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Towards a green shipping gateway

Establishing a green hydrogen economy in Egypt

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Imprint

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Executive Summary

Executive Summary

Decarbonizing global maritime trade is crucial for reaching climate goals and mitigating climate change. Egypt has a significant role in maritime trade, as 12 % of international trade passes through the Suez Canal. Firstly, this study discusses the potential impact of green fuels on shipping. Secondly, it analyzes the potentials and challenges green shipping offers for Egypt from the geopolitical and economic perspective. Thirdly, it discusses how a shipping-based hydrogen economy can be embedded in Egypt's domestic economy. Lastly, the study concludes with policy recommendations on how Egypt might utilize its full potential in green shipping.

Green fuels in international shipping

Today, ship engines run on fossil fuels. Green hydrogen-based fuels have different properties than fossil fuels, which may lead to changes in international shipping. Due to economies of scale, maritime trade is organized in a **hub and spoke system**. Hubs are large, highly connected ports through which all smaller ports transact their trade. Fuel is a significant cost factor for the shipping company. Choosing the bunkering port is a strategic decision.

Advantages and disadvantages of green shipping fuels

The production of **hydrogen** has the highest energy efficiency, but hydrogen has the lowest energy density of all hydrogen-based fuels, making it difficult to transport and store. Ship engines running on hydrogen have yet to be commercially available at scale. Notable infrastructure does not yet exist.

Ammonia has a higher energy density than hydrogen but brings safety and environmental risks as it is toxic and corrosive. Ammonia is a globally traded commodity with existing and tested infrastructure. The development of ammonia engines for ship propulsion systems is in its final stages.

Methanol has the highest energy density of hydrogen-based fuels but contains carbon. Transport and storage are possible with established infrastructure. Methanol can be used in typical marine engines with little modification.

Viability of green shipping fuels

Methanol, ammonia, or hydrogen **require retrofitting** of existing ships and infrastructure to be used. The extent of retrofitting needed is the lowest for methanol and highest for hydrogen.

Hydrogen-based fuels have **lower volumetric energy density** than fossil marine fuels, resulting in a lower range or lower cargo capacity of ships. Lower ranges might increase the number of bunkering stops per trip.

Without policy measures, the production costs of hydrogen-based green fuels are significantly higher than market prices of heavy fuel oil. While the costs for hydrogen-based fuels are projected to decrease until 2050, a **cost gap** to today's heavy fuel oil prices remains.

Egypt as a green shipping gateway: geopolitical challenges and economic potential

Green shipping offers many opportunities for Egypt due to its location on the Suez Canal and its enormous renewable energy resources. Embedding a hydrogen economy into the domestic economy and competing with neighboring states pose challenges for Egypt to reap the benefits of green shipping.

The Suez Canal connects the Mediterranean and the Red Sea and is the **key bottleneck** in the Asia-Europe trade. The canal is of significant economic relevance for Egypt, accounting for about 10 % of the country's GDP. In 2019, almost 19,000 ships, representing **12 % of global trade,** passed through the Suez Canal. Container shipping and tankers dominated, as container cargo made up half of the cargo transiting the Suez Canal in 2019. Global trade routes and trade patterns may change due to developments in the global economy, climate change, or green shipping. There is a risk that the Suez Canal will lose parts of its traffic volume to the **North-East Route** if it becomes reliably passable in the future.

Green shipping corridors in international maritime trade

Ports are pivotal nodes in steering the shipping industry towards a greener future. Leading ports, like Rotterdam, Singapore, and Shanghai, are adopting **decarbonization strategies**. Major shipping routes such as the Panama Canal and Suez Canal are focal points for global trade. Individual ports and canals are relevant for decarbonizing maritime trade. Collective action and cooperation along trade routes is essential to establish **green shipping corridors**.

Economic potential of producing green shipping fuels

Green shipping has a significant **economic potential** for Egypt. On the one hand, Egypt has great potential to produce renewable energies and thus also green fuels. On the other hand, there is potentially a large and constant demand for green fuels by the ships that pass through the Suez Canal.

Due to its location at the Suez Canal, Egypt is well suited to become a **green refueling station** for ships on the route from Europe to Asia in the future. To exploit the full potential of green shipping, Egypt must overcome some economic challenges.

At the Red Sea, Saudi Arabia might be a **regional competitor** in producing green fuels and providing bunkering services as it can produce green fuels at lower costs due to lower weighted average costs of capital. Besides, Saudi Arabia has the largest port with established bunkering infrastructure for conventional marine fuels at the Red Sea.

At present, large ships on the trunk lines **bunker at hubs** in Asia and Europe but not in Egypt. The lower energy density of green fuels like ammonia and methanol does not lead to the necessity of a stop in Egypt.

Bunkering in Egypt has a cost advantage against exporting fuels for bunkering in European ports. If ships could bunker within their waiting time before entering the Suez Canal, the bunkering stop would require less additional time and costs.

Embedding a shipping-based hydrogen industry in the Egyptian economy.

The development of renewable energy and green hydrogen production capacities opens up opportunities to drive domestic green industrialization processes but is also associated with economic traps that need to be avoided through smart policymaking.

Leveraging the renewable energy potential along the coast

Egypt has **great potential** for renewable energy production along the coast: solar, wind, and geothermal. These need to be harnessed to meet both growing domestic demand and the production of green marine fuels. **New capacity** should be planned along existing infrastructure axes to reduce costs. Long-term planning can consider a green hydrogen development corridor along the coast.

Risks and opportunities of establishing a hydrogen economy

Foreign direct investments in the green hydrogen sector need to be accompanied by government policies to avoid dependencies and maximize development impact. Policy design requires carefully assessing the local industrial structure and potential synergies. The creation of **forward and backward linkages** with the domestic petrochemical, fertilizer, glass, and cement industries holds significant development potential for the economy of Egypt.

Creating clusters to maximize development impact.

To produce marine fuels, exploiting the potential of strong winds and high solar radiation, combined with the exploration of geothermal resources along the Suez Gulf, is particularly relevant and has considerable potential for **job creation**. However, the literature warns that new industries need to be carefully embedded in existing industrial structures. To this end, linkages can be created to realize synergy potential.

The existing industry has great potential to be linked to new green hydrogen investments, especially the petrochemical, steel, and fertilizer industries. It is recommended to apply cluster thinking to achieve agglomeration effects between these industries.

Producing green hydrogen close to where it is used will have a favorable cost effect. In the long term, an efficient hydrogen **pipeline infrastructure** will allow green industrial processes elsewhere in the country, such as the glass industry around Cairo.

Supporting measures for building a shipping-based hydrogen economy

Based on the previous analysis, various recommendations can be derived for decision-makers so Egypt can utilize its full potential in green shipping. The following policy measures are recommended:

Technological Roadmap: Monitor tech and market trends to define green hydrogen and decarbonization priority areas.

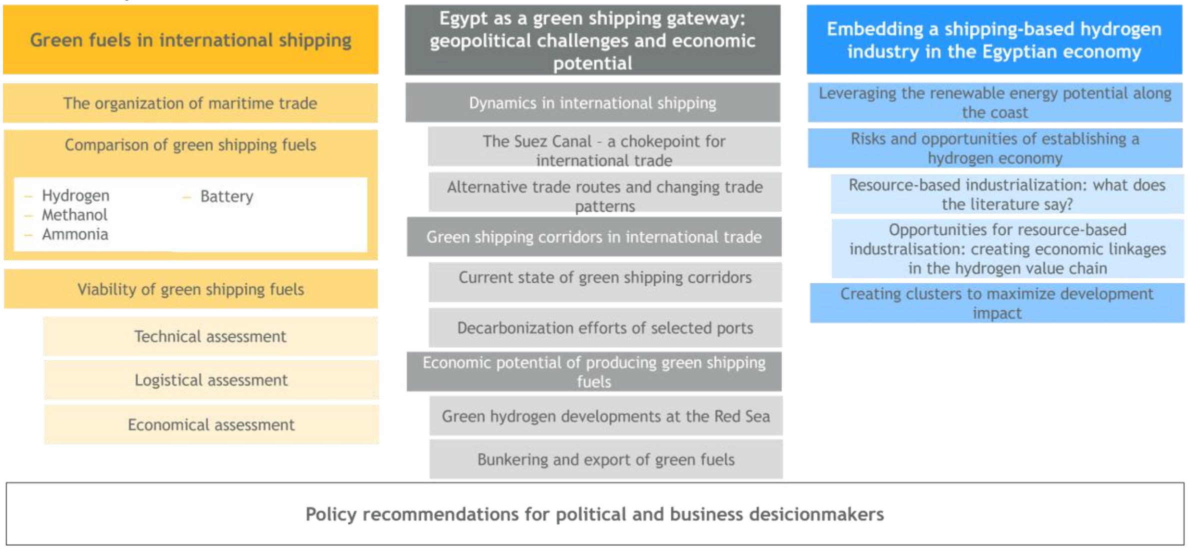
Green Maritime Strategy: Collaborate with global maritime hubs to establish green shipping routes. Encourage sustainable shipping fuels through reduced Suez Canal tolls and promote decarbonization of port and canal infrastructure to set an example for the industry.

Legislative Framework: Establish a legislative framework for the green hydrogen industry to implement taxation and payment mechanisms and ensure compliance with local content regulations for fiscal benefits.

Green Hydrogen Growth Corridor: Create a dedicated growth corridor to combine renewable energy generation with green hydrogen investment and support related industries. The coastal area from Ain Sokhna to Rais Ghareb could be a growth corridor.

Cross-Sectoral Collaboration: Foster cross-sectoral collaboration, knowledge transfer, and capacity building to leverage skills and institutional frameworks, enhancing of regional development initiatives' effectiveness and promoting economies of scale.

Figure 1: *Graphical abstract*



Source: *Own illustration*

01

Introduction

1 Introduction

Amidst the challenge of combating the global climate crisis and promoting sustainable development, the International Maritime Organization (IMO) has committed to reducing GHG emissions from international shipping and aims to achieve net-zero GHG emissions by or around 2050. According to a recent strategy, carbon emissions are to be reduced by at least 40 % by 2030 compared to 2008 levels (IMO, 2023). With a staggering 90 % of the world's traded goods transported by sea, maritime trade is responsible for 2.89 % of the planet's man-made CO_2 emissions (1,056 million tCO_2 in 2018 (IMO, 2020)). As a critical link in the production and distribution of goods, the maritime industry, including ports, will be indispensable in achieving a decarbonized global economy.

As with other transport sectors, the transition to sustainable shipping requires radical systemic changes that touch almost every aspect of the energy system. Not only is the shipping industry a significant source of greenhouse gas emissions, but its impact goes far beyond the movement of cargo - it affects the environment and society. From rethinking ship propulsion and using cleaner fuels to optimizing shipping routes and redesigning ships, the journey towards greener maritime trade involves profound changes that touch every facet of the current system. This report delves into the intricacies of this transition, highlighting its interconnected nature and the collaborative efforts required to make the maritime sector a beacon of sustainability and innovation.

While the shift towards decarbonized maritime trade challenges existing economies and maritime trade locations, the changes also open new opportunities for proactive policymaking: green shipping corridors (GSCs) are emerging, new propulsion systems are opening markets for green fuels, and route planning is adapting to new conditions, valuing previously neglected locations along shipping routes. In addition, understanding the changing geography of maritime trade helps to identify synergies and means to increase domestic value creation.

The Middle East and North Africa (MENA) region has unique potential to become a leading hub for hydrogen production. Factors such as abundant land, robust winds, abundant solar radiation, and coastal seawater provide a favorable environment for hydrogen production. In line with its ambition to decarbonize its industries, the European Union (EU) is looking to work with Mediterranean countries, particularly those in the 'Southern Neighbourhood' (European Commission, 2021). Currently, the EU is heavily dependent on imports of fossil fuels, including natural gas, hard coal, crude oil, and uranium from non-EU countries (EWI, 2022). The MENA region can benefit from its proximity to the EU market and position itself as a potential supplier of hydrogen.

The momentum towards a thriving regional green hydrogen industry was catalyzed by COP27, with Egypt playing a leading role. Egypt has signed framework agreements with international energy companies to establish nine green hydrogen and ammonia plants in the Suez Canal Economic Zone. Once fully operational, these plants are expected to collectively produce up to 7.6 million tonnes of green ammonia and 2.7 million tonnes of hydrogen per year (Enterprise, 2022). Within Egypt, the Suez Canal Economic Zone stands out as an emerging cluster of green hydrogen production and related industries. Recent announcements even raise hopes of locating electrolyzer production in the country

(FuelCellsWorks, 2023). To maximize local benefits, these industries need to be embedded in the existing economy to drive a process of green industrialization.
The aim of this report is, therefore, to provide an initial overview of this complex, fluid, and rapidly changing new field. Technology is developing rapidly, and new investments are announced on an almost daily basis. Policymakers aiming to position their region as a center for sustainable shipping in the global rush for hydrogen are struggling to find reliable data on future trends on which to base their decisions.

By reviewing existing studies on the subject, adding recent first-hand insights from stakeholders, and applying basic econometric and spatial analysis, this report will provide solid information on the advantages and disadvantages of hydrogen and hydrogen-based fuels; Egypt's potential position in a hydrogen-based shipping industry; the geopolitical implications of the Suez Canal as a green shipping hub; and the requirements of hydrogen-based shipping for Egypt.

The report is structured as follows: in the first chapter, the role of hydrogen and its derivatives in international trade is assessed from a technical-economic point of view. This includes a basic overview of the organization of maritime trade, the advantages and disadvantages of different marine fuels, and an analysis of the viability of hydrogen and its derivatives from a technical, logistical, and economic perspective.

The second part deals with the geopolitical and economic aspects of sustainable green shipping in Egypt. It examines the overall importance of the Suez Canal in current maritime trade and its suitability as a green shipping hub and assesses Egypt's potential as part of a green shipping corridor. This will be done from a geopolitical perspective.

Finally, the impact and requirements of hydrogen-based shipping for Egypt and the wider Suez region will be examined from an economic geography perspective. Based on a baseline assessment of the production potential analysis, this chapter looks at the possibility of creating economic linkages and the associated risks and opportunities in establishing a hydrogen economy.

In the concluding part, these three perspectives are brought together and translated into initial policy recommendations. As the field is developing rapidly, further research needs are clearly articulated.

02

Green fuels in international shipping

2 Green fuels in international shipping

This chapter introduces operations in maritime trade. Moreover, it compares and assesses green shipping fuels from a technical, economical, and logistical perspective.

2.1. The organization of maritime trade

Before turning to green shipping fuels, this section briefly introduces the topic of maritime trade and sets out basic concepts.[1]

Bunkering

Typical harbor services include the refueling of ships, called bunkering (Dorsch, 2021). Bunkering can be done in ports or at sea near ports via ship-to-ship bunkering using barges. Bunkering large volumes of fuel is a risky activity requiring careful planning, management, and supervision to avoid pollution.

Today, bunkering fuel prices can vary significantly between ports and over time. Therefore, choosing the right time and port for bunkering is a strategic decision for the shipping line. The efficiency, i.e., the time necessary to bunker at the port, is an important consideration in the choice of the bunkering port, as any additional time to the voyage means additional costs (Maritimesa, 2023).

International trade routes

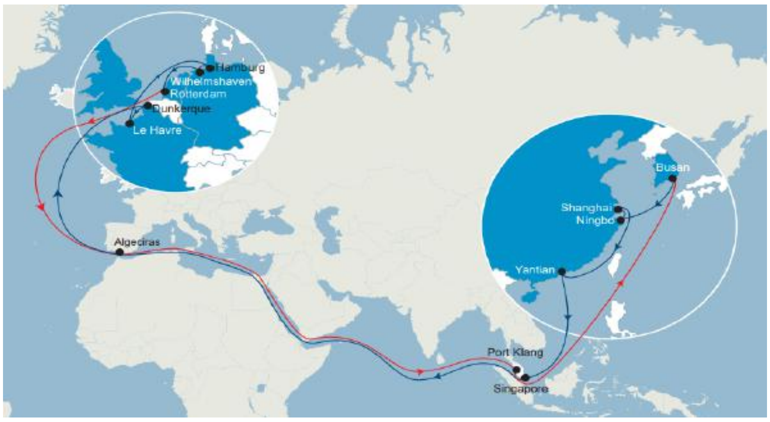
Maritime trade is primarily organized in a hub & spoke system. In contrast to point-to-point systems, in which each point has a direct route to every other point, hub & spoke is an organization of routes that connect outlying points to a central "hub". Hubs are large, highly connected ports through which all smaller ports transact their trade. A small number of hubs are the most important and largest ports. The largest cargo ships steam on the trunk routes between hubs. From a hub, cargo is distributed to smaller ports by so-called feeders. Feeder routes are either cyclic when connecting many feeder ports with lower demand to a hub or shuttle routes when connecting a large feeder port to a hub.

Figure 2 shows an example of a line connecting hubs in Asia and north-western Europe and a feeder line connecting the Hub port of Hamburg with feeder ports in the Baltic Sea. The Hub & Spoke system was established in cargo shipping due to economies of scale. It is more economical to shuttle or make round trips between hubs with larger vessels and then distribute from these hubs with smaller vessels than to call[2] smaller ports directly with larger vessels. A large cargo ship can exploit economies of scale best the more time it spends at sea. Thus, large cargo ships limit their number of port calls per trip to a minimum.

The liner operator sets the schedule and pays for the fuel of a cargo ship, which is a significant cost factor. Fuel consumption rises exponentially with increasing speed. Therefore, vessels mostly travel at slow steaming speed (Maritimeesa, 2023). Schedule management is crucial to the operators' commercial success. Mobility patterns and networks differ between cargo ship types. Container ships follow regularly repeating paths, whereas bulk dry carriers and oil tankers move less predictably between ports (Kaluza et al., 2010).

