

Strategic Assessment of Egyptian Ports for Green Energy Logistics Hub: The Case for Gargoub Port

Shady Magdy Mahmoud ¹, Mostafa Abdel Geliel ², and Sara El Gazzar ³

¹ Arab Academy for Science, Technology and Maritime Transport (AASTMT), The Maritime Postgraduate Studies Institute, Egypt

² Arab Academy for Science, Technology and Maritime Transport (AASTMT), College of Engineering and Technology, Energy Research Unit, Electrical and Control Engineering, Alexandria, Egypt

³ Arab Academy for Science, Technology and Maritime Transport (AASTMT), College of International Transport and Logistics, Alexandria, Egypt

shadymagdy026@gmail.com, mostafa.geliel@aast.edu, sara.elgazzar@aast.edu

Abstract

The European Union's goal to produce 10 million tons of renewable hydrogen annually by 2030 presents a strategic opportunity for Egypt to become a key supplier. This study evaluates four Egyptian ports (Damietta, East Port Said, Sokhna, Gargoub) for their suitability as hydrogen export hubs, informed by expert interviews with stakeholders in the energy and maritime sectors via a three-round Delphi. A Weighted Evaluation Matrix Framework was applied to compare the four ports across 16 criteria grouped into three categories: renewable energy sources, infrastructure, and operational readiness. To ensure analytical consistency, criteria with uniform characteristics across all ports were treated as constants. The research introduces a revised conceptual framework that includes wave energy as part of the renewable energy assessment. The analysis reveals that Gargoub Port holds the highest potential with a composite score of 7.2, due to its exceptional solar (842.7 GW) and wind (40 GW) resources, ample space for expansion, and geographic advantage for European exports. Ain Sokhna and East Port Said follow, benefitting from robust logistics and infrastructure development, while Damietta's strength lies in container throughput and industrial integration. The analysis covers port infrastructure, development plans, and compliance with hydrogen and ammonia export standards. The findings offer Gargoub as the most viable site for exporting green hydrogen derivatives and call for further research into operational and financial models to support the full realization of Gargoub Port as a regional green energy hub.

Index-words: Green hydrogen, Green ammonia, Hydrogen hubs, Weighted evaluation matrix, Solar potential, Wind potential, EU hydrogen strategy, Conceptual framework.

I. Introduction

Green hydrogen has emerged as a key component in the transition toward a sustainable energy future because of its high energy content and its ability to generate power in fuel cells without producing carbon emissions [1]. In recent years, global interest in green hydrogen has grown substantially, driven by its potential to deliver economic benefits such as generating export revenues, fostering the development of new industries, and creating employment opportunities. Additionally, the adoption of green hydrogen facilitates the decarbonization of multiple sectors, including

electricity generation, heating, transportation, and industry. Beyond environmental advantages, it enhances the resilience of energy systems and expands energy choices available to consumers [2]. The European Union has set an ambitious target to scale up renewable hydrogen production to 10 million tons annually by 2030, coupled with a similar target for hydrogen imports. This objective presents a significant opportunity for Egypt to become a key supplier of renewable hydrogen to the European market. However, Egypt will face strong competition from other countries in the Middle East and North Africa (MENA) region, such as Morocco, Algeria, Saudi Arabia, and Oman, as well as from

emerging exporters like Namibia [3]. Globally, current hydrogen demand stands at approximately 90 million tons, comprising around 70 million tons of pure hydrogen and an additional 20 million tons of hydrogen contained within carbon-based synthesis gas [4]. According to the IEA hydrogen database, over 448 projects are currently underway across 48 countries, spanning different stages of development [5]. Egypt's domestic hydrogen demand accounts for roughly 2% of the global total [3]. The European Commission projects that electricity will meet approximately 50% of the final energy demand by 2050, a significant increase from the current 23%. To support this rising demand alongside the large-scale deployment of renewable energy sources, Europe's electricity grid capacity will need

to expand by 47% by 2030 and by 144% by 2040. Additionally, the development of the hydrogen backbone is anticipated to exceed 50,000 kilometers by 2040, with around 60% of the network expected to be repurposed from existing infrastructure and 40% constructed as new pipelines, according to various industry stakeholders [6]. As illustrated in Figure 1, the limited availability of renewable energy sources and rising energy demand, Europe and Japan are expected to become net importers of energy. In contrast, Africa, South America, and MENA countries are projected to emerge as key energy exporters due to their abundant renewable resources. Meanwhile, Australia and China may achieve energy self-sufficiency, leveraging their domestic renewable energy capabilities [7].

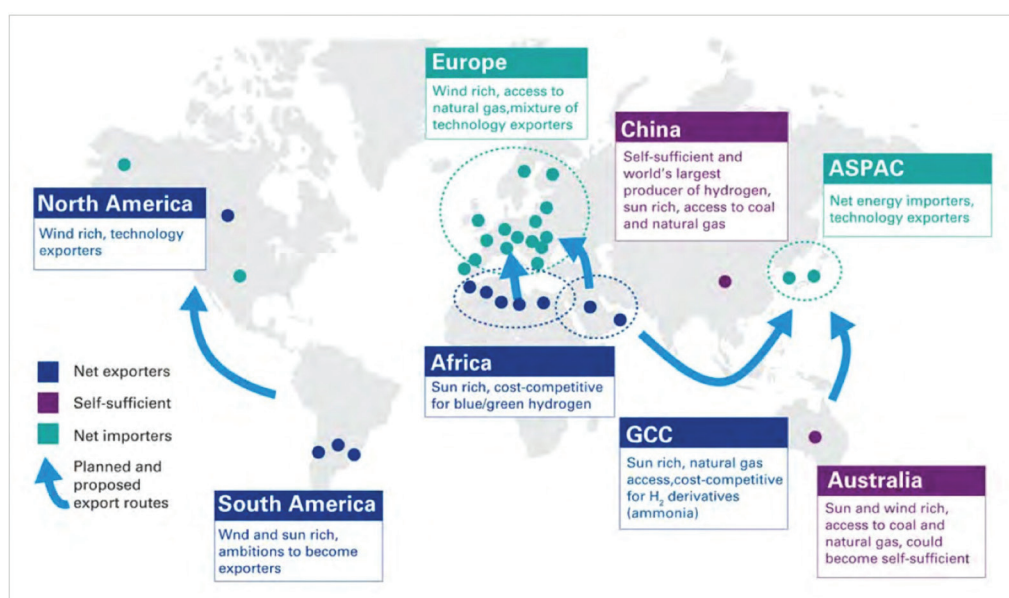


Figure 1: Global hydrogen hot spots and corridors [7].

Greece is seeking to establish itself as a major hydrogen hub within Europe. One prominent initiative advancing this goal is the 'White Dragon' project cluster, as shown in Figure 3, which envisions the large-scale production of green hydrogen in Western Macedonia using solar-powered electrolysis. The distribution of the produced hydrogen is planned to be facilitated through the existing Trans Adriatic Pipeline (TAP) [8]. Another geopolitical strategy placing Greece at the center of regional energy dynamics is being promoted with the Support of Saudi Arabia. This initiative envisions the large-scale import of hydrogen from the Middle East and North Africa (MENA) to Europe via Greece. It aligns with the European Union's objective, articulated amid the ongoing war in Ukraine, to import 10 million tons of renewable hydrogen annually by 2030 [8]. Hydrogen imports into Europe

are not confined to pipeline transport; they can also be carried by ship, either in pure form or through various hydrogen carriers. As illustrated in Figure 2, potential maritime import routes to the EU market span North America, Latin America, the Middle East, North Africa, and South-West Africa, mainly via the North Seas Corridor. The feasibility of these routes, however, will largely rely on significant investments in building new infrastructure and upgrading current assets. Critical elements include systems for the transport, shipping, reconversion (or cracking), and distribution of both liquefied hydrogen (LCH) and renewable hydrogen derivatives [6]. As illustrated in Figure 3, the North Tyrrhenian Ports Network, situated along the western coast of Tuscany, comprises the ports of Livorno, Piombino, Capraia, Portoferraio, and Rio Marina, all marked with red placemarks. This network is pursuing the

development of a green hydrogen hub, building upon its established expertise and infrastructure across the hydrogen value chain to support the decarbonization of industrial applications. Within this region, the transport sector is projected to be the primary consumer of hydrogen, accounting for 56% of total demand by 2050. The Port of Livorno is strategically positioned to function as a gateway for hydrogen and derivative imports, enabling further distribution to the European hinterland. Additionally, its central location in the Mediterranean enhances its role as a logistical hub, connecting hydrogen supply chains from the Middle East and North Africa (MENA) to Europe. Similarly, the Port of Piombino is well-suited to become a hydrogen energy hub, facilitating imports from Latin America (LATAM), North Africa, and the Middle East, and linking them to key industrial regions in Northern Italy and Bavaria, marked with a purple placemark. Other notable European ports with hydrogen ambitions include the Port of Klaipėda, Port of Antwerp-Bruges, and Port of Rotterdam (indicated with blue placemarks). The Port of Klaipėda anticipates hydrogen demand to rise from 554 tonnes in 2030 to 3,600 tonnes in 2040, reaching 6,700 tonnes by 2050, an 86% increase compared to 2040. The Port of Antwerp-Bruges has adopted a clear commitment to a net-zero transport future, actively encouraging partners and concessionaires to engage in the green transition. Meanwhile, The Port of Rotterdam has set ambitious hydrogen goals: it aims to import 20 million tonnes (Mt) of hydrogen annually by 2050, in addition to producing 2 Mt locally [9].

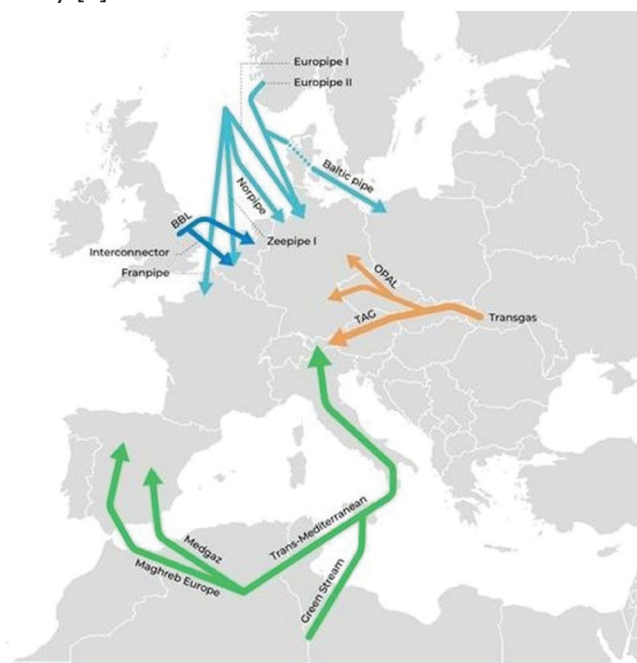


Figure 2: Hydrogen imports corridors via pipelines [6].

