricity from solar panels and wind turbines installed on residential rooftops in the city. Any surplus electricity produced will be used for electrolysis to generate green hydrogen. The hydrogen produced will be employed across various sectors within the city, reducing environmental pollution and contributing to the achievement of SDGs.

This paper examines the processes of green hydrogen production and its integration into urban systems, with its application on Ras Ghareb.

Keywords: Green hydrogen; Sustainable development; Renewable energy; Clean energy.

1 Introduction

Green hydrogen is a type of hydrogen produced using renewable energy sources, such as solar and wind energy, through the process of water electrolysis. This form of hydrogen is more sustainable and environmentally friendly compared to other types that rely on fossil fuels.

Renewable energy is also a central focus of climate change conferences, with the ultimate aim of achieving net-zero carbon emissions. Energy production is critical to achieving sustainable development, especially given the pressing environmental, social, and economic challenges that threaten spatial sustainability. Therefore, the adoption of renewable energy, including hydrogen production in its various forms, is essential. Green hydrogen, in particular, is considered environmentally friendly, as its production through electrolysis generates no carbon emissions.

Green hydrogen contributes significantly to sustainable transportation, as it does not produce polluting gases during its combustion or production processes, thereby minimizing environmental impacts.

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This research explores the importance of green hydrogen, its applications, economic benefits, and its role in achieving sustainable development. The study specifically focuses on its implementation in the city of Ras Ghareb.

2 Research Aim and Framework

2.1 Research aim

This paper aims to understand the concept of green hydrogen, highlight the role of green hydrogen in achieving Sustainable Development Goals (SDGs), investigate the role of renewable energy in Ras Ghareb in producing green hydrogen and reducing its production costs, and use it in different sectors in Ras Ghareb.

2.2 Research framework

The first part: green hydrogen (the concept of green hydrogen - its importance - areas of its use - the increasing importance of green hydrogen at the international level and the benefits of its use - economic benefits of using green hydrogen - the role of green hydrogen in energy transfer and carbon disposal - the role of green hydrogen in achieving sustainable development - methods of producing green hydrogen).

-The second part: Global and local trends and plans for the localization of the hydrogen industry and its effects on sustainable development.

-Third part: Requirements for the application of green hydrogen in Ras Ghareb city.

2.2.1 Green hydrogen

2.2.1.1 The concept of green hydrogen and its uses

Green hydrogen is a global, lightweight, and highly reactive fuel produced through a chemical process known as electrolysis. This process involves using electricity generated from renewable energy sources to split hydrogen from oxygen in water. Unlike traditional energy sources such as natural gas and oil, which cause environmental pollution, renewable energy sources ensure a clean production process. Moreover, producing green hydrogen using conventional energy sources is significantly more expensive compared to renewable energy sources [1].

2.2.1.2 The importance and applications of green hydrogen

Green hydrogen is considered the fuel of the future due to its versatility and wide range of applications across various sectors. It can be utilized in transportation, residential activities such as heating, and numerous industries, including natural gas and green ammonia production. Plans are currently underway to use green hydrogen as a fuel for different types of vehicles.

Studies have demonstrated that hydrogen serves as a viable alternative to natural gas for domestic uses such as heating, kitchen services, and other household applications [2].

Renewable energy sources, such as solar and wind power, often face challenges related to intermittent availability and limited storage capacity. Green hydrogen addresses these challenges, offering unlimited storage capabilities and acting as a long-term, clean, and environmentally friendly energy resource.

Green hydrogen is an important global fuel source for several reasons:

- It serves as a solution to climate change, global warming, and environmental pollution.
- It is the primary solution for storing energy from renewable sources, overcoming the limitations of intermittent availability and inadequate long-term storage capacity.
- It provides a pathway to achieving net-zero carbon emissions globally.
- It stimulates the green economy and protects both public and private assets [1].

2.2.1.3 The role of green hydrogen in energy transmission and decarbonization

Green hydrogen plays a main role in energy transmission and decarbonization, particularly in sectors where achieving carbon neutrality is challenging. For instance, hydrogen can provide a revolutionary solution to energy storage challenges in fuel cell-powered buses, trains, and even ships. Industrial heat applications also benefit from hydrogen, as its long-term capabilities align with the energy requirements of residential heating, cooling, and power generation. Globally, approximately 55% of hydrogen production is used in ammonia manufacturing, 25% in refineries, and around 10% in methanol production. Notably, nearly two-thirds of hydrogen is produced on-site for direct use, eliminating the need for transportation or the development of a broader market. Green hydrogen can fulfill all these applications, further supporting decarbonization efforts [3].

2.2.1.4 Economic benefits of using green hydrogen

Theoretically, this innovative and clean energy resource does not require the development of an extensive or expensive infrastructure. Existing natural gas pipeline networks around the world can be repurposed for hydrogen transport. Additionally, natural gas power plants can be retrofitted to burn green hydrogen, making them valuable assets in helping the energy grid during periods of high demand. Although the primary challenge for green hydrogen is its high production cost, which has hindered widespread adoption, this cost is expected to decrease significantly. Production costs, which were approximately \$6 per kilogram eight years ago, are projected to drop to nearly \$2 per kilogram by 2025. This anticipated reduction represents a critical turning point, making green hydrogen far more economically attractive than before.

