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SPECIAL FLOATING WIND-H_2 DESIGN FOR AJMAN - UAE: NAVIGATING THE TURBULENT WATERS OF THE ENERGY TRANSITION AND BUILDING CLIMATE RESILIENCE

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Abstract

A Floating Wind-H_2 System can support efforts toward a net-zero future through its synergistic potential. This paper overviews the powerful synergy between floating wind and hydrogen technologies. Floating wind technology has made significant advances in terms of turbine size and efficiency, opening a vast offshore wind resource. H_2's multifaceted advantages and the trajectory of these systems within the broader energy landscape are analysed in a multidimensional approach to assessing their transformative potential. Floating Wind-H_2 Systems are examined, revealing current and prospects based on existing projects. As floating wind technology evolves, they shed light on H_2's nuanced role in the energy transition and provide insights into the feasibility and impact of integrating these technologies at scale. Using Ajman, UAE, as a case study to illustrate regional adaptation, this paper discusses the significance of floating wind and hydrogen technologies for achieving global net-zero targets. The comparison of centralised onshore and decentralised offshore electrolysis demonstrated the importance of flexible solutions, particularly in regions like Ajman with limited land availability. An innovative approach to clean energy infrastructure is demonstrated by the proposed wind-H_2 system in Ajman, which relocates offshore facilities to overcome land constraints, reduce costs, and facilitate free trade. The system can produce more than 5 Tons of H_2 per day considering power generation of 3.4 MW per wind turbine for 3 turbines.

Keywords: Ajman – UAE, Climate change, Energy transition, Floating wind farm, H_2, Sustainable energy.

1. Introduction

Climate change unleashes powerful headwinds on global energy transition. With wind power becoming more prevalent in the global energy mix, practical solutions to manage its variability and intermittency have become increasingly important. One promising approach to integrating wind power and hydrogen production is using excess electricity wind turbines generate to produce hydrogen through electrolysis. As a result, green hydrogen can be stored and used in various sectors, enabling hard-to-abate industries to decarbonise and support economic transitions.

Renewable energy sources have never been more crucial as the world stands on the brink of a global energy transition. Among the potential avenues for sustainable energy storage and production, hydrogen holds excellent promise. Climate change effects can be mitigated, and carbon emissions can be reduced through its use to navigate turbulent energy waters [1]. In addition to providing a viable alternative to traditional energy sources, transitioning offshore wind to hydrogen would increase climate resilience. A sustainable energy ecosystem can be achieved by converting offshore wind power into hydrogen [2]. The challenges and opportunities of this transition must be understood to navigate the complexities of the energy landscape and build a more sustainable and resilient world [3]. This paper discusses the technology advancements needed for efficient offshore wind-to-hydrogen conversions and the environmental impacts of large-scale conversions [4]. In addition, new jobs can be created in the renewable energy sector by deploying hydrogen production infrastructure.

In offshore wind farms, the wind is stronger and steadier at sea than on land, so the power of the wind can be harnessed. However, the cost of transmitting this energy to shore, especially for locations far from shore, can be high. Countries seeking to reduce carbon emissions and achieve energy independence will benefit significantly from the offshore wind to hydrogen transition. Reducing the amount of pollution is possible [5].

Tap into this abundant renewable energy resource to reduce your reliance on fossil fuels. Hydrogen use is also advantageous during periods of high energy demand or periods of wind power [6]. Hydrogen integration can address the intermittency challenges associated with renewable energy sources by providing long-term energy storage and grid stability. As a result, society's fluctuating energy needs can be met through a reliable and resilient energy infrastructure [2].

The discussion of offshore wind to hydrogen shows that energy is being fundamentally reimagined, not just technologically changed. It is a paradigm shift to achieve a greener, more sustainable future, but also presents challenges. Extensive case studies illustrate offshore wind's successes and shortcomings in hydrogen projects. Collaboration between industry stakeholders, policymakers, and research institutions is essential for the offshore wind to hydrogen transition [6]. As a result of creating collaborative partnerships, offshore wind-to-hydrogen technology can be developed and deployed faster while the legal framework supports its widespread adoption [7]. Infrastructure for the transport and storage of hydrogen is also crucial. It is essential to build a robust hydrogen distribution infrastructure to realise offshore wind-to-hydrogen projects. Regulatory considerations and safety planning should be involved in planning hydrogen pipelines and storage facilities [8]. Designs for integrating floating wind turbines with hydrogen-generating systems, including storage, are to be discussed [9].