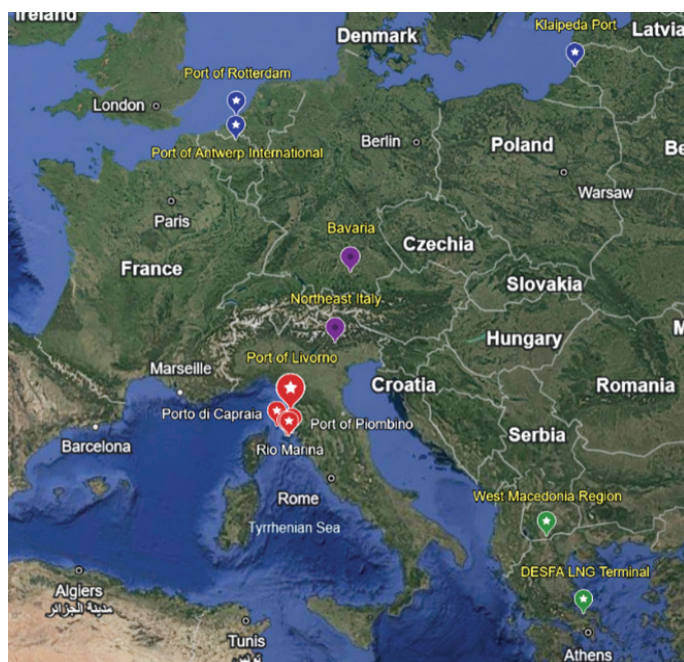


Figure 3: Potential ports for importing hydrogen to Europe. (Source: Author, based on strategic port initiatives and hydrogen infrastructure plans)

Egypt's Vision 2030 sets ambitious renewable energy targets, aiming for 42% of electricity to come from renewables by 2030 [10] and 60% of the overall energy mix, with \$40 billion allocated to green hydrogen projects. The government's Nexus of Water, Food, and Energy program also plans to add 10 GW of renewable capacity by year-end through a \$10 billion investment. To achieve these goals [11], so that wind energy will contribute 14%, hydropower 1.98%, photovoltaic (PV) solar 21.3%, and concentrated solar power (CSP) 5.52%, while conventional energy sources will make up 57.33%. Currently, this plan is under review by the Supreme Council for Energy, with proposed revisions targeting 33% renewable energy by 2025, 48% by 2030, 55% by 2035, and 61% by 2040. Additionally, Egypt plans to expand its renewable energy capacity from 3.2 GW in 2020 to 54 GW by 2035, alongside significant advancements in energy efficiency [7]. Egypt must prioritize energy self-sufficiency by expanding renewable generation, gradually replacing natural gas, and maximizing LNG exports to fund infrastructure. With strategic policies, investment, and international collaboration, Egypt has the potential to become a leading global clean energy hub [12]. As illustrated in Figure 4, a structured mapping process outlines the entities and sectors that could contribute to advancing the green hydrogen ecosystem across five key dimensions:

- Policy and Governance,
- Technical Support,

- c. Capacity Building,
- d. Private Sector Engagement,
- e. Financial Support,

These elements collectively play a crucial role in establishing Egypt as a competitive player in the global green hydrogen market [7].



Figure 4: Entities and sectors supporting the green hydrogen value chain in Egypt [7].

II. Case Study of Selected Egyptian Ports

Site selection for hydrogen hubs must weigh weather conditions, infrastructure, and production methods against end-use demands. Key factors include energy sources, feedstock, grid access, and logistics for domestic and export markets. Each location presents trade-offs, requiring early risk assessment during planning. Economic viability and strategic alignment are essential for identifying high-potential investment hubs [13].

A. Potential sites

Drawing upon insights from various ports and sites, as well as interviews conducted with energy sector experts and port authority representatives, four strategic Egyptian ports have been selected for evaluation as potential hubs for green energy logistics, as illustrated in Figure 5. These ports include Damietta Port, East Port Said Port, Ain Sokhna Port, and Gargoub Port. Each has been color-coded to enhance visual clarity: Gargoub Port is marked with a green placemark, highlighting its focal role in this study as an emerging candidate for green energy development. Damietta Port is marked in blue, East Port Said Port in red, and Ain Sokhna Port in yellow. The selection of these ports is based on their strategic

geographic positions, infrastructural capabilities, and connectivity to regional and international trade routes. Damietta Port is distinguished by its advanced container handling infrastructure and proximity to major industrial zones. East Port Said Port, situated at the northern entrance of the Suez Canal, is a key transshipment hub, serving as a vital node in global maritime trade. Ain Sokhna Port, located on the Red Sea, plays a central role in the energy and logistics sectors, particularly in liquefied natural gas (LNG) and petrochemical industries. Meanwhile, Gargoub Port, a developing facility on the Mediterranean coast, is being positioned as a new gateway for trade and energy projects. In addition to the Egyptian ports under review, several European ports have been identified as significant entry points for hydrogen imports. These include the Port of Klaipeda, Port of Antwerp-Bruges, Port of Rotterdam, Port of Livorno, and the Western Macedonia region ("White Dragon" project), each marked with orange placemarks. These ports are strategically linked to key industrial zones in Northern Italy and Bavaria, represented with purple placemarks, reinforcing their relevance within the broader hydrogen supply chain to Europe. Finally, a black line refers to a project known as the "GREGY-Elica Interconnector," which connects Sidi Barrani, Egypt, with Attica, Greece via a submarine electricity cable, designed to carry 100% green energy produced from renewable energy plants in Egypt.



Figure 5: Geographic locations of the selected Egyptian ports and maritime route to potential ports for importing hydrogen to Europe.

(Source: Author, based on strategic port initiatives and hydrogen infrastructure plans)

1. Damietta Port

Damietta Port, located near the Nile Delta and key Egyptian ports, serves as a strategic gateway for international trade and energy exports. Its 11.8 km² area and protective breakwaters support efficient access to major global shipping routes [14].

1.1. Geographical overview

1. Entrance channel:

Damietta Port features an 11.4 km, 15-meter-deep entrance channel with 18 illuminated buoys for safe navigation [15].

2. Breakwaters:

Damietta Port is secured by two breakwaters extending 1,640 m west and 750 m east for structural protection [16].

3. Port capacity:

The Port's maximum designed throughput capacity is estimated at 19.75 million tons annually, distributed across various cargo types. This includes 7 million tons of general cargo, 7.5 million tons of dry bulk, 3.9 million tons of liquid bulk, and 5.25 million tons of containerized cargo. In terms of container volume, the Port is capable of handling approximately 1.2 million TEUs (Twenty-foot Equivalent Units) per year. Operations are

conducted around the clock, organized into three daily shifts to ensure continuous service and operational efficiency [17].

4. Turning Dock:

Damietta Port's 500-meter-diameter turning dock enables efficient vessel maneuvering, with depths of 14.5 m at the container berth and 12 m at the general cargo berth [18].

5. Berths:

Damietta Port has 9 Km with a total of 36 berths plus service facilities, with a 16 m deep waterway and 15 m harbor basin, supporting large vessels and diverse cargo operations as follows [19]:

- (6) berths at Damietta Container Handling Company, 1450 meters long and 17 meters deep.
- (8) berths (Tahya Misr 1), with a length of 1970 meters and a depth of 18 meters.
- (4) berths (general cargo docks), 720 m long and 12 m deep.
- (3) berths (multipurpose docks), 680 m long and 17 m deep.

- Berth (liquid discharge), 225 meters long and 12 meters deep
- Berths (dry dock) with a length of 675 meters and a depth of 17 meters.
- Berths (grain), 600 m long and 14.5 m deep.
- (2) berths (multipurpose), 660 meters long and 15 meters deep.
- Specialized berth for trading gas derivatives (the United Company for Gas Derivatives), 300 meters long, and 14 meters deep.
- Specialized berth for trading liquefied gas (Damietta Natural Gas Liquefaction Company), 500 meters long, and 14.5 meters deep.
- Specialized berth for exporting methanol (Methanex Company), 300 meters long, and 14.5 meters deep.
- RoRo berths, berth No. 1, 60 meters long and 14.5 meters deep, berth No. 8, 60 meters long, and 12 meters deep.
- Berth (multipurpose), 90 meters long and 8 meters deep.
- River berth to receive river units and multipurpose, 340 meters long and 5 meters deep, with an equipped asphalt yard with an area of 50 thousand square meters, working as a rear outpost for operating the river port.
- In addition to two scaffoldings to supply ships with fuel, (the Petroleum Cooperative Society), as well as marine service platforms with lengths of approximately 550 meters.

1.2. Development and strategic significance of Damietta Port

Damietta Port is undergoing a comprehensive expansion plan that includes the construction of a new western breakwater stretching 5,400 meters and the establishment of a grain and cereal terminal with an 850-meter quay. The Port's navigational efficiency is being enhanced through dredging works to deepen the navigation channel to 19 meters and the turning basin to 18 meters. In addition, four tractor tugboats, each with a 70-ton bollard pull capacity. The development also features the Tahya Misr 2 multipurpose terminal, located behind the western breakwater, with a total quay length of 3,320 meters and cargo yards spanning 2.2 million square meters [20].

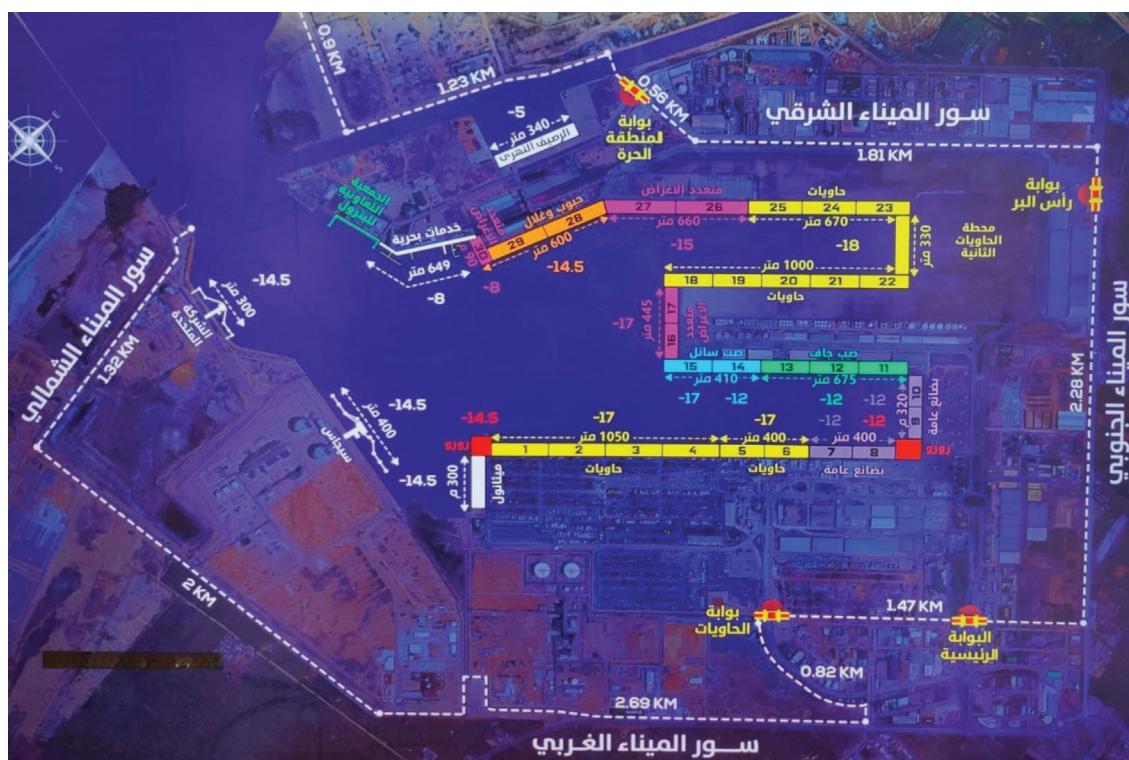


Figure 6: Dameietta Port development layout [20].

2. East Port Said Port

East Port Said Port, located at the northeastern entrance of the Suez Canal, serves as a vital global trade hub linking East and West. Bordered by key geographic and industrial zones, it is anchored by the Suez Canal Container Terminal to enhance Egypt's role in international shipping [21].

2.1. Geographical overview [22]

1. Entrance channel:

The Port's navigational channel extends approximately 9.1 kilometers (4.9 miles) with a depth of 18.5 meters, facilitating the passage of large, deep-draft vessels.