Moreover, International financial institutions are actively discussing ways to facilitate funding for green hydrogen projects worldwide, which could accelerate their adoption and further enhance their economic feasibility [2].

2.2.1.5 The role of green hydrogen in achieving sustainable development

Regional and international initiatives and agreements have highlighted the importance of green hydrogen in fostering a hydrogen-based economy due to its significant role in reducing harmful emissions that contribute to global warming. This supports the achievement of sustainable development goals (SDGs) and aligns with various global and regional agreements. Key contributions of green hydrogen to sustainable development are outlined below:

Sustainable development goal 7 (affordable and clean energy)

•Target 7.1: Ensure universal access to affordable, reliable, and modern energy services by 2030.
•Target 7.2: Substantially increase the share of renewable energy in the global energy mix.
•Target 7.3: Double the global rate of improvement in energy efficiency by 2030 and net-zero carbon neutrality by 2050 [4].

Sustainable development goal 11 (Sustainable cities and communities)

The adoption of clean hydrogen will significantly reduce air pollution from current transportation methods, contributing to the development of sustainable urban environments [5].

Sustainable Development Goal 13 (Climate Action)

Green hydrogen is essential for mitigating the effects of climate change, addressing the urgent need for clean energy solutions to combat its impact [4].

The paris agreement on climate change (2015)

The goals of the Paris Agreement align with the promotion of long-term strategies for reducing greenhouse gas emissions, limiting global temperature rise, and encouraging nations to adopt sustainable energy solutions.

Conference of the parties to the United Nations framework convention on climate change (COP26)

Thirty-two countries, along with the European Union, agreed to collaborate on accelerating the development and deployment of clean hydrogen technologies.

The Middle East Green Initiative (2021)

This initiative marked the first regional coalition to combat climate change in the Middle East. Its objectives include increasing vegetation cover, reducing carbon emissions, combating pollution and land degradation, and protecting marine life in the region.

United nations green hydrogen catapult initiative (2020)

This global initiative aims to reduce the cost of green hydrogen to below \$2 per kilogram and increase its production by 50-fold by 2026.

Global ports hydrogen coalition (2022)

The first global forum that brings together port representatives, government decision-makers, and stakeholders to discuss the adoption of hydrogen technologies and fuels [4].

2.2.1.6 The role of green hydrogen in various sectors

Hydrogen, the lightest and first element on the periodic table, is the most abundant chemical substance in the universe. It is often referred to as the "missing link" in energy transition due to its critical role in connecting different sectors. As an energy carrier, hydrogen facilitates the integration of energy-consuming sectors such as buildings (heating and cooling), transportation, and industry with the energy production and development sectors.

In short, green hydrogen plays a vital role in urban development by providing sustainable energy sources, minimizing negative local impacts, and creating new employment opportunities in secondary sectors.

2.2.1.7 Green hydrogen production methods

Green hydrogen is a carbon-free fuel that can be generated from various renewable energy sources, including water, wind energy, solar energy, nuclear energy, and other power-generation technologies. The production process involves splitting hydrogen molecules from oxygen molecules in water through electrolysis, using electricity generated from renewable energy sources.

This environmentally friendly fuel relies on renewable natural resources, making it a sustainable energy solution that reduces greenhouse gas emissions and mitigates global warming by removing carbon from the energy production process.

For instance, renewable energy sources like wind and solar power are naturally intermittent. However, converting their energy output into green hydrogen enables the full utilization of these resources, ensuring environmental sustainability. By transforming renewable energy into storable and transportable hydrogen, this method addresses the challenges of intermittency and maximizes the benefits of clean energy production [6].

2.2.1.8 Kenya's experience in producing electricity from solar panels

The reason for choosing Kenya is that it has an average of 5-7 hours of peak sunshine per day and uses photovoltaic (PV) solar cells and concentrated solar power (CSP) to produce electrical energy, which is consistent with the idea of producing electrical energy from solar energy in Ras Ghareb.

The utilization and development of solar energy in Kenya remained slow until the year 2000, despite the country's geographic advantage of being situated on the equator. Kenya enjoys consistent and intense sunlight throughout the year, with an average of 5–7 hours of peak solar intensity daily. Compared to other renewable energy sources, the percentage of solar energy utilized by households and industries remains minimal relative to the country's potential.

In 2012, the Kenyan government initiated a program aimed at encouraging individuals and institutions to generate off-grid solar power. However, this initiative did not attract significant investments, partly because, in the last quarter of 2013, the government imposed a 16% value-added tax on solar energy products. This tax was rescinded in 2014 to improve access to solar energy products, particularly for populations without grid electricity.

Despite the availability of diverse solar energy technologies, the two primary methods employed in Kenya are photovoltaic (PV) systems and concentrated solar power (CSP).

The Kenyan government has focused on financing rural electrification through solar power, targeting schools and health centers. By December 2017, government data indicated that over 5,000 rural units, including health centers, primary and secondary schools, dispensaries, and administrative centers, had been equipped with photovoltaic solar systems.

Since then, the solar market in Kenya has witnessed the entry of numerous new investors, spearheading significant initiatives in small-scale photovoltaic systems with capacities ranging from 12 to 50 watts peak (Wp). These systems, suitable for household use, lighting, and device charging, consist of cost-effective amorphous silicon modules and both monocrystalline and polycrystalline silicon modules.