The versatility, clean combustion, and long-term hydrogen (H_2) storage make it an ideal energy carrier, smoothing out wind's inherent variability. By converting offshore wind directly into transportable H_2, they minimise losses and maximise efficiency. This paper explores the potential for floating wind and hydrogen technologies to facilitate the global energy transition towards the net zero target. Through a case study from the Emirate of Ajman in the UAE, the paper utilized the weather data of a selected city in Ajman.

2. Wind-H_2 System Technology

A typical layout of the proposed wind-H_2 energy system is shown in Fig. 1.

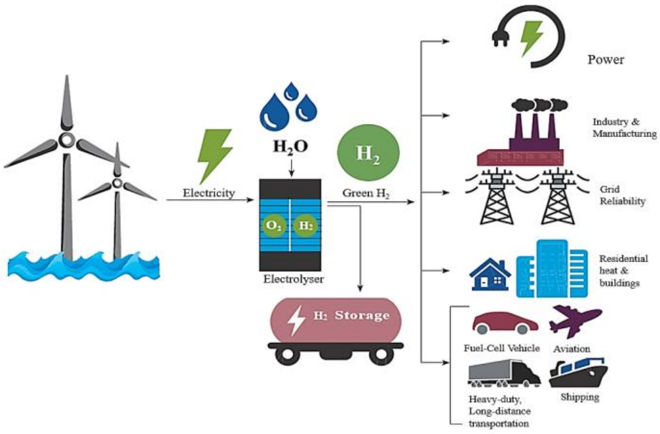

Fig. 1. Offshore wind-H_2 production system [10].

The system shown in Fig. 1 consists of the following facilities:

2.1. Offshore wind farm

- An array of wind turbines (ranging in capacity from 3 to 15 MW) makes up the wind farm. The wind resource and a desired project output are assessed to select turbine capacity [11].
- Water depth, seabed characteristics, and wave loads must be considered when designing support structures (monopile, jacket, or floating foundation) [12].
- A transformer substation is responsible for converting electrical energy into a suitable voltage for transmission through electrical cables that connect turbines to a central hub. The transmission of power over long distances is usually achieved by high-voltage (HV) direct current (DC) cables [13].

2.2. Electrolyser

Using electricity, this process breaks down water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2). Considering the expected wind conditions and desired hydrogen production rate, the electrolyser capacity is sized to match the wind farm's power output [14]. A variety of electrolysers are available depending on their efficiency, operational characteristics, and cost, as shown in Table 1.

Table 1. Comparison of three types of electrolysers [15, 16].

Electrolyser Type	Alkaline Electrolysers	Polymer Electrolyte Membrane (PEM) Electrolysers	Solid Oxide Electrolysers (SOEL)
Technology Maturity	Mature	Mature	Developing
Operating Conditions	Temperatures and pressures are typically moderate	Suitable for portable applications at low temperatures and pressures	Operation requires elevated temperatures
Current Density Performance	Performs well at high current densities	Efficient at low current densities	Efficiencies at elevated temperatures are possible
Efficiency	Moderate efficiency	High efficiency at low current densities	Potential for high efficiency
Compactness	Moderate size	Compact size	A high-temperature operation typically results in a larger size, depending on the specific design
Renewable Energy Integration	Less suited for fluctuating renewable energy sources	Better suited for fluctuating renewable energy sources	A better overall efficiency can be achieved by integrating waste heat
Application	Suitable for large-scale applications	Suitable for portable and small-scale applications	Industrial applications, especially on a large scale
Cost	Generally lower cost compared to PEM and SOEL	Typically, higher cost compared to alkaline electrolysers	Components for high-temperature applications may be more expensive
Durability	Long-lasting with proper maintenance	Durable with proper maintenance	Materials and operation at high temperatures may affect the durability of the product

Desalination units might be needed for offshore electrolysers using seawater to avoid impurities.

2.3. Storage

In periods of high wind generation, excess hydrogen is produced that can be stored for later use when winds are low. As wind resource variability and power grid integration needs are considered, storage capacity is determined by the desired buffer between hydrogen production and consumption. Types of storage are selected based on factors such as cost, efficiency, safety, scalability, and proximity to existing infrastructure [10]. Common types are:

- **Compressed Hydrogen Storage:** High-pressure tanks are used to store hydrogen gas. The compression and decompression process loses energy [15].