2. Breakwaters:

East Port Said Port is protected by two breakwaters: a 2.3 km eastern and a 5.6 km western structure, shielding it from sea conditions [23].

3. Port capacity:

East Port Said Port boasts a robust capacity across multiple cargo types, handles between 1.3 to 1.8 million tons of general cargo annually and 15.6 million tons of bulk cargo. Its Ro-Ro terminal accommodates up to 800,000 vehicles per year. Additionally, with current, under-construction, and planned developments combined, the Port's total container handling capacity reaches approximately 8.2 million TEUs annually [24].

4. Turning Dock:

The Port features a turning basin with a diameter of 950 meters and a depth of 18.5 meters at the container berth, allowing safe maneuvering of vessels within the harbor [23].

5. Berths:

East Port Said Port encompasses multiple berths totaling approximately 7.755 kilometers in length. These berths are designed to accommodate various cargo types and vessel sizes, enhancing the Port's capacity and operational efficiency.

- **Container Terminal:** The total area for the container terminal is 1.2 million m², and the annual capacity of the terminal amounts to 4.6 TEU, with an average capacity of 30 containers/hr /Crane [23].

(1) *CT1 Container Terminal:* Operated by APMT-Maersk Group (Suez Canal Container Terminal – SCCT), featuring 2.4 km of quay.

❖ **Phase I of Port Quay Development:** Covers approximately 5 km.

(1) *SCCT Expansion (CT2):* Quay length: 955 meters, Terminal area: 518,000 m²

(2) *Port Reception Facility:* Quay length: 100 meters, Area: 40,000 m²

(3) *Ro-Ro Terminal:* Quay length: 600 meters, Area: 225,000 m².

(4) *Multipurpose Terminal (Sky Logistics):* Quay length: 900 meters, Area: 374,000 m²

(5) *Grain Terminal (VALC):* Quay length: 500 meters, Area: 267,000 m²

(6) *CT3 Container Terminal (Planned):* Quay length: 1.5 km, Terminal area: 802,000 m²

❖ **Phase II Quay Development:** Approx. 6.3 km of additional quay under study to determine optimal use.

2.2. Development and Strategic Significance of East Port Said Port

East Port Said Port, established in 1999 with container operations starting in 2004, is a key part of the 145 km² East Port Said Zone under the SCZone master plan. As in Figure 7, the zone includes 63 km² of industrial space, 24 km² of logistics areas, and a port with 7.4 km of berths and a 950-meter turning basin. Facilities include two container terminals, a Ro-Ro terminal, a multipurpose terminal, and dry bulk handling. It offers full maritime services and a 4.4 km² logistics hinterland with warehousing and value-added services. Ranked 15th in the World Bank's 2021 index, it is a rising Mediterranean transit hub [22].

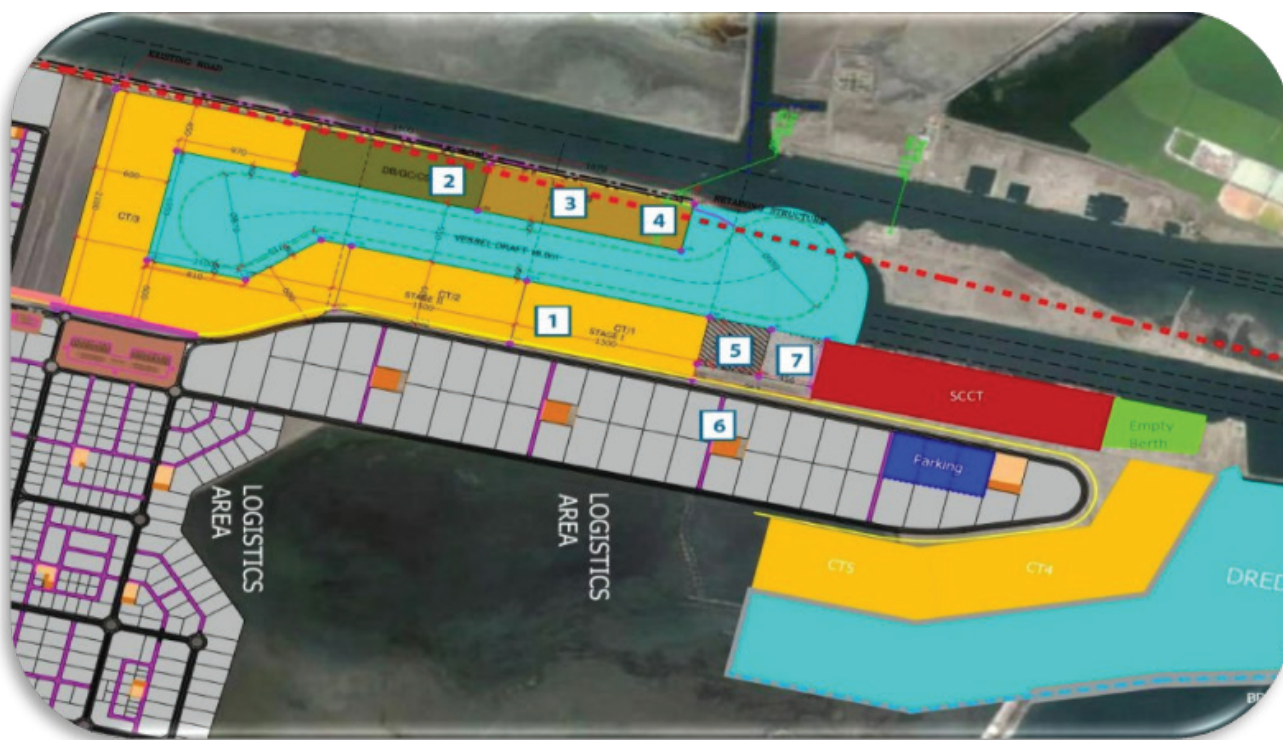


Figure 7: East Port Said Port development layout [22].

3. Sokhna Port

Sokhna Port, known as the “Port of the Century,” is Egypt’s first multipurpose hub developed under the B.O.T system, aiming to elevate the country’s global trade role. As a Third-Generation port, it supports diverse cargo operations with advanced technology and international-standard logistics [21].

3.1. Geographical overview

1. Entrance channel:

Sokhna Port’s entrance channel spans 3,650 meters in length and 250 meters in width, leading to a 560-meter-wide, 17-meter-deep turning basin.

2. Breakwaters:

While exact specifications are not disclosed, Sokhna Port is equipped with protective breakwaters to ensure safe and efficient maritime operations.

3. Port capacity:

Sokhna Port is designed to handle a maximum cargo capacity of 8.5 million tons annually. This includes 4.75 million tons of general cargo and 3.75 million tons of containerized cargo. The Port’s container handling capacity is approximately 400,000 TEUs per year, supporting its role as a key logistics hub on the Red Sea [25].

4. Turning Dock:

The turning basin within Sokhna Port has a diameter of 560 meters and a depth of 17 meters, facilitating the maneuvering of large vessels.

5. Berths [26]:

• Current development

- (1) Container terminal: 640,000 m²
- (2) Livestock terminal: 211,000 m²
- (3) Liquid bulk terminal: 400,000 m²

• Future expansion

- (1) Container terminal: 1,490,000 m²
- (2) RO RO Terminal Basin 2: 880,000 m²
- (3) Cruise Terminal Basin 2: 60,000 m²
- (4) Liquid Bulk Terminal Basin 3: 420,000 m²
- (5) Dry Bulk Terminal Basin 3: 445,000 m²
- (6) Container Terminal Basin 4: 815,000 m²
- (7) General Cargo Terminal Basin 4: 545,000 m²
- (8) Dangers Cargo Terminal Basin 5: 615,000 m²
- (9) Multipurpose Terminal Basin 5: 755,000 m²

3.2. Development and Strategic Significance of Sokhna Port

As in Figure 8, Sokhna Port is undergoing major upgrades, including four new basins, 18 kilometers of berths with 18-meter depth, and 9.6 million m² of trading yards, alongside 5.3 km² of logistics and commercial zones.

These are integrated with a 33-kilometer railway linked to Egypt's high-speed electric train network and a 17-kilometer, six-lane arterial road. To support expanded maritime operations, the Port will also feature 3,270 meters of new breakwaters [27]. DP World is developing the Sokhna Logistics Park, a 300,000 m² hub with an \$80 million investment to provide integrated supply

chain solutions. The first phase of the project is currently about 65% complete [28]. The Sokhna Logistics Park, strategically located 10 km from Sokhna Port, offers direct access to Greater Cairo, featuring bonded warehousing, cold chain storage, and customs services, with multimodal road and rail connectivity for efficient regional distribution [29].

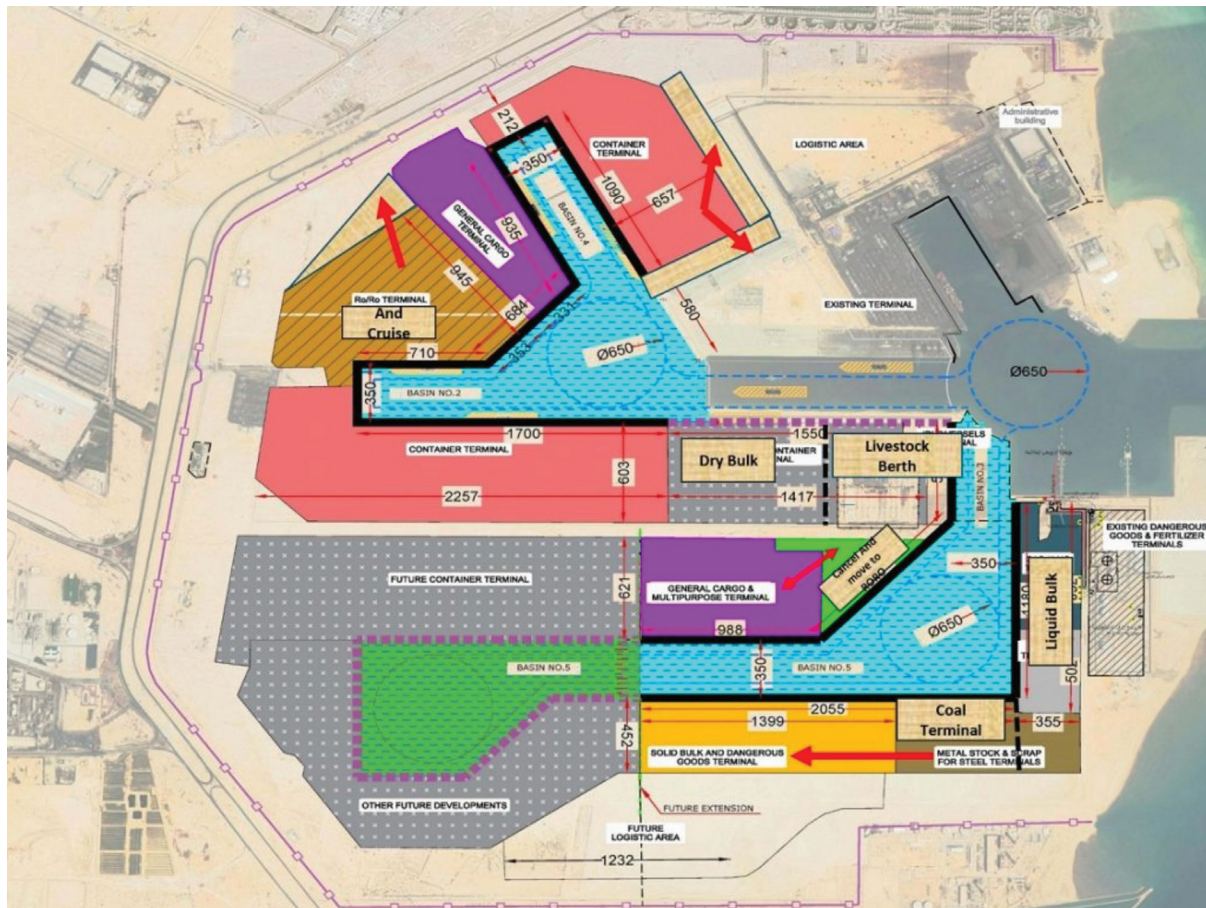


Figure 8: Sokhna Port development layout [52].

