PROPOSING A FRAMEWORK FOR ESTABLISHING A GREEN ENERGY LOGISTIC HUB: AN EMPIRICAL STUDY IN EGYPT

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Abstract

The International Energy Agency (IEA) has emphasized the opportunity to create "hydrogen hubs" to reduce costs associated with low-carbon hydrogen pathways. A "hub" is a region capable of aggregating hydrogen demand, typically found in coastal industrial clusters or near ports. The development of these hubs is seen as a vital step toward expanding the hydrogen economy. This research aims proposing a framework for establishing a green energy logistic hub in Egypt. The suggested Framework is developed based on the Australian Hydrogen Hubs Study (ARUP 2019) [1], which has identified seventeen critical variables for establishing a hydrogen hub. The main focus of this paper is to analysis each variable based on the previous theoretical and empirical studies and map this analysis on Egyptian context through carrying out some technical interviews with Egyptian experts in the energy sector. The main outputs of these studies and the interviews lead to the development of a conceptual framework that includes assessment criteria to support decision-making. The developed conceptual framework will be used to study the feasibility of establishing Hydrogen Hub in one of the Egyptian ports in particular Gargoup Port.

Keywords: green energy, logistic hub, theoretical framework, conceptual framework.

1. INTRODUCTION

The Green Hydrogen plays a potential role recent years have seen a significant increase in global interest in moving towards a more sustainable energy future, fueled by its ability to offer economic advantages such as export income, the development of new industries, and job creation. Moreover, this transition supports the adoption of low-emission energy across various sectors, including electricity, heating, transportation, and industry. It also strengthens the resilience of energy systems and broadens choices for consumers. There are many announced low emission green hydrogen globally as illustrated in Figure 1 at 2024 [2]. In May 2022, in response to the ongoing crisis in Ukraine, the EU introduced the Repower EU Plan to decrease its dependence on Russian fossil fuels. The initiative aims to boost renewable hydrogen production to 10 million tons per year by 2030, with a corresponding target for imports. This creates a significant opportunity for Egypt to export hydrogen to the EU, but it will face competition from other MENA countries like Morocco, Algeria, Saudi Arabia, and Oman, as well as nations like Namibia, which are also looking to supply renewable hydrogen to Europe. The global demand for hydrogen is currently estimated at around 90 million tons, including approximately 70 million tons of pure hydrogen and 20 million tons of carbon-based synthesis gas. Egypt's hydrogen demand represents about 2% of the worldwide total. The 2030, 2040 vision and the hydrogen market scenarios, set the direction and Egypt's overarching goal for developing a hydrogen economy center around establishing a prominent international export hub for hydrogen and its derivatives. Key elements of the strategic framework include advancing hydrogen production technologies, fostering partnerships with global stakeholders, and leveraging Egypt's geographic advantages. Additionally, the strategy seeks to strengthen the nation's energy security by broadening its energy sources and ensuring a dependable, sustainable energy supply.

Accordingly, the anticipated strategic outcomes by 2040 are as follows [3]:

(1) The production of 5.6 million tons of low-carbon hydrogen.
(2) Capturing 8% of the global hydrogen market share.
(3) Establishing and localizing the electrolyzer manufacturing industry within the country.
(4) Supporting the decarbonization efforts of key industrial sectors in Egypt.
(5) Contribution to the growth of the country's economy by boosting GDP (USD 10-18 billion), providing upwards of 100,000 thousand new jobs.

Figure 1-announced low emission hydrogen production projects for 2024 [2]

Many variables can affect establishing a green energy logistic hub that will be highlighted and discussed in this work to conduct a conceptual framework for Egyptian hydrogen hubs based on theoretical framework, obtained from the literature review, and carried out interviews with experts in the field of energy producing.

1.1. Main variables for establishing a green energy logistic hub

Several studies have identified the key infrastructure needed to produce hydrogen for export and hub development. These infrastructure requirements serve as a foundation for evaluating potential export opportunities. A set of criteria was created to evaluate the feasibility of both export and domestic hydrogen hubs, which includes [1]:

(1) Health and safety provisions.
(2) Environmental considerations.
(3) Economic and social considerations.
(4) Water availability.
(5) Land availability with appropriate zoning and buffer distances & ownership (new terminals, storage, solar PV, industries etc.).
(6) Availability of gas pipeline infrastructure.
(7) Availability of electricity grid connectivity, backup energy supply or co-location of renewables.
(8) Road & rail infrastructure (site access).
(9) Community and environmental concerns and weather. Social license consideration.

(10) Port potential (current capacity & occupancy, expandability & scalability).
(11) Availability of, or potential for, skilled workers (construction & operation).
(12) Availability of, or potential for, water (recycled & desalinated).
(13) Opportunity for co-location with industrial ammonia production and future industrial opportunities.
(14) Interest (projects, priority ports, state development areas, politics etc.).
(15) Shipping distance to target market.
(16) Availability of demand-based infrastructure (i.e., refueling stations).
(17) Berths (berthing depth, ship storage, loading facilities, existing LNG and/or petroleum infrastructure etc.).

The research aims to propose a framework for establishing a green energy logistic hub in Egypt,that will be accomplished through the following research objectives:

(1) specify determinants of establishing a global green energy logistic hub.
(2) examine global practices on establishing a global green energy logistic hub.
(3) identify requirements for converting gargoup into a global green energy logistic hub.

Hence, the achievement of research objectives will support the development of the feasibility study of using Gargoup port as a hydrogen hub for exporting to EU to participate in EU energy problem The rest of this paper is structured as follows. Section 2 provides a theoretical overview of the key variables influencing the establishment of a hydrogen hub. Section 3 explains the research methodology to establish a conceptual frame work for establishing hydrogen hub in Egypt. Section 4 clarifies interview findings with experts and officials in the energy sector. Section 5 describes the conceptual framework and the conclusion of the work is discussed in Section 6.