Kenya now has established one of the most dynamic and fastest-growing markets for commercial photovoltaic systems in the developing world, with an installed photovoltaic capacity of approximately 10 megawatts. It is estimated that more than one million rural households in Kenya use solar energy for lighting purposes. Annual sales of photovoltaic systems in the country range between 25,000 and 30,000 units [7].

2.2.2 Green hydrogen application in Egypt

2.2.2.1 National trends for the production of green hydrogen

Egypt Considered Green hydrogen as sources Energy and adjusted its strategy for electricity production from Green hydrogen 2035 And done The signing of an agreement to produce green hydrogen as a feedstock for the production of green ammonia between the Sovereign Fund of Egypt, the Norwegian company "Scatec", and the Dutch company "Vertiglobe" as shown in **Fig. 1** [8].

2.2.2.2 National plans for hydrogen production projects in Egypt

In 2022, Egypt emerged as the leading Arab country in terms of the number of hydrogen projects. Egypt has nine hydrogen initiatives, including five dedicated to green hydrogen production. Egypt plans to produce approximately 220,000 tons of green hydrogen annually [10].

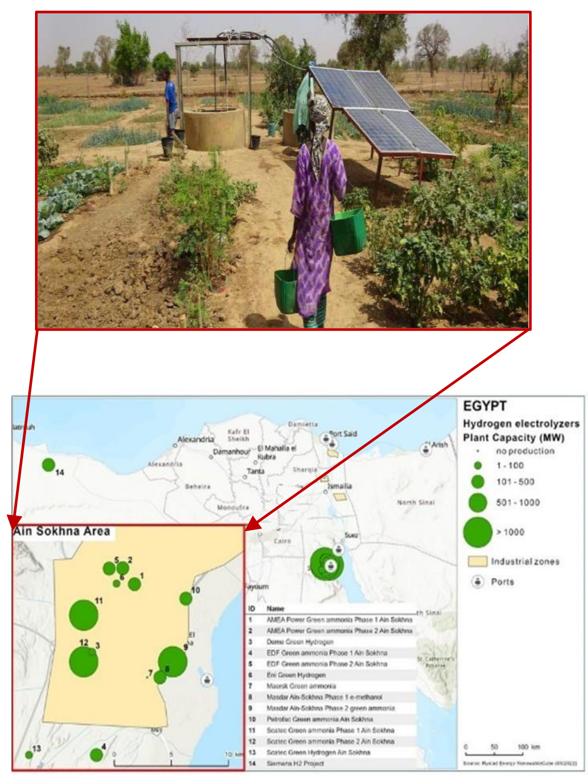

Fig. 1: Proposed green hydrogen projects in Egypt [9]

2.2.2.3 Egyptian green hydrogen initiatives and projects

The agreements Egypt has established with entities and governments from the UAE, India, Germany, Norway, Saudi Arabia, and other nations reflect the country's commitment to positioning itself as a significant player in the green hydrogen market. By proactively pursuing a share in this burgeoning sector, Egypt aims to secure a competitive edge before the market becomes saturated in the future.

One of the promising steps in Egypt's renewable energy diversification strategy is the launch of a project by the Indian company Renew Power. The company signed agreements with major Egyptian entities, including the Sovereign Fund of Egypt, alongside various governmental organizations, particularly those involved in electricity supply and management. Additionally, partnerships include the Suez Canal Economic Zone (SCZone). Under this agreement, ReNew Power is authorized to develop green hydrogen production plants and complexes located in Ain Sokhna on the Red Sea coast, within the Suez Governorate. The facility is projected to produce over one million tons of green hydrogen annually, with a target output of 1.32 million tons, positioning it as one of the leading green hydrogen plants in Egypt and the Middle East and North Africa (MENA) region. Notably, ReNew Power is the eighth company to launch a renewable green hydrogen project in Egypt.

The green hydrogen facility in Ain Sokhna is being developed in multiple phases. The first phase involves constructing a plant capable of producing 100,000 tons of green ammonia annually. Furthermore, the plant is expected to contribute significantly to Egypt's green hydrogen production between 2023 and 2025, with an estimated annual output of 20,000 tons [11].

The second phase is projected for implementation between 2025 and 2029, during which production capacity is anticipated to reach 200,000 tons of green hydrogen annually.

Egypt has also introduced a comprehensive strategy to localize the green hydrogen industry, focusing on three main pillars:

1. Manufacturing green fuels, including green hydrogen, green ammonia, and e-methanol.
2. Developing complementary industries for green hydrogen production, such as electrolyzers, solar panels, and turbines.
3. Providing green fuel bunkering services for ships through ports managed by the Suez Canal Economic Authority.

Egypt aspires to become a global hub for exporting green hydrogen and its derivatives to Europe and other international markets. The country also aims to attract foreign investments to develop projects in this sector [11].

2.2.3 Challenges facing hydrogen utilization globally

-The high cost of producing green hydrogen remains a significant challenge, primarily due to the current expenses associated with generating electricity from renewable energy sources, such as solar and wind power.
-Hydrogen combustion units currently in use are also costly, further limiting the widespread adoption of this technology [12].