4. Gargoub Port

Gargoub Port, located 70 km west of Marsa Matruh, is a B.O.T. project spanning 2,169 feddans, featuring a 1,081-meter quay and a 450-meter turning basin. Strategically positioned as Egypt's nearest Port to Europe, it aims to become a major trade and tourism hub, generating around 30,000 jobs and boosting regional economic growth. Plans have been proposed to revitalize the region's economic potential through the reconstruction of new berths totaling 14 kilometers in length and 7 meters in depth, accompanied by cargo handling yards covering 7 square kilometers within a total development area of 10 square kilometers. Currently, limited maritime activity is taking place, with expectations of significant expansion as these development initiatives progress [30].



Figure 9: Gargoub Port updated satellite view (20/03/2025) with Coordinates (31°30'10"N 26°33'46"E).

4.1. Geographical overview

1. Entrance channel:

The Port targets a depth of 17 meters in front of the piers [31].

2. Breakwaters:

The eastern breakwater, stretching 2,770 meters, has been finalized. The construction of the main breakwater, which will extend 3,050 meters, is currently in progress.

3. Port capacity:

The Port is designed to handle 15 million tons of cargo annually. It has a capacity of 5 million TEUs (twenty-foot equivalent units) for container handling [21].

4. Turning Dock:

The turning basin within Gargoub Port has a diameter of a turning circle with an 18.5-meter depth.

5. Berths [32]:

• Current development

- (1) Container berths extending 970 m have been successfully constructed. [21].
- (2) General cargo berths measuring 360 meters and 670 meters were successfully constructed.

• Future expansion

- (1) Dry Bulk Terminal.
- (2) Multipurpose Terminal.
- (3) Cruise Terminal & Passenger Terminal (for Local, Regional & International Tourism).
- (4) Mediterranean Cruise Lines Hub & Departure/Arrival/Docking Port Station.
- (5) RORO Terminal.
- (6) Customs inspection building.
- (7) Station Building & Development of railway connecting Gargoub, Alexandria, and Saloum to Libya.
- (8) Liquid Terminal.
- (9) Touristic Port.

4.2. Development and Strategic Significance of Gargoub Port

The investment partnership between the Egyptian government and STX Corporation of South Korea encompasses several key development projects aimed at transforming the Gargoub Special Economic Zone into a strategic hub for trade, industry, and logistics. These projects include [33]:

- As in Figure 10, **Development of Gargoub Port and industrial logistics zone:**

Aligning with Egypt's national master plan, the project involves developing grain silos within the Port and its desert hinterland to meet Egypt's domestic needs and facilitate re-exports.

- **Automotive reassembly plant:**

Establishing a facility to reassemble used cars imported from South Korea and Japan, with the aim of re-exporting them to African markets.

- **Oil pipeline construction:**

Developing a petroleum pipeline connecting Libya to Gargoub Port, enabling the re-export of oil to European countries [34].

- **Container terminal at Gargoub Commercial Port:**

Building a container terminal dedicated to handling goods arriving from East Asia, with onward shipment to North and South America.

- **Logistics base and naval shipbuilding collaboration:**

Creating a logistics hub to support Egypt's shipping lines and partnering with Alexandria Shipyard to build naval vessels, starting with coastal patrol boats, with the potential to sell to third-party countries.

- **Residential expansion:**

Constructing a residential city as part of the future expansion of the Gargoub region to accommodate growing populations.

- **Tourism and entertainment areas:**

Developing tourist villages and entertainment zones to promote tourism in the region.

- **Agricultural land reclamation:**

Reclaiming land for agriculture, supporting industries such as oil production, and agricultural product packaging.

- **Textile factory:**

Establishing a textile manufacturing facility to contribute to Egypt's industrial sector. Support in establishing a private free zone, Support with land reservation, approximately 400 km² of renewables, and ~3 km² in Gargoub's

commercial Port. Support with the sale of
excess electricity, grid connection, and green

electricity certificates [35].

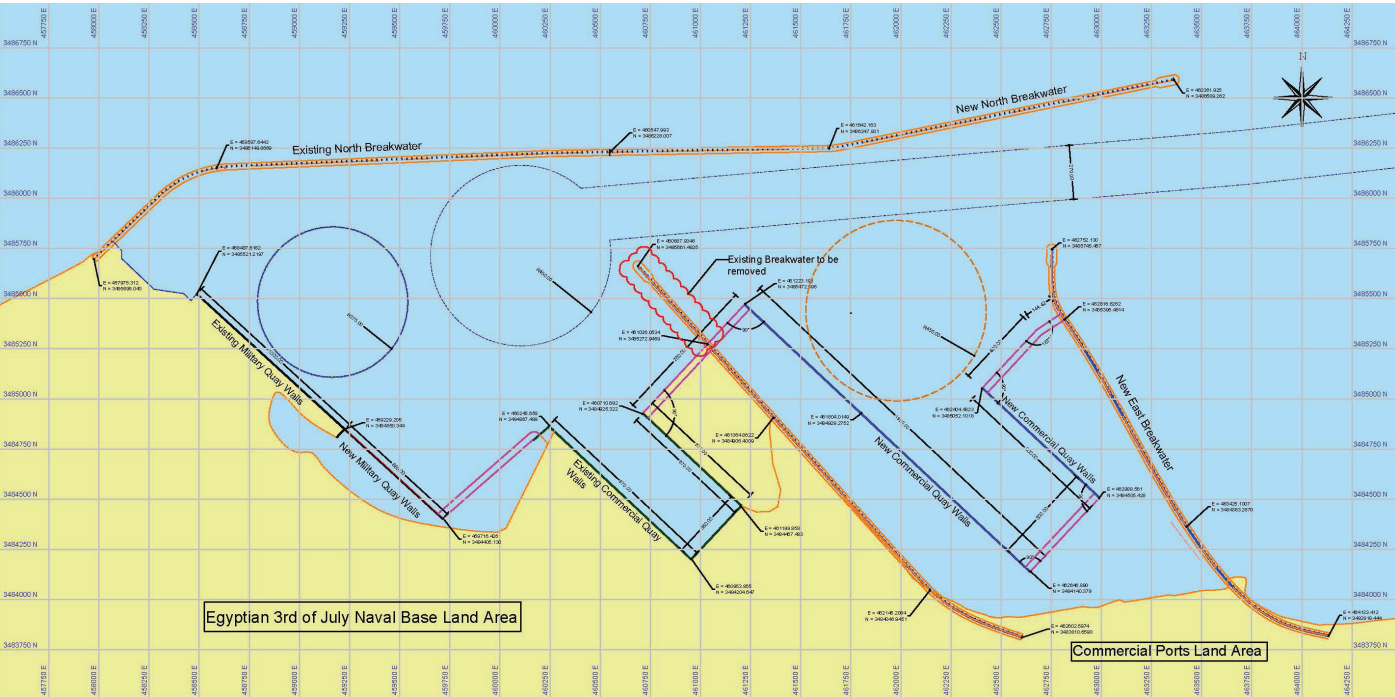


Figure 10: Gargoub Port development layout [35].

As in Figure 11, the wave energy potential along Egypt's Mediterranean coastline spans approximately 1,200 km. The analysis indicates that average wave conditions characterized by a significant wave height (H_s) of 1.09 meters and a peak wave period (T_p) of 6.26 seconds correspond to an estimated average wave power density of 5.67 kW per meter (kW/m). The highest potential is observed in the northwestern region, particularly

near Mersa Matruh, where Wave Energy Converters (WECs) located in deeper offshore waters exhibit the greatest capacity for energy generation [36]. However, high development costs and slower technology maturation compared to offshore wind have limited wave energy investment, though future technological advances may enhance its competitiveness [37].

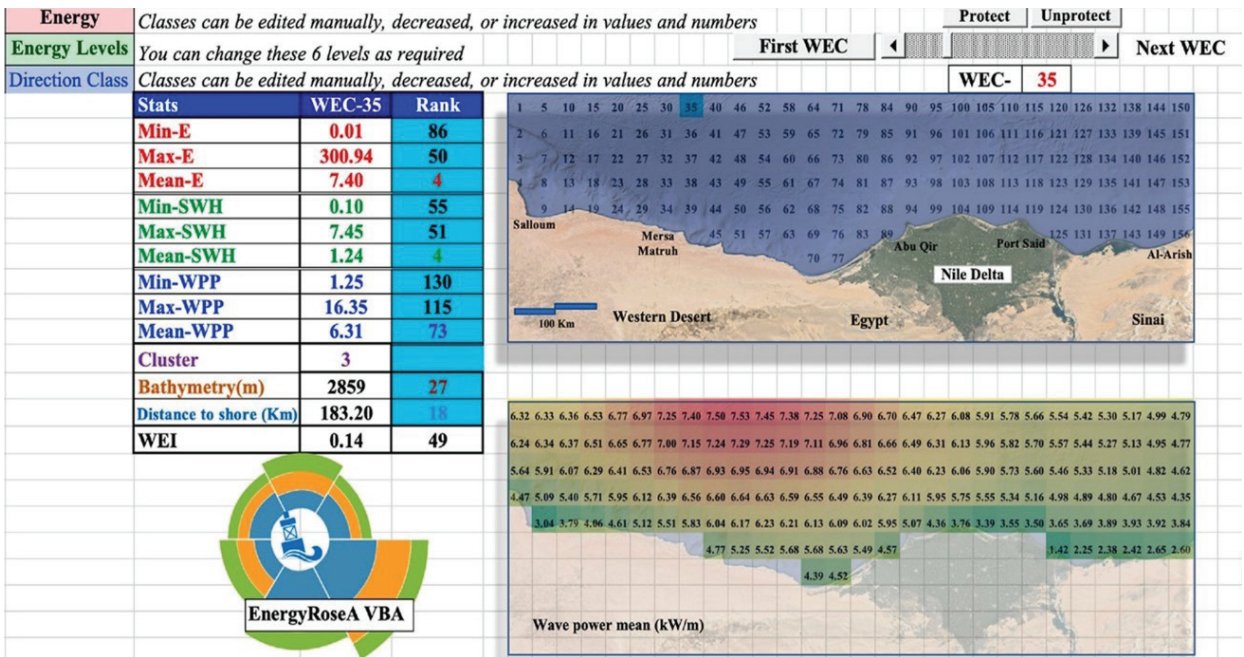


Figure 11: Wave energy potential near Gargoub Port, as represented by average wave height and period data [36].

B. Channel and berths specifications vs. Anticipated export requirements

As illustrated in Table 1, the comparison of the four ports (Damietta Port, East Port Said Port, Ain Sokhna Port, Gargoub Port) against the anticipated berth requirements for anhydrous ammonia and hydrogen exports highlights the critical role of deep-draft berths (15–16 meters) and specialized infrastructure. While ports such as Damietta and Sokhna already demonstrate relatively advanced

readiness in terms of berth capacity and technical facilities, East Port Said presents opportunities for further enhancement in export-oriented infrastructure. Gargoub, supported by ongoing development projects, is already undertaking upgrades in berth depth, safety systems, and handling facilities to align with the stringent requirements of hydrogen and ammonia shipping. These advancements strengthen its potential role in positioning Egypt as a competitive global hub in the green energy export market.