- **Salt Cavern Storage:** Hydrogen can be stored underground in salt caverns. Caverns are limited in number but have a large storage capacity [16].
- **Liquid Organic Carrier (LOC) Storage:** Organic liquids and hydrogen react to form a carrier molecule. Transports and stores are easier than compressed hydrogen but require additional processing [16]. End-use applications for green hydrogen are numerous. Hydrogen produced by offshore wind can be used to fuel cell vehicles, long-distance heavy-duty trucks, maritime shipping, aviation, and energy storage [10].

2.4. Scenarios for integrating offshore and hydrogen

Three scenarios are to be discussed and presented in Fig. 2 [6]:

Scenario 1: Centralised onshore electrolysis: To benefit from stronger and more consistent wind speeds, large-scale floating offshore wind farms are deployed in deep waters. Subsea cables would transport the electricity produced by wind turbines onshore, which would power centralised electrolysis facilities to produce green hydrogen. Hydrogen production and distribution infrastructure on land would be well-suited to regions with strong offshore wind resources.

Scenario 2: Decentralised offshore electrolysis: Electrolysis units would be co-located with floating wind farms on offshore platforms. The hydrogen produced at sea would be transported to shore via pipeline or other means of transport. This approach would be beneficial for regions that do not have onshore space for electrolysis equipment, or that cannot transmit subsea electricity for long distances.

Hybrid scenario: Both scenarios 1 and 2 could be combined in a hybrid approach. Some offshore wind farms might connect to onshore electrolysis facilities, while others might use pipelines to transport hydrogen and offshore electrolysis. This scenario would offer greater flexibility depending on a region's needs and resources.

The first scenario involves managing infrastructure straightforwardly and cost-effectively. This design emphasises simplicity and practicality to reduce maintenance costs. Avoiding complex systems minimises initial investment and ongoing costs. Streamlining maintenance tasks reduces downtime and improves operational efficiency. The goal of this scenario is to maximise effectiveness while keeping overheads to a minimum while prioritising cost-effectiveness and ease of management. Sustainability and productivity take centre stage in Scenario 2. To achieve high efficiency and minimal environmental impact, the infrastructure eliminates electrical losses and enables continuous production. Maximising energy efficiency reduces resource consumption and waste. Continuous production guarantees optimal resource utilisation and increased output. This scenario demonstrates a commitment to eco-friendly practices while maintaining peak productivity.

Keeping production continuity is the focus of scenario 3, which returns to simplicity and cost-effectiveness. The infrastructure is designed to minimise disruptions to production processes by emphasising easier maintenance and lower costs. This way, maintenance can be conducted efficiently without compromising production schedules. While keeping workflows smooth and uninterrupted, this scenario aims to optimise resource allocation while balancing operational efficiency with stability. Three scenarios are compared in Table 2.

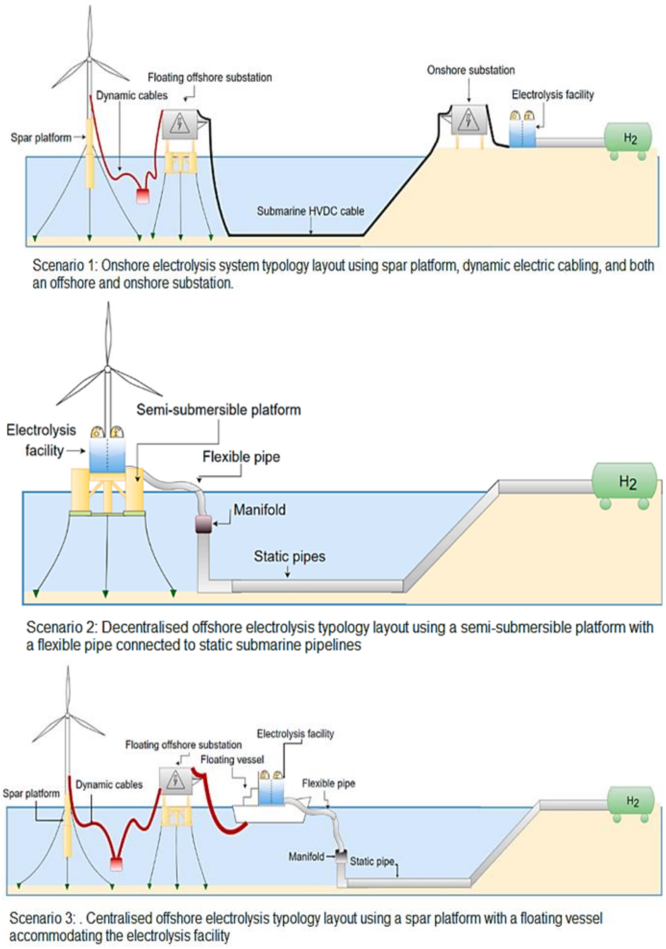

Fig. 2. Scenarios for integrating offshore floating wind farms with hydrogen production [6].