2.2.4 Proposed urban sites for green hydrogen utilization in Egypt

A study to develop a Green Hydrogen Atlas for Egypt was conducted, based on the availability of renewable energy resources, specifically solar and wind energy, across various Egyptian governorates. This initiative aligns with Egypt's Vision 2030, leveraging the country's favorable climatic conditions. The analysis indicates that the Red Sea and northern coastal areas are particularly suitable for hydrogen production using wind energy. Conversely, Upper and Central Egypt demonstrate substantial potential for photovoltaic-based hydrogen production.

Egypt possesses a range of annual averages for solar irradiance and wind speed, with minimum and maximum values of 451.89 W/m² and 565 W/m² for development. In contrast, areas shaded in yellow, where wind energy density ranges between 300 and 400 watts per square meter, have marginal economic potential at best. Solar energy, as shown in **Fig. 2**, and development. In contrast, areas shaded in yellow, where wind energy density ranges between 300 and 400 watts per square meter, have marginal economic potential at best.2.37 m/s and 9.43 m/s for wind speed development [13]. In contrast, areas shaded in yellow, where wind energy density ranges between 300 and 400 watts per square meter, have marginal economic potential at best, as shown in **Fig. 3**, respectively. The annual production of green hydrogen is illustrated, highlighting the Red Sea Governorate as the region with the highest production levels. Based on the findings of the Green Hydrogen Atlas, the initial implementation of green hydrogen projects is recommended in the Red Sea and northern coastal governorates. These regions are expected to achieve the highest green hydrogen production rates, driven by their favorable environmental conditions in **Fig. 4**.

Egypt is classified as a "sunbelt country" according to the Solar Energy Atlas, as it receives between 2,000 and 3,000 kWh/m^2 annually of direct solar radiation. The country experiences sunshine for 9 to 11 hours daily from its northernmost to southernmost regions, except for a few cloudy days. Consequently, Egypt is one of the most suitable regions globally for harnessing solar energy, which can be utilized for electricity generation as well as thermal heating.

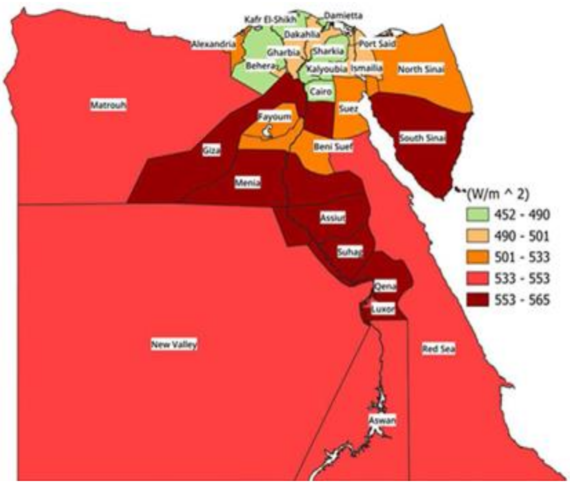

Fig. 2 Annual average solar radiation [13]

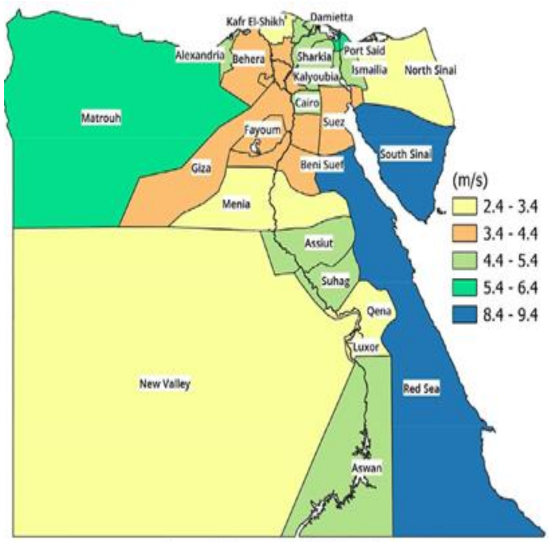

Fig. 3 Annual average wind speed [13]

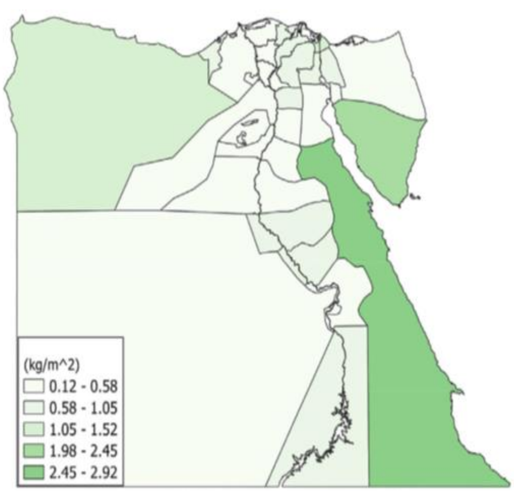

Fig. 4 Annual production of green hydrogen [13]

solar energy, which can be utilized for electricity generation as well as thermal heating.