Table 1: Anticipated berth requirements for hydrogen ship export transportation

Channel & Berth Specification	Req. for hydrogen [13]	Req. for anhydrous ammonia [13]	Damietta Port	East Port Said Port	Sokhna Port	Gargoub Port
Channel depth	14.2m	11m	15 m [38]	18.5m [22]	17 [39]	17m [31]
Depth alongside	15.7m	12.4m	14.5m [20]	16.5 [22]	14 - 17m [40]	15m [31]
DWT	80,000 tonnes	50,000 tons	153,514 tons [41]	228,406 tons [22]	150,000 tons [42]	150,000 tons [35]
Berth pocket size	350m x 90m	330m x 53m	660m x 50m [20]	900m x 90m [23]	1180m x 50m [43]	800m x 50m [35]
LOA	300m	300m	367m [41]	350m [23]	350m [43]	350 [31]

III. Research methodology

The research methodology is designed to employ primary and secondary data to develop the conceptual framework for establishing a green energy logistics hub for production and export. 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 and port authorities.

A. Criteria development

The Delphi study was conducted in three structured rounds to gather expert insights on Egypt's potential to establish a global green energy logistics hub. The focus was on evaluating four key ports (Damietta Port, East Port Said Port, Ain Sokhna Port, and Gargoub Port) against 16 essential criteria across three major sections: renewable energy sources, infrastructure, and operational.

1. Round 1: Initial expert consultation

In the first round, several face-to-face meetings

were held with experts and officials from the energy sector and port authorities. These interviews, lasting approximately one hour each, allowed for in-depth discussions tailored to the interviewee's area of expertise within the broader theoretical framework. The discussions were structured into four key themes [3]:

- **Current situation:** Assessing the existing capabilities of the ports and energy sector.
- **Obstacles and challenges:** Identifying barriers to establishing a green energy hub.
- **Functions needed in the platform:** Determining key operational and policy requirements.
- **Verification of the theoretical framework:** Refining the conceptual foundation based on real-world insights.

2. Round 2: Refining the conceptual framework & variable ranking

Building upon the insights from Round 1 and the expert-driven analysis in Round 2, the second

phase involved ranking key variables within the conceptual framework. Experts evaluated the 16 essential criteria under the three major sections [3]:

- **Section 1: Renewable Energy Sources** (solar, wind, hydropower, geothermal, biomass, as in Figure 12, with the framework now modified to incorporate **wave energy** as an additional renewable source).
- **Section 2: Infrastructure** (land and water availability, grid connectivity, port potential, berthing facilities, demand-based infrastructure).
- **Section 3: Operational** (health and safety, environmental concerns, workforce availability, investor interest, shipping distance to target markets).

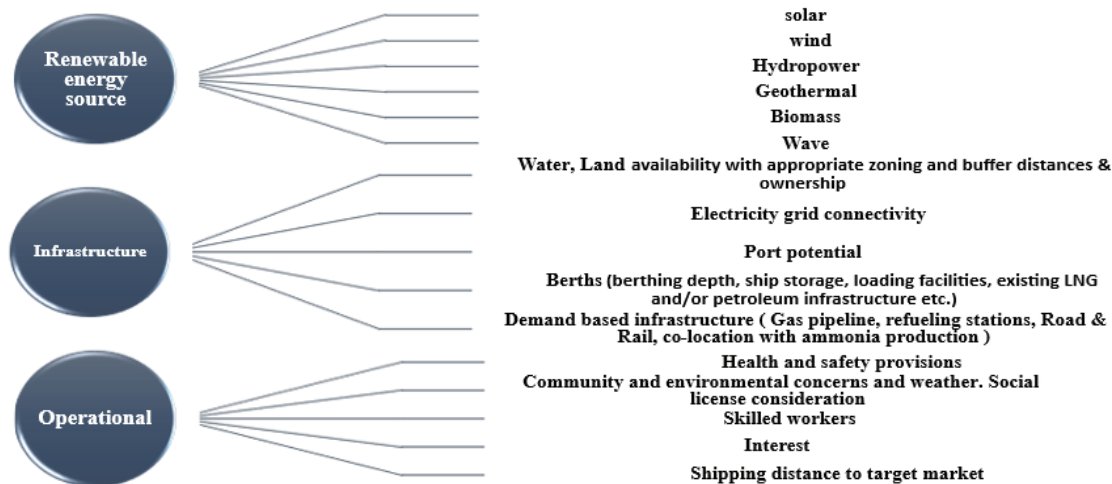


Figure 12: The conceptual framework includes 16 essential criteria for establishing a green energy logistics hub.

3. Round 3: Final refinement & consensus building

In the final evaluation phase, expert input was systematically refined through a structured consensus process to rank four Egyptian ports. The procedure is outlined as follows:

3.1. Development of evaluation matrix

As in Table 2, a standardized evaluation matrix was developed, organizing the 16 criteria into three main categories: (Renewable Energy Sources- Infrastructure - Operational).

3.2. Assignment of raw values and expert scoring

For each criterion, site-specific values were identified based on the characteristics of each Port.

These values reflected measurable indicators such as resource availability, infrastructure readiness, and operational feasibility. Experts assigned qualitative scores ranging from 1 to 5 to each criterion:

- **Score 1:** Very low potential (minimal resources or poor feasibility).

- **Score 2:** Low potential (limited viability or weak economic conditions).
- **Score 3:** Moderate potential (average feasibility).
- **Score 4:** High potential (favorable conditions for development).
- **Score 5:** Very high potential (excellent resources and strong alignment with national energy goals).

3.3. Normalization of indicators

The Min-Max normalization method was applied to standardize all indicators on a scale of [0,1].

This ensured comparability across diverse criteria with different units of measurement.

3.4. Weighting and aggregation

Normalized values were multiplied by the expert-assigned scores to derive weighted performance scores for each criterion. Weighted scores across all 16 criteria were aggregated to calculate a composite score for each Port.

3.5. Expert consensus and ranking

A consensus process was conducted to validate the aggregated results. Final rankings identified the Port offering the most favorable

conditions, providing a robust and data-driven basis for policy-making and investment planning.

Table 2: Weighted evaluation matrix framework

Section	Criterion	Value (0-1)	Score (1-5)	Purpose/Justification
Section 1: Renewable Energy Sources	Solar	0-1	1-5	Evaluate solar irradiance levels and land suitability for solar farms.
	Wind	0-1	1-5	Assess wind resource availability and consistency.
	Hydropower	0-1	1-5	Presence of freshwater bodies and hydroelectric feasibility.
	Geothermal	0-1	1-5	Subsurface geothermal potential and energy capture opportunities.
	Biomass	0-1	1-5	Availability of biomass feedstocks (agricultural/industrial).
	Wave	0-1	1-5	Availability of wave energy potential.
Section 2: Infrastructure	Land & Water Availability	0-1	1-5	Assess physical area, zoning, and access to maritime waters.
	Electricity Grid Connectivity	0-1	1-5	Evaluate grid strength, redundancy, and renewable integration capacity.
	Port Potential	0-1	1-5	Depth, throughput, expansion capability, strategic location.
	Berthing Facilities	0-1	1-5	Evaluate quay length, berthing depth, loading/unloading infrastructure.
	Demand-Based Infrastructure	0-1	1-5	Includes road/rail, hydrogen/ammonia refueling, and pipelines.
Section 3: Operational	Health & Safety	0-1	1-5	Infrastructure, emergency response, and hazard management.
	Environmental & Social	0-1	1-5	Environmental risks, social license, and climate resilience.
	Skilled Workforce	0-1	1-5	Labor market access for construction and operations phases.
	Investor Interest	0-1	1-5	Government, public, and Private sector interest in investment.
	Shipping Distance to Markets	0-1	1-5	Distance to key markets for export and import efficiency.

where Score=1 means Very Low Potential, while Score=5 means Very High Potential

IV. Export hub assessment framework

To ensure a robust and objective assessment of the four Egyptian ports (Damietta, East Port Said, Sokhna, and Gargoub), a structured consensus process involving expert input was employed. This process led to the development of a standardized evaluation matrix based on 16 weighted criteria, systematically grouped into three main categories: Renewable Energy, Infrastructure, and Operational Factors.

A. Renewable energy

This category considers a range of potential sources (solar, wind, hydropower, geothermal, biomass, and

wave energy). Regarding solar energy potential, Egypt benefits from high solar irradiance, with annual solar radiation levels ranging from 2,000 to 3,200 kWh/m²/year from the northern to the southern regions. Sunshine duration spans approximately 9 to 11 hours per day throughout the year, with very few cloudy days, making the country well-suited for solar energy generation [44]. For each Port, the nearest viable site with optimal solar potential was identified and evaluated using the Min-Max method, which converts indicators to a common scale with range [0, 1]. The normalized indicator is calculated according to the formula in Eq. (1) [45]:

$$Y_{i,j} = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (1)$$

Where:

Y_{ij} is the value for indicator Y at port " i " $\in$ {Damietta, East Port Said, Sokhna, and Gargoub} and selected criterion " j " $\in$ {Solar, Wind, Distance}.

x_{max} : maximum values across all ports.

x_{min} : Minimum values across all ports.

Hence, the solar indicators for each Port are obtained as follows:

$$Y_{Damietta,S} = \frac{2025.9 - 2000}{3200 - 2000} = 0.02 \quad (2)$$

$$Y_{East\ port\ said,S} = \frac{2306.9 - 2000}{3200 - 2000} = 0.25 \quad (3)$$

$$Y_{Sokhna,S}^{norm} = \frac{2647.6 - 2000}{3200 - 2000} = 0.54 \quad (4)$$

$$Y_{Gargoub,S}^{norm} = \frac{2181.8 - 2000}{3200 - 2000} = 0.15 \quad (5)$$

By the same way, Egypt's annual wind speed ranges from approximately 2.3 m/s in inland areas like Dekhela to 5.8 m/s along the Red Sea coast in Hurghada, with peak speeds reaching up to 13.8 m/s [46] The wind speed data used in the analysis was selected based on measurements at a height of 200 meters, which aligns with the typical hub height of modern utility-scale wind turbines.

Therefore, the wind indicators for each Port are obtained as follows:

$$Y_{Damietta,W} = \frac{6.67 - 2.3}{13.8 - 2.3} = 0.1 \quad (6)$$

$$Y_{East\ port\ said,W} = \frac{9.36 - 2.3}{13.8 - 2.3} = 0.4 \quad (7)$$

$$Y_{Sokhna,W} = \frac{13.77 - 2.3}{13.8 - 2.3} = 1 \quad (8)$$

$$Y_{Gargoub,W} = \frac{9.37 - 2.3}{13.8 - 2.3} = 0.4 \quad (9)$$

The significance of location-specific renewable energy potential, as illustrated in Appendix A2, Figure 17, and Figure 19, serves as a critical determinant in evaluating the suitability of port sites for green energy development. This approach

highlights the strategic advantage of Gargoub Port, which demonstrates exceptional renewable energy potential, with recorded estimates of approximately 40 GW for wind energy and 842.7 GW for solar energy. Such figures position Gargoub as a highly favorable site for large-scale renewable energy infrastructure deployment [47].

To ensure consistency and comparability across all selected sites, a uniform PV system configuration was applied in the analysis. The photovoltaic system is modeled as a ground-mounted, large-scale installation with an installed capacity of 1000 kWp. The azimuth angle of the PV panels is set to the default orientation of 180°, facing due south to maximize solar exposure in the northern hemisphere. Similarly, the tilt angle is fixed at the default value of 32°, which approximates the optimal tilt for the geographic latitude of the examined Egyptian sites.

1. Damietta Port

Damietta port is located at coordinates (31.476001°, 031.781101°), and it exhibits relatively low solar energy potential. The annual average of direct normal irradiation (DNI) is approximately **2025.9 kWh/m²/year**, which implies very low potential and poor feasibility for large-scale solar energy development, as there is insufficient available land for dedicated energy projects; while installations above buildings are possible, they offer limited capacity and do not significantly enhance the overall solar potential.