[1] Additional explanation of basic terms can be found in the glossary.
[2] "Port of call" means an intermediate stop for a ship on its route

Figure 2: *Trunk line connecting hubs in Asia and Europe (left) and feeder line connecting the hub port of Hamburg with feeder ports in the Baltic Sea (right)*



Source: *CMA CGM (2023)*

Fossil marine fuels

Ships can either be propelled via a conventional Internal Combustion Engine (ICE) or an electric motor. Additionally, ships use generators to run electric motors for their steering and on-board electricity demand. Currently, different types of fuel are used for propelling ships. Conventional ICEs in ships usually run on Heavy Fuel Oil (HFO), Marine Gas Oil (MGO), or Liquified Natural Gas (LNG). LNG is broadly used as fuel in LNG carriers that use boil-off gas[3]. On-board generators usually consume MGO or marine diesel oil (Maritimesa, 2023; IRENA, 2021).

In 2020, the IMO imposed sulfur limits on marine fuels to reduce emissions[4]. Since then, fuel shifted from regular Heavy Fuel Oil (HFO) to very low sulfur fuel oil, MGO, or LNG. LNG is cleaner than HFO in sulfur oxide emissions but has a methane slip between 2-5 % when used in engines (Mallouppas & Yfantis, 2021). The carbon content of methane compared to HFO is 26 % lower, but the Global Warming Potential over 20 years (GWP20) of methane is 56 times the GWP20 of CO_2. Hence, the Greenhouse Gas (GHG) emissions from ships using LNG are significantly higher than the GHG emissions of ships using HFO.

Box 1: Key takeaways on the organization of maritime trade

> Today, ship engines typically run on fossil marine fuels. Typical harbor services include the refueling of ships, called bunkering. Choosing the right bunkering port is a strategic decision. Fuel is a significant cost factor for the shipping company.
>
> Maritime trade is organized in a hub & spoke system due to economies of scale. Hubs are large, highly connected ports through which all smaller ports transact their trade.

[3] Boil-off-gas is evaporated LNG that needs to be vented from the LNG storage tank to preserve the tanks pressure. LNG is transported in insulated tanks to keep the amount of Boil-off gas to a minimum.
[4] Combustion of sulphurous fuel produces sulphur oxides which can cause acid rain and are harmful to human health when released in the atmosphere.

2.2. Comparison of green shipping fuels

This section discusses energy storage possibilities based on renewable electricity. Molecule-based energy storages, like hydrogen, ammonia, or methanol, and electrochemical storages, like batteries, have numerous advantages and disadvantages. In the following, the main advantages and disadvantages are shown in a non-exhaustive comparison.

Green Hydrogen

Hydrogen is considered green if net GHG emissions released during production are zero. For instance, green hydrogen can be produced from water electrolysis using electricity from renewable energies. Green hydrogen is the feedstock for green hydrogen-based fuels like ammonia and methanol. Therefore, electrolytic hydrogen production has the highest energy efficiency of all hydrogen-based fuels. However, the low volumetric energy density of gaseous hydrogen and energy-intensive liquefaction make hydrogen transport costly. In comparison, the volumetric energy density of HFO is more than four times larger than that of liquid hydrogen and almost seven times larger than that of compressed hydrogen at 700 bar. Hydrogen tanks would have to be larger and heavier than fuel tanks for HFO, resulting in a reduced cargo capacity of the ships (IRENA, 2021). Storage of compressed hydrogen requires much space, and storage of liquid hydrogen requires liquefaction, which reduces the energy efficiency of the fuels' well-to-wake balance. The liquefaction of hydrogen is challenging as it requires temperatures of -253°C. Hydrogen can be used in fuel cells to produce electricity or in ICEs to produce mechanical energy.

While hydrogen ICEs and fuel cells for ships are technically possible, they require development. Currently, neither is available at scale. One of the largest fuel cells for hydrogen in operation today has a rated electricity generation capacity of 17,000 kW. Fuel cells are modular and can provide power for electric engines or ship auxiliaries. The largest hydrogen ICE available to date has a power of 216 kW (290 hp) (Ginger, 2022). In comparison, the engine of the Emma Maersk, Neopanamax-class containership, has a power of about 98,080 kW (130,000 hp) (Hamburger Hafen, 2023), a feeder container ship of the SSW Super 1000 class has a power of about 9,000 kW (12,237 PS) (HS Schiffahrts Gruppe, 2023).

Green Ammonia

Ammonia is gaseous at ambient conditions but is easier to liquefy than hydrogen. Ammonia becomes liquid at -33°C and atmospheric pressure. Alternatively, ammonia can be transported or stored in the liquid state at a pressure of 10 bar at ambient temperatures. These physical properties and the fact that liquid ammonia has 30 % higher volumetric energy density than liquid hydrogen make transporting ammonia less expensive than transporting hydrogen. The production of ammonia requires hydrogen and nitrogen. Like hydrogen, ammonia has zero carbon content. On the downside, ammonia transport brings safety and environmental risks as it is a toxic and corrosive substance. Compared to other fuels, substantial safety measures are necessary to use ammonia. Among measures to reduce the risk of handling ammonia are double-walled pipings, increased ventilation of spaces containing ammonia equipment, leak detectors and alarms, and shutdown mechanism of the fuel system in case of an ammonia leak (ZCS, 2023).

Unlike hydrogen, ammonia is a globally traded commodity, and there are existing logistics and ships to transport ammonia and infrastructure for the handling and storage of ammonia in many ports. Ammonia can be used as a fuel for fuel cells or ICEs. The development of ammonia ICEs for ship propulsion systems is in its final stages, with some applications already in place (IRENA, 2021). For instance, manufacturer MAN Energy Solutions plans to deliver their first full-scale commercial engine by 2024 (MAN Energy Solutions, 2023).

Green Methanol

Methanol is liquid at ambient conditions and has a volumetric energy density of 5.5 kWh/l, which is about half the energy density of HFO but almost twice the energy density of liquid ammonia. The physical properties make the transport and storage of methanol more economical than the transport and storage of ammonia or hydrogen. However, methanol production has the lowest energy efficiency of the three fuels discussed. Methanol contains carbon, which reacts to CO_2 during combustion. Therefore, methanol based on fossil fuels is not climate neutral. Green methanol can be produced via methanol synthesis using green hydrogen and CO_2 extracted from the air or from biomass. The high cost of CO_2 extracted from the air via direct air capture makes the production of green methanol less economical than the production of green ammonia.

ICEs using methanol are well-developed. Methanol can be used in typical marine ICEs running on HFO with little modifications (IRENA, 2021). If existing vessels switch from HFO to methanol, adjustments to the fuel injectors and the fuel supply system are necessary. A small number of commercial ships have been retrofitted with methanol engines and operate today (DNV GL, 2019). Many methanol engines can run on methanol and marine diesel. Next to ICEs, methanol can be used in fuel cells. Methanol transport and storage can use the established infrastructure of oil-based commodities, which is already in place at scale in almost any port. Bunkering practices for Methanol would most likely be the same as it is for fossil marine fuels. Ports in the Middle East or the Netherlands already possess large methanol storage facilities (Wissner et al., 2023).

Battery

Instead of converting electricity to molecule-based energy carriers like hydrogen, the electricity could be stored directly in a battery. Storing electricity in batteries is more energy efficient than converting electricity into a molecular energy carrier. The storage efficiency of lithium-ion batteries is about 90 %, whereas the energy efficiency of hydrogen production via electrolysis is about 70 %, the energy efficiency of green ammonia production is about 45 %, and the energy efficiency of green methanol production is about 32 % (Moritz et al., 2023; EWI, 2021a). This does not include the conversion efficiency of the engine, which is the most efficient for an electric engine.

The volumetric energy densities of today's batteries are about 100 times smaller than the energy density of HFO (Clean Energy Institute, 2023*)*. Therefore, batteries are not suited as energy storage for long-distance shipping. However, batteries might be an option for short-distance inland waterway shipping or harbor vessels.

Box 2: Key takeaways on the comparison of green shipping fuels

> The production of hydrogen has the highest energy efficiency, but hydrogen has the lowest energy density of all hydrogen-based fuels, making it difficult to transport and store. Ship engines running on hydrogen are not yet commercially available at scale and no notable infrastructure exists.
>
> Ammonia has a higher energy density than hydrogen but brings safety and environmental risks as it is a toxic and corrosive substance. Unlike hydrogen, ammonia is a globally traded commodity with existing and tested infrastructure. The development of ammonia engines for ship propulsion systems is in its final stages with some applications already in place.
>
> Methanol has the highest energy density of hydrogen-based fuels but contains carbon. Transport and storage are possible with established infrastructure. Methanol can be used in typical marine engines with little modification.

2.3. Viability of green shipping fuels

Based on the previously discussed advantages and disadvantages, this section assesses the viability of hydrogen and hydrogen derivatives from technical, logistical, and economic perspectives.

Technical assessment

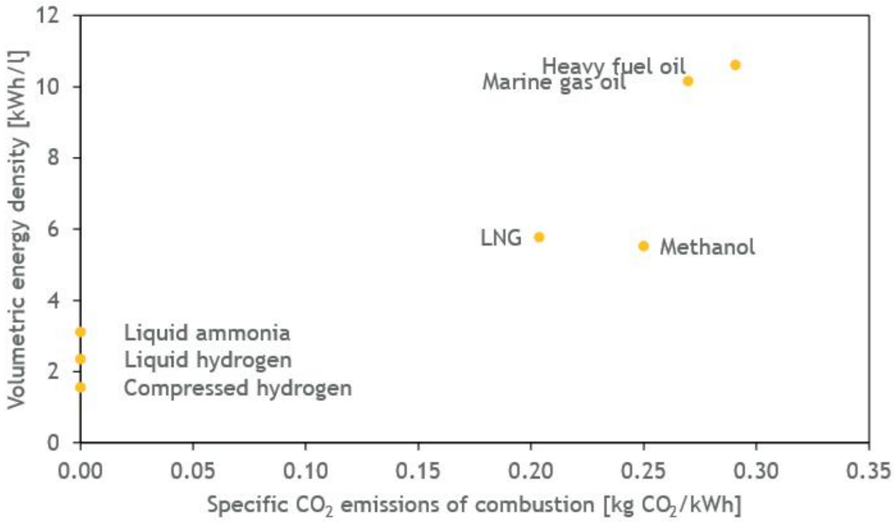
Green hydrogen and hydrogen derivatives can be used as fuels for ships. Only synthetic methane or Fischer-Tropsch fuels can be used as drop-in fuels for common ship ICEs. Methanol, ammonia, or hydrogen require retrofitting of existing ships and design changes for newly constructed ships. The extent of retrofitting required is lowest for methanol and highest for hydrogen. Modifications are necessary in the engine system, fuel handling, and storage.

Bunkering hydrogen and hydrogen derivatives requires a different infrastructure than bunkering HFO. HFO infrastructure typically involves large storage tanks and piping systems for fuel transfer, similar to the infrastructure methanol would require. Ammonia requires storage tanks designed to handle its corrosive properties. Due to ammonia's toxicity, secondary containment mechanisms like double-walled piping might be necessary to reduce the risk of ammonia leaks. Liquid hydrogen is stored in cryogenic storage tanks with appropriate insulation to store liquid hydrogen at temperatures of -253°C.

Logistical assessment

Hydrogen-based fuels have lower volumetric energy density than HFO. The volumetric energy density of methanol is about 50 %, of ammonia about 70 %, and of hydrogen about 80 % lower than the volumetric energy density of HFO. The lower energy density of the fuels might result in a lower range of the ships or in modifications of the ship's design.

Figure 3: *Tradeoff between volumetric energy density and GHG emission intensity of marine fuels*



Note: Calorific values refer to the net calorific value. Compressed hydrogen refers to a pressure of 700 bar.

Source: *Own illustration based on Møller et al., 2017; Engineeringtoolbox, 2023*

Assuming that the volume of the tank on the ships remains constant, a ship that runs on ammonia would have a 70 % shorter range than a ship that runs on HFO. If a larger tank is installed, this would be at the expense of transport capacity for cargo. A study (MMKMC, 2022) concluded that the loss of container space for a 15,000 TEU vessel would be less than 1 %. Another study finds that the methanol-fueled fleet could maintain 93 % of current cargo/bulk operations (Stolz et al., 2022).

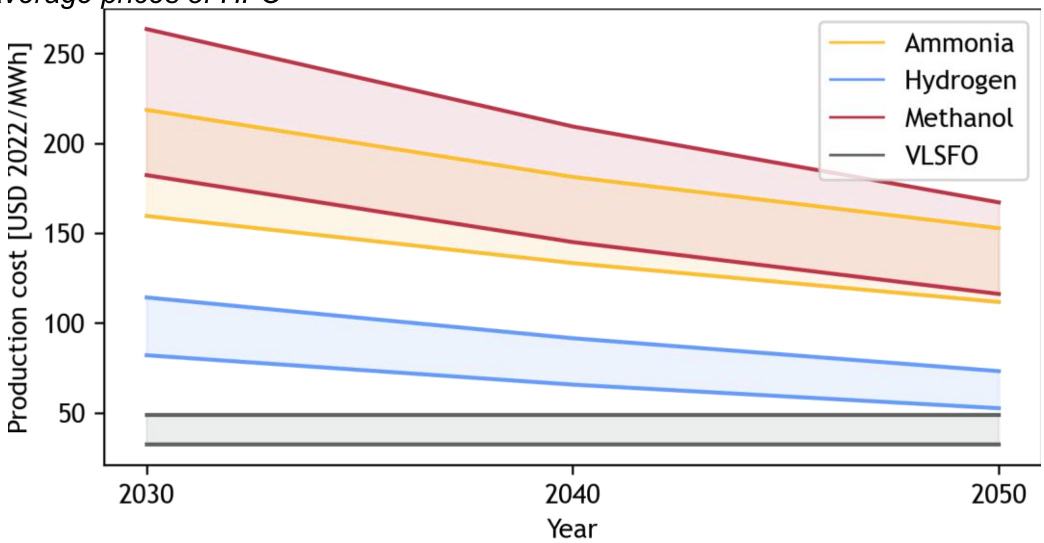
Lower ranges may also influence bunkering patterns. Today, bunkering is highly concentrated. The top 20 bunker ports provide over 90 % of all bunkers. Many ships currently have longer ranges than their usual trip length, so they often only make a single bunkering stop per round trip at the most economical port. Due to the potentially lower range of ships using green fuels, more than one bunkering stop per round trip might be necessary. Thus, bunkering patterns might disperse in the future.

Large cargo ships on trunk lines between Asian and European hubs make ten or more stops on a roundtrip. However, these stops are mostly at hubs in Asia or Europe. For instance, of the nine Europe-Asia lines the French shipping company CMA CGM offers, none includes a port call in Egypt, and only one includes a port call in the Red Sea (namely Jeddah, Saudi Arabia) (CMA CGM, 2023). Therefore, an additional bunkering stop in Egypt would mean additional costs for the line operators as it means at that time, the ship is not at sea. For a bunkering stop in Egypt to be economical, the savings in fuel costs of bunkering in Egypt must outweigh the costs of the additional port call. A more detailed discussion of the potential for bunkering is given in Chapter 3.3, using the Shanghai-Rotterdam route as an example.

Economical assessment

The economic viability of green hydrogen and its derivatives in the shipping sector depends on several factors, including the cost of hydrogen production, the availability of infrastructure, and the price of competing fossil fuels. Green hydrogen's cost competitiveness compared to conventional marine fuels, like Very Low Sulfur Fuel Oil (VLSFO) or marine diesel oil, is currently a significant barrier to the widespread adoption of hydrogen-based fuels. Figure 4 shows levelized production cost projections for green hydrogen, methanol, and ammonia in the Red Sea Region in comparison to historical average prices for VLSFO (Moritz et al., 2023; IEA, 2020). The comparison shows that the production costs of hydrogen-based green fuels are significantly higher than the market prices of VLSFO. In 2030, hydrogen production is projected to be more than twice as expensive as VLSFO. The production of green ammonia is about twice as expensive as hydrogen, and the production of methanol is the most expensive of the fuels compared. The production costs of all hydrogen-based fuels are projected to decrease until 2050 due to decreasing investment costs for renewable energies and electrolyzers but remain above the historical average price of VLSFO. Thus, policy measures like a CO_2 price on bunkering fuels are necessary to close the cost gap between green and fossil shipping fuels. The CO_2 price in Europe is expected to rise, and initiatives like the Carbon Border Adjustment Mechanism (CBAM) may impact fuel choices beyond the EU, especially for logistics companies and shipping firms involved in imports to Europe. Given that goods passing the Suez Canal are transported to and from, European regulations might play a pivotal role. Moreover, international commitments and the climate policies of large economies such as the EU, the USA, and China will undoubtedly influence the attractiveness of VLSFO as a fuel, both in terms of pricing and regulations.

Figure 4: *Levelized production cost projections of green fuels in the Red Sea region in comparison to historical average prices of HFO*



Source: *Own illustration. Hydrogen, ammonia, and methanol production cost projections for Egypt and Saudi Arabia based on Moritz et al., 2023; VLSFO historical average prices based on IEA, 2020. CO_2 emission costs are excluded.*

Box 3: Key takeaways on the viability of green shipping fuels

Methanol, ammonia, or hydrogen require retrofitting of existing ships and infrastructure to be used. The extent of retrofitting required is lowest for methanol and highest for hydrogen.

Hydrogen-based fuels have lower volumetric energy density than fossil marine fuels which results in a lower range or lower cargo capacity of ships running on hydrogen-based fuels and might increase the number of bunkering stops per trip necessary. Large cargo ships usually do not call a port at the Suez Canal. For a bunkering stop in Egypt to be economical, the saving in fuel costs of bunkering in Egypt must outweigh the costs of the additional port call.