Table 2. Comparison between the three scenarios.

Feature	**Centralised Onshore Electrolysis**	**Decentralised Offshore Electrolysis**	**Centralised Offshore Electrolysis**
Electrolyser	Alkaline Electrolyser	Proton Exchange Membrane Electrolyser	Similar to Centralised Onshore
FOW Platform	Spar platform (deep water)	Semi-Submersible platform	Spar platform
Energy Transmission	Submarine HV, DC cables	Submarine hydrogen pipelines	Submarine hydrogen pipelines
Advantages	- Sensible for near-shore projects - Established technology	- Compact - Dynamic operation - Expansion potential	- High capacity - Efficient for long distances
Disadvantages	- Energy losses - Limited expansion flexibility	- Requires further development	- Complex infrastructure - Requires large-scale deployment

3. Case Study Scenario for the Emirate of Ajman - UAE

In Ajman, the smallest Emirate in the UAE, wind-H_2 technology is proposed as a strategic solution to overcome inherent challenges. It is suggested that a pioneering approach should be taken due to the limited land availability that poses significant obstacles to the traditional placement of infrastructure. All system facilities, including storage and transportation facilities, are to be relocated offshore to overcome land scarcity constraints. In addition to addressing logistical hurdles, this innovative strategy promotes free trade, reduction of costs, and simplified infrastructure. The project does not require extensive land acquisition, so it incurs lower costs and streamlines operations. Furthermore, the absence of complex onshore infrastructure facilitates smoother implementation and public acceptance by enhancing efficiency and safety. As depicted in Fig. 3, this forward-looking design highlights the potential of wind-H_2 technology and underscores Ajman's commitment to sustainable energy solutions and economic prosperity through international trade.

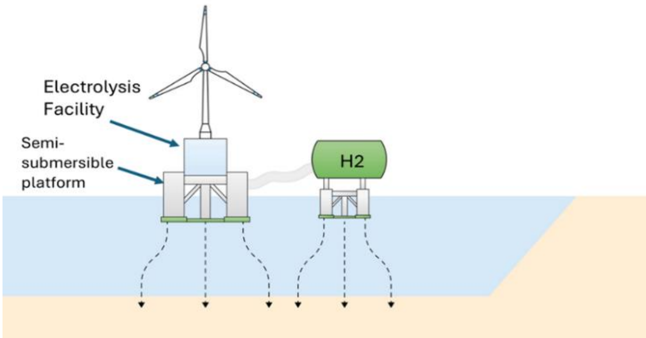

Fig. 3 Proposed floating offshore Wind-H_2.

3.1. Wind potential and turbine selection in Ajman

Figure 4 shows the coastal area's monthly mean wind speed at different heights in Ajman. Monthly mean wind speeds are in the range of 6.5-7.5 m/s, most likely at heights higher than 50 m [17].

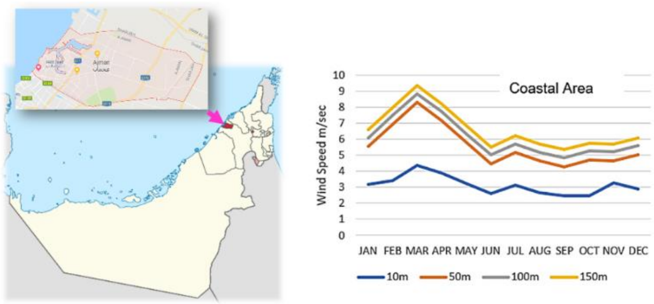

Fig. 4. Coastal area monthly mean wind speed at different heights [17].

In the offshore area, wind energy potential has been identified as promising [18]. For the proposed system, this step involves selecting an appropriate wind turbine. The wind conditions described are carefully considered. According to

Darwish's criteria, turbines with higher hub heights and larger rotor diameters maximise energy capture. According to the selection methodology [18], 3.4 MW turbines are selected for their balance between power output and feasibility see Fig. 5. Optimising energy production and minimising wake effects between turbines depends on the wind farm layout. To demonstrate the proposed wind-H_2 system in the pilot project, a conservative approach is adopted using three turbines based on the limited area in which the project will be conducted. The offshore wind farm is carefully positioned near the coast to maximise energy capture while minimising environmental impacts. It is important to tailor foundation design according to the seabed conditions of offshore sites, such as monopiles or jackets. To connect the turbines to an offshore substation, where the generated electricity will be converted and used for onsite electrolysis and desalination, subsea cables must be laid.