2. East Port Said Port

It was assessed based on two nearby locations: The first site, as in Figure 13, located approximately 80 km from the Port at (30.742121°, 033.052368°), records an annual total photovoltaic (PV) power output of **1.897 GWh/year**, global tilted irradiation of **2405.6 kWh/m²/year**, and DNI of **2306.9 kWh/m²/year**. The surrounding area with similar solar characteristics spans **1,765.20 km²**, making it suitable for scalable solar projects. The second site, as in Figure 14, situated about 110 km from the Port at (30.568319°, 033.278961°), shows an annual PV output of **1.947 GWh/year**, global tilted irradiation of **2466.0 kWh/m²/year**, and DNI of **2472.1 kWh/m²/year**. This site offers **651.05 km²** of land with comparable potential. Both locations near East Port Said suggest high solar potential and favorable development conditions.

3. Ain Sokhna Port:

As in Figure 15 with nearby coordinates at

(29.350165°, 032.223816°) approximately 27 km inland, it demonstrates strong solar metrics: a PV output of **2.034 GWh/year**, global tilted irradiation of **2562.8 kWh/m²/year**, and DNI of **2647.6 kWh/m²/year**. The land area with similar solar characteristics totals **506.59 km²**, confirming high potential and suitability for solar energy investments.

4. Gargoub Port

As in Figure 16, evaluated near the site at (30.849303°, 026.551208°), roughly 72 km from the Port, it has an annual PV output of **1.891 GWh/year**, global tilted irradiation of **2392.7 kWh/m²/year**, and DNI of **2181.8 kWh/m²/year**. Notably, the surrounding land area spans **19,764.58 km²**, offering.

Significant expansion potential. Despite slightly lower irradiance compared to Ain Sokhna and East Port Said, the vast land availability and good solar metrics imply high potential with favorable development conditions. Mediterranean Cruise Lines Hub & Departure/Arrival/Docking Port Station.

B. Infrastructure

Several sub-criteria influenced this dimension, including land and water access, grid connectivity, port potential, berthing facilities, and demand-driven infrastructure. Land availability for scalable expansion favored Gargoub and East Port Said, while Sokhna port stood out for its existing maritime infrastructure. All ports are currently integrated into the national electricity grid and meet the berthing requirements for handling anhydrous ammonia and hydrogen. Notably, Gargoub port demonstrated distinct strategic potential due to its alignment with the (GREGY-Elica Interconnector project), a planned submarine electricity cable connecting Sidi Barrani, Egypt, with Attica, Greece. This interconnector is specifically designed to transport 100% green electricity generated from Egypt's renewable energy plants, thereby enhancing the Port's value proposition for future green energy exports.

C. Operational

Considerations in this category included health and safety standards, environmental impact, workforce availability, investor interest, and shipping distance to primary European markets. While the first four factors were found to be broadly comparable across all ports, shipping distance emerged as a critical differentiator. As referenced in the literature, major

European destinations for hydrogen imports include Antwerp, Livorno, and Attica. In this context, Gargoub holds a logistical advantage, offering the shortest average shipping distance to these key markets. This is particularly relevant for minimizing boil-off losses potentially as high as 5% per day caused by environmental heat transfer during maritime transport. Table 6 shows the distance between the selected ports of the case study and the three European ports. The normalized distance will be considered as a distance indicator. Since there are three distances for each Port, as in Table 6, the average distance for each Port will be used in the normalized distance indicator as follows:

$$d_{\text{Damietta}} = \frac{3440 + 1449 + 561}{3} = \frac{5450}{3} = 1816.6 \text{ NM} \quad (10)$$

$$d_{\text{East Port Said}} = \frac{3482 + 1492 + 593}{3} = \frac{5567}{3} = 1855.6 \text{ NM} \quad (11)$$

$$d_{\text{Sokhna}} = \frac{3573 + 1583 + 689}{3} = \frac{5845}{3} = 1948.3 \text{ NM} \quad (12)$$

$$d_{\text{Gargoub}} = \frac{3200 + 1200 + 442}{3} = \frac{4842}{3} = 1614 \text{ NM} \quad (13)$$

Where: d_{Damietta} , $d_{\text{East Port Said}}$, d_{Sokhna} , and d_{Gargoub} are the average distances of Damietta, East Port Said, Sokhna, and Gargoub ports, respectively.

Applying the Min-Max method based on Eq. (1), considering lower distance means better performance, the normalized distance indicator for each Port will be obtained as follows:

$$Y_{\text{Damietta},D} = \frac{1948.3 - 1816.6}{1948.3 - 1614} = 0.4 \quad (14)$$

$$Y_{\text{East port said},D} = \frac{1948.3 - 1855.6}{1948.3 - 1614} = 0.3 \quad (15)$$

$$Y_{\text{Sokhma},D} = \frac{1948.3 - 1948.3}{1948.3 - 1614} = 0 \quad (16)$$

$$Y_{\text{Gargoub},D} = \frac{1948.3 - 1614}{1948.3 - 1614} = 1 \quad (17)$$

As shown in Table 3, a 'traffic light system' is employed to visually represent the relative distances between ports and hub sites. This system serves as a comparative performance indicator: a red rating denotes the farthest distance among the options, highlighting a less favorable positioning; a yellow

rating indicates a moderately close distance that could potentially be improved through strategic measures; and a green rating signifies the nearest proximity, suggesting that the Port is well-positioned and preferable for that specific criterion.

Table 3: Distance between ports,
(Source: Author, distance in nautical miles (NM))

Port	Destination 1 (Antwerp)	Destination 2 (Livorno)	Destination 3 (Greece)
Damietta	3440	1449	561
East Port Said	3482	1492	593
Sokhna	3573	1583	689
Gargoub	3200	1200	442

D. Overall Assessment

Since some evaluation criteria have a small variation among the selected ports, they are considered fixed

criteria for all ports. The analysis incorporates a subset of criteria that were treated as constant across all evaluated ports to ensure analytical consistency and avoid distorting the composite index. Hence, Table 4 distinguishes the constant and variable criteria for the selected ports. These invariant criteria include national grid connectivity, berthing facility compliance, port infrastructure standards, and access to essential port services, all of which exhibit negligible variation across the ports based on current development plans and operational capabilities. Additionally, indicators such as policy alignment, regulatory framework, and investor interest were also considered constant. This decision is justified by the ports' shared governance under the Egyptian government's unified strategic vision for developing green energy logistics hubs, which promotes a harmonized policy and investment environment across national port infrastructure.

Table 4: criteria with constant values or identical results across all ports, indicating the presence of potential with a ✓ mark and the absence of potential with a X mark

Criterion		Damietta Port		East Port Said Port		Sokhna Port		Gargoub Port	
		✓	X	✓	X	✓	X	✓	X
1	Hydropower		X		X		X		X
2	Geothermal		X		X		X		X
3	Biomass		X		X		X		X
4	Wave		X		X		X		✓
5	Land & Water Availability		X		✓		✓		✓
6	Electricity Grid Connectivity		✓		✓		✓		✓
7	Port Potential		✓		✓		✓		✓
8	Berthing Facilities		✓		✓		✓		✓
9	Demand-Based Infrastructure		✓		✓		✓		✓
10	Health & Safety		✓		✓		✓		✓
11	Environmental & Social		✓		✓		✓		✓
12	Skilled Workforce		✓		✓		✓		✓
13	Investor Interest		✓		✓		✓		✓

Based on the ports analysis, the most effective criteria for the selected ports, considered in this study, are solar energy, wind energy, and shipping distance, as illustrated in Table 5. The normalized values "V" of each criterion for all ports are obtained from eq. (2) to eq. (17). While the "Weight "W" is quantified based on the expert surveys. The calculated Values and Weights are summarized in Table 5. The overall evaluation of each Port is calculated based on the following formula:

$$\text{Total}_j = \sum_{i=1}^3 W_i \cdot V_i \quad (18)$$

Where i is the criterion number, j is the port number, V_i is the value of criterion number i , and W_i is the Weight of Criterion number i .

The rank of each Port is determined based on the maximum and minimum total values of the ports. Rank "1" means highest Total value and "4" means least Total values.

Table 5: Summarizes the calculated values based on equation 1, and weights based on the feedback of stakeholders and port situation of each Port according to the selected criteria

Criterion		Damietta Port		East Port Said Port		Sokhna Port		Gargoub Port	
		V	W	V	W	V	W	V	W
1	Solar	0.021	1	0.20	3	0.54	3	0.15	4
2	Wind	0.1	1	0.4	2	1	3	0.4	4
3	Shipping distance to markets	0.4	3	0.3	2	0	1	1	5
		1.321		2		4.62		7.2	
		4		3		2		1	
								Total	
								Rank	

Based on that, the evaluation value of each Port was calculated across the 16 criteria developed from the conceptual framework. The results identify Gargoub Port as the most promising location, achieving the highest composite total score of 7.2. It is followed by Sokhna Port with a total score of 4.62, East Port Said with 2.0, and Damietta Port with the lowest score of 1.321. These scores represent the priority ranking of the selected ports, indicating their relative potential to serve as a green energy logistics hub. Therefore, it is evident that Gargoub demonstrates the strongest alignment with the assessment criteria and holds the greatest potential for future development in line with Egypt's green energy ambitions. This prioritization directly supports Egypt's Vision 2030, which emphasizes export competitiveness, sustainable development, the use of renewable energy resources, and access to international markets [48]. It also aligns with the National Low-Carbon Hydrogen Strategy, which targets large-scale hydrogen production and export growth, along with incentives for infrastructure that meet international standards of safety and export readiness [49]. Furthermore, this port ranking is consistent with the European Union's hydrogen import strategies, which project significant reliance on North African supply chains, thereby positioning Gargoub as a critical node in linking Egypt to future European demand [50].

E. Limitations

This study acknowledges certain limitations that frame the interpretation of its findings. First, although renewable energy data were used with a high degree of accuracy, they are best regarded as indicative rather than absolute measures, given the dynamic nature of resource assessments. Second, the geographic scope of the study is limited to four Egyptian ports, without extending the comparison to other potential regional hubs that may also

serve as gateways for green energy exports to Europe. Recognizing these limitations enhances the transparency of the study and clarifies the contextual boundaries of its results. Third, the study focuses primarily on the export potential of Egyptian ports to Europe; however, other emerging markets such as Japan and South Korea, whose combined hydrogen import demand is projected to exceed 6 million tonnes annually by 2030 [51], also represent significant opportunities, suggesting an important direction for future research.