Over the past years, the New and Renewable Energy Authority (NREA) in Egypt has undertaken significant efforts to develop a highly detailed Wind Atlas, based on the latest data. This initiative was carried out in collaboration with the Rise National Laboratory of the Technical University of Denmark, making the Wind Atlas a critical reference for Egypt. As shown in **Fig. 5**, Egypt possesses substantial wind energy resources, particularly in the Gulf of Suez region. With consistent wind speeds ranging from 8 to 10 meters per second at an altitude of 100 meters and vast, uninhabited desert areas, this site is among the world's most significant wind energy hubs.

The typical height of wind turbine stations is 50 meters above the ground. The shaded areas in red, pink, and purple on the map indicate regions where wind energy density exceeds 400, 500, and 600 watts per square meter, respectively. These regions are considered optimal for economic development. In contrast, areas shaded in yellow, where wind energy density ranges between 300 and 400 watts per square meter, have marginal economic potential at best.

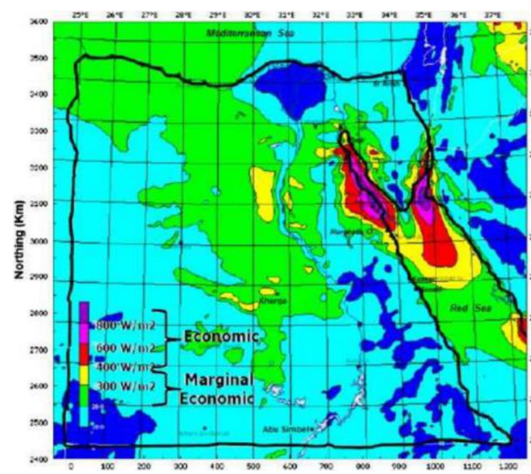

Fig. 5 Wind speed in Egypt [14]

The Red Sea coast in Egypt represents an exceptional wind energy resource, with average wind speeds ranging from 8 to 10.5 m/s at a height of 25 meters. Several key areas with significant wind energy potential have been identified through the Wind Atlas data, including:

1. The Gulf of Suez Region: Wind energy density ranges from 400 to 600 watts per square meter, with areas closer to the city of Suez ranging between 400 and 500 watts per square meter.
2. The Gulf of Aqaba Region: Wind energy density ranges from 400 to 600 watts per square meter.

Recently, the Egyptian government allocated approximately 31,000 square kilometers in the Gulf of

Suez and along the Nile coast to the NREA to facilitate the development of additional wind energy projects. In December 2019, the Ras Ghareb wind farm, with a capacity of 262.5 megawatts, was inaugurated in the Gulf of Suez. This project marks the first wind energy initiative implemented under the Build-Own-Operate (BOO) model.

3 Requirements For Implementing Green Hydrogen In Egypt

3.1 Identify the suitable application place in Egypt

Egypt has huge potential in terms of land and resources for the production of green hydrogen on a large scale, as it has 2450 km of coastline along the Red Sea and the Mediterranean and 1530 km along the Nile River, in addition to the energy necessary for production, whether solar due to its geographical location within what is known as the solar belt, which is between 31.5 and 22 lines north latitude, making it one of the richest countries in the world with solar energy, with the sun remaining between 9 and 11 hours on average per day except Some cloudy days and 2000 to 3200 kWh/m2 of direct solar radiation, or wind energy in the presence of areas with high and constant wind speeds. (Egyptian Center for Thought and Strategic Studies) [6].

Given these conditions, the Red Sea Governorate is among the most suitable regions in Egypt for renewable energy production. It is characterized by wind speeds exceeding 8 m/s and solar radiation levels ranging from 553 to 565 W/m². These factors position the region as a key source for green hydrogen production.

A case study will focus on Ras Ghareb, one of the most prominent cities in the Red Sea Governorate, which hosts the Ammont Wind Power Plant with a capacity of 500 MW, located just 9 kilometers from Ras Ghareb [15]. As a result of the natural resources in Ras Garb, it will be relied upon to produce green hydrogen.

3.2 Ras Ghareb city application

The city of Ras Ghareb is located in the Red Sea Governorate of Egypt. It represents one of the administrative regions in the northernmost part of the governorate, which is divided into six administrative zones represented by the cities of Ras Ghareb, Hurghada (the capital), Safaga, El Quseir, Marsa Alam, and Shalateen, as shown in **Fig. 6**. The city located on the western shore of the Gulf of Suez, approximately 150 km north of Hurghada and about 220 km south of Suez. The nearest city in the Nile Valley is Minya, located approximately 250 km away.

Fig. 6 Location map of Ras Ghareb area [16]

3.3 Potential for green hydrogen production from new and renewable energy in Ras Ghareb

Ras Ghareb benefits from optimal wind speeds suitable for operating turbines to generate electricity, as well as solar radiation levels that can efficiently power solar panels. The proposed plan involves initially utilizing residential rooftops for solar energy generation. Centralized satellite dishes will be installed on the facades of homes, while rooftop spaces will be used for solar panel systems. A solar panel with a capacity of 10 kW requires approximately 60 square meters of roof space, while a wind turbine with the same capacity requires only a 1x1 square meters. The electricity generated from these renewable sources will be used to meet household energy needs, with the surplus directed toward the electrolysis process for green hydrogen production.

This approach aligns with the vision of transforming Ras Ghareb into a sustainable city. Renewable energy sources, including solar and wind, will be utilized for street lighting, while green hydrogen will replace natural gas for thermal energy production. Additionally, green hydrogen will be used to power vehicles, converting existing natural gas stations into green hydrogen fueling stations.