Sustainable development integrates environmental considerations, including marine habitat protection and maritime safety. Furthermore, stakeholder engagement and regulatory compliance are prioritised throughout the project lifecycle, aligning with the principles of inclusive decision-making and standard compliance. Moreover, the wind farm project ensures a robust and efficient design to maximise energy production while minimising environmental impact and ensuring stakeholder satisfaction. The designed wind farm pilot project leverages Ajman's offshore wind energy potential to demonstrate the feasibility and benefits of renewable energy integration. At the proposed offshore location in Ajman, the selected wind turbine can produce the same power output as the available wind speeds.

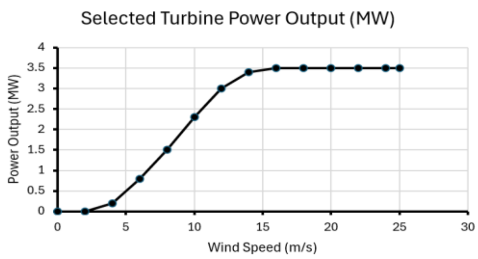

Fig. 5. Power output of the selected wind turbine at the offshore proposed location in Ajman.

3.2. Expected H_2 production

It is estimated from this study that the system can produce more than 5 Tons/per day considering the following factors:

- Consistent power generation of 3.4 MW per wind turbine for 3 turbines (total of 10.2 MW).
- The lower heating value of 39.2 kWh/kg for hydrogen.
- Efficiency of 80% (0.8 kg of hydrogen per 1 MWh of electricity).
- The cost of 1 kg of H_2, offshore wind farms, disclination and battery desalination is $7 [19].

3.3. The H_2 production system components

In the hydrogen production chain, several critical components are powered by the offshore wind farm:

Offshore Substation: An offshore substation collects the electricity generated by wind turbines and transmits it via subsea cables. A crucial role is played by this substation [20]:

In the floating Wind-H_2 station, AC electricity collected from turbines is converted to DC for efficient transmission. The hydrogen production system is powered by low-voltage DC power, which is separated from the grid connection electricity at high voltages.

Desalination Unit: Hydrogen is produced through electrolysis, which requires freshwater. A desalination unit is incorporated to purify seawater and provide clean water [21]. Multi-stage flash (MSF) or multi-effect distillation (MED) are common desalination technologies in offshore applications.

Electrolyser: This is the heart of the hydrogen production system. A process called electrolysis is used to split water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2) by using DC electricity from the substation and purified water from the desalination unit. A widely adopted technology for integrating renewable energy is polymer electrolyte membrane (PEM) electrolysis [21].

Hydrogen Compression and Storage: Hydrogen gas is typically produced at low pressure. To transport or store goods efficiently, compressors are used to increase their pressure [22]. Wind-H_2's floating station can then store compressed hydrogen in high-pressure tanks.

3.4. Integration and installation:

To maximise synergy among its components, the floating Wind-H_2 station is meticulously engineered:

- Depending on the seabed conditions, wind turbines are secured to the seabed using monopiles or jackets [23].
- Electricity is reliably transmitted from the offshore substation to the wind turbines via subsea cables.
- Floating platforms house the substation, desalination unit, electrolyser, and compression/storage units. A marine-friendly anchoring system anchors the platform to the seabed [6].
- By interconnecting pipelines, desalinated water can be transported to the electrolyser, and compressed hydrogen can be transported to storage tanks or exported.

3.5. Environmental considerations

Floating Wind-H_2 stations are designed and installed in accordance with stringent environmental regulations [24]. To minimise the impact on sensitive ecosystems, marine habitat surveys are to be conducted to consider [25]:

- Construction activities will not disrupt marine life migration patterns.
- Desalination unit discharges are treated to meet compliance levels before being released into the ocean.
- Construction and operation noise pollution is mitigated through appropriate measures.

4. Sustainable Waste Management for Wind-H_2 system

4.1. Waste streams in Wind-H_2 systems

The wind turbine waste might be:

- Operation and Maintenance (O&M) Waste: Hazardous and non-hazardous waste is generated by lubricants, filters, and minor blade repairs [26].
- Decommissioning **Waste:** Dismantling wind turbines yield large volumes of composite materials (blades), steel, and concrete foundations.
- Electrolysis **waste**
- Membrane **replacement:** Water electrolysis units must properly dispose of used membranes.
- **Pre-**treatment/**post-treatment residuals:** Solid or liquid wastes may result from the purification and drying of water.