2. LITERATURE REVIEW

According to the foundational work of the ARUP study [1], it has identified seventeen key variables essential for establishing a green hydrogen logistics hub. Each variable has been analyzed based on previous theoretical frameworks and empirical studies.

2.1. Theoretical framework

For future investigation, each variable has been addressed as follows:

2.1.1. Health and safety provisions

Incorporating health and safety provisions in energy hub development is crucial for risk mitigation, regulatory compliance, public trust, and operational efficiency. Prioritizing these measures fosters a sustainable and responsible energy infrastructure that benefits all stakeholders. Internationally many societies and organizations have documented Health and safety in hydrogen applications [4] , [5]:

- ISO/TR 15916:2004(E) (Fundamental considerations for the safety of hydrogen systems).
- IGC Doc 75/01/E/rev (Guidelines for determining safety distances).
- NSS 1740.16 (Safety Standard for Hydrogen and Hydrogen Systems: Guidelines for the Design, Materials Selection, Operation, Storage, and Transportation of Hydrogen Systems).

2.1.2. Environmental considerations

An annual Port Environmental Review released by the European Sea Ports Organization (ESPO), which highlights the top ten environmental priorities of European ports [6]. the environmental priorities of European ports in 2023 along with the results of the previous years [7]:

(1) Climate change.
(2) Air quality.
(3) Energy efficiency.
(4) Noise.
(5) Water quality.
(6) Ship waste.
(7) The relationship with the local community.
(8) Port development (land related).
(9) Port development (water related).
10) (Garbage/ port waste)

2.1.3. Economic and social considerations

The most promising markets for green hydrogen production are those with ample and affordable renewable resources. For example, areas like the Middle East, Africa, Russia, the US, and Australia have the potential to produce green hydrogen at a cost of €3 to €5 per kilogram as of now. In contrast, production costs in Europe range from €3 to €8 per kilogram. However, these costs are expected to decrease over time, driven by the continuous decline in renewable energy production costs, economies of scale, insights gained from ongoing projects, and technological advancements. As a result, green hydrogen will become more economically viable, further enhancing its potential as a sustainable energy source [8]. The launch of a clean hydrogen economy, in line with the Sustainable Development Goals, necessitates the following essential actions [9]:

(1) Facilitating Investments: Unlocking capital and attracting foreign investment initiatives.
(2) Reducing Financing Costs: Ensuring access to affordable financing options.
(3) Creating a Level-Playing Field: Offering operational subsidies for green hydrogen through at least the end of 2030.
(4) Creation of Demand: Stimulating demand for green hydrogen through sectoral initiatives and regulatory obligations that incentivize its adoption across industries.

The hydrogen economy has significant social implications, which include [10]:

(1) Acceptability
(2) Accessibility
(3) H2 markets
(4) Information
(5) Policies & Regulation
(6) Research & Development
(7) Responsibility
(8) Stakeholders
(9) Externalities
(10) Socio-economic factors
(11) Socio-political factors
(12) Technological safety

2.1.4. Water availability

The water requirements for hydrogen production vary by method with over 9 liters needed for every kilogram of hydrogen. making reliable access to treated water essential for efficient production. To address the growing climate risks, the energy sector is increasingly integrating water considerations into its planning and operations. By transitioning to renewable energy sources, the sector can greatly reduce its water-related risks, as renewable energy technologies like wind, solar, and geothermal generally use much less water than conventional fossil fuel-based power generation. [11]. Water used in hydrogen production can be sourced from a variety of resources, each offering different advantages and challenges [12]:

(1) Surface Water: This includes water from lakes, dams, rivers, and creeks.
(2) Groundwater: Sourced from wells, aquifers, and boreholes.
(3) Recycled Water: Treated wastewater effluent is an increasingly popular option for hydrogen production.
(4) Brackish Water: This is water with a higher salinity than freshwater but lower than seawater.
(5) High Salinity Water Sources: Seawater, estuary water.

2.1.5. Land availability with appropriate zoning and buffer distances & ownership (new terminals, storage, solar PV, industries etc.)

Land access is critical for hydrogen project development. A thorough understanding of land ownership and access is essential for scalability, as ample land is needed for expansion. project sponsors who are looking to develop green hydrogen projects have a strong incentive to (conduct comprehensive due diligence, engage with governments and local communities) [13].

2.1.6. Availability of gas pipeline infrastructure

The hub's purpose will determine the required transport infrastructure. Large-scale domestic hydrogen production needs pipelines for distribution, while export facilities benefit from dedicated hydrogen pipelines. Currently, there are over 4,300 kilometers of hydrogen transportation pipelines in operation, with more than 90% of this infrastructure located in Europe and North America. According to Rystad Energy, approximately 91 planned pipeline projects are projected globally, totaling 30,300 kilometers, with an expected completion by around 2035. [14].

2.1.7. Availability of electricity grid connectivity, backup energy supply or co-location of renewables

Co-location refers to the ability to store power when wind or solar energy generation is low. Additionally, co-located projects offer a price arbitrage opportunity, where electricity is bought during off-peak hours (when prices are lowest) and stored for later use during peak hours (when prices are highest) [15]. Renewable energy-to-grid integration involves the development of microgrids that utilize solar, wind, and storage systems, particularly in remote areas or as a backup during grid disruptions (islanding). This process includes developing new standards and codes for connecting distributed energy systems, aiming to enhance energy resilience without requiring significant upgrades to existing infrastructure [16]. When considering connecting your energy system to the electric grid, several key factors need to be taken into account [17]:

(1) Equipment needed to link your system to the grid.
(2) Grid connection requirements from your energy provider.
(3) State and community codes and requirements.