Without policy measures, the production costs hydrogen-based green fuels are significantly higher than market prices of VLSFO. While the production costs for hydrogen-based fuels are projected to decrease until 2050, a cost gap to today's VLSFO prices remains. The cost gap can be closed by policy measures like a CO_2 price.

03

Egypt as a green shipping gateway: geopolitical challenges and economic potential

3 Egypt as a green shipping gateway: geopolitical challenges and economic potential

This chapter assesses the geopolitical and economic implications for and of green shipping in Egypt. The Suez Canal plays a key role in global maritime trade as a bottleneck in what is currently the shortest route between Asia and Europe. While Egypt has the potential to become part of a green shipping route by facilitating green shipping infrastructure, it also faces challenges such as alternative shipping routes between Asia and Europe, competition in the bunkering market, and a global hydrogen market. This chapter sheds light on both opportunities and challenges associated with the establishment of a green shipping route.

3.1. Dynamics in international shipping

This section outlines the role of the Suez Canal in global maritime trade and reflects on major shifts in the global maritime trade.

The Suez Canal – a chokepoint for international maritime trade

90 % of global trade is carried out by ships. Thus, shipping plays a crucial role in global value chains and globalization. UNCTAD projects a growth rate of maritime trade to expand at an annual average of 2.1 % for the period 2023-2027. Container trade on the Asia-Europe route increased by 10 % in 2022 (UNCTAD, 2022).

The Suez Canal is an artificial canal located in Egypt and one of the most heavily trafficked shipping lanes in the world (SCA, 2019a). Since its opening in 1869, it has been crucial for global trade, providing a direct route for shipping between Europe and Asia. 52 cargo ships usually pass through the Suez Canal every day (IfW Kiel, 2021). The tolls on the canal are an important source of revenue for Egypt. The canal represents almost 10 % of Egypt's GDP (2016), with a revenue of $6.3 bn in 2021 (Kenawy, 2016; Abd-Alaziz, 2022).

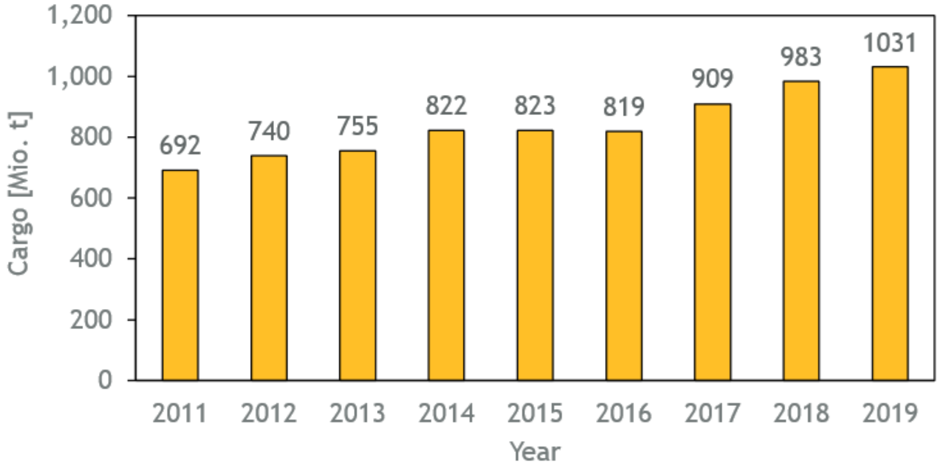
Table 1 displays the key characteristics of the canal. Usually, ships need 12 hours to pass the 193.3 km long Suez Canal (IfW Kiel, 2021). The largest vessel size transiting the Suez Canal is referred to as Suezmax (see Table 10). One such container ship can hold just over 20,000 containers (IfW Kiel, 2021). Over the last decades, the size of ships increased significantly. The blockade through the container ship "Ever Given" in 2021 has shown the vulnerability of the canal. Thus, the Suez Canal Authority (SCA) has commissioned several canal-widening programs. In 2015, the New Canal opened (SCA, 2023c). Additionally, the canal is currently being enlarged, and a second channel is extended, increasing traffic safety and the number of ships potentially passing through the canal to 100 ships per day (MFAT, 2021; Hechler, 2022).

Table 1: *Technical characteristics of the Suez Canal*

Category	Value (2015)	Plans	Unit
Total length	193.3		km
ByPasses Length	113.3		km
Width in 11 m depth	205/225		m
Max. Water depth	24		m
Draft of the vessel	20	22	m
Cross-sectional area	4,800/5,200		m²
Max. loaded vessel	240,000		DWT
Vessels per day	45	97	Vessels

Source: *SCA, 2019a*

Figure 5: *Cargo traversing the Suez Canal between 2011 and 2019*

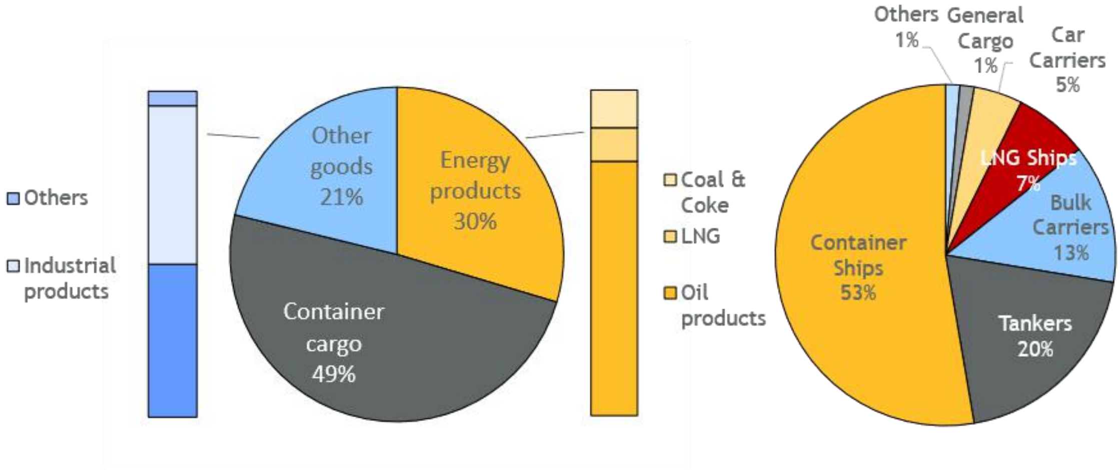


Source: *Own illustration based on SCA, 2019c*

In 2019 around 19,000 ships, mostly container ships (5,375) and tankers (5,163), with a cargo of 1.03 billion tons of transporting goods worth over USD 1 trillion, passed the Suez Canal (see Figure 5 & Figure 6), accounting for 12 % of global trade and 30 % of global container ships (MFAT, 2021; SCA, 2019c).

In 2019, 572.3 Mio tons of cargo were navigated through the canal from the Mediterranean Sea towards the South, and 458.8 Mio tons of cargo were shipped from the Red Sea through the canal to the north (SCA, 2019c). Figure 7 shows the origin and destination of cargo going through the Suez Canal. In 2019, more than 11 % of cargo in tons transiting the canal from North to South originated from the Netherlands, around 10 % from Egypt's Mediterranean shore, 8 % from the United States, and around 6 % each from Spain, Greece, the United Kingdom, and Russia (SCA, 2019b). From South to North, 20 % of the cargo navigation through the canal was of Saudi Arabian origin, 17 % from Singapore, 11 % from China, 9 % from India, and 8 % from Malaysia in 2019 (SCA, 2019b).

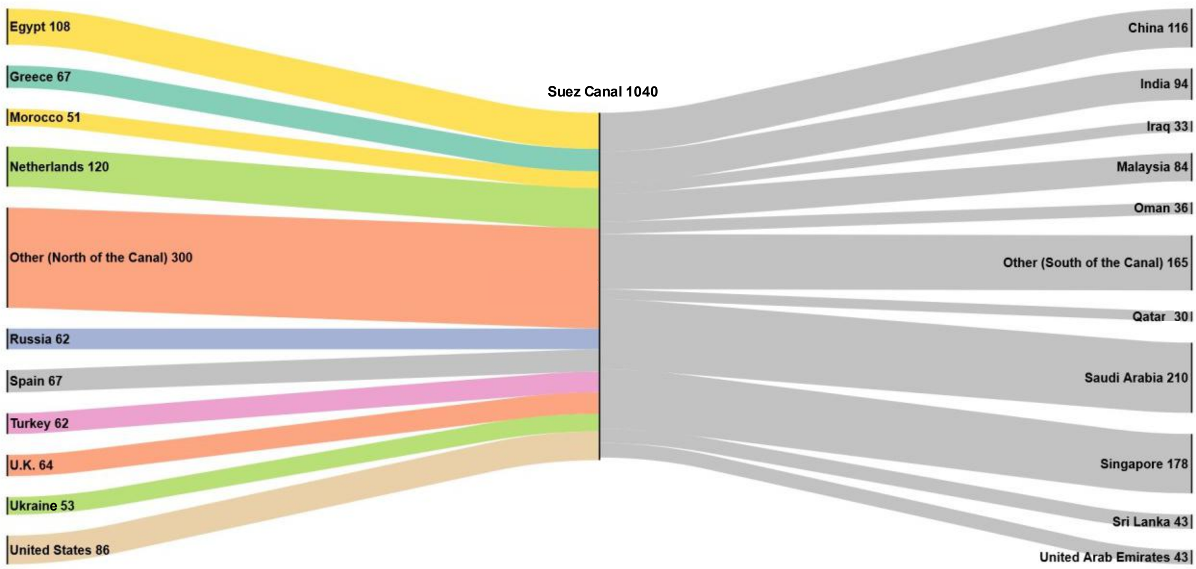
Figure 6: *Cargo by Cargo type navigating through the Suez Canal in 2019 (left) and share of ship types passing the Suez Canal in 2019 (right)*



Source: *Own illustration based on SCA, 2019b; SCA, 2019c*

Besides its significance for container cargo, the Suez Canal plays an important role in global energy markets (see Figure 7). The Suez Canal currently is the main trunk line for oil and LNG trade from Asia and the Middle East to Europe. In 2019, 238.6 Mio cargo tons of oil products were transferred through the Suez Canal (SCA, 2019b). In 2021, about 5 % of the world's crude oil, 10 % of the world's oil products, and 8 % of LNG was transferred through the Suez Canal (IEA, 2021).

Figure 7: *Origin and destination countries of cargo transiting the Suez Canal in 2019*



Source: *Own illustration based on (SCA, 2019b)*

Alternative trade routes and changing trade patterns

Due to global warming and shifting global trade patterns, shipping routes and their competitiveness could change. Besides the Suez Canal route, the North-East route and the Cape Route are relevant for Europe-Asia trade.

Today, the Suez Canal Route is the trunk line between Europe and Asia. Currently, the second shortest route and alternative to the Suez Canal is the Cape Route via the Cape of Good Hope. The North-East Route, along the Arctic coast of Russia, is gaining relevance under global climate change influence as the ice in the Arctic Ocean recedes (Vukic & Cerban, 2022; Rahman et al., 2014)

The relative attractiveness of the shipping routes may vary depending on the fuel prices, as bunkering is a key factor in shipping costs. The incremental costs are fundamental in the route selection (Vukic & Cerban, 2022). The attractiveness of the route also depends on the specific origin and destination of the shipment and the type of vessel and cargo.

Figure 8: *Shipping routes between Asia and Europe*

Source: *Own illustration*

The **Suez Canal Route** is the shortest route between Europe and Asia (see Table 2). For vessels transiting the Suez Canal, the SCA levies a transit fee based on the net tonnage of carriers, the type of vessel, and vessel size (Vukic & Cerban, 2022). The toll is adjusted each year and has increased in 2023 by 10-15 % (SCA, 2023; Staber, 2022).

The Suez Canal has a restriction on the maximum vessel size that can pass the canal (Vukic and Cerban, 2022). Very large crude carriers (VLCC) and ultra-large crude carriers (ULCC) can only navigate through the Suez Canal when not fully laden (IEA, 2021). However, plans exist to make the canal passable for larger vessels (Hechler, 2022).

The Suez Canal faces the general risk of blockage due to natural disasters, human failure, piracy, or war. The Canal was closed several times in history. In the most recent event, the canal was blocked for six days by the container carrier “Ever Given”, which accidentally ran aground and turned sideways in the canal. Most ships on the Suez-Route also pass the chokepoint of Bab-el-Mandeb, which incorporates security risks due to piracy. Vessels have additional costs of appointing security guards (Vukic & Cerban, 2022).

The **Cape Route** is longer than the Suez Canal Route (see Table 2). Depending on the cargo and the vessel, the Cape Route requires an additional 6-14 days of travel time compared to the Suez Canal

Route. The longer shipping time adds costs and poses risks to time-sensitive cargo such as medical equipment or food (MFAT, 2021). Therefore, the Cape Route is more relevant for slow vessels with low-value cargo (Martínez-Zarzoso, 2013). The absence of tolls can make the Cape Route competitive with the Suez Canal Route in times of low fuel prices (Brigham, 2021; Vukic and Cerban, 2022). There is no restriction on vessel size on the Cape Route. Cape-size bulk carriers that cannot pass the Suez Canal must take the Cape Route (Vukic and Cerban, 2022). However, Cape-size bulk carriers only account for 9% of the global bulk carrier fleet (Shafran, 2023). Regarding security, the Cape Route faces risk concerns due to piracy (MFAT, 2021).

The **North-East Route** is the shortest route between North-West Europe and East Asia (see Table 2) (Vukic and Cerban, 2022; Rahman et al., 2014). The North-East Route could increase operational efficiency for maritime trade since the lower distance reduces travel time, fuel costs, and CO_2 emissions. In 2021, more than 80 ships transited through the North-East Route (CHNL, 2021).

At present, the North-East Route is only passable during the warm season for four to five months since most of the North-East Route passes through areas of thick long-term ice. The Arctic Ocean remains at least partially ice-covered in late autumn, winter, and spring, and the difficult climatic conditions form an obstacle to maritime shipping. Until now, this route has had low competitiveness due to the limited navigability as well as a lack of shipping and port infrastructure, such as the absence of transshipment points, well-developed transit ports, limited mapping, satellite coverage, and communication capabilities. Additionally, this route faces size limitations for large carriers (Deutsches Arktisbüro am Alfred-Wegener-Institut, 2019; Martínez-Zarzoso, 2013; Vukic and Cerban, 2022).

Shipping via the North-East Route faces additional costs due to escorting by ice breakers (Vukic and Cerban, 2022) and fees charged by Russian authorities.

The North-East Route may become more passable as global warming progresses, and the Arctic Ocean could, in the future, be used more reliably for shipping. By 2100, the North-East Route could be navigated for an additional four to six months per year (Deutsches Arktisbüro am Alfred-Wegener-Institut, 2019).

However, uncertainty regarding territories along the North-East Route remains (Martínez-Zarzoso, 2013). Russia makes claims to a major part of the North-East Route. The country is investing significantly in the North-East Route infrastructure and collaborates with China on its development (Lutmar & Rubinovitz, 2023). Russian authorities and politicians formulated ambitious targets to increase the cargo volume along the North-East Route (Ministry of Transport of the Russian Federation, 2019). The development of the North-East Route offers economic opportunities for the regions, mainly Siberia. Russia's invasion of Ukraine and the resulting geopolitical situation and Western sanctions make it improbable that Western shipping companies transit the North-East Route, which is administrated by Russia’s Rosatom (Digges, 2022).

Due to the limited navigability, the North-East Route currently is no alternative for Asia-Europe trade. Whether it will become a global container route is controversial (Brigham, 2021) and depends on the scope of global warming. Due to the shorter distance and the associated time and cost savings, if commercial shipping through the North-East Route becomes viable, this could challenge the position of the Suez Canal and Egypt's revenues for routes between Europe and East Asia. However, the Suez Canal route passes major economic centers between Europe and East Asia, for instance, South East Asia and India. This allows the opportunity for port calls on the way. In contrast, the North-East Route mainly passes no man's land at the shores of the Arctic Ocean.

Table 2: *Comparison of Asia-Europe shipping routes for a container ship*

	Route	**Sea distance [km]**
Rotterdam - Shanghai	North-East	15,200
	Suez Canal	21,442
	Cape	28,200
Rotterdam - Singapore	North-East	19,300
	Suez Canal	15,700
	Cape	22,300

The role of the Suez Canal Route, the Cape Route, and the North-East Route in green shipping will depend on the efforts of concerned countries to establish green shipping infrastructure and, specifically, on the availability and the costs of green fuels. While the Russian government announced plans for an Arctic Hydrogen Cluster (Vechkinzova et al., 2022), the war against Ukraine and the imposed sanctions hinder Russia's hydrogen ambitions (Patonia, 2022). Regarding the Cape Route, the two countries, South Africa and Namibia, have significant renewable energy and green hydrogen potential and facilitate hydrogen projects. How the decarbonization of global maritime trade may influence the attractiveness and competitiveness of the three discussed trade routes has not yet been analyzed, and implications remain partly unknown.

Global energy trade routes are about to change with the energy transition, and new trade patterns may appear. Due to global climate change mitigation efforts and decarbonization targets, the demand for fossil fuels is expected to decline in the long term. Thus, trade in fossil fuels is expected to decrease. With its ambitious climate targets, the EU's fossil imports are expected to decrease significantly in the mid-term. At the same time, trade is expected to increase for other commodities, goods, and regions. The demand for green fuels, such as renewable hydrogen and ammonia, is expected to increase. New energy suppliers endowed with large renewable energy potentials may position themselves in the global green commodity trade (IRENA, 2019).

In addition to the impact of changing energy commodity trade patterns, other factors affect global trade in the future. Trade in renewable energy and green technologies, such as photovoltaic (PV) modules, batteries, etc., might increase. The trade in components and parts for the manufacturing of technologies and critical raw materials is expected to increase (IRENA, 2019).