V. CONCLUSION

This study provides a comprehensive strategic assessment of four Egyptian ports (Damietta, East Port Said, Ain Sokhna, and Gargoub) evaluated against 16 critical criteria to determine their potential as a green energy logistics hub. These criteria covered aspects such as renewable energy potential, infrastructure readiness, and operational. The evaluation matrix, informed by both empirical data and expert insights through a three-round Delphi method, offers a rigorous framework to guide investment and policy decisions. The findings rank Gargoub Port as the most promising site with a total score of 7.2, followed by Sokhna Port (4.62), East Port Said (2), and Damietta (1.321). Gargoub's leading position is attributed to its exceptional renewable energy resources estimated at (40 GW) for wind, (842.7 GW) for solar, and with potential for wave energy, in addition to its vast expansion potential and strategic proximity to European markets. Ain Sokhna and East Port Said benefit from strong logistical integration and ongoing infrastructure upgrades, while Damietta remains a significant player due to its container handling capabilities and industrial linkages. Crucially, it was observed that several criteria exhibit uniform characteristics across all ports. As such, these factors were assigned constant values in the evaluation

framework to ensure analytical consistency and to prevent skewing the composite index. Specifically, criteria such as national grid connectivity, berthing facility compliance, port infrastructure standards, and access to port services demonstrated negligible variation based on current development plans and operational capabilities. Similarly, indicators related to policy alignment, regulatory framework, and investor interest were considered constant due to the ports' shared governance under the Egyptian government's unified strategic vision for green energy logistics. The study highlights that all four ports are interconnected through Egypt's national electricity grid, allowing renewable energy generated at any site to be distributed efficiently across the country to support domestic and export demand. This national grid connectivity enables a unified energy strategy, where site-specific renewable energy advantages, such as Gargoub's high solar and wind potential, can benefit the entire national system. For export purposes, the planned Egypt-Greece electrical interconnection represents the most viable route to Europe, reinforcing Egypt's role as a future green energy supplier to the continent. Moreover, if green energy is to be converted ammonia was selected as the benchmark product due to its superior logistical and economic advantages over liquid hydrogen and Levelized Cost of Hydrogen (LCOH), particularly in terms of storage and transport, Gargoub Port offers the most strategic location for maritime shipment, as supported by proximity analysis and

comparative distance metrics (see Table 3). This adds to Gargoub's competitive edge as a dual-mode hub capable of supporting both direct electricity export and green hydrogen derivatives. Sensitivity analysis confirmed that Gargoub consistently ranked highest under alternative weighting schemes, reinforcing the robustness of the study's findings. A visual traffic light system was applied in the evaluation to visually represent the relative distances between ports and hub sites. Looking forward, any investor or policy-maker aiming to establish a green energy hub would benefit from applying the 16 evaluation criteria outlined in this study. These factors serve as a practical, standardized framework for site selection based on economic, logistical, and environmental viability. The study's findings should be interpreted in light of its limitations, particularly the indicative nature of renewable energy data and the restricted geographic scope to four Egyptian ports. Future research could expand the scope to include additional regional hubs across the Mediterranean to provide a broader comparative perspective. Also, future research should focus on developing a comprehensive operational and financial model for utilizing Gargoub Port as a green energy logistics hub, optimizing both production and export mechanisms aligned with Egypt's national energy strategy and global sustainability goals.

A. List of Interviews with experts in the field of energy & port Authorities

Table 6: List of interviews with experts and officials in the field of energy

Interviewee	Duration	Place
1 Dr. Maged Mahmoud , Director of Projects and Technical Affairs and Lead RE Advisor at Regional Center for Renewable Energy and Energy Efficiency (RCREEE)	1 hour	Regional Center for Renewable Energy and Energy Efficiency (RCREEE)
2 Dr. Ahmed Samy from the Ministry of Electricity and Renewable Energy	1 hour	Ministry of Electricity and Renewable Energy
3 Dr. Mohamed El-Khayat , Executive Chairman of the New and Renewable Energy Authority (NREA)	1 hour	The New and Renewable Energy Authority (NREA)
4 Prof. Adil Khalil , Professor in the Mechanical Power Engineering Department at Cairo University (FECU)	1 hour	Faculty of Engineering, Cairo University
5 Dr. Ali Mohamed Abdel-Fattah , Undersecretary for the Minister's Office Affairs Ministry of Electricity and Renewable Energy	1 hour	Ministry of Electricity and Renewable Energy
6 Eng. Ahmed Mahrous Elbakly , General Manager of Energy Research and Studies Ministry of Electricity and Renewable Energy	1 hour	Ministry of Electricity and Renewable Energy
7 Dr. Mostafa Hasaneen , PhD, Senior Sustainable Energy Expert at the Regional Center for Renewable Energy and Energy Efficiency (RCREEE)	1 hour	Regional Center for Renewable Energy and Energy Efficiency (RCREEE)

Table 7: List of interviews with experts and officials from port authorities

Interviewee	Duration	Place
1 Rear Admiral Dr. Ashraf Nabil El-Assal, Chairman of the Egyptian Authority for Maritime safety, Ministry of Transport	1 hour	Egyptian Navy Hydrographic Department
2 Rear Admiral Mohamed Abd El Aziz, Chairman Ports Advisor to the SCZONE	1 hour	Suez Canal Economic Zone (SCZONE)
3 Dr. Mohamed Abo Eldahab, Green Economy General Manager at Suez Canal Economic Zone	1 hour	Suez Canal Economic Zone (SCZONE)
4 Capt. Aly Assem Mahmoud Ibrahim, Ports Director at Sky ports Group	1 hour	East Port Said Port Authority
5 Capt. Islam Ahmed Mosa, General Manager East Port Said Port	1 hour	East Port Said Port Authority
6 Mennatallah Ayman Eid, EIA Specialist at SCZONE	1 hour	East Port Said Port Authority
7 Capt. Yaser Abd Ellatif Ahmed, Head of the Central Administration for Maritime Services at the Damietta port Authority	1 hour	Damietta Port Authority
8 Eng. Nageib Mohamed Elsaid, Manager of Maritime and Marine Safety Department	1 hour	Damietta Port Authority
9 Eng. Samira Mattar, Safety Engineer Firefighting Department Manager	1 hour	Damietta Port Authority

B. Ports Renewable Energy potential

These figures represent strategically recommended positions in proximity to the assessed ports, specifically selected based on their renewable energy potential (solar). The chosen locations demonstrate high solar irradiance levels, making them particularly suitable for solar energy harvesting. Their proximity to port infrastructure

ensures logistical feasibility for future integration into green energy value chains, including hydrogen production and export. These siting recommendations are aligned with Egypt's national renewable energy targets and support the broader objective of establishing the country as a key player in the global green energy market.

1. East Port Said Port

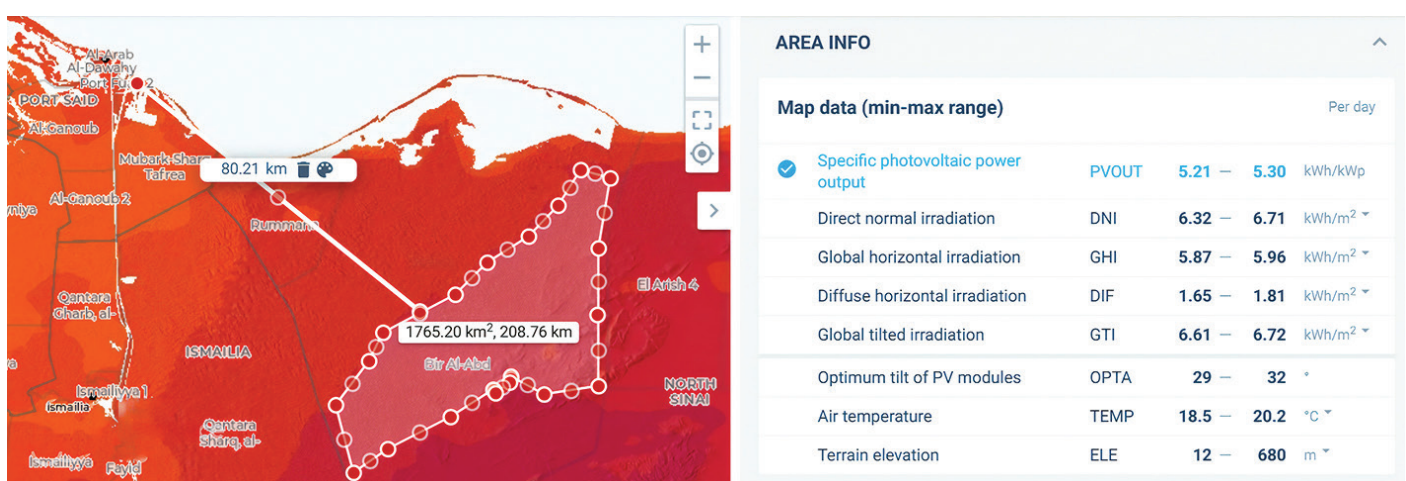


Figure 13: East Port Said Port solar potential 1 with Area: 1765.20km², Perimeter: 208.76km.
(Source: Edited by the author using data from the Global Solar Atlas (World Bank & Solargis, 2025) [53])



Figure 15: Sokhna Port solar potential with Area: 506.59km², Perimeter: 99.44km.
(Source: Edited by the author using data from the Global Solar Atlas (World Bank & Solargis, 2025) [53])

Figure 16: Gargoup Port solar potential with Area: 19764.58km², Perimeter: 702.82km.
(Source: Edited by the author using data from the Global Solar Atlas (World Bank & Solargis, 2025) [53])

C. Egypt's wind and solar potential

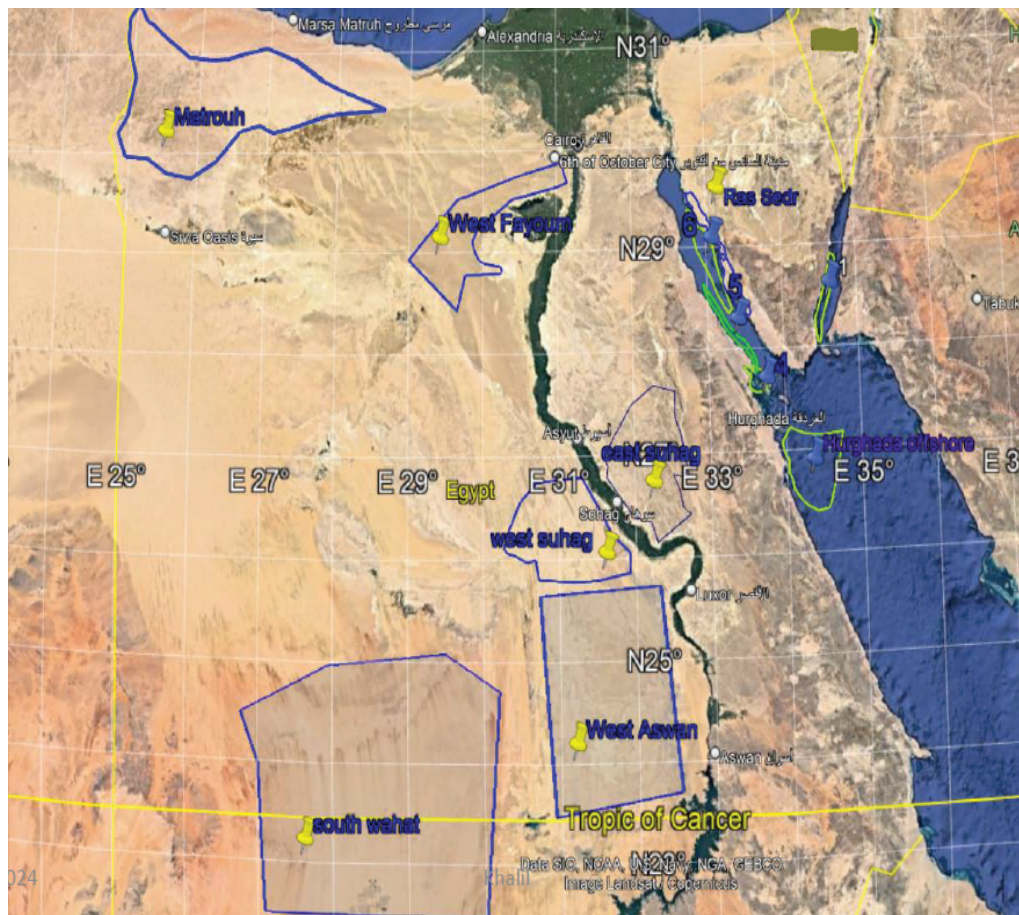


Figure 18: Designated onshore and offshore wind potential sites [47].