2.1.8. Road & rail infrastructure (site access)

Road and rail networks support smaller projects, Hydrogen production for road transport is increasingly recognized as a viable solution for heavy-duty vehicles, particularly those that operate over long distances. India has taken a significant step announcing its National Hydrogen Mission, the mission specifically highlights the role of hydrogen in transforming various sectors, with a particular focus on the transport sector. [18]. road access is a critical requirement, Rail infrastructure, while not essential, can offer additional advantages. If rail networks are available, they could support the transportation of bulk feedstocks, which are often required in large quantities for hydrogen production. Additionally, rail could facilitate the transportation of liquid hydrogen or anhydrous ammonia [1]. Apart from international transport regulations, various national-level measures may be required to guarantee the safe and efficient distribution of energy carriers, like hydrogen, for domestic transport. These measures could include: Additional requirements for drivers, specialized equipment for fire brigades, extra equipment on vehicles, infrastructure and road modifications, as well as monitoring and reporting systems [19].

2.1.9. Community and environmental concerns and weather. Social license consideration

Environmental, sustainability, and community impacts also play significant roles, affecting planning and operational approvals, as well as corporate social responsibility. Hydrogen hubs, particularly in regions prone to adverse weather conditions such as cyclones and flooding, must be designed to address a range of operational challenge, these challenges are similar to those faced by existing LNG (liquefied natural gas) and renewable energy projects in areas like northern Australia, where extreme weather events can disrupt operations [1]. Low-emissions hydrogen projects, typically require substantial land areas. This land is not only needed for the renewable energy assets themselves but also for the enabling infrastructure Given that these projects may span across multiple jurisdictions, it is essential to engage with local and indigenous communities to ensure that projects provide socio- economic benefits and respect the interests of the community [2].

2.1.10. Berths (berthing depth, ship storage, loading facilities, existing LNG and/or petroleum infrastructure etc.)

Ports designed to handle bulk liquids like ammonia and LNG will play a critical role in supporting the investment requirements of the growing hydrogen export market. The infrastructure needed at these ports varies depending on the hydrogen form. For export hubs, Hydrogen production plants are often situated near ports to reduce transportation costs. For example, the hydrogen hubs funded by the Australian government are located close to port facilities. Conversion plants are typically positioned near or within the port area, along with storage tanks. At import ports, once the hydrogen or its derivatives are unloaded, they are usually transported via pipelines or road tankers. Depending on the chosen technical approach, multiple infrastructure setups may be necessary, adding complexity to port layout design and risk management challenges. The infrastructure requirements for ports vary, as summarized in Figure 2, which outlines the necessary infrastructure for handling different hydrogen forms. [20].

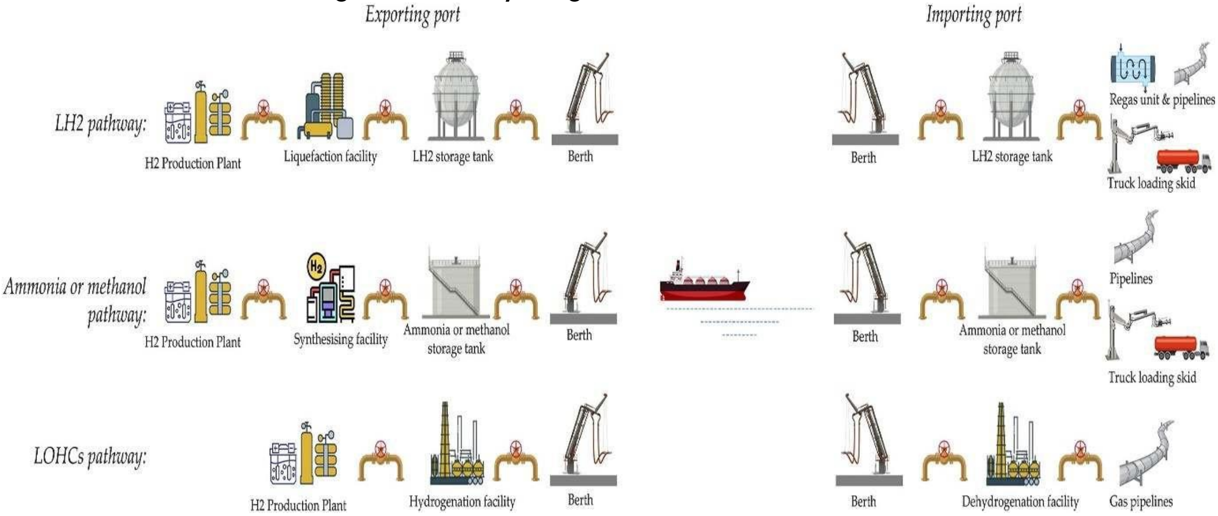

Figure 2-Hydrogen port infrastructure [20]

2.1.11. Port potential (current capacity & occupancy, expandability & scalability)

Ports that avoid new dredging or channel development will be more advantageous. Those with bulk liquids jetties seeking increased capacity and space for expansion are especially attractive for hydrogen projects Identifying potential hydrogen (H2) energy exporters and importers is essential for selecting appropriate port locations. Three key factors influence the potential of a country as an H2 exporter or importer:

(1) The presence of H2 production resources and the need for H2.
(2) The nation's strategic plans for hydrogen development.
(3) The progress made in implementing hydrogen-related actions.

As in Figure 3 illustrates 20 potential early hydrogen ports, with 12 designated as export ports, including those in Australia (Hedland, Darwin, Townsville, Newcastle, Hastings, Geelong, Bonython, Bell Bay), Chile (San Antonio), Mauritania (Nouadhibou), Saudi Arabia (Yanbu), and Norway (Egersund). The 8 import ports include Hamburg and Wilhelmshaven in Germany, Rotterdam in the Netherlands, Cromarty Firth in the UK, Kobe and Onahama in Japan, Ulsan in South Korea, and Singapore [20].