The population in countries in Africa and Asia and the demographic change in Europe and Japan are additionally affecting global trade patterns and may potentially result in a shift in global trade flows (WTO, 2013).

Another point to consider is the varying economic growth rates in different countries and regions. For instance, several countries in Asia and Africa have shown robust GDP growth over the last decades, while European countries tend to stagnate or grow at lower rates (IMF, 2023). The Maldives, Philippines, India, Cambodia, Vietnam, Bangladesh, and China have a real GDP growth of >5 % in 2023 (IMF, 2023). Moreover, various African countries (Senegal, Democratic Republic of Congo, Côte d'Ivoire, Rwanda, Ethiopia) have a strong GDP growth. In the long run, this can induce a shift in trade flows with implications for shipping.

Finally, the future of world trade is certainly affected by political affairs. Various geopolitical dynamics, international relations, and policy decisions can significantly impact trade patterns (EWI, 2023). While free trade agreements and alliances may positively impact and facilitate global and regional trade, (protectionist) measures such as tariffs and sanctions can restrict or hinder the smooth functioning of global trade. As a result, trade flows can be impacted, as can be seen in the sanctions against Russia that followed the war against Ukraine in early 2022.

As a result of intensified tensions between China and the United States, both countries utilize protectionist measures. Green de-risking strategies are utilized to incentivize domestic production of strategically important goods, such as semiconductors and components crucial for the energy transition. This does not only affect both countries but could shift trade flows (ADB, 2020; WTO, 2020). Geostrategic considerations can impact trade flows as countries form strategic trade relations, prioritizing certain markets for political reasons to advance their geopolitical interests. Additionally, domestic regulatory changes (e.g., concerning labor standards, human rights, property rights, and environmental and sustainability standards) may impact trade flows to the European Single Market (EWI, 2021b). Political and economic instability has an implication on trade dynamics.

Political instability and conflicts can disrupt trade by damaging infrastructure and creating an uncertain business environment (EWI, 2023). Currency values and exchange rates affect industrial competitiveness and may have effects on import and export dynamics, which can influence trade patterns. Global governance and International Organizations such as the World Trade Organization (WTO) provide a framework for global trade, settling disputes, and establishing rules (WTO, 2023). The further development of these economic and fiscal governance structures impacts the effectiveness of these organizations with potential implications for the global trade system (Chatham House, 2020).
Not only do (geo-)political issues affect global trade, but supply-side disruptions can also stem from other issues, such as natural disasters and health crises such as the 2019 COVID pandemic, resulting in a disruption in production and shipping, driving prices (De Santos, 2021).

Box 4: Key takeaways on the alternative trade routes and changing trade patterns

> The Suez Canal connects the Mediterranean and the Red Sea and is the key bottleneck in the Asia-Europe trade. The canal is of major economic relevance for Egypt as it accounts for about 10% of the country's GDP.
>
> In 2019, almost 19,000 ships, 12% of global trade, passed through the Suez Canal. Container shipping and tankers dominated, as container cargo made up halve of the cargo transiting the Suez Canal in 2019.
>
> Global trade routes and trade patterns may change in the future due to developments in the global economy, climate change or green shipping. There is a risk that the Suez Canal loses parts of its traffic volume to the North-East Route, if the North-East Route becomes reliably passable in the future.

3.2. Green shipping corridors in international maritime trade

This section discusses current efforts to decarbonize maritime trade, initiatives for establishing green shipping corridors on the one hand, and decarbonization efforts of port infrastructure on the other hand.

Current state of Green Shipping Corridors

Green Shipping Corridors (GSC) can be defined as a shipping route on which zero-carbon emission ships and other emission reduction programs are deployed. Emission reductions are measured and enabled through public and private actions and policies (C40, 2023). GSC are seen as an important instrument to push for decarbonization in the shipping sector (Getting to Zero Coalition & Global Maritime Forum, 2022). Certain unclarity remains regarding the "greenness" of GSCs and the corridor concept underlying it (this can either be understood as port-centric or route-centric, Global Maritime Forum, 2022). Nevertheless, GSCs are generally associated with emission reduction and/or the deployment of green technology and infrastructure. GSC are described as "[…] shipping routes where the technological, economic and regulatory feasibility of the operation of zero-emission ships is catalyzed by a combination of public and private actions" (Global Maritime Forum, 2022).

In 2021, at COP26, over 20 countries declared to support the establishment of at least six GSCs by the middle of this decade (UK Department for Transport, 2022). Norway and the United States initiated the Green Shipping Challenge at COP27 in Egypt and thereby ramped up decarbonization efforts in global shipping.

Various GSC projects have been announced worldwide, including more than 15 intergovernmental initiatives (see Table 3). These GSC initiatives are mainly at an early stage of development. While some initiatives are currently undergoing pre-feasibility studies, others have signed Memorandums of Understanding (MoU) or Letters of Interest (LoI). Most of the proposed GSCs focus on container vessels. Only one GSC has been proposed for dry bulk and tankers (Environmental Defense Fund, 2022).

Table 3: *Overview of announced interstate Green Shipping Corridor projects*

Title	Port 1	Country of port 1	Port 2	Country of port 2	Year announced	Status
Rotterdam-Singapore Green and Digital Corridor	Singapore	Singapore	Rotterdam	Netherlands	2022	MoU
LA-Shanghai green corridor	Shanghai	China	Los Angeles	United States	2022	MoU
Andalusian Green Hydrogen Valley	Rotterdam	Netherlands	Algeciras	Spain	2022	MoU
Australia-East Asia iron ore Green Corridor		Australia		East-Asia	2022	LOI for assessment
Australia-Japan iron ore route		Australia		Japan	2022	Pre-feasibility assessment completed
U.S.-UK Green Shipping Corridor		United States		United Kingdom	2022	Launch of a task force
Halifax-Hamburg Green Shipping Corridor	Halifax	Canada	Hamburg	Germany	2022	MOU
European Green Corridors Network	Rotterdam	Netherlands	Hamburg	Germany	2022	Conducting pre-feasibility assessment
Rotterdam West-Coast Norway Green Corridor	Rotterdam	Netherlands	Finnfjord	Norway	2022	Announced
North Atlantic Green Shipping Corridor	Antwerp	Belgium	Montreal	Canada	2021	Announced
Seattle-Busan Green Shipping Corridor	Busan	Republic of Korea	Seattle	United States	2022	Announced
Alaska Green Corridor	Seattle	United States	Vancouver	Canada	2022	Conducting pre-feasibility assessment
Clean Tyne Shipping Corridor	Tyne	United Kingdom			2022	Conducting pre-feasibility assessment

Gotheburg-Ghent Green Corridor	Gothenburg	Sweden	Ghent	Belgium	2022	Announced
SILK Alliance Green Corridor Cluster		Various Asian partners			2021	Creating and implementing a green corridor roadmap
US-Japan Green Corridor	Los Angeles	United States	Tokyo and Yokohama	Japan	2023	LOI

Announced GSC are mainly intra-regional initiatives, where both ports are either located within one country or within one region (e.g., Rotterdam West-Coast Norway Green Corridor, Alaska Green Corridor, Chilean Green Corridors Network, Great Lakes - St. Lawrence Corridor) (Mission Innovation, 2023).

The Asia-Europe container route is the global trading route that currently generates the most GHG emissions, accounting for about 3 % of global shipping emissions, and thus offers the largest potential for emission reduction (Global Maritime Forum, 2021). Until today, only one of the announced GSC initiatives – Rotterdam-Singapore Green and Digital Corridor- transfers through the SC. The first sustainable vessels shall navigate the route by 2027 (Port of Rotterdam, 2022b). The Asia-Europe route has significant potential to become a GSC, as several cargo owners have set emission reduction targets. Many green hydrogen projects have been announced in Europe, the Middle East, and Australia, which will be sufficient to supply green bunkering along the corridor.

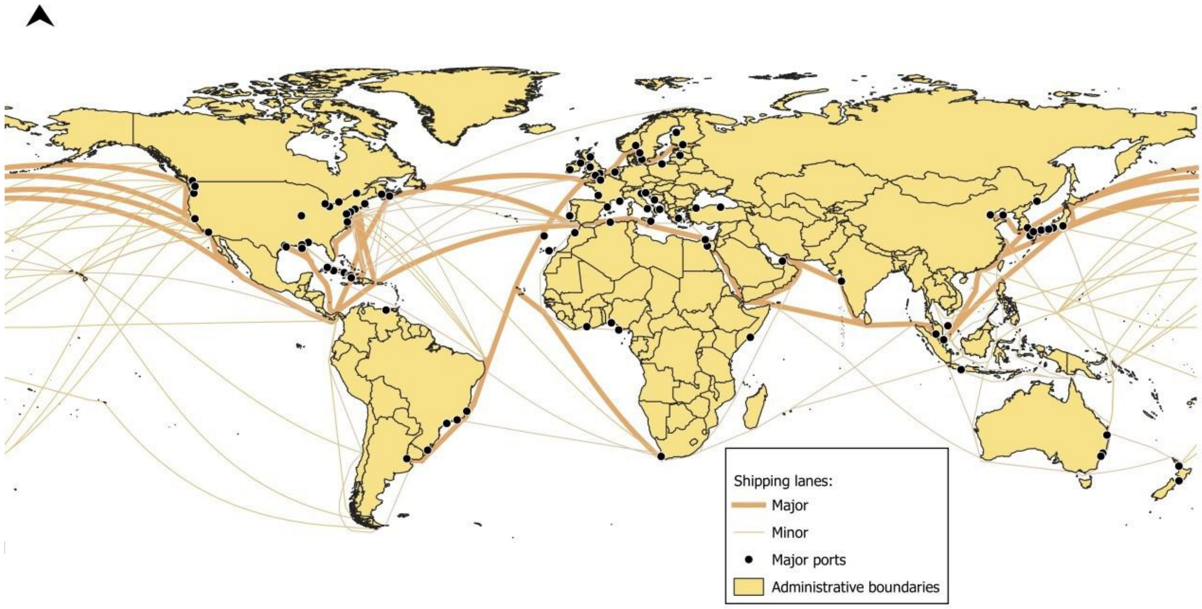
To establish GSCs, sufficient green shipping fuels need to be available and economically competitive with conventional fuels. Therefore, the renewable hydrogen production potential, as well as the realization of hydrogen projects, are essential to produce low-cost green hydrogen. Ports along the GSC need access to low-cost green hydrogen to perform as potential green bunkering ports. The lower energy density of hydrogen-based fuels reduces a ship's range and increases the amount of bunkering stops on a voyage. Bunkering may transfer to ports that can supply green fuels at low costs. Thus, the importance of the Middle East in bunkering along the Asia-Europe route could increase significantly (Global Maritime Forum, 2021). This offers, among others, major opportunities for Egypt. Which ports, canals, and corridors are able to accelerate their full potential will depend on their infrastructure, green bunkering costs, and whether ports can function as transshipment hubs.

Decarbonization efforts of selected ports

Ports play a key role in global maritime shipping and are crucial for the global economy and for decarbonizing shipping. While Singapore, Fujairah, and Rotterdam have the highest sales of bunker fuels, the Panama Canal, the Strait of Malacca, and the Suez Canal are the most relevant choke points in global trade (IRENA, 2021) (see Figure 9).

Decarbonization in central ports, particularly trading ports and ports relevant to fuel supply, could decrease the CO_2 emissions of maritime shipping significantly. By enabling access to renewable bunkering fuels, stakeholders in key shipping routes play a central role (IRENA, 2021). Additionally, with dedicated policies, canals can play an important role (financially) in incentivizing the utilization of sustainable shipping fuels. Various public authorities and port authorities have announced their ambitions to establish a hydrogen-based shipping hub.

Figure 9: *Major ports and global shipping lanes*



Source: Own illustration

The **Panama Canal** is a central chokepoint for the Atlantic-Pacific Ocean trade and functions as a major transshipment hub in the region, as it offers the shortest route from the East Coast of the United States and from the Caribbean to Asia and Australia (Notteboom & Haralambides, 2023). Balboa Port, located on the Pacific Coast of Panama, is the third largest port in Latin America. Additionally, several ports are located on the Caribbean coast of Panama (FAL, 2022). Ambitiously striving for carbon neutrality for port facilities by 2030, the Panama Canal Authority aims to establish a green shipping corridor. The canal targets phasing out the use of fossil fuels and integrating clean energy projects, energy efficiency measures, and nature conservation programs (Global Maritime Forum, 2021; Canal de Panama, 2021).

The **Port of Rotterdam** is the largest port on the European side of the Asia-Europe route and among the largest bunkering ports worldwide. The port aims to establish itself as a major entry point for green hydrogen imports: by 2030, 4.6 million t of green hydrogen is expected to be supplied to north-western Europe via the port. By 2050, the Port of Rotterdam expects a demand of 20 million t of hydrogen per year to pass through its industrial complex (Port of Rotterdam, 2021; Port of Rotterdam, 2022a). To become a green shipping hub, the Port of Rotterdam will rely heavily on hydrogen and hydrogen derivatives imports to provide green fuel bunkering due to the limited production potential in the Netherlands.

The **Port of Singapore** is among the largest bunkering ports and the primary transshipment port on the Asia-Europe route. The port of Singapore adopted a Long-Term Low Emissions Development Strategy to halve emissions from its peak to 33 Mt CO_2e by 2050. The Maritime and Port Authority of Singapore (MPA) aims to decarbonize until 2050, whereby hydrogen will play a role in port operation (MPA, 2022b). The Port of Singapore is one of the major bunkering ports. Similar to the Port of

Rotterdam, the Port of Singapore needs to secure sufficient green fuel supply from low-cost production locations, e.g., Australia (Global Maritime Forum, 2021)

The **Port of Shanghai** is the world's busiest container port (World Shipping Council, n.d.), the world's best-connected port (UNCTAD, 2023), and the largest port on the Asia-Europe route. The port handles approximately 25 % of China's foreign trade (Shiphub, 2022). The port aims to become carbon neutral by 2060 and is working with the Port of Los Angeles to achieve this (C40 Cities, 2022). The Port of Shanghai is one of the world's leading bunkering ports.

The **Port of Walvis Bay** is located on the Cape Route. Namibia is currently attracting foreign investment to expand domestic green hydrogen production. Walvis Bay is to be developed into a green bunkering station along the Cape Route. Four pilot projects have been initiated in the vicinity of the port, including a hydrogen refueling station that will decarbonize various port facilities. The Namibian port has signed an agreement with the Port of Rotterdam to supply green hydrogen to Europe (Namport, 2023; Hydrogen Central, 2021).

Table 4: *Selected Ports and Canals and their carbon targets*

Port / Canal	Country	Year of carbon neutrality target	Throughput in mil. t
Suez Canal	Egypt	no target announced	1,031 (2019)
Singapore	Singapore	2100	578 (2022)
Shanghai	China	2060	545 (2019)
Panama Canal	Panama	2030	519 (2022)
Rotterdam	Netherlands	2050	467 (2022)
Walvis Bay	Namibia	2050	6.6 (2022)

Source: *SCA, 2023a; MPA, 2023a; MPA, 2022a; ACP, 2022b; MT, 2022; NAMPORT, 2022; Port of Rotterdam, 2022c; Søgaard et al., 2021*

For the **Suez Canal,** a “Green Canal” strategy has been released by the SCA, declaring the aim to transition to a green canal, studying the option to incentivize green fuels, but without setting clear targets (SCA, n.d.). Port Said and Port Suez are not yet among the relevant worldwide bunkering ports, as vessels shipping from Asia to Europe today stop mainly in Asia and Europe; bunkering in Egypt currently does not play a major role. With changing fueling patterns and route planning, in the future, ships could bunker green hydrogen or hydrogen derivatives in Egypt. Egypt and other countries of the MENA region have a significant potential to produce green hydrogen and derivates.

While ports and canals are pivotal in decarbonizing shipping by offering green infrastructure and promoting the use of sustainable fuels, individual hub decarbonization alone cannot address the global shipping industry's emissions. Collaborative efforts are essential across trade routes and among various regions and stakeholders to establish the requisite green shipping infrastructure.

Box 5: Key takeaways on the decarbonization efforts of selected ports

Ports are pivotal nodes in steering the shipping industry towards a greener future. Leading ports, like Rotterdam, Singapore, and Shanghai, are adopting decarbonization strategies. Major shipping routes such as the Panama Canal and Suez Canal are focal points for global trade.

While individual ports and canals are relevant for decarbonizing maritime trade, collective action and cooperation along trade routes is essential to establish GSCs.

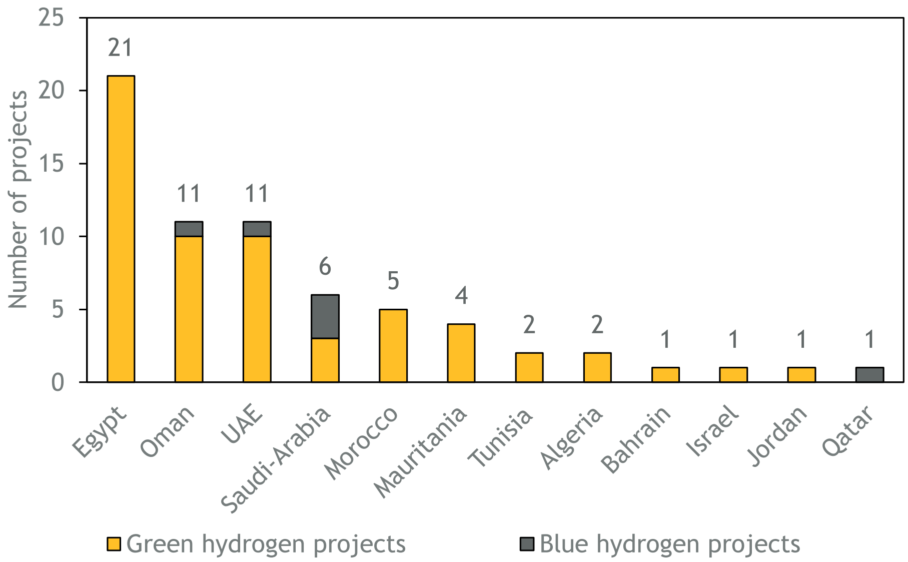
3.3. Economic potential of producing green shipping fuels

This chapter deals with an assessment of the potential and challenges for Egypt to exploit its location at the Suez Canal to become part of a green shipping corridor.