By implementing this model, residential buildings will not only become energy self-sufficient but will also generate surplus energy that can be exported to the main grid. This surplus will contribute to green hydrogen production and provide a financial return for households, as excess energy can be sold to other sectors. This innovative approach positions Ras Ghareb as a pioneer in sustainable urban development and renewable energy utilization.

3.4 Steps and requirements for green hydrogen production in Ras Ghareb

The surplus electricity generated by households will be utilized in a hydrogen production plant, as illustrated in **Fig. 7**. The existing natural gas network in the city will be repurposed as a hydrogen distribution network, with necessary modifications to accommodate the pressure and safety requirements of hydrogen. This will enable hydrogen to serve as a clean energy source for Ras Ghareb.

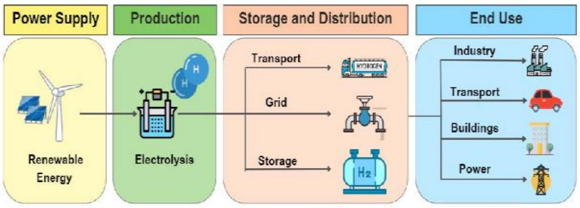

Fig. 7 Stages of green hydrogen production [17]

Therefore, there is a set of requirements for the use of hydrogen as an energy source in the city of Ras Ghareb, which are:

-Infrastructure Development: The city's infrastructure must include an extensive network for transporting and distributing hydrogen. Ras Ghareb already possesses an extensive natural gas network, with a total length of approximately 60,000 km, connecting the industrial and residential areas. This network could be adapted, in whole or in part, to transport hydrogen or a hydrogen-natural gas blend. Any required technical and engineering modifications must be implemented in end-user equipment to accommodate the use of gas mixture.

-For home use, heaters and cookers must be modified to fit with hydrogen.

-Transportation Applications: Vehicles must undergo modifications to use hydrogen as a fuel. Existing natural gas fueling stations can be converted to hydrogen fueling stations. The table below highlights the properties of hydrogen fuel compared to gasoline. Unlike gasoline, which emits significant amounts of carbon dioxide, hydrogen combustion produces no carbon dioxide emissions, making it an environmentally friendly alternative, as shown in Table 1.

Table 1 Hydrogen and gasoline fuel properties **[18]**

CO2 emissions (kg/l)	Minimum ignition power (mJ)	Flame temperature (°C)	Fuel / Properties
2.3	0.7	2307	benzene
0	0.02	2207	Hydrogen

Advantages of Using Green Hydrogen in Transportation:

- **Enhanced Technological Performance**: The incorporation of green hydrogen into transportation technologies offers significant advantages in vehicle range. While electric vehicles currently achieve a range of approximately 300 kilometers per charge, vehicles powered by green hydrogen can cover a distance of approximately 530 kilometers.
- **Faster Refueling Time:** Hydrogen-powered vehicles provide a distinct advantage in refueling speed compared to electric vehicles. Refueling a hydrogen-powered car takes only 15–20 minutes, whereas recharging an electric vehicle can require up to 8 hours.
- **Reduced Production Costs:** The cost of producing green hydrogen is expected to decrease significantly by 2030, which will further encourage its adoption in the transportation sector. This projection aligns with advancements in renewable energy technologies and is illustrated in **Fig. 8**.

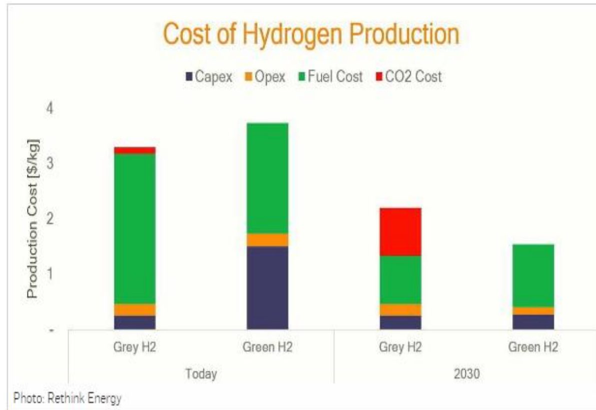

Fig. 8 Cost of green hydrogen production [19]

3.4.1 Economic prices for renewable energy

Currently, the cost of renewable energy production stands at approximately \$0.02 per kilowatt-hour for solar energy and \$0.03 per kilowatt-hour for wind energy. By 2030, these costs are projected to decline by 50–65 %. This reduction in renewable energy costs will play a critical role in making green hydrogen a more viable and competitive option for sustainable transportation [20].

3.5 Criteria and requirements for the implementation of renewable energy in Ras Ghareb city

3.5.1 Criteria and requirements for installing solar panels on building rooftops:

Among the key requirements for implementing solar water heaters is ensuring that building heights are relatively uniform, especially in areas with low-rise buildings. Variations in building heights can cause shading effects, which block sunlight for varying durations throughout the day, reducing solar water heater efficiency and energy output [21]. In Ras Ghareb, building heights are relatively consistent, as illustrated in **Fig. 9**. Approximately 90% of the city's buildings have one or two floors, facilitating the efficient installation of Photovoltaic (PV) cells on roofs of houses and working efficiently [21].