Figure 3- Potential initial hydrogen ports (green marks indicate export ports; blue marks represent import ports) [20]

2.1.12. Availability of, or potential for, skilled workers (construction & operation)

Areas with a skilled workforce in industries like gas pipelines, LNG processing, ammonia, or petroleum refining will have a strategic advantage in establishing a new hydrogen sector. In Australia, several federal and state initiatives have identified the workforce needs for the emerging hydrogen industry. Two major workforce challenges are [21]:

(1) A limited number of workers available to assist in the construction and operation of hydrogen projects.
(2) skills and training gap, preventing workers from performing safe and high-quality jobs.

The Victorian Hydrogen Hub and PwC conducted a survey of the gas industry and categorized the workforce into three groups based on skill and training gaps:

(1) Green roles: Jobs similar to current gas industry positions, such as chemical, civil, and electrical engineers, grid connection engineers, and specialist technicians.
(2) Orange roles: Jobs similar to current gas industry roles but requiring additional training, including general gas and electrical fitters, plumbers, electricians, marine engineers, plant operators, safety officers, and managers.
(3) Red roles: Jobs not currently performed by gas workers, requiring specialized training, such as welders, industrial gas fitters, technicians, heavy-duty fitters, truck drivers, machinery operators, and stevedores.

2.1.13. Availability of, or potential for, water (recycled & desalinated)

The use of recycled water and desalination in hydrogen production offers a promising solution to meet the high-water demands associated with the process. At present, hydrogen production consumes approximately 1.5 billion cubic meters (m^3) of freshwater, representing less than 5% of the total water usage in the energy sector. The global capacity of desalination plants has grown significantly, with an installed capacity of approximately 145 million m^3 per day, nearly double that of 2010 [2]. The water demand for hydrogen production is influenced by three main factors: the production process itself, cooling requirements, and the form in which hydrogen is stored or transported. However, each project is unique, and various project-specific variables can significantly impact the overall water demand [21].

2.1.14. Opportunity for co-location with industrial ammonia production and future industrial opportunities

Ammonia is a widely recognized substance with extensive industry experience. Globally, Ammonia is exported from 38 ports and imported through 88 ports, with six ports managing both export and import activities [20]. As demand for green molecules grows (until cost parity between green and grey ammonia is reached), some of this demand for green ammonia is expected to come from fertilizer plants. In addition to domestic needs, export opportunities are likely to arise from major demand centers such as the EU, Japan, and Korea. Consequently, a greenfield green ammonia plant should be strategically located to meet both domestic and export demands[21]. H2Global has announced that Fertiglobe has won its inaugural pilot auction for renewable ammonia. The Fertiglobe project will establish a supply chain connecting the Suez Canal Economic Zone to the Port of Rotterdam and will be powered by 273 MW of new renewable electricity generation. [22].

2.1.15. Interest (projects, priority ports, state development areas, politics etc.)

State government departments recognize the economic development potential of the hydrogen energy sector. However, reaching early consensus on initial investment priorities is crucial to maintain national competitiveness in global markets and avoid dilution of efforts. Certain countries, such as Brazil, have begun exploring the potential of their domestic markets, with Brazil particularly focused on utilizing low-emissions hydrogen for fertilizer production [2].

2.1.16. Shipping distance to target market

Extended shipping distances will drive up costs, leading to a higher landed price of hydrogen per kilogram in export markets. In 2022, several green shipping corridors were announced, where zero- emission solutions are implemented along key maritime trade routes [18]. "There is no silver bullet" For mass hydrogen transport, each alternative performs more effectively than the others depending on specific combinations of distance and hydrogen mass flow rates [24]. There are four attractive options for hydrogen transport: liquid hydrogen, ammonia, and liquid organic hydrogen carriers (LOHC), all of which use shipping, and compressed hydrogen via pipelines [23].

2.1.17. Availability of demand-based infrastructure (i.e., refueling stations)

Ports can become central "hubs", both on the port side for the bunkering of ships and the refueling of handling equipment, and on the land side for the refueling of trucks, trains, buses and cars [24]. In 2017, there were approximately 320 operational hydrogen refueling stations (HRS), increasing to 375 in 2018 and 470 in 2019. By the end of 2019, Asia led with over 200 operational stations, primarily in Japan. Europe ranked second with 185 stations, with Germany alone having 81. The United States had around 70 stations [25].

3. RESEARCH METHODOLOGY

The research methodology is designed to employ primary and secondary data to develop the conceptual frame work for Egypt hydrogen Hub as illustrated in Figure 4. The primary data is obtained based on the main variables for establishing a green energy logistic hub compiled by reviewing the literature and recent reports. Secondary data were extracted from interviews with experts in the field of energy. By combining the primary and secondary data, the conceptual framework is conducted as in Figure 4