Green hydrogen developments at the Red Sea

Several countries in the MENA region are exploring hydrogen production from renewable energy sources with different strategic approaches. In addition, governments, sovereign funds, and industrial players have announced major hydrogen production projects, such as blue ammonia production in Qatar (Qatar Energy, 2022). The race is on for investment, innovation, and potential hydrogen importers (Cantini, 2023), with Egypt taking a pole position when it comes to announced projects (see Figure 10). The comparison in the graph below shows Egypt's progress in attracting domestic and foreign investments in the field of hydrogen production, making it the leader in the MENA region.

Figure 10: *Announced hydrogen projects in the MENA region*



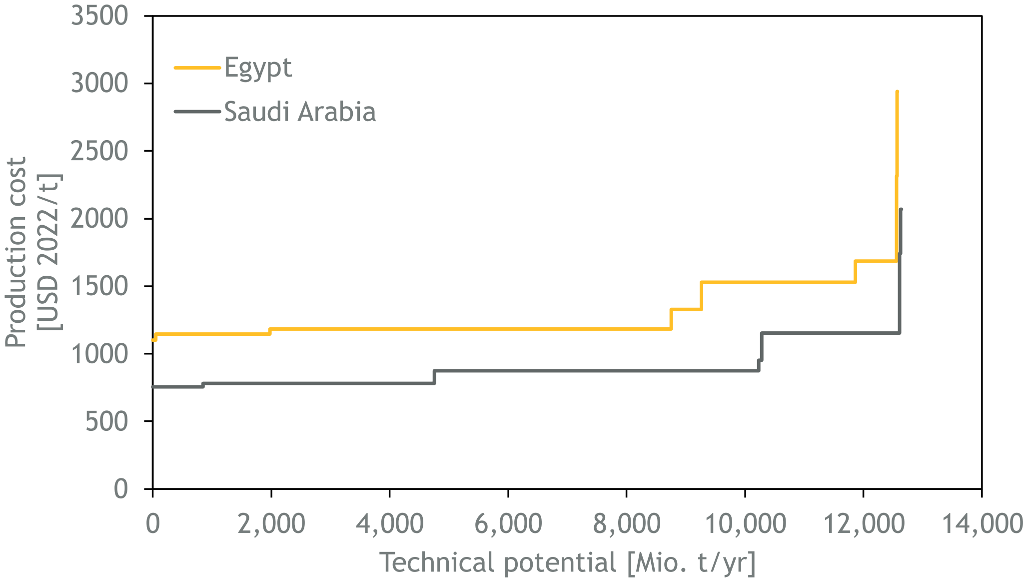
Source: *Own illustration based on Van Son & Aruffo, 2023*

The UAE officially supports the green fueling initiative (International Chamber of Shipping, 2022) and announced its “Hydrogen Leadership Roadmap” in 2021. Committing to net zero by 2050 makes the UAE the first MENA country with a carbon neutrality target. In addition to political commitment, the first hydrogen projects have been announced in UAE. Among these projects is a project for green methanol

for shipping in Jebel Ali, UAE (Mandra, 2022). While the UAE has major RE potential and a beneficial investment environment, it is not directly located along the Europe-Asia trade route. Therefore, for bunkering at the UAE ports, e.g., Port of Jebel Ali, vessels navigating from Asia to Europe and vice versa would have to take a detour. Thus, although the UAE may be a regional competitor in green hydrogen development, it is not further considered in the following calculations.
All ships passing the Suez Canal are passing the Red Sea. Thus, all states adjacent to the Red Sea are potential suppliers of green bunkering fuels. Therefore, the question arises of how competitive Egypt is in terms of production costs, production potentials, and bunkering of green fuels. The Sudan and Yemen will not be considered in the following analysis due to their current politically and economically unstable situation as well as ongoing conflict within these states.

From the neighboring states of the Red Sea, Egypt and Saudi Arabia are the most stable and developed economies. Saudi Arabia launched its Saudi Green Initiative in 2021, planning significant green hydrogen and ammonia production. In Saudi Arabia, the first green hydrogen and green ammonia projects have started. Saudi Arabia's NEOM plans to produce green ammonia at scale and export from 2025 onwards (Öko-Institut e.V., 2022; NGHC, 2022).

Figure 11: *Projection of supply curves of green ammonia produced in Egypt and Saudi Arabia in 2030*



Source: *Own illustration based on Moritz et al., 2023*

Figure 11 shows a projection of the supply curve of green ammonia from Egypt and Saudi Arabia for the year 2030[5]. The supply curve represents the specific production costs over the technical potential. Egypt and Saudi Arabia have large technical production potentials. Cost drivers for the production costs are country-specific renewable energy capacity factor profiles and weighted average costs of capital. Despite similar technical potentials and profiles, the average production costs in Saudi Arabia are lower than in Egypt. The cost difference is primarily related to differences in the weighted average cost of capital (WACC). WACC represents the average cost of the different sources of financing a company

[5] The costs represent levelized costs of green ammonia based on dedicated renewable energy sources via power purchase agreements. The cost estimation is based on an optimization model. The model minimizes the production cost of hydrogen (or a derivative) by adjusting plant capacity and operation of a system consisting of a renewable energy source (either wind onshore, wind offshore, or PV), an electrolyzer, a hydrogen storage tank, and a hydrogen conversion plant (for derivatives). A detailed explanation can be found in Moritz et al. (2023).

uses, taking into account the cost of equity and the cost of debt. The average investment risk in Saudi Arabia is valued lower than in Egypt. In the cost estimation, the average WACC of 14 % for Egypt and 7 % for Saudi-Arabia are applied (Moritz et al., 2023). The average country-specific WACC provides only a rough estimate of how the production costs might differ between countries. It is important to note that WACC is project-based and can vary significantly from project to project within one country.
The comparison shows that Egypt is at a disadvantage compared to Saudi Arabia in terms of WACC. However, WACC is not a stable factor and can be influenced by various factors such as technology risk or government support. Green hydrogen projects are typically seen as more environmentally friendly and in line with sustainability goals. This could lead to favorable regulatory treatment and lower financing costs. Governments around the world are increasingly supporting green energy projects, which may result in subsidies, tax incentives, or grants that reduce financing costs and WACC. Therefore, Egypt's green hydrogen policy will be decisive for the attraction of FDI.

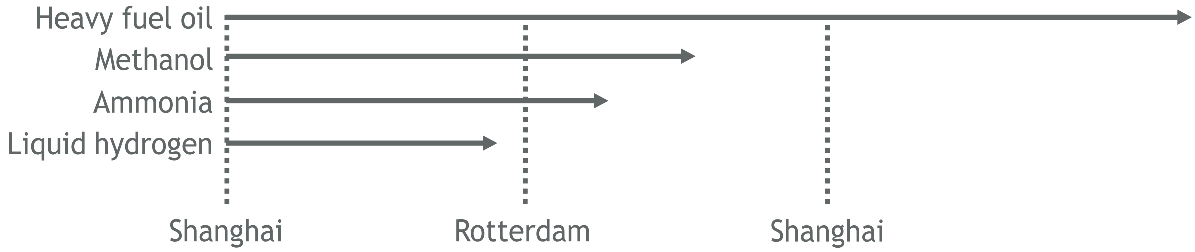
Looking at existing port infrastructure, Jeddah Islamic Port in Saudi Arabia is the largest port on the Red Sea, with large-scale bunkering infrastructure in place. About a third of the container lines of the shipping companies MAERSK and CMA CGM between Europe and Asia make a port call at Jeddah (CMA CGM, 2023; MAERSK, 2023). Thus, Jeddah is already an established bunkering location for fossil fuels, while the development of bunkering capacity in Egypt has only accelerated in recent years. It remains to be seen whether the port of Jeddah can leverage its existing fossil fuel bunkering facilities to attract green shipping lines and build green bunkering infrastructure. As Egypt is not yet a major bunkering location, early joint planning with shipping companies can make it an attractive location for green fuel bunkering.

Bunkering and export of green fuels

Green shipping fuels produced in Egypt could be either used directly to provide bunkering to ships on the Suez Canal Route, or these fuels could be exported to large ports in Europe or Asia. Today, most ships on the trunk line between Europe and Asia bunker in large hubs where these ships handle cargo. Most of these ships typically do not stop at Egyptian ports. For example, the shipping companies CMA CGM and Maersk offer 23 container shipping lines between Europe and East Asia. On average, 12 ports are called per route, of which four are in Europe, six are in Asia, and two are between Europe and Asia. A bit less than half of all routes call a Port at the Red Sea. About 15 % of the routes call a port at the Suez Canal. This suggests that bunkering in Egypt would require an additional stop for most of the ships passing the Suez Canal. We will assess the feasibility of Egypt as a bunkering hub for green fuels from two perspectives.

From a technical perspective, hydrogen-based fuels have a lower volumetric energy density than HFO or MSG. Thus, ships steaming with green fuels have a lower range. An additional bunkering stop between Europe and Asia might be necessary. We investigate this question by an exemplary calculation.

Figure 12: *Ranges of a container ship in relation to a roundtrip from Shanghai to Rotterdam and back using different fuels assuming identical tank sizes*



Source: *Own illustration based on Møller et al., 2017; Engineeringtoolbox, 2023*

Figure 12 compares the range of a Container Carrier[6] using different fuels with the length of a roundtrip from Rotterdam to Shanghai. The range is the largest when HFO is used. In this case, only one bunkering stop per roundtrip is necessary. The ship operator has the choice to decide at which port to bunker during a roundtrip. If hydrogen-based fuels are used, the range is shorter than the distance of a roundtrip. Therefore, at least two bunkering stops per roundtrip are necessary, which poses a potential cost disadvantage compared to HFO-fueled ships.

- Using methanol, the ship could bunker in Shanghai and Rotterdam. Alternatively, the range would be long enough to bunker in Shanghai, go to Rotterdam, and bunker on the return trip to Egypt.
- Using ammonia, the range is long enough for a one-way trip from Shanghai to Rotterdam but barely long enough to make a bunkering stop on the return trip in Egypt without bunkering in Rotterdam.
- Using liquid hydrogen, the range would be below the length of a one-way trip from Shanghai to Rotterdam, and at least three bunkering stops would be necessary. The range would allow us to make one bunkering stop in Shanghai and two bunkering stops in Egypt on the outward and return journey.

As an alternative to additional bunkering stops, larger fuel tanks could be installed on the ships to compensate for the lower energy density of hydrogen-based fuels. Additional tank capacity most likely comes at the expense of cargo capacity.

Due to the lower range of ships using hydrogen-based fuels, route planning might have to move to shorter distances between two bunkering stops. Egypt is a potential additional stop for ships on the Suez Canal route. However, shipping companies still have flexibility in their route planning and will turn to locations along the route that are able to provide green fuels at low prices. Cost will be one of the most important factors in route planning. It is, therefore, vital for Egypt to achieve economies of scale.

From an economic perspective, the question arises if bunkering in Egypt can be more economical than bunkering elsewhere. Green maritime fuels produced in Egypt could be used for bunkering in Egypt or could be exported to larger ports in Europe or Asia that are already today major bunkering ports.

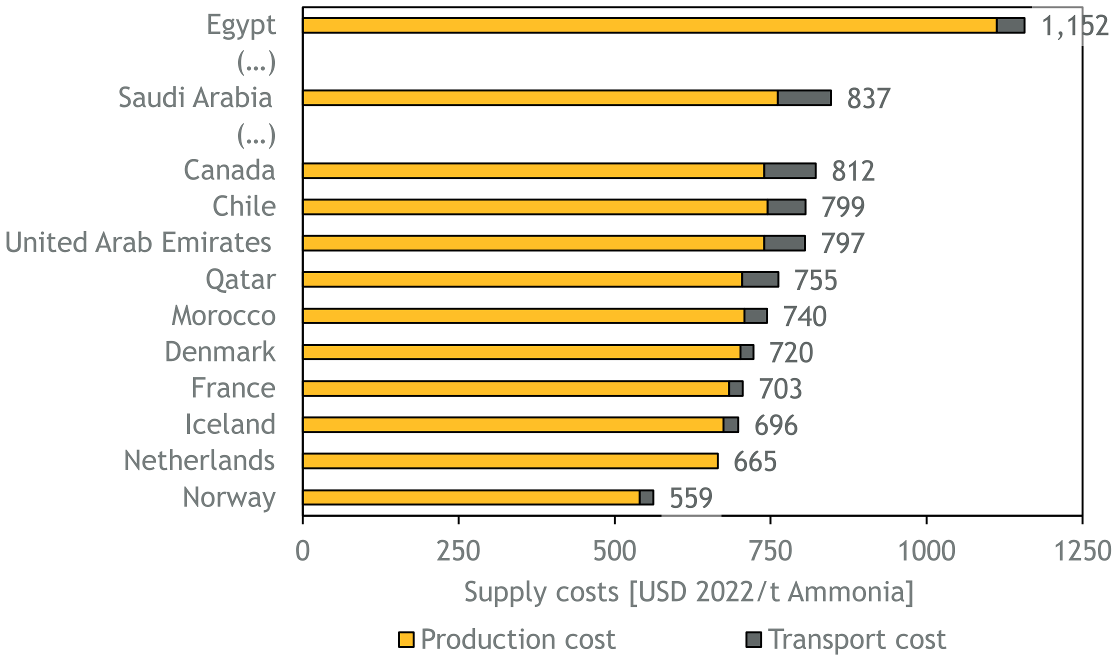
[6] Neopanamax Carrier: Gudrun-Maersk class with a cargo capacity of 9,500 TEU. The volume of the fuel tank is assumed the same for each fuel type.

We conduct an exemplary calculation comparing bunkering costs in Egypt with transport costs of fuel from Egypt to Rotterdam. We assume identical port costs in Egyptian and European ports, a waiting time of 1 day, a port time of 1.5 days, and ammonia as fuel.

A bunkering stop of a Neopanamax class Container Carrier at the Suez Canal would cost around 33 USD/t bunkered ammonia. In comparison, transporting ammonia in a Suezmax class wet bulk carrier from Egypt to Rotterdam would cost about 60 USD/t transported ammonia. Thus, bunkering green ammonia from Egypt in Egypt could have a small cost advantage compared to bunkering Egyptian ammonia in Rotterdam.

However, the cost advantage of 27 USD/t might be insignificant compared to the fuel cost of green ammonia in Egypt, which is projected from 1,100 USD/t upwards (Moritz et al., 2023). If Egypt exports green fuels to bunkering ports in Europe and Asia, it cannot take advantage of its favorable location at the Suez Canal. Egypt would have to compete with many other countries selling green fuels on the global market. As Figure 13 shows[7], multiple countries could supply green ammonia to Rotterdam at lower costs than Egypt. Based on this cost comparison, the economically most promising scenario is to bunker Egyptian green fuels in Egypt.

Figure 13: *The ten most economical suppliers of green ammonia for the Port of Rotterdam in relation to Egypt and Saudi Arabia.*



Note: Costs are projected for 2030 and a quantity of 3 Mt/yr. Supply costs are given as levelized costs.

Source: *Own illustration based on Moritz et al., 2023*

Ships have to wait for permission before entering the Suez Canal since the canal is partially one-way, and northbound and southbound voyages are organized in convoys by the canal authority. Typical waiting times range from several hours up to a day (Hellenic Shipping News, 2023). Already now, the

[7] The import costs of green ammonia are estimated based on production via power purchase agreements from dedicated renewable energies in the origin country and transport in commercial LPG Carriers from the origin country to the Netherlands. The import quantity of 3 Mt/yr equals the historic ammonia demand of the Netherlands. All estimations are based on Moritz et al. (2023).

SCA is looking into the option of bunkering ships within their waiting time so that the bunkering stop would not require additional time and costs. If bunkering fuels in Egypt can be offered at a similar or lower price than in European or Asian Hubs, bunkering at the Suez Canal might be attractive for shipping companies.

As shown in the two exemplary cost calculations, it remains unclear if Egypt could exploit potential cost advantages when producing green fuels. This is mainly due to the yet unknown transition of the maritime shipping sector. Due to various possible transition paths, the future range of ships, thus the future amount of necessary bunkering stops, is unknown. However, the most promising scenario seems to be bringing down the production costs through economies of scale for green fuels in Egypt and establishing itself as an attractive bunkering stop on the Europe-Asia route by using the waiting time for ships in the canal. One important factor to achieving this will be government policy to bring down WACC, but also synergizing with existing industries to increase domestic demand, as outlined in the next chapter.

Box 6: Key takeaways on the economic potential of producing green shipping fuels

Green shipping has a significant economic potential for Egypt. On the one hand, Egypt has great potential to produce renewable energies and thus also green fuels. On the other hand, there is potentially a large demand for green fuels by the ships that pass through the Suez Canal. Due to its location at the Suez Canal, Egypt is well suited to become a green refueling station for ships on the route from Europe to Asia in the future. To exploit the full potential of green shipping, Egypt must overcome a number of economic challenges.

Saudi Arabia might be a regional competitor in producing green fuels and providing bunkering services as it can produce green fuels at lower costs due to lower weighted average costs of capital. Besides, Saudi Arabia currently has the largest port with established bunkering infrastructure at the Red Sea.