Area	Maximum estimated capacity (GW)	Capacity factor (%)
Fayoum	253.4	31.8
Ras Sadr	18.7	32.2
Matrouh	842.7	31.2
West Sohag	329	32
West Aswan	933.4	32.7
South of Wahaat	2291.1	32.6
Al Tur	23	32.2
Aswan	13.75	30.9
EL Kharga Oasis	5.5	31.4
El Dakhla Oasis	5.5	31.4
West of Sohag	11	30.3
East of Minia	5.5	29.1
West of Minia	5.5	29.2
Kurimat	5.5	29.1
October	11	29.2
Alexandria	5.5	28.3
Total	4760.05	—

Figure 17: Estimated wind maximum capacity and its average capacity factor for certain sites in Egypt [47].

Area	Maximum estimated capacity (GW)	Capacity factor at hub height 150 m (%)
Fayoum	11.9	60.2
Ras Sedr	0.88	70
Matrouh	40	58.4
West Sohag	15	61.9
West Aswan	44	65.8
South of Wahaat	100	65.7
Al-Tur	1.08	55.4
Gulf of Suez	3.23	53.8
West of Minia	4.53	59.4
East of Minia 1	0.99	43.2
East of Minia 2	0.42	36.5
East of Minia 3	3.55	43.4
El-Kharga 1	2.08	61.4
El-Kharga 2	2.4	60.4
Total	230.06	–

Figure 19: Estimated PV maximum capacity and average capacity factor for certain sites in Egypt [47].

References

- [1] S. A. Al-Ani and M. K. Dhahir, "Laser-enhanced hydrogen production: designing a PEC cell photoanode with an exclusive dye material for superior efficiency," *Renewable Energy and Sustainable Development*, vol. 10, no. 2, p. 407, Nov. 2024, doi: 10.21622/resd.2024.10.2.1050.
- [2] IEA, "Global Hydrogen Review 2024," *International Energy Agency*, 2024.
- [3] S. M. Mahmoud, M. A. Geliel, and S. El Gazzar, "PROPOSING A FRAMEWORK FOR ESTABLISHING A GREEN ENERGY LOGISTIC HUB: AN EMPIRICAL STUDY IN EGYPT," *The International Maritime Transport and Logistics Journal (MARLOG)*, 2025, doi: <https://dx.doi.org/10.21622/MARLOG.2025.14.1.41>.
- [4] A. Mahrous, "Egypt's National Low Carbon Hydrogen Strategy," *Interview*, 2024.
- [5] R. M. Habour, K. Y. Benyounis, and J. G. Carton, "Green hydrogen production from renewable sources for export," *Int J Hydrogen Energy*, vol. 128, pp. 760–770, May 2025, doi: 10.1016/j.ijhydene.2025.04.291.
- [6] H. Europe, "Hydrogen Infrastructure: The Recipe for a Hydrogen Grid Plan," 2024. [Online]. Available: <https://hydrogeneurope.eu/>
- [7] F. Fattori, "Assessment of low carbon hydrogen production, demand, business models and value chain in egypt Main findings 2." [Online]. Available: <https://www.unido.org/sites/default/files/unido-publications/2023-11/Assessment%20of%20low%20carbon%20hydrogen%20%20production%2C%20demand%2C%20business%20models%20and%20value%20chain%20in%20Egypt.pdf>
- [8] A. Dimou, "Greece Locks the East Mediterranean into a European Energy Strategy," *moderndiplomacy*, 2022.
- [9] D. Belgium, *Study on hydrogen in ports and industrial coastal areas*. Belgium: Clean Hydrogen Partnership, 2023.

- [10] M. Ringel, G. Stöckigt, H. Shamon, and S. Vögele, "Green hydrogen cooperation between Egypt and Europe: The perspective of locals in Suez and Port Said," *Int J Hydrogen Energy*, vol. 79, pp. 1501-1510, Aug. 2024, doi: 10.1016/j.ijhydene.2024.06.239.
- [11] jcookson, "The green gold rush: Why renewable energy is Egypt's next big opportunity," Sep. 2025. [Online]. Available: <https://www.atlanticcouncil.org/blogs/new-atlanticist/the-green-gold-rush-why-renewable-energy-is-egypts->
- [12] G. Maguire, "Beware Egypt's smokestack onshoring as cement exports surge," *Reuters*, 2025.
- [13] ARUP, "Australian Hydrogen Hubs Study," ARUP, 2019.
- [14] "Damietta Port", [Online]. Available: Damietta Port
- [15] "sanmar Damietta," 2025. [Online]. Available: <http://www.sanmar.gr/>
- [16] "EgyMar Shipping & Logistics Services S.A.E," 2022. [Online]. Available: <https://egymar.com.eg/>
- [17] M. Transport and L. Sector, "Abu Qir Port – Maritime Transport and Logistics Sector," Sep. 2025. [Online]. Available: <https://www.mts.gov.eg/ar/port/%d9%85%d9%8a%d9%86%d8%a7%d8%a1->
- [18] EMDB, "EMDB, Egyptian Ports," 2025. [Online]. Available: https://web.archive.org/web/20060222065551/http://www.emdb.gov.eg/english_v/ports_e/dam_ports_e.htm
- [19] S. mattar, "Investments and Opportunities in Damietta Port," *Interview*, 2025.
- [20] N. M. E. Yaser Abd Ellatif Ahmed, "Role of Dameitta port in the Mediterranean," *Interview*, 2024.
- [21] A. Q. P. – M. Transport and L. Sector, "Abu Qir Port – Maritime Transport and Logistics Sector," Sep. 2025. [Online]. Available: <https://www.mts.gov.eg/en/port/%D9%85%D9%8A%D9%86%D8%A7%D8%A1->
- [22] maritime transport and L. sector, "maritime transport and Logistic sector," Sep. 2025. [Online]. Available: <https://www.mts.gov.eg/en/port/%D9%85%D9%8A%D9%86%D8%A7%D8%A1->
- [23] A. I. A. M. M. A. Assem, "Renewable potential at East port said port," *Interview*, 2025.
- [24] M. Transport and L. Sector, "East Port Said Port – Maritime Transport and Logistics Sector," Sep. 2025. [Online]. Available: <https://www.mts.gov.eg/ar/port/%d9%85%d9%8a%d9%86%d8%a7%d8%a1-%d8%b4%d8%b1%d9%82->
- [25] M. Transport and L. Sector, "SOKHNA PORT," Sep. 2025. [Online]. Available: <https://www.mts.gov.eg/en/port/%D9%85%D9%8A%D9%86%D8%A7%D8%A1->
- [26] "Sokhna port, Egypt," 2025. [Online]. Available: <https://arabseaports.com/egypt-ports/sokhna-port>.
- [27] "Minister of Transportation and the President of the Economic Zone follow up on the implementation of the Ain Sokhna Port development project - Sczone Utilities," Sep. 2024. [Online]. Available: <https://sczoneutilities.com/the-minister-of-transport->
- [28] "container news," Sep. 2022. [Online]. Available: <https://container-news.com/dp-world->
- [29] S. R. Rahman, "port technology", [Online]. Available: <https://www.porttechnology.org/news/dp-world-begins-first-phase-of-80-million-sokhna-logistics-park/>
- [30] MESCO, "Middle East Survey & Control Office," 2025. [Online]. Available: <https://www.mescoalex.com/>
- [31] "NATIONAL REPORT of EGYPT," in *24th CONFERENCE OF THE MEDITERRANEAN AND BLACK SEAS HYDROGRAPHIC COMMISSION (MBSHC-24th)*, Constanta, Romania: Egyptian Navy Hydrographic Department (ENHD), 2024.
- [32] "DC - Commercial Port | GARGOUB," 2024. [Online]. Available: <https://www.gargoub.com/dc-commercialport>

- [33] "Economic Zone in Jarjoub," 2024. [Online]. Available: <https://www.sis.gov.eg/Story/190979/Economic-Zone-in-Jarjoub?lang=en-us>.
- [34] "South Korea's STX to help develop Egypt's Gargoub port + logistics zone," Sep. 2021. [Online]. Available: <https://enterprise.news/logistics/en/news/story/efcd096e-ac76-4d81-a0cc->
- [35] A. N. El-Assal, "Director of Egyptian Navy Hydrographic Department," *Interview*, 2024.
- [36] A. A. Masoud, "Analysis of thirty years of wave power potential in the mediterranean coast of Egypt with Excel-VBA development for rose diagram plot," *Energy*, vol. 315, p. 134461, Jan. 2025, doi: 10.1016/j.energy.2025.134461.
- [37] W. M. L. Monteiro, A. Sarmento, B. Semedo, A. Carvalho, T. Tavares, and J. A. L. Monteiro, "Utilizing maritime caves for wave energy: wells turbine performance and household power supply from cave-generated electricity," *Renewable Energy and Sustainable Development*, vol. 10, no. 2, p. 384, Nov. 2024, doi: 10.21622/resd.2024.10.2.1019.
- [38] Seapace, "Seapace international shipping," 2025. [Online]. Available: <https://www.seapace.com/ports/index.htm>
- [39] S. P. S. O. (Suez), "Noatum Maritime," 2018. [Online]. Available: https://www.safinashipping.com/resource_center/egyptian_ports/details/Sokhna-Port
- [40] "AIN SUKHNA Port," 2025. [Online]. Available: <https://ports.marinelink.com/ports/port/ain-sukhna>
- [41] shipnext, "Damietta EGDAM Details: Departures, Expected Arrivals and Damietta (Egypt) Calls | Shipnext," 2016. [Online]. Available: <https://shipnext.com/port/damietta-egdam-egy>
- [42] D. P. World, "Master Plan and Capacity," 2020. [Online]. Available: <https://www.dpworld.com/egypt/why-dpws/master-plan-and-capacity>
- [43] M. A. Eldahab, "Green economy," *Interview*, 2024.
- [44] H. Abdulhady, H. Metwally, and T. Abdul fattah, "Review of the Factors Affecting the Solar Energy Yield in Egypt," *The Egyptian International Journal of Engineering Sciences and Technology*, vol. 29, no. Electrical Engineering, pp. 51–60, Jan. 2020, doi: 10.21608/eijest.2020.97330.
- [45] M. Mazziotta and A. Pareto, "Normalization methods for spatio-temporal analysis of environmental performance: Revisiting the Min-Max method," *Environmetrics*, vol. 33, no. 5, Aug. 2022, doi: 10.1002/env.2730.
- [46] K. S. M. Essa and F. Mubarak, "Survey and Assessment of Wind-Speed and Windpower in Egypt, Including Air Density Variation," *Wind Engineering*, vol. 30, no. 2, pp. 95–106, Mar. 2006, doi: 10.1260/030952406778055081.
- [47] A. H. A. El-Sayed, A. Khalil, and M. Yehia, "Energy storage systems impact on Egypt's future energy mix with high renewable energy penetration: A long-term analysis," *J Energy Storage*, vol. 95, p. 112583, Aug. 2024, doi: 10.1016/j.est.2024.112583.
- [48] "Ministry of Planning and Economic Development," *Egypt's Vision 2030*, 2023.
- [49] "Green Hydrogen Organization," *Green Hydrogen Vision (Egypt)*, 2024.
- [50] E. Commission, "Hydrogen," 2023. [Online]. Available: https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen_en
- [51] L. Al-Ghussain, M. A. Hassan, and Z. Lu, "Renewable hydrogen horizon: Geospatial techno-economic feasibility and life cycle greenhouse gas analysis in the Middle East and North Africa," *ResearchGate*, 2025.
- [52] S. C. E. Z. (SCZone), "Sokhna port – SCZONE," 2015. [Online]. Available: <https://sczone.eg/services/ain-sokhna-port/>
- [53] G. S. Atlas, "Global Solar Atlas," 2025. [Online]. Available: <https://globalsolaratlas.info/map?c=26.931865>