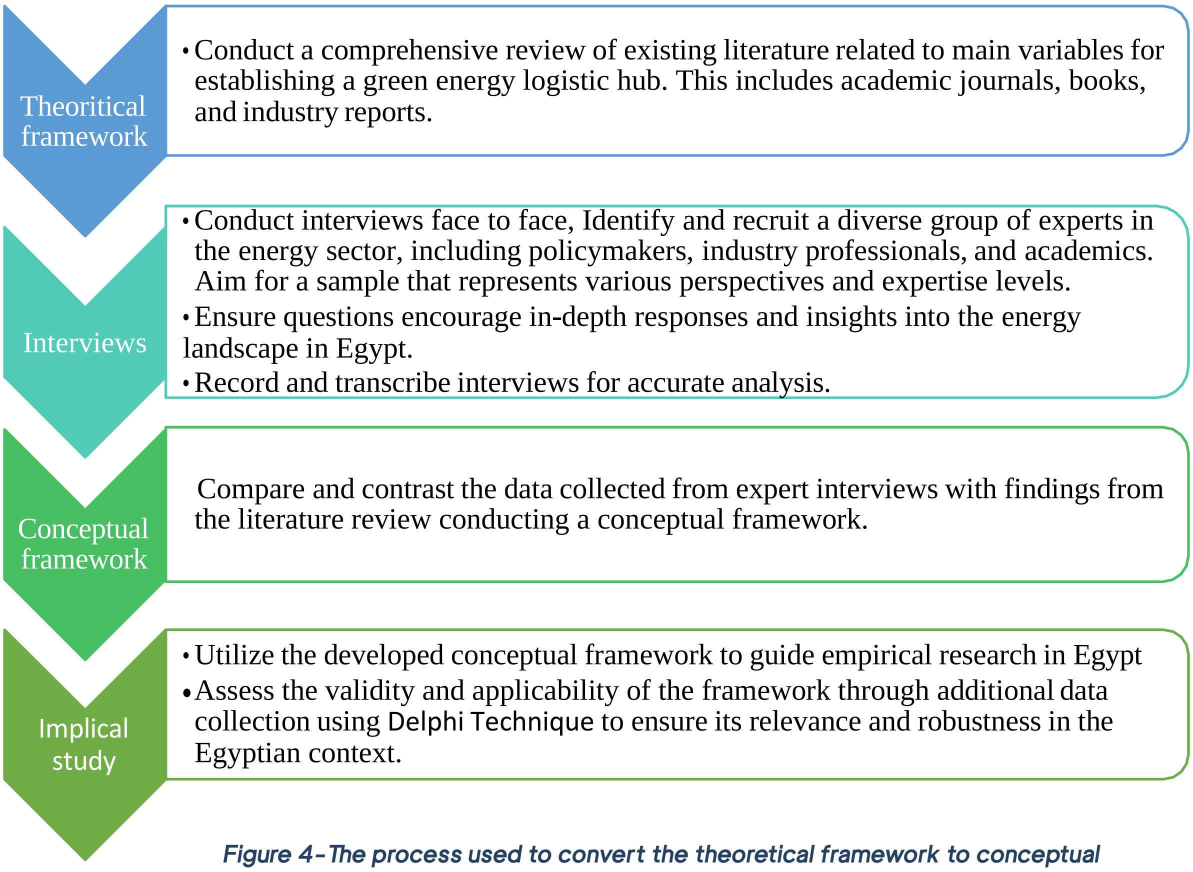

Figure 4-The process used to convert the theoretical framework to conceptual

4. Interview Findings

Several meetings were conducted with experts and officials in the energy sector as in Table 2 in A2. The interviews explored various topics as in appendix A1 including part one: Current Situation, part two: Obstacles and Challenges, Part 3: Functions needed in the Platform, Part 4: verifying the research theoretical framework, interviews was conducted face to face for about an hour ,where discussion took place with each interviewee according to the relevant part of theoretical framework allowing for in-depth discussions tailored to assess the current situation of the Egyptian market to host Egyptian hub for energy, verifying the theoretical framework developed based on literature review in order to convert it to conceptual framework to be tested in the Egyptian context and identifying determinants of establishing a global green energy logistic hub.

4.1. The current situation

based on interviews responses Egypt has recently revealed its plans to produce green hydrogen, with the goal of becoming a leading exporter. These initiatives are in line with the global shift toward decarbonization and the adoption of renewable energy sources. The country's hydrogen strategy divides its goal for the sector into three stages:

(1) **Pilot Projects 2022** (Building on Egypt's hydrogen experience the pilot projects will lay the foundations for the developing low carbon hydrogen economy and export market. Providing close support for initial projects, and establishing a fit for purpose governance structure)

(2) **Scale Up 2030**(Securing market position in the growing hydrogen economy, using the lower costs for hydrogen to support the wider decarbonization of Egypt replacing grey hydrogen. Scaling up hydrogen production to the GW scale and beyond)

(3) **Full Market Implementation 2040** (Maintain market position in the low carbon hydrogen economy. Using hydrogen across society to support decarbonization and secure Egypt's low carbon future in industry and transport).

Based on the hydrogen production and uses forecast included in the preceding analysis, the following indicators and metrics are proposed [3]:

4.1.1. If having a Central level of ambition

By 2030

- Progress with the implementation of signed MoUs for hydrogen production
- Overall hydrogen production capacity (13 GW) and the corresponding renewable energy capacity (19 GW)
- Low carbon hydrogen uses in industry (ammonia and steel production), presented in % or tons.

By 2040

- Overall hydrogen production (48 GW) and the corresponding renewable energy capacity (72 GW)
- Global leadership in the hydrogen export market (5% / 3.5 million tons/year)
- Low carbon hydrogen uses in industry (ammonia, methanol and steel production, refineries, heavy-duty transport applications), presented in % or tons
- Contribution to GDP growth by an estimated USD 10-18 billion and job creation by approximately 100 thousand new posts

4.1.2. If having a High (Green) level of ambition

By 2030

1. Progress with the implementation of signed MoUs for hydrogen production
2. Overall hydrogen production capacity (27 GW) and the corresponding renewable energy capacity (41 GW)
3. Low carbon hydrogen uses in industry (ammonia and steel production), presented in % or tons.

By 2040

1. Overall hydrogen production (76 GW) and the corresponding renewable energy capacity (141 GW)
2. Global leadership in the hydrogen export market (8% / 5.6 million tons/year).
3. Low carbon hydrogen uses in industry (ammonia, methanol and steel production, refineries, heavy-duty transport applications), presented in % or tons.
4. Contribution to GDP growth by an estimated USD >18 billion and job creation by over 100 thousand new posts.