Large ships on the trunk lines bunker at hubs in Asia and Europe but not in Egypt at present. The lower energy density of green fuels like ammonia and methanol does not lead to the necessity of a stop in Egypt.

Bunkering in Egypt has a cost advantage against exporting fuels for bunkering in European ports. If ships could bunker within their waiting time before entering the Suez Canal, the bunkering stop would not require additional time and costs.

04

Embedding a shipping-based hydrogen industry in the Egyptian economy

4 Embedding a shipping-based hydrogen industry in the Egyptian economy

This chapter focuses on the regional development potential of green marine fuel production. The development of renewable energy and green hydrogen production capacities opens up opportunities to drive domestic green industrialization processes but is also associated with economic traps that need to be avoided through smart policymaking. Therefore, the aim of this chapter is, first, to assess the renewable energy production potential along the coast to meet the demand for the production of green marine fuels. Secondly, it reviews the current industrial structure, and thirdly, it identifies opportunities to create economic linkages.

4.1. Leveraging the renewable energy potential along the coast

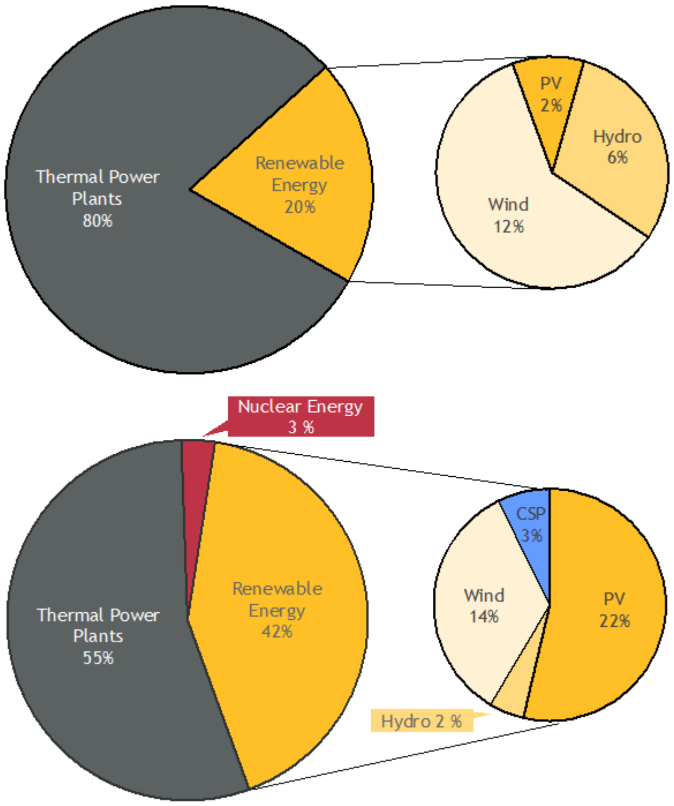
This section looks at the renewable energy generation potential to fuel green hydrogen production along the Suez coast.

Egypt's energy consumption is growing rapidly at 6 % per year. The country is a major exporter of oil and gas in Africa and is also heavily dependent on oil and gas for its own energy needs. In 2022, 80 % of electricity generation came from fossil fuel-fired thermal power plants, while 20 % was generated from renewable energy sources such as wind (12 %), hydro (6 %), and photovoltaic (2 %, compared to Figure 14) (Mondal et al., 2019).

Frequent blackouts have been a problem since 2011, exacerbated by a shortage of natural gas. To bridge the gap between supply and demand, Egypt has resorted to importing LNG and building new power plants. However, with ongoing projects and increasing consumption, a significant electricity shortfall is projected over the next decade. In response, Egypt's Vision 2030 emphasizes the importance of the energy sector to sustainable development and advocates efficient, indigenous, and diversified energy resources, including renewables (Moharram et al. 2022).

Renewable energy plays a key role in Egypt's Vision 2030 (SDS, 2016). The country aims to diversify its power generation mix and reduce greenhouse gas emissions by promoting clean and sustainable energy sources. The government's strategy is to significantly increase the share of renewable energy in the electricity generation mix. A 20 % share of electricity from renewable sources by 2022 has already been accomplished, and the next target is a substantial 42 % by 2035. The breakdown of these targets is 14 % for wind, 2 % for hydro, and 22 % for solar (Figure 14).

Figure 14: *Egypt's power generation mix in 2022 (top) and its power generation mix target for 2035 (bottom)*

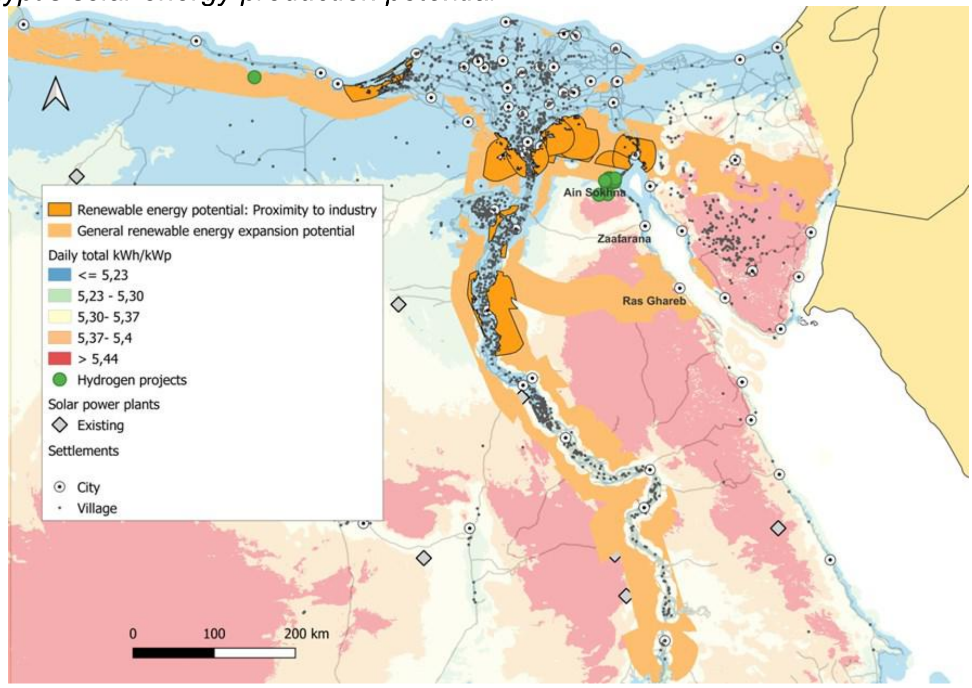


Source: Own illustration based on Mondal et al. (2019)

Egypt's favorable climate, abundant solar radiation, and significant wind resources position the country well for the exploitation of renewable energy. Egypt is blessed with vast wind energy potential, particularly in the Sinai Peninsula and the areas surrounding the Gulf of Suez. Egypt is one of the most important places in the world for wind energy because of its high, consistent wind speeds, which vary between 8 and 10 meters per second at a height of 100 meters, and the presence of large, uninhabited, deserted areas. The potential for solar energy is particularly promising, with average sunshine hours and irradiance levels that make various solar technologies feasible, such as PV and concentrated solar power plants. These projects are not only economically viable but also in line with Egypt's long-term sustainability goals. Net metering programs and partnerships with international organizations and financial institutions have been instrumental in advancing these projects (Salah et al., 2022).

Figure 15 and Figure 16 show that along the Gulf of Suez, strong winds and high solar radiation could potentially be harnessed through the construction of combined wind and solar farms. PV production is concentrated around the three solar power plants in Egypt: Benban Solar Park (1.5 MW), Siwa Solar Plant (10 MW), and ISCC Kuraymat (20 MW). In addition, there are significant wind energy projects such as Zafarana 1-8, Gulf of El-Zayt, and Gulf of Suez. Finally, the Aswan hydroelectric plants have a total capacity of 2,800 MW.

Figure 15: *Egypt's solar energy production potential*



Source: *Own illustration based on Global Solar Atlas (2023)*

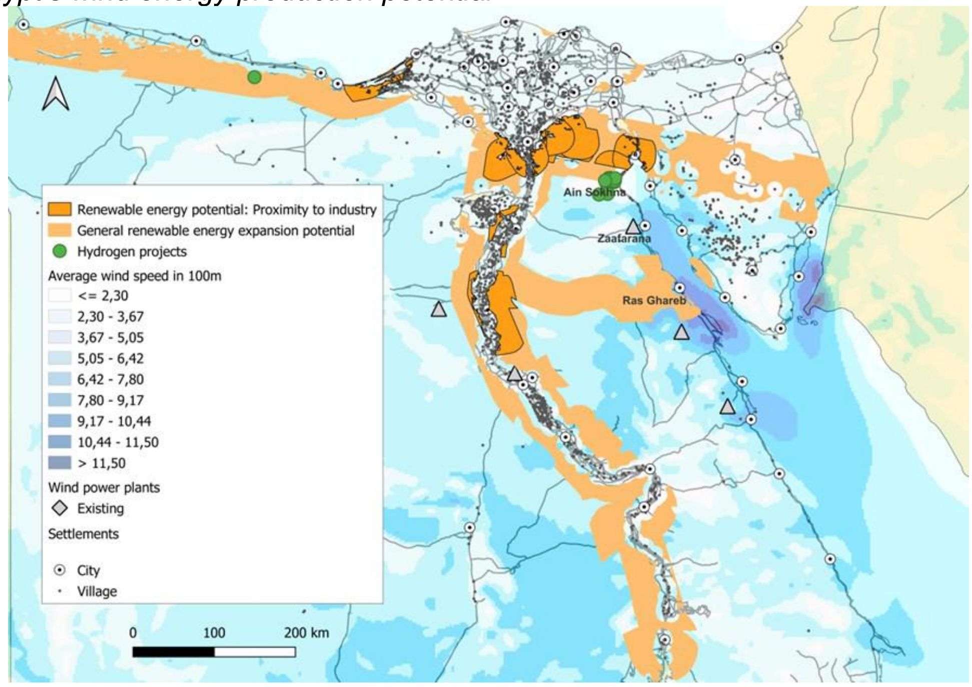
In 2021, the total amount of electricity generated from renewable energy resources has been approximately 19.2 GW, with a target of 62.6 GW by 2035 (Mondal et al., 2019). This results in a domestic supply gap of 43.4 GW until 2035.

While the first solar and wind power plants have been erected, the full potential for renewable energy production has yet to be realized. There is not only great potential in solar and wind power plants, but a previous study has also found the region viable for geothermal development (Zaher et al., 2018).
It is clear that there is already a gap between the demand for renewable energy for domestic consumption and current production. If additional capacity is to be created for the production of green marine fuels, the identification of suitable sites for large-scale energy projects will be crucial.

The following maps show a basic land potential analysis for the construction of renewable energy production facilities that could be used for electrolyzers. This is based on three key assumptions.

1. It is more cost-effective to reuse existing infrastructure assets such as roads, which are necessary for construction and maintenance, and high voltage transmission lines to transport the generated electricity to the electrolyzers. Therefore, only areas within 20 km of roads and 50 km of power lines are included.
2. In order to create synergies with existing industrial clusters, proximity to production facilities that could potentially use excess hydrogen capacity in times of high production and/or low demand is required. This is operationalized in this baseline analysis as a maximum buffer of 20 km around special economic zones and hydrogen investments.
3. Renewable energy production should not compete with scarce agricultural land and/or encroach on settlement areas. Therefore, only bare land is considered in the analysis, and a buffer of 10 km around settlement areas is applied.

Figure 16: *Egypt's wind energy production potential*



Source: *Own illustration based on Global Wind Atlas (2023)*

Figure 15 shows that solar radiation is high along both coasts of the Suez Gulf. There is also potential in the southwest region of the Nile. However, the economically viable areas, which are also relevant for the production of marine fuels, lie between the Nile and the Suez Gulf. Because of its proximity to Suez port, existing infrastructure, and industry, this should be the target area for investment.

Figure 16 clearly shows the strong winds along the Suez Gulf coastline. The Ras Ghareb area, in particular, shows great potential both onshore and offshore. Here, future studies could explore the possibility of building large wind farms to harness wind energy.

Ain Sokhna has a strong existing industrial cluster and incoming green hydrogen investments. Although the potential for renewable energy production is somewhat lower here, investment in the electricity grid and road infrastructure could pay off to further develop the areas to the south.

The area around Ras Ghareb is very suitable for renewable energy production, but it is still remote from other industrial activities, and the port is not suited for larger ships. A combination of onshore and offshore wind farms, coupled with photovoltaics, could produce significant amounts of renewable energy. However, the area would only become attractive for green shipping with significant investment in port infrastructure.

While this is very preliminary, and more research is needed that takes into consideration morphological barriers and investment costs of infrastructure, the two maps give a rough indication of where future studies are worthwhile.

Based on recent studies, it is possible to estimate the employment factors of the expansion of renewable energy capacity (GIZ, 2023; Kim & Mohommad, 2022; Pestel, 2019; IRENA, 2018):

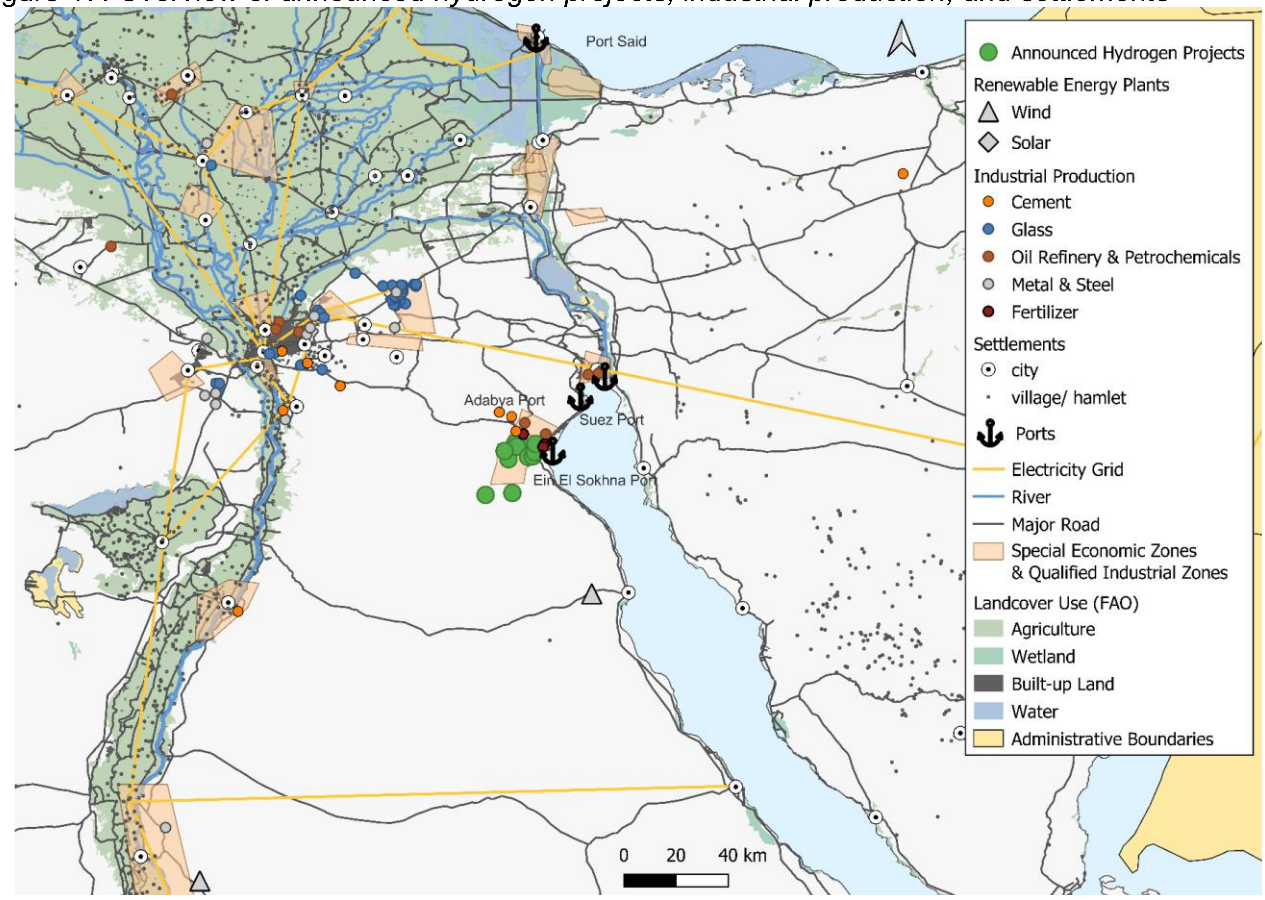
Vision 2030 aims to increase renewable power production by 40 GW until 2035 to cover domestic demand. Not considering other sources such as geothermal and hydropower, adding 20 GW of solar and 20 GW of wind plants would have an employment effect of up to 100,000 temporary jobs during construction and permanent job creation for maintenance and operation of 4,000-6,000 (see Table 5).

Table 5: *Employment effects of increased renewable power production*

	PV: amount of jobs per 20 GW	**Wind plant: amount of jobs per 20 GW**	**The total amount of jobs**
Construction & Installation	20,000	80,000	100,000
Operation & Maintenance	2,000	2,000-4,000	4,000-6,000

Source: *Own calculation based on GIZ, 2023; Kim & Mohammed, 2022; Pestel, 2019; IRENA, 2018*

Figure 17: *Overview of announced hydrogen projects, industrial production, and settlements*



Source: *Own illustration based on Rystad Energy RenewableCube (n.d.), as seen in E&M Combustion (2022)*

Box 7: Key takeaways on leveraging the renewable energy potential along the coast

> Egypt has great potential for renewable energy production along the coast: solar, wind and geothermal. These need to be harnessed to meet both growing domestic demand and the production of green marine fuels.
>
> New capacity should be planned along existing infrastructure axes to reduce costs. Long-term planning can consider a green hydrogen development corridor along the coast.