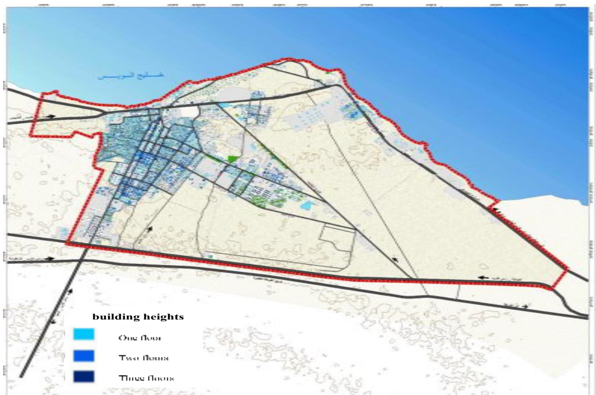

Fig. 9 Building heights in Ras Ghareb [22]

3.5.1.1 Applications of distributed PV systems for residential

The proposed approach involves the use of distributed PV systems connected to the electrical grid. These systems are designed for installation on residential buildings, administrative buildings, and various government facilities. A critical requirement for this application is the ability to sell surplus electricity generated by the PV cells to the unified electrical grid. Distributed systems connected to the grid do not require energy storage batteries, as the grid serves as a means of storing excess energy generated by the PV cells and compensates for any energy deficits [21].

3.5.1.2 The photovoltaic effect

The PV effect is the process of converting sunlight directly into electrical energy using the electronic properties of certain materials (e.g., silicon) and compounds (e.g., cadmium telluride and gallium arsenide), which are classified as semiconductors. The conversion of sunlight into electrical energy occurs through electronic structures known as solar cells.

These cells contain a thin PN junction layer, where light exposure generates a voltage across the cell's terminals and produces an electric current in an external load. The diagram below illustrates the simplified structure of a solar cell. Solar cells are categorized based on the materials used in their fabrication and their efficiency levels [23].

Fig. 10 Solar panels on rooftops [24]

The Installation of Solar Panels on Rooftops in **Fig. 10** contains photovoltaic cells that convert sunlight into electrical energy. The electricity generated by these cells is transmitted to households through electrical cables, providing power for lighting, televisions, electronic devices, and other appliances. Any surplus electricity is utilized for producing green hydrogen.

3.5.2 Criteria and requirements for standards and requirements for the application of wind turbines on rooftops

There are two primary types of wind turbines:

1. Horizontal-axis wind turbines

2. Vertical-axis wind turbines

Wind turbines vary significantly in size, with the length of the blade being the primary factor determining the amount of electricity they can generate. Small wind turbines, for example, can produce enough electricity to power a single home. A typical small wind turbine for residential use can generate up to 10 kilowatts of electricity, as depicted in **Fig. 11**, which presents the flowchart for wind turbine design.

3.5.2.1 Wind turbine theory

Savonius wind turbines are among the simplest types of wind turbines, operating based on the differential forces acting on their blades. The concave side of the blade faces the wind, capturing the airflow and forcing the blade to rotate around its vertical axis. Conversely, the convex side of the blade faces the wind, deflecting it and generating less drag than the concave side. As illustrated in **Fig. 11**, the concave blade generates greater drag, causing the rotor to rotate with more force than the other half of the turbine. This design enables the efficient conversion of wind energy into mechanical energy, which can then be used to generate electricity, as shown in **Fig. 12**.

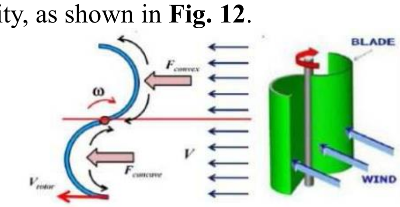

Fig. 11 Two-blade Savonius wind turbine with the drag forces [25]

Fig. 12 Schematic Diagram of the proposed system [26]

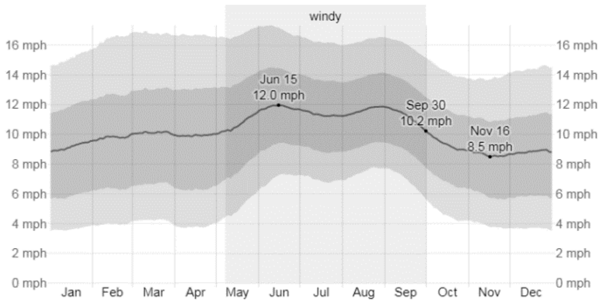

Fig. 13 Average wind speed in Ras Ghareb city [27]

One of the critical factors influencing turbine performance is wind speed, which averages 8 m/s, as illustrated in **Fig. 13**.

After generating electricity through solar cells and wind turbines, the energy is distributed primarily for residential use. The surplus energy is then supplied to the main electrical grid to produce green hydrogen. This green hydrogen can be utilized in domestic applications such as water heaters, stoves, and as fuel for vehicles. This approach aligns with the goals of sustainable development, leveraging a clean and environmentally friendly energy source for the city of Ras Ghareb.