As the international response, there is currently no unifying law in Egypt that specifically applies to hydrogen projects. Over time, regulations and national strategies focused on hydrogen and related technologies will be required to manage the production, storage, and transportation of hydrogen [27]. Egypt affirmed its transition to clean energy by revising its Nationally Determined Contribution (NDC) in June 2023, it states the goal of installing additional renewable energy capacity to raise the share of renewable electricity generation in the energy mix to 42% by 2030, moving the target five years earlier than the previous 2035 deadline [26]. In recent years, Egypt has implemented various regulations and policies to promote investment in renewable energy. These include the implementation of a feed-in tariff and the provision of both tax and non-tax incentives for renewable energy projects [27], For qualifying projects, up to 30% of the workforce may be foreign, 70% of the investment cost must come from foreign investments, and at least 20% of the project components must be produced locally. The government has designated 41,700 km^2 for renewable hydrogen production. Additionally, it aims to guarantee the financial obligations of the government off-taker while gradually phasing out subsidies on traditional fuels [2]. Egypt has around 2850 MW of existing hydropower capacity, which supplies approximately 7.2% of the total Egyptian power generation, The strategy projects that the hydrogen economy will grow sevenfold by 2050, The benefits to Egypt in achieving the vision [3]:

(1) Economic: Benefit The low carbon hydrogen economy is expected to be at least double the current demand, obtaining a significant proportion of the market will provide a major boost to Egypt's GDP in the order of 10-18 billion USD by 2040.
(2) Jobs: it is expected that over 100,000 jobs will be created, a high proportion being highly skilled. With the right training, the domestic workforce will take many of these. It is estimated that each 1000 MW facility would require a workforce of around 750 personnel.
(3) Energy Security: An increase in hydrogen produced locally will provide increased energy security to Egypt, with less reliance on petroleum imports. Decarbonization The development of the hydrogen economy will not only help Egypt decarbonize but enable Egypt to support decarbonization globally [3].

Milestone Achievements [28]:

- November 2022: Signing of Egypt's first green hydrogen facility in the SCZONE.
- August 2023: Launch of Egypt's first green bunkering operation in East Port Said.
- September 2023: Export of the first green ammonia shipment to India from Egypt's green hydrogen facility.
- November 2023: Fertiglobe made the first shipment of certified renewable ammonia from its Egypt plant.

4.2. Obstacles and Challenges

Based on interviews responses, Research and development, supply chain expansion, and new deployments will be necessary to support the widespread growth of hydrogen demand. This is due to hydrogen's relatively low volumetric energy density, which results in substantial costs for its transportation, storage, and delivery to end-users, leading to energy inefficiencies when used as an energy carrier. The obstacles to make a hydrogen powered locomotive in Egypt summarized in [29]:

(1) High cost of equipment needed to produce green hydrogen.
(2) A lack of off-takers and supply chain risks present financial and scalability challenges.
(3) The effects of green hydrogen projects on water and land resources.

(4) Infrastructure is required to enable the transport of hydrogen from production sites to end-use locations.
(5) By 2030, all sectors under the European Union Emissions Trading System will be included in the Carbon Border Adjustment Mechanism (CBAM).
(6) Future demand for green hydrogen is not guaranteed.

4.3. Functions needed in the Platform

Based on interviews responses, it has been found that there are different criteria based on the assumption of production volume for local consumption and/or export purposes. That should be specified for the investor. So that whenever having a developer to manage a hub, these items based on condition of the port should be considered:

- The Battery Limits which known as ISBL (Inside Battery Limits) in that project.
- The water required for hydrogen production actors such as water source quality, cooling methods, water treatment methods, climatic conditions, the hydrogen production technique and the hydrogen carrier conversion process all play a vital role in the hydrogen production process. Additionally, the components and capacity of the hydrogen generation plant are essential considerations
- The life cycle assessment (LCA) of hydrogen from water electrolysis, including PEM (proton exchange membrane) electrolysis and other types of electrolysis, evaluates the environmental impact of hydrogen production across its entire life cycle.
- The plant's Electricity consumption.
- The outlet hydrogen concentration (Specs.) Pressure, temp, impurities, O2 traces.
- The capacity of downstream Ammonia production unit.

4.3.1. Verifying the research theoretical framework

All experts agreed on the importance of the points mentioned above with regard to energy sector, and some suggested merging similar criteria. Finally, by analysis and combine the expert feedbacks, it has been found that all criteria have been grouped into three main categories named Renewable energy source, Infrastructure and Operational, which lead to concluding a new structure for establishing a green energy logistic hub which called the conceptual framework as shown in Figure 5 and it will be described in section 5.