4.2. Risks and opportunities of establishing a hydrogen economy

In the following, light will be shed on the academic discourse on resource-based industrialization strategies.

Resource-based industrialization: what does the literature say?

The production of green hydrogen relies on the exploitation of naturally occurring resources, such as wind, solar radiation, desalinated seawater, and the availability of large plots of land. The analysis above has shown Egypt's immense endowment in these resources, thus creating opportunities to increase economic growth. However, exploiting resources for the benefit of the country is not an automatic process.

There is a long-standing debate in economics and related sciences regarding the prospects of resource-based regional development strategies. While intuitively, the development of these resources may be regarded as the key to sustained economic growth, the experience of previous energy carriers, such as oil and gas, shows that a successful development strategy based on the exploitation of natural resources carries several risks (Auty, 2002).

The experience of oil and gas shows that, paradoxically, some countries that are rich in natural resources tend to grow at a slower pace than countries with fewer natural resources. Lack of investment capital, industrial know-how and technology, and regulatory frameworks can lead to structural dependence on foreign firms (Breul et al., 2019).

In a nutshell, there are three main macroeconomic mechanisms that put resource-based industrialization strategies at risk (Badeeb et al., 2017): the "Dutch Disease", volatility in commodity prices, and institutional quality.

1. **Dutch disease** occurs when increased income from resource booms leads to inflation, an appreciation of the exchange rate, and a decrease in the competitiveness of non-resource commodities. This results in a decline in investment and the contraction of non-resource sectors, such as manufacturing and agriculture, causing a reduction in overall economic growth.
2. **The volatile nature of natural resource prices in global markets** hampers economic growth by creating uncertainty, making revenue measurement and economic planning difficult. The fluctuations in resource prices, exacerbated by international lending, can lead to pro-cyclical fluctuations in government revenues and export earnings, negatively impacting public and private investments.

3. **Institutional quality:** The presence of resource rents can lead to economic mismanagement when fiscal discipline and tax collection suffer. This can result in overspending and neglecting essential infrastructure and social development. Additionally, windfall resource revenues often exacerbate income inequality and hinder sustainable investments. Moreover, resource rents may negatively impact institutional quality, impeding economic growth.

Yet, there are countries that have exited the resource trap and created socioeconomic benefits from their exploitation of natural resources. Norway is a prime example of a country that has successfully translated its oil and gas resources into an unprecedented path toward prosperity and economic growth (Moses, 2021). Another prominent example is Botswana, which has created a Joint-Venture with one of the leading diamond companies in the world and thus is able to channel considerable amounts to the state budget, which then can be used for investments into infrastructure, education, and social services, creating the conditions for long-term economic success (Fessehaie & Rustomjee, 2018). Moreover, South Africa has achieved a high degree of embeddedness of large mining companies into local industries, and through forward- and backward linkages with other sectors, positive effects spread from the mining sector to other parts of the economy (Morris et al., 2012).

There are a number of linkages that can be created between primary sectors (including energy production) and other sectors. The most commonly described linkages in the literature are as follows (Weldegiorgis et al., 2021):

1. **Fiscal linkages:** revenue generated through taxation and other payments to governments
2. **Demand linkages:** Domestic spending of earnings such as wages and profits along the supply chain
3. **Infrastructure linkages:** physical and/or social infrastructure developed by companies for own or shared use
4. **Production linkages:**
    a. **Backward linkages**: Local sourcing of production inputs (goods, services, labor)
    b. **Forward linkages**: Processing of primary commodities to produce a processed or final product and add value
    c. **Horizontal linkages**: use of skills and capabilities as well as institutional, administrative, and socio-political capabilities that serve the economy more generally

All in all, the literature on resource-based regional development strategies highlights risks, especially of macro-economic nature. However, the experience from mining and extractive industries shows that by creating linkages between primary sectors and other sectors, such as fiscal, demand, infrastructure, production, and horizontal linkages, positive development outcomes can be achieved. In the following, we will focus on the success factors for creating economic linkages and spill-over effects to identify possible synergies and opportunities for value-added.

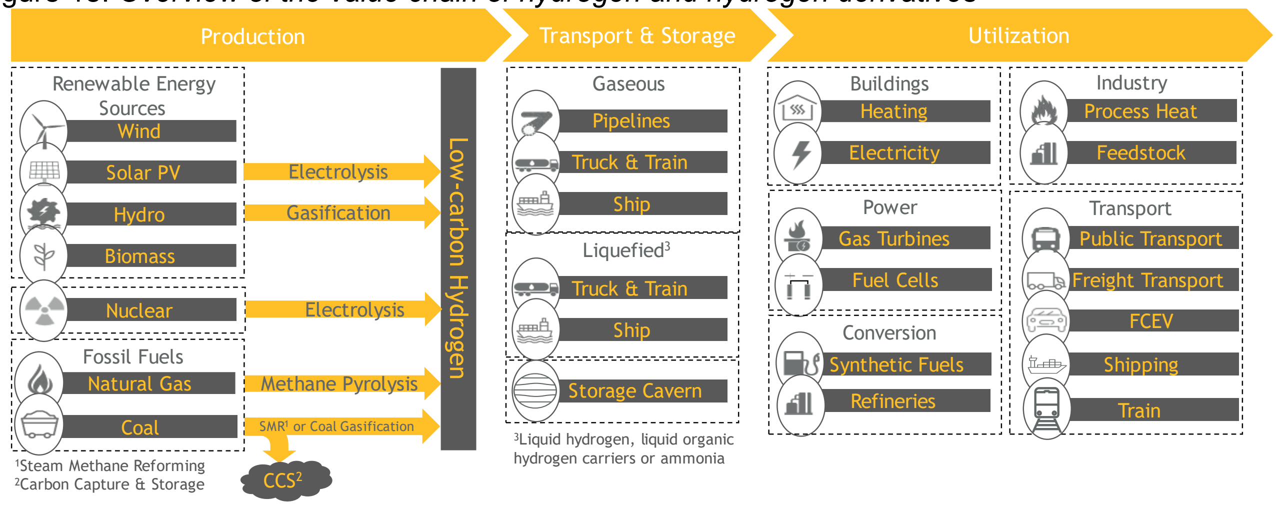
Opportunities for resource-based industrialization: creating economic linkages in the hydrogen value chain

The above linkage creation logic will be used in the following to identify opportunities for amplifying regional development effects along the hydrogen value chain. To produce green hydrogen, green electricity, such as wind and solar power, is used to separate hydrogen from oxygen through electrolysis. In water-scarce regions such as Egypt, seawater needs to be desalinated to feed the production cycle. This requires the installation of solar and wind parks, electricity grids, pipelines, pumping systems, and storage facilities to transport electricity and water to the location of the electrolyzer.

Following, the hydrogen needs to be **transported** to its location of consumption or processing. Using hydrogen and hydrogen derivatives for maritime shipping requires the installation of hydrogen-proof pipelines and bunkering facilities at the ports and a hydrogen liquefaction plant. Furthermore, hydrogen can potentially be used as a feedstock for the fertilizer industry, for heating in industrial processes, and as a power storage medium to be re-electrified (see Figure 18).

The matrix below distinguishes between three components of the value chain: production, transport & storage, and utilization. For each component of the value chain, the possibility of creating linkages is analyzed (see Table 6).

Figure 18: *Overview of the value chain of hydrogen and hydrogen derivatives*



Source: *Own illustration*

Table 6: *Matrix on production, transportation, and end-use with reference to linkages*

	Production	Transportation & storage	Utilization
Fiscal linkages	Establish taxation for RE generation and transportation, water desalination, & hydrogen		
Demand linkages	Provide housing for workers, access to shops and domestic investment & saving plans		
Infrastructure linkages	Give excess power to local businesses for reduced rates	Increase access through new electricity grids and distribute excess desalinated water for agricultural purposes	Use hydrogen pipelines for local businesses and create a "green hydrogen corridor."
Backward Linkages	Encourage locally produced components to be included Investments in renewable energy generation Maintainance of power plants & electrolyzers by local companies	Local maintenance of pipelines and storage facilities Link to the manufacturing industry Incentivize investments into the pipeline/ storage industry	Promote the nitrogen separation industry
Forward linkages	Promote industrial application of green hydrogen	Support hydrogen refueling stations along hydrogen pipelines	Promote fertilizer industry, refining, fuel-cell industry, hydrogen-based products, and services
Horizontal linkages	Leveraging skills, capabilities, and institutional frameworks to support the broader economy beyond the green hydrogen sector		

Source: *Own analysis based on Morris et al. (2012)*

Box 8: Key takeaways on risks and opportunities of establishing a hydrogen economy

FDI in the green hydrogen sector needs to be accompanied by government policies to avoid dependency and maximize development impact. This requires a careful assessment of the local industrial structure and potential synergies.

In Egypt, creating forward- and backward linkages with the domestic petrochemical, fertilizer, glass, and cement industry holds significant development potential.

4.3. Creating clusters to maximize development impact

This section looks at opportunities to embed a green hydrogen industry into existing industrial clusters in Egypt.

While the analysis above is done on a general level, in the following, the linkage framework will be applied to the Egyptian case to identify place-specific opportunities for value addition. While the implementation of policies to create fiscal, demand, and horizontal linkages requires further attention on the national level, from a regional perspective, the specific potential of creating infrastructural, backward, and forward linkages is particularly relevant (see also the business opportunity analyzer tool (Oeko-Institut, Agora Energiewende & Agora Industry, 2023)).

Egypt is a leader in the MENA region when it comes to the attraction of hydrogen investments. Table 7 lists recent investment agreements. The envisaged amount of produced hydrogen adds up to 3.2 mt of green hydrogen and 7.14 mt of ammonia produced annually.

Table 7: *Investment agreements on green hydrogen and green ammonia production in Egypt*

Investor[4]	Annual green hydrogen production	Annual green ammonia production
ReNew Power	220,000 t	1,100,000 t
Gobeleq	2,000,000 t	
Alfanar	500,000 t	
Infinity	480,000 t	
Fortescue		2,000,000 t
Scatec		3,000,000 t
AMEA Power		390,000 t
TotalEren		300,000 t
EDF		350,000 t

Source: *Based on Enterprise, 2022*

Except for one project on the Mediterranean coast, all the investments will be located near the port of Ein El Sokhna on the western coast of the Gulf of Suez. This is a favorable location for four reasons:

1. The port is close to the main shipping lanes for Asia-Europe trade, which means it can be used to export ammonia and green hydrogen, as well as provide bunkering fuel for ships running on hydrogen or hydrogen derivatives (compare chapter 3).
2. The area is in the vicinity of an uninhabited region with great potential for renewable energy production.
3. The Special Economic Zones offer low tariffs, and
4. There is an existing industrial cluster that could potentially develop into a large consumer of green hydrogen (cement, refinery & petrochemicals, and fertilizer industries).

A recent study analyzing clustering in Egypt's economy ranked the top manufacturing industries in Egypt (see Table 8). In this ranking, many industries related to the green hydrogen sector can be found.

Table 8: *Ranking of top manufacturing industries in Egypt*

Rank	By employees	By no. of establishments	By capital	By output
1	Bakery products	Furniture	Basic iron & steel	Refined petroleum products
2	Furniture	Bakery products	Glass & glass products	Basic iron & steel
3	Wearing apparel	Wearing apparel	Fertilizers & nitrogen compounds	Bakery products
4	Basic iron & steel	Structural metal products	Refined petroleum products	Cement, lime & plaster
5	Structural metal products	Other fabricated metals	Furniture	Glass & glass products

Source: *Abdelaziz et al. (2018)*

To mobilize the full potential for regional development, the green hydrogen industry needs to be embedded into these pre-existing clusters. Table 9 showcases the potential for creating forward and backward linkages for each of the sectors.

Table 9: *Forward- and backward linkage opportunities of existing clusters*

	Forward linkage opportunity	Backward linkage opportunity
Iron & Steel industry	Provision of cheap energy to automatize and scale up production	Input for the construction of power plants, electricity grids, pipelines
Fertilizer and nitrogen compounds	Provision of hydrogen as a feedstock	Shared pipelines, provision of electrolyzers
Refined petroleum products	Provision of hydrogen as feedstock for synthetic fuels	Provision of synthetic fuels for maintenance fleet
Cement, lime and plaster	Hydrogen as a clean fuel and reducing agent	Provision of cement for foundations when erecting infrastructure
Glass and glass product	Hydrogen as a clean fuel & glass coloring	Provision of glass for office buildings

Source: *Own analysis, based on Barrera et al., 2023; Genovese et al., 2023; Bhaskar et al., 2022; El-Emam et al., 2021; Jensen et al., 2007*

Box 9: Key takeaways on creating clusters to maximize development impact

For the production of marine fuels, exploiting the potential of strong winds and high solar radiation, combined with the exploration of geothermal resources along the Suez Gulf, is particularly relevant and has considerable potential for job creation.

However, the literature warns that new industries need to be carefully embedded in existing industrial structures. To this end, linkages can be created to realise synergy potential.

Existing industry has great potential to be linked to new green hydrogen investments, especially the petrochemical, steel and fertiliser industries. It is recommended to apply cluster thinking to achieve agglomeration effects between these industries.

Producing green hydrogen close to where it is used will have a favourable cost effect. In the long term, an efficient hydrogen pipeline infrastructure will provide the opportunity to green industrial processes elsewhere in the country, such as the glass industry around Cairo.

05

Conclusion and recommendations

5 Conclusion and recommendations

A number of dynamics are expected to change the spatial organization of maritime trade. On the one hand, rapid economic growth rates in East Asia may further shift the center of gravity of global trade eastwards, with direct implications for maritime trade. Climate change may lead to the emergence of new competitive routes, such as the North-East Passage. Finally, the decarbonization aim by IMO is one of the main factors shaping this transition: the use of green fuels, including hydrogen and its derivatives, could change shipping route planning. As technology changes, logistical planning will adapt, creating the opportunity for new bunkering locations to emerge.

Today, maritime trade follows a hub-and-spoke system, with economies of scale determining the geography of bunkering facilities. If and where new hubs will emerge is yet to be determined and will depend on many unknown variables. However, by achieving economies of scale in the production of green fuels, Egypt has the potential to position itself as a new stop on the Europe-Asia shipping route.

Whether or not the unique geographical location along the Suez Canal can be exploited depends on several factors. On a technical and economic level, Egypt has an advantageous location to produce low-cost green hydrogen. However, as in other parts of the world, further technological advances and/or fossil fuel taxation are needed to close the cost gap with fossil fuels. While the production efficiency of green hydrogen is expected to increase further, challenges arise from its low energy density and energy-intensive liquefaction, which increases transport costs. Ammonia benefits from established logistics, ships, and port infrastructure suitable for fuel cells or engines. Methanol is also a good fit, using existing oil-based infrastructure, but questions remain regarding the provenience of the carbon. As of now, batteries are only suitable for short trips or port vessels.

The economics of bunkering depend on fuel savings versus port costs. To date, green hydrogen production costs exceed traditional fuel prices by far. Hydrogen-based shipping hubs and GSCs aim to reduce emissions, which could become a competitive advantage in the future. However, success depends on affordable green hydrogen and overcoming energy density issues.

The properties of green shipping fuels, such as lower energy density affecting range, could require additional bunkering stops on long voyages. Investment cycles in the shipping industry are long, leading to significant technological path dependencies. Whether or not shipping companies invest in renewable fuels remains to be seen. However, once investments are made, shipping companies will rely on green bunkering ports to fuel their ships. The fact that leading shipping companies are already taking the first steps to implement a forward-looking greening strategy points to interesting developments in this area.

If policymakers in Egypt decide to position themselves in this yet insecure market through progressive policy-making, the challenge is to build the hydrogen infrastructure in the short to medium when the market is not yet secured. During this period, the creation of a domestic market will be crucial to secure the return on investments while achieving lower production costs through economies of scale. Creating synergies with existing Egyptian industry can have two positive effects: on the one hand, as a potential off-taker for the first generation of hydrogen, production capacities will be increased. On the other hand, the greening of industrial output gives a competitive advantage for exports in a growing market for green industrial products. The CBAM to be set up by the EU is particularly interesting in this respect.

This procedure would allow basic hydrogen infrastructure to be established, the relevant technologies to be embedded in the country, and the green upgrading of the domestic fertilizer, petrochemical, glass, and cement industries to be achieved. In this way, green hydrogen will gradually achieve economies of scale, making the production of green fuels more competitive in the long term. This could be accompanied by policies to promote domestic consumption of green fuels: service vessels, port infrastructure, and public transport could gradually be fueled by green hydrogen and its derivatives.

Need for further research

In light of the evolving climate change mitigation efforts and the complex shipping industry, there are several areas that require in-depth research to guide Egypt's strategic approach towards sustainable maritime shipping:

- **Feasibility study for a green hydrogen development corridor in Egypt**: Conducting an in-depth feasibility study is essential to identify and define the practicability and potential of the establishment of a green hydrogen development corridor in detail. This study should focus on the technical, economic, logistical, and environmental aspects of such a corridor. Factors such as infrastructure requirement, supply chain integration, and the potential for maximizing domestic value creation should be assessed.
- **Labor market readiness**: Understanding the labor market readiness for a green hydrogen sector in Egypt is essential. An analysis of the skills required and potential employment opportunities will display how Egypt can align its labor resources with the demand for a hydrogen market ramp-up.
- **Potential integration into a green shipping route:** This study displayed the first indications of the feasibility of Egypt's integration into a green shipping route. For final comprehensive results on the potential and the pathway for implementation of Egypt as part of a green shipping route, an extensive study including a variety of different Egyptian and international stakeholders should be conducted.
- **Technical-economic prospection for the cost of green hydrogen and its derivatives**: The costs supply costs for hydrogen and hydrogen derivatives should be analyzed on a local level to identify the most competitive locations for green hydrogen production sites in Egypt.