4.2. Sustainable waste management strategies

The identified fundamentals of the system circular economy:

- Ensure long-term durability and recyclability**:** Electrolyser components and wind turbine parts must be easily disassembled, reused, and remanufactured.
- Establishing a robust recycling infrastructure for composite materials, steel, and concrete to repurpose and recycle decommissioned turbines is essential.
- Rehabilitation and remanufacturing: We are extending their lifespans and reducing generated waste by reusing and refurbishing wind turbine parts and electrolyser components [27].
- Minimising waste
- To reduce the environmental impact of end-life waste of the system components, the following may be adopted as procedures to minimize the waste.
- Optimisation of operations and maintenance practices: It is possible to minimise waste generation during operation by extending the life of lubricants and implementing preventive maintenance programs [27].
- Cleaning up processes: Developing easier-to-recycle and safer-to-dispose-of materials for turbine blades and membranes.

4.2.1. Environmental impact of waste

When lubricants, filters, or decommissioning materials are improperly disposed of, soil and water can become contaminated. In addition to occupying valuable space, composite materials and concrete wastes take a long time to decompose when disposed of in landfills [27]. Chemicals can be released into the environment when used membranes are improperly disposed of.

4.2.2. Project impact on air quality

There are many advantageous features of the proposed system on air quality.

- Wind turbines: Run on wind movement without combustion processes, so they don't produce greenhouse gases or particulates.

- **Electrolysis:** A process of electricity splitting water molecules into hydrogen and oxygen. The process is clean if the electricity is generated from renewable sources like wind.
- **Hydrogen**: Using hydrogen as fuel in a fuel cell produces only water vapour as a by-product [28].

There are, however, some indirect impacts on air quality to consider during the lifecycle of the Wind-H_2 system:

- **Manufacturing:** Manufacturing wind turbines, electrolysers, and other components can release pollutants into the environment.
- **Transport:** Transporting components to construction sites and hydrogen fuel can involve emissions, but electric or hydrogen cars can minimise the impact [28].

Wind farm construction and decommissioning activities can temporarily affect air quality. Implementing dust suppression techniques can mitigate the impact.

5. Conclusion

As discussed in this paper, global net-zero targets can be achieved through floating wind and hydrogen technologies. An example from Ajman, UAE, illustrates how these technologies can be tailored to address regional challenges and opportunities. The need for flexible solutions is highlighted by centralised onshore electrolysis vs. decentralised offshore electrolysis. Land availability was a significant obstacle in Ajman. By relocating all offshore facilities (including storage and transportation), the proposed Wind-H_2 system overcomes this hurdle. As a result of this innovative design, costs can be reduced, infrastructure can be simplified, and restrictions on land can be eliminated, facilitating free trade. The Darwish methodology will be incorporated as part of the project to assess wind resources efficiently and optimally select turbines. As a result of this commitment to best practices, Ajman can harness offshore wind energy sustainably and robustly.

The potential of Wind- H_2 stations for decarbonising various sectors is enormous, and it can be optimised in terms of efficiency and cost-effectiveness through ongoing research and development. Cleaner energy futures require collaboration and innovative thinking, as illustrated by the case of Ajman. Regions like Ajman can contribute significantly to net-zero emissions by adopting floating wind and hydrogen technologies. To ensure Wind-H_2's long-term viability, it is crucial to manage waste sustainably. Creating a clean energy future with minimal environmental impact is possible by adopting circular economy principles, reducing waste production, and designing cleaner processes. Moreover, regarding air quality, Wind-H_2 systems offer a significant advantage over fossil fuels. Air quality impacts associated with the Wind-H_2 system can be further minimised by using clean manufacturing processes, sustainable transportation options, and dust control measures.

It is recommended for future works to Investigate the long-term economic viability and operational efficiency of large-scale deployments of floating Wind-H_2 stations across a variety of geographic contexts through detailed techno-economic feasibility studies. The use of this technology in energy infrastructure would offer investors and policymakers valuable insights.

Abbreviations

DC	Direct current
H_2	Hydrogen
HV	High voltage
MED	Multi-effect distillation
MSF	Multi-stage flash
O&M	Operation and Maintenance
UAE	United Arab Emirates

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