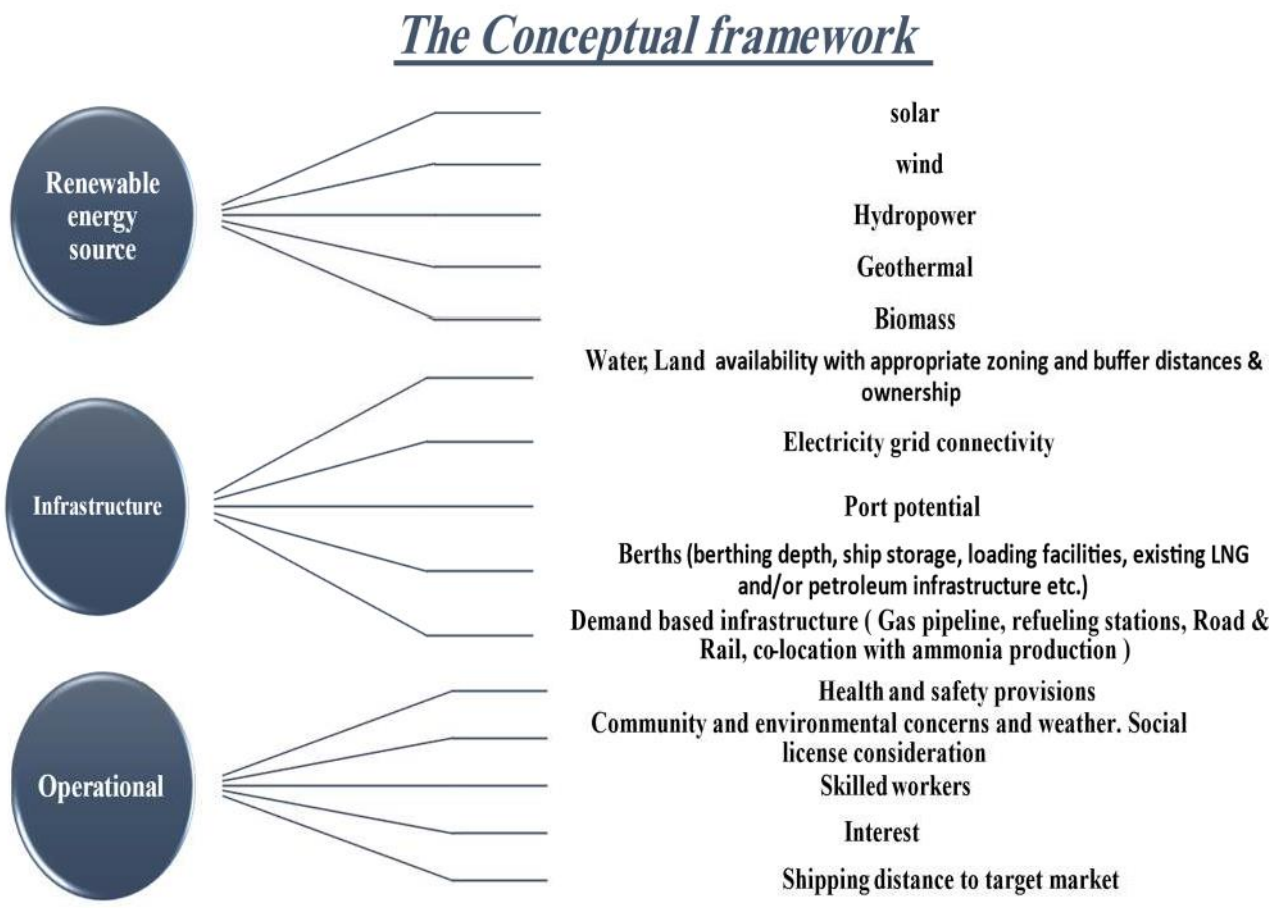

Figure 5- The Conceptual framework

5. The Conceptual framework

Experts emphasize the importance of integrating variables that serve similar functions or fulfill complementary roles within the theoretical framework, environmental considerations should be aligned with economic and social factors to create a holistic understanding of their interdependencies. recognizing that sustainable practices not only benefit the environment but also enhance economic viability and social acceptance. Similarly, demand-based infrastructure should be closely integrated with essential elements required for a green logistics hub. This includes factors such as the availability of gas pipelines, efficient road and rail networks, and strategic proximity to industrial ammonia facilities, which together facilitate seamless operations and support sustainable practices.

Furthermore, the availability of water resources whether recycled or desalinated must be assessed in conjunction with land availability. This is crucial, as regulations in many countries often intertwine these two resources, reflecting a broader understanding of resource management. also, the distinction between types of water is less critical than the processes employed to obtain demineralized water, underscoring the need for a nuanced approach to resource utilization. As illustrated in Figure 5, all experts unanimously confirmed the significance of the identified criteria, which were prioritized according to their importance. The criteria are categorized into three main groups: Renewable energy source, Infrastructure and Operational. **Renewable energy source** the presence of renewable energy sources such as wind, solar, geothermal, hydropower, and biomass in any region offers immense opportunities and potential for developing impactful projects. These projects can generate eco-friendly and sustainable power, significantly reduce greenhouse gas emissions, and are crucial for fostering a low-carbon economy while ensuring energy security and environmental protection. **Infrastructure** encompasses essential elements such as water supply, land availability, electricity grid connectivity, port potential, berths, and demand-based infrastructure. Each of these components plays a critical role in establishing a functional green energy logistics hub. For instance, adequate water supply is necessary for various operational processes, while land availability ensures that there is sufficient space for development. Electricity grid connectivity is crucial for integrating renewable energy sources, and the potential of the port itself, along with the availability of berths and gas pipelines, facilitates efficient logistics and energy distribution. **Operational** criteria include health and safety provisions, community and environmental concerns, weather considerations, social license, availability of skilled workers, interest, and shipping distance to the target market. Health and safety provisions are paramount to ensure the well-being of workers and local communities. Addressing community and environmental concerns is essential for gaining social license, which reflects the community's acceptance of the project. Furthermore, having a skilled workforce is vital for the operational efficiency of the logistics hub, while understanding the interests of various stakeholders or state can enhance collaboration and support. Lastly, the shipping distance to target markets influences logistics costs and overall operational effectiveness.

6. CONCLUSION

A conceptual framework for establishing hydrogen hub in Egypt ports is developed by combining the theoretical and empirical studies with the expert interviews feedbacks. The essential variables that affect the establishing of a hydrogen hub has been analyzed. The expert feedback about the priorities of these variables in Egypt has been conducted. Hence, several steps are required to develop a hydrogen hub. Stakeholders must conduct detailed assessments based on specific site considerations, to determine the feasibility and optimal development of the hub. Building upon the conceptual framework established, further studies will conduct an in-depth analysis of the feasibility of implementing these key variables at Gargoup Port. This comprehensive evaluation will assess the port's readiness and capacity to integrate the critical infrastructure and operational criteria necessary for a successful green energy logistics hub.

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A. Appendix

A1. Interview Protocol

Title

Converting Gargoup Port into a Global Green Energy Logistic Hub for Production and Exporting.