Supporting measures for building a shipping-based hydrogen economy

Based on the previous analysis, various recommendations can be given to decision-makers so Egypt can utilize its full potential in green shipping.

- **Technological Roadmap:** Monitor tech and market trends to define priority areas in green hydrogen and decarbonization. These areas, determined through analysis and stakeholder input, will guide focused investments and foreign partnerships for research and development and sharpen Egypt's profile in the global green hydrogen market.
- **Green Maritime Strategy:** Collaborate with global maritime hubs to establish green shipping routes, positioning Egypt and the Suez Canal as key players in decarbonizing the shipping industry. Encourage sustainable shipping fuels through reduced Suez Canal tolls and promote decarbonization of port and canal infrastructure to set an example for the industry.

- **Legislative Framework:** Establish a legislative framework for the green hydrogen industry to implement taxation and payment mechanisms and ensure compliance with local content regulations for fiscal benefits.
- **Labor and Demand Linkages:** Prioritize labor embeddedness to create strong demand linkages in local contexts, drafting policies that encourage high local expenditures and strengthen the local economy.
- **Infrastructure Development:** Develop distribution systems to improve access to electricity, water, and hydrogen for local households and businesses, fostering local growth, especially in agriculture and manufacturing.
- **Green Hydrogen Growth Corridor:** Create a dedicated growth corridor to combine renewable energy generation with green hydrogen investment and support related industries, providing inputs such as solar panels, pipelines, electrolyzers, and wind turbines and facilitating industrial processes such as steel and fertilizer production using green hydrogen. The coastal area from Ain Sokhna to Rais Ghareb could be suitable for this.
- **Cross-Sectoral Collaboration:** Foster cross-sectoral collaboration, knowledge transfer, and capacity building to leverage skills and institutional frameworks, enhancing regional development initiatives' effectiveness and promoting economies of scale.

References

References

Abd-Alaziz, M. (2022). Suez Canal revenues hit $6.3 bln in 2021 vs $5.6 bln in 2020. *Reuters*. URL: https://www.reuters.com/world/middle-east/suez-canal-revenues-hit-63-bln-2021-vs-56-bln-2020-2022-01-02/, published on 1/2/2022.

Abdelaziz, F., El-Enbaby, H., Zhang, X., & Breisinger, C. (2018). Clusters as drivers of local industrial development in Egypt: Which are the promising sectors and locations? *MENA working papers* 10. International Food Policy Research Institute (IFPRI).

Barrera, F., Hauser, P., Carlino, H., Carlino, M., & Caratori, L. (2023). Argentina as a hub for green ammonia: A forward-looking development strategy for addressing the global energy and climate crises. URL: https://static.agora-energiewende.de/fileadmin/Projekte/2022/2022-09_H2_Introduction_PtX_Argentina/AET_284_Argentina-hub-green-ammonia_WEB.pdf.

Al-Breiki, M., Bicer, Y. (2020). Comparative cost assessment of sustainable energy carriers produced from natural gas accounting for boil-off gas and social cost of carbon. *Energy Reports* 6 (1897–1909). URL: https://doi.org/10.1016/j.egyr.2020.07.013.

Asian Development Bank (ADB). (2020). Assessing the Impact of the United States–People's Republic of China Trade Dispute Using a Multiregional Computable General Equilibrium Model. *ADB Economics Working Paper Series.* URL: https://www.adb.org/sites/default/files/publication/640651/ewp-620-impact-us-prc-trade-dispute.pdf.

Auty, R. (2002). Sustaining development in mineral economies: the resource curse thesis. *Routledge*. URL: http://dx.doi.org/10.4324/9780203422595.

Badeeb, R.A., Lean, H.H., Clark, J. (2017). The evolution of the natural resource curse thesis: A critical literature survey. *Resources Policy* 51 (123-134). URL: https://doi.org/10.1016/j.resourpol.2016.10.015.

Benelux Overseas. (2017). SHIP'S PARTICULARS, GAS GLORIA . URL: https://www.benelux-ship.com/pdf/benelux-inc/07/ship-particulars-gas-gloria.pdf, retrieved 7/31/2023.

Bhaskar, A., Abhishek, R., Assadi, M., & Somehesaraei, H. N. (2022). Decarbonizing primary steel production: Techno-economic assessment of a hydrogen based green steel production plant in Norway. *Journal of Cleaner Production*, 350, 131339. URL: https://doi.org/10.1016/j.jclepro.2022.131339.

Breul, M., Revilla Diez, J., & Sambodo, M. T. (2019). Filtering strategic coupling: territorial intermediaries in oil and gas global production networks in Southeast Asia. *Journal of Economic Geography*, 19(4), 829-851. URL: https://doi.org/10.1093/jeg/lby063.

Brigham, Lawson. (2021). The Suez Canal and Global Trade Routes. Proceedings 147/5/1: 419. U.S. Naval Institute. URL: https://www.usni.org/magazines/proceedings/2021/may/suez-canal-and-global-trade-routes

C40 Cities. (2022). Port of Los Angeles, Port of Shanghai, and C40 Cities announce partnership to create world’s first transpacific green shipping corridor between ports in the United States and China. URL: https://www.c40.org/news/la-shanghai-green-shipping-corridor/, published on 1/28/2022.

C40 Cities (2023): Green Shipping Corridors. URL: https://www.c40.org/what-we-do/scaling-up-climate-action/ports-and-shipping/green-shipping-corridors/#:~:text=A%20green%20shipping%20corridor%20is,and%20private%20actions%20and%20policies, checked on 9/12/2023.

Canal de Panama. (2021). Sustainability - Panama Canal. URL: https://greenroute-micanal.azurewebsites.net/index.php/sustainability/, checked on 7/31/2023.

Cantini, G. (2023). Hydrogen in the MENA region: Priorities and steps forward. URL: https://www.atlanticcouncil.org/blogs/energysource/hydrogen-in-the-mena-region-priorities-and-steps-forward/, published on 2/14/2023.

Chatham House. (2020). Reforming the World Trade Organization: Prospects for transatlantic cooperation and the global trade system. URL: https://www.chathamhouse.org/sites/default/files/publications/research/2020-09-11-reforming-wto-schneider-petsinger.pdf.pdf.

CHNL. (2021). Transit Voyages on NSR in 2021. URL: https://www.chathamhouse.org/sites/default/files/publications/research/2020-09-11-reforming-wto-schneider-petsinger.pdf.pdf, published on 12/17/2021, checked on 8/22/2023.

Clean Energy Institute. (2023): What are some advantages of Li-ion batteries? URL: https://www.cei.washington.edu/education/science-of-solar/battery-technology/, updated on 8/4/2023.

CMA CGM. (2021). Lines & Services Flyer. URL: https://www.cma-cgm.com/products-services/flyers, checked on 8/23/2023.

CMA CGM. (2023). Lines & Services Flyer. URL: https://www.cma-cgm.com/products-services/flyers, updated on 7/21/2023.

De Santis, R. (2021). Sources of supply chain disruptions and their impact on euro area manufacturing. *ECB Economic Bulletin* 8. URL: https://www.ecb.europa.eu/pub/economic-bulletin/focus/2022/html/ecb.ebbox202108_07~e6aad7d32f.en.html.

Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ). (2023). ENHANCING EMPLOYABILITY: Skills Needs and Gap Analysis in Namibia’s PtX Sector and Recommendations for a Skills Development Programme. URL: https://ptx-hub.org/wp-content/uploads/2023/08/International-PtX-Hub_202308_Namibia-PtX-skills-needs-assessment.pdf.

Deutsches Arktisbüro am Alfred-Wegener-Institut. (2019). Fact Sheet: Schifffahrt in der Arktis. URL: https://www.arctic-office.de/fileadmin/user_upload/www.arctic-office.de/PDF_uploads/FactSheet_Schifffahrt.pdf.

Digges, C. (2022). Russia’s Rosatom consolidates control over the Northern Sea Route. URL: https://bellona.org/news/nuclear-issues/2022-05-russias-rosatom-consolidates-control-over-the-northern-sea-route, published on 5/24/2022, checked on 8/31/2023.

Det Norske Veritas Germanische Lloyd (DNV GL). (2019). Alternative fuels in the Arctic. URL: http://hdl.handle.net/11374/2422, checked on 8/31/2023.

Dorsch, M. (2021). Verkehrswirtschaft. Eine Einführung mit Fallstudien. 3., überarbeitete Auflage. München, Tübingen: UVK Verlag; Narr Francke Attempto Verlag GmbH + Co. KG (utb Wirtschaftswissenschaften, 5521).

E&M Combustión. (2022). Egypt authorizes the production of green hydrogen by several large energy groups. URL: https://emcombustion.es/en/egypt-authorizes-the-production-of-green-hydrogen-by-several-large-energy-groups/, published 04/17/2022, checked on 09/13/2023.

El-Emam, R. S., & Gabriel, K. S. (2021). Synergizing hydrogen and cement industries for Canada’s climate plan–case study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 43(23), 3151-3165. URL: http://dx.doi.org/10.1080/15567036.2021.1936699.

Engineeringtoolbox. (2023). Fuels - Higher and Lower Calorific Values URL: https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html, checked on 8/1/2023.

Enterprise. (2022). Egypt Signs Framework Agreements for Green Hydrogen + Ammonia Plants Worth USD 83 Bn. URL: https://enterprise.press/stories/2022/11/16/egypt-signs-framework-agreements-for-green-hydrogen-ammonia-plants-worth-usd-83-bn-87840, published on 12/5/2022, checked on 8/1/2023.

Environmental Defense Fund. (2022). Green shipping corridors: criteria for success. *EDF Blogs.* URL: https://blogs.edf.org/energyexchange/2022/11/18/green-shipping-corridors-criteria-for-success/, published on 11/18/2022, checked on 7/6/2023.

European Commission. (2021). Renewed partnership with the Southern Neighbourhood: A new Agenda for the Mediterranean. *Joint Communication to the European Parliament, the Council the European Economic and Social Committee and the Committee of the Regions.* URL: https://www.eeas.europa.eu/sites/default/files/joint_communication_renewed_partnership_southern_neighbourhood.pdf, published on 2/9/2021, checked on 8/1/2023.

EWI. (2021a): dena-Leitstudie Aufbruch Klimaneutralität. Klimaneutralität 2045 - Transformation der Verbrauchssektoren und des Energiesystems. Datenanhang Parameter. Herausgegeben von der Deutschen Energie-Agentur GmbH (dena). URL: https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2021/Abschlussbericht_dena-Leitstudie_Aufbruch_Klimaneutralitaet.pdf.

EWI. (2021b). Implikationen eines europäischen CO2-Grenzausgleichs (CBAM) für den internationalen Handel: Betrachtung mit Fokus auf den Eisen- und Stahlsektor. URL: https://www.ewi.uni-koeln.de/cms/wp-content/uploads/2021/10/EWI_Policy-Brief_CO2-Grenzausgleich-in-der-EU_20210927-1.pdf.

EWI. (2022). Natural Gas, Hard Coal, Oil: Analysis of European Energy Imports. URL: https://www.ewi.uni-koeln.de/en/news/erdgas-steinkohle-erdoel-analyse-der-europaeischen-energieimporte, published on 3/25/2022.

EWI. (2023). H2-Geopolitics: Geopolitical risks in global hydrogen trade. URL: https://www.ewi.uni-koeln.de/cms/wp-content/uploads/2023/02/230110_EWI_H2_Geopolitik_EN.pdf.

Facilitation of Transport and Trade in Latin America and the Caribbean (FAL). (2022). 2021 Port Report: early signs of a recovery in international container shipping in Latin America and the Caribbean. Bulletin 391, no.1. URL: https://repositorio.cepal.org/bitstream/handle/11362/48012/1/S2200342_en.pdf.

Fan, A., Yan, X., Bucknall, R., Song, R. (2017). Study of real-time fuel consumption model for large bulk carrier. *ResearchGate*. URL: https://www.researchgate.net/publication/336666018_Study_of_real-time_fuel_consumption_model_for_large_bulk_carrier.

Fessehaie, J., Rustomjee, Z. (2018). Resource-based industrialisation in Southern Africa: Domestic policies, corporate strategies and regional dynamics. *Development Southern Africa* 35 (1-15). URL: http://dx.doi.org/10.1080/0376835X.2018.1464901.

FuelCellsWorks. (2023). Egypt Collaborates with Chinas Beric for Hydrogen Production. URL: https://fuelcellsworks.com/news/egypt-collaborates-with-chinas-beric-for-hydrogen-production/, published 8/21/2023, checked 8/31/2023.

Gardiner, G. (2022). Cummins debuts 15-liter hydrogen engine and partners with Daimler for fuel cell trucks. *Composites World.* URL: https://www.compositesworld.com/news/cummins-debuts-15-liter-hydrogen-engine-and-partners-with-daimler-for-fuel-cell-trucks

Genovese, M., Schlüter, A., Scionti, E., Piraino, F., Corigliano, O., & Fragiacomo, P. (2023). Power-to-hydrogen and hydrogen-to-X energy systems for the industry of the future in Europe. *International Journal of Hydrogen Energy*. URL: https://doi.org/10.1016/j.ijhydene.2023.01.194.

Getting to Zero Coalition & Global Maritime Forum. (2022). Annual Progress Report on Green Shipping Corridors. URL: globalmaritimeforum.org/content/2022/11/The-2022-Annual-Progress-Report-on-Green-Shipping-Corridors.pdf.

Global Maritime Forum. (2021). The Next Wave: Green Corridors. URL: https://www.globalmaritimeforum.org/content/2021/11/The-Next-Wave-Green-Corridors.pdf

Global Maritime Forum. (2022). Green Corridors: Definitions and Approaches. *Discussion Paper.* URL: https://www.globalmaritimeforum.org/content/2022/08/Discussion-paper_Green-Corridors-Definitions-and-Approaches.pdf, published on 8/25/2022.

Global Solar Atlas. (2023). URL: https://globalsolaratlas.info/map, checked on 09/13/2023.

Global Wind Atlas. (2023). URL: https://globalwindatlas.info/, checked on 09/13/2023.

Hamburger Hafen. (2023). Emma Maersk. URL: https://www.hafen-hamburg.de/de/schiffe/emma-maersk-31425/, updated on 7/20/2023.

Hechler, D. (2022). Erweiterung des Suez-Kanals: Weg frei für künftige „Ever Givens". *tagesschau.de*. URL: https://www.tagesschau.de/ausland/afrika/suezkanal-erweiterung-101.html, published 3/23/2022.

Hellenic Shipping News. 2023. All you need to know about the New Suez Canal. Published 04/10/2019. URL: https://www.hellenicshippingnews.com/all-you-need-to-know-about-the-new-suez-canal/.

HS Schiffahrts Gruppe. (2023). SSW Super 1000. URL: https://www.hs-schiffahrt.com/die-flotte-2/container-schiffe/ssw-super-1000/, checked on 8/28/2023.

Hydrogen Central. (2021). Namibian Port Signs MoU with Port of Rotterdam, to Become Green Hydrogen Export Hub for Europe and the Rest of the World. URL: https://hydrogen-central.com/namibian-port-port-rotterdam-green-hydrogen-export-hub-europe, published on 11/15/2021, checked on 7/31/2023.

International Chamber of Shipping. (2022). Canada and United Arab Emirates First to Back Maritime Sector's Green Fuel Initiative. URL: https://www.ics-shipping.org/press-release/canada-and-united-arab-emirates-first-to-back-maritime-sectors-green-fuel-initiative/, published on 9/22/2022.

International Energy Agency (IEA). (2021). Suez Canal closure highlights Asia's growing dependence on Eastward oil flows. URL: https://www.iea.org/commentaries/suez-canal-closure-highlights-asia-s-growing-dependence-on-eastward-oil-flows, published on 3/27/2021, checked on 7/31/2023.

International Energy Agency (IEA). (2020). Indicative shipping fuel cost ranges. URL: https://www.iea.org/data-and-statistics/charts/indicative-shipping-fuel-cost-ranges, published on 11/10/2020.

International Maritime Organization (IMO). (2020). Fourth IMO GHG Study 2020. URL: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf.

International Maritime Organization (IMO). (2023). Strategy on reduction of GHG emissions from ships. URL: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf.

International Monetary Fund (IMF). (2023). Real GDP growth: Annual percent change. URL: https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD, checked on 8/28/2023.

International Renewable Energy Agency (IRENA). (2018). Renewable Energy Outlook EGYPT. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_Outlook_Egypt_2018_En.pdf.

International Renewable Energy Agency (IRENA). (2019). A New World: The Geopolitics of the Energy Transformation. URL: https://www.irena.org/-/media/files/irena/agency/publication/2019/jan/global_commission_geopolitics_new_world_2019.pdf.

International Renewable Energy Agency (IRENA). (2021). A pathway to decarbonise the shipping sector by 2050. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf.

Jensen, S. H., Larsen, P. H., & Mogensen, M. (2007). Hydrogen and synthetic fuel production from renewable energy sources. *International Journal of Hydrogen Energy*, 32(15), 3253-3257. URL: https://doi.org/10.1016/j.ijhydene.2007.04.042.

Kaluza, P., Kölzsch, A., Gastner, Michael T. & Blasius, B. (2010). The Complex Network of Global Cargo Ship Movements. *Journal of the Royal Society Interface* 7 (48): 1093–1103. URL: https://doi.org/10.1098/rsif.2009.0495.

Kenawy, E. (2016). The Economic Impacts of the New Suez Canal. *IEMed Mediterranean Yearbook 2