3.5.2.2 Challenges, objectives, and incentives for promoting green hydrogen projects in Ras Ghareb City

Objective 1: Overcoming Cost and Regulatory Barriers to Affordable Green Hydrogen Production

1. Supporting and encouraging electricity generation projects from renewable energy sources to assist green hydrogen project developers.
2. Reducing electricity costs specifically allocated for water electrolysis.
3. Facilitating the work of entrepreneurs to expand renewable energy generation capacities.
4. Lowering investment costs in electrolyzer production projects by providing grants and concessional loans.

Objective 2: Promoting Mechanisms to Accelerate Demand for Green Hydrogen

1. Establishing a comprehensive platform to finance green hydrogen projects, involving both project developers and representatives of public and private development finance institutions.
2. Offering financial incentives to consumers and producers of high-cost green goods, such as green fertilizers.
3. Clarifying the environmental advantages of green products through labeling systems that highlight hydrogen usage [28].

4 Results and Discussion

First, the possibility of broad application in Egypt's vast potential to attract both domestic and foreign investments in green hydrogen underscores the importance of enacting legislation to regulate hydrogen production projects and their diverse applications. This would enhance Egypt's integration into the global green hydrogen market. Currently, hydrogen projects are governed by laws regulating the gas, transport, and water sectors, such as Gas Market Law No. 196 of 2017, which classifies hydrogen as a gas under Article 2. However, this law does not address the production of hydrogen generated from renewable electricity sources. To address this gap, a proposed law should incorporate the following key points:

• Providing financial and non-financial incentives, including tax exemptions, for green hydrogen projects, in alignment with global efforts to reduce carbon emissions and combat climate change.
• Defining the scope of green hydrogen projects.
• Identifying regulatory authorities responsible for project oversight and licensing.
• Establishing economic zones to promote activities that utilize green hydrogen.
• Implementing measures to reduce capital expenditures for green hydrogen projects in the short term.
• Ensuring the availability of skilled labor for solar water heater installation, considering plumbing requirements, maintenance, and repair challenges [20].

Secondly, the production of green hydrogen from new and renewable energy has been applied in the city of Ras Ghareb to produce electrical energy in residential units through solar cells and turbines located on the roofs of residential buildings. The electrical energy produced will be used to cover the needs of homes, and the remainder will be exploited in the electrolysis process to produce green hydrogen.

Green hydrogen will be used for street lighting and the production of thermal energy that is used in heaters and heating instead of natural gas, and the exploitation of green hydrogen to operate cars, while modifications to the natural gas network are made to suit the properties of green hydrogen.

-This study proposes adopting green hydrogen as a cleaner and more sustainable alternative to natural gas. Utilizing the existing natural gas infrastructure for hydrogen distribution could significantly reduce CO_2 emissions, potentially by 100 million metric tons annually. Furthermore, transitioning gasoline-powered vehicles to hydrogen fuel would eliminate a substantial source of carbon emissions in the transportation sector. To facilitate this transition, policies and strategic plans must be implemented to develop the necessary infrastructure for hydrogen production, distribution, and utilization. These efforts would represent a major step toward reducing carbon reliance in energy and transportation sectors, thereby advancing sustainable development goals and thus achieving sustainable development in the city of Ras Ghareb.

5 Conclusion

The implementation of green hydrogen offers the following benefits:

1. Meeting the increasing demand for clean and renewable energy sources to combat climate change and satisfy the rising global energy needs.
2. Playing a significant role in transitioning to a low-carbon economy as an alternative to fossil fuels.
3. Significant advancements in green hydrogen production technology in recent years, with the potential for greater economic feasibility.
4. Reducing greenhouse gas emissions and achieving climate goals.
5. Providing scalable and flexible energy sources to meet growing energy demands, especially for energy storage and transport applications.
6. Supporting the rising demand for clean and efficient transportation solutions, driven by growing awareness of sustainability and public health.

6 Recommendations

To activate the use of green hydrogen and mitigate environmental impacts, particularly in the transportation sector, the following recommendations are proposed:

• Reducing Costs: Develop strategies and mechanisms to lower the cost of green hydrogen production.

• Regulatory Reforms: Strengthen and amend regulations to facilitate collaboration among stakeholders, enhancing the capacity of current and future green hydrogen plants. This includes leveraging international interest in climate change to remove export barriers and create opportunities for exporting environmentally friendly technologies and products to the European Union and beyond.

• Transportation: Promote the use of hydrogen-powered transportation systems to achieve sustainable mobility.

• Export Infrastructure: Establish hydrogen export stations, capitalizing on Egypt's strategic location and favorable climate for green hydrogen production.

• Infrastructure Development: Begin developing the infrastructure for green hydrogen distribution networks to supply industrial and urban clusters.

• Legislation: Enact laws mandating the use of renewable and clean energy in transportation.

• Safety Standards: Implement stringent safety measures for hydrogen-powered transportation, considering hydrogen's high flammability. Pipelines must be securely sealed and designed to prevent hydrogen leakage.

• Environmental Benefits: Emphasize the environmental advantages of green hydrogen, which produces no pollutants such as carbon dioxide, unlike other fuels. This aligns with sustainable urban development plans and contributes to mitigating climate change and achieving sustainable cities and communities.

• Institutional Reforms: Establish companies dedicated to green hydrogen production, supported by various financing systems, to boost green hydrogen production in Egypt.

By addressing these areas, Egypt can position itself as a leader in the global green hydrogen market while achieving its sustainable development goals.

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