Purpose:

- To assess the current situation of the Egyptian market to be Egyptian hub for clean energy.
- To verify the theoretical framework developed based on literature review in order to convert it to conceptual framework to be tested in the Egyptian context.
- To identify determinants of establishing a global green energy logistic hub.

Participants:

The interview will be conducted with some of the experts in Hydrogen industry sector:

- Sczone (Suez Canal Economic Zone).
- The Sovereign Fund of Egypt.
- Fertiglobe company.
- Scatec company.
- New and renewable energy Authority.
- Port Authority.

Introduction:

Thanks for the opportunity to interview (name of expert in company or authority).

Interview today is mainly concerned with assessing the current situation of the Egyptian market to host Egyptian hub for energy, verifying the theoretical framework developed based on literature review in order to convert it to conceptual framework to be tested in the Egyptian context and identifying determinants of establishing a global green energy logistic hub. This discussion will take approximately 1 hour. Anything you say here will be held in strict confidence.
Thank you again for taking time out of your busy day. I look forward to hearing from you again soon

Questions:

The following questions will be asked in Sequence:

A) Part 1: Current Situation

- What are the current strengths, opportunities, threats, weaknesses of Egypt to be one of the largest exporters of clean Hydrogen in the region?
- What are the economic, social and environmental benefits from producing and exporting clean Hydrogen in Egypt?
- What are the main determinants to establish a global green energy logistic hub?

B) Part 2: Obstacles and Challenges

- What are the obstacles (besides infrastructure issues) to making a hydrogen powered locomotive in Egypt?
- How can Egypt overcome those obstacles?
- What is a hydrogen economy? What are the obstacles for hydrogen to become a cheap future fuel?
- Is it technically and economically feasible to transform ships to use hydrogen as fuel?
- What are challenges for shipping hydrogen and possibility for bunkering in ports?

C) **Part 3: Functions needed in the Platform.**

- What are the Battery Limits which known as ISBL (Inside Battery Limits) in that project?
- What is the water required for hydrogen production, Water source quality, water treatment method, climatic conditions, the hydrogen production method, the cooling method, and the hydrogen carrier conversion process?
- What are the Components & Capacity of Hydrogen Generation Plant?
- What is the Life cycle assessment of hydrogen from water electrolysis (PEM proton exchange membrane) in the future energy systems? and also from the different types of Electrolysis?
- what is the plant's Electricity consumption?
- What is the outlet hydrogen concentration (Specs.) Pressure, temp, impurities, O2 traces?
- what is the capacity of downstream Ammonia production unit?

D) **Part 4: verifying the research theoretical framework**

- According to the literature review the following dimensions as in Table 1 [1] has been identified as main requirements for establishing energy logistics hub do you agree or not?
- What is the most important dimension from your point of view? And Periodized them?

Table 1-Criteria relevant to assessing the viability of production and export hubs (theoretical framework)

Dimension	
1	Health and safety provisions
2	Environmental considerations
3	Economic and social considerations
4	Water availability
5	Land availability with appropriate zoning and buffer distances & ownership terminals, storage, solar PV, industries etc.)
6	Availability of gas pipeline infrastructure.
7	Grid connectivity
8	Road & rail infrastructure (site access)
9	Community and environmental concerns and weather. Social license considerati
10	Berths (berthing depth, ship storage, loading facilities, existing LNG and/or petro infrastructure etc.)
11	Port potential (current capacity & occupancy, expandability & scalability)
12	Availability of, or potential for, skilled workers (construction & operation)
13	Availability of, or potential for, water (recycled & desalinated)
14	Opportunity for co-location with industrial ammonia production and future indu opportunities
15	Interest (projects, priority ports, state development areas, politics etc.)
16	Shipping distance to target market
17	Availability of demand-based infrastructure (i.e., refueling stations)

Conclusion:
What I have heard you saying............. , did I summarize your words correctly? Is there anything you would like to add or modify?

Thank you for your participation.

A2. Interview Description

As in Table 2 several meetings were held with experts and officials in the field of energy and the meeting was for about an hour ,where discussion took place with each interviewee according to the relevant part of theoretical framework to assess the current situation of the Egyptian market to host Egyptian hub for energy, verifying the theoretical framework developed based on literature review in order to convert it to conceptual framework to be tested in the Egyptian context and identifying determinants of establishing a global green energy logistic hub

Table 2- list of interviews with experts and officials in the field of energy

Interviewee	Date	Duratio n	place
1 DR. Maged Mahmoud, Director of			Regional Center for
Projects and Technical Affairs and			Renewable Energy and
Lead RE Advisor at Regional	27/06/2 024	1 hour	Energy Efficiency
Center for Renewable Energy and			(RCREEE)
Energy Efficiency (RCREEE)			
2 DR. Ahmed Samy from the ministry			ministry of electricity and
of electricity and renewable energy	02/07/2 024	1 hour	renewable energy
3 Dr. Mohamed El-Khayat, Executive			The New and Renewable
Chairman of the New and	08/07/2 024	1 hour	Energy Authority
Renewable Energy Authority			(NREA)
(NREA)			
4 Rear Admiral Dr. Ashraf Nabil El-			Egyptian Navy
Assal, Director of Egyptian Navy	09/07/2 024	1 hour	Hydrographic
Hydrographic Department			Department
5 Prof. Adil Khalil, professor in the			
Mechanical Power Engineering	16/07/20 24	1 hour	Faculty of Engineering,
Department at Cairo University			Cairo University
(FECU)			
6 Dr. Ali Mohamed Abdel-Fattah,			
Undersecretary for Minister's Offic			Ministry of electricity and
e Affairs Ministry of Electricity	13/08/20 24	1 hour	renewable energy
and Renewable Energy			
7 Eng. Ahmed Mahrous Elbakly,			
general manager of Energy			Ministry of electricity
Researches and studies	12/09/20 24	1 hour	and Renewable Energy

Ministry of electricity			
and Renewable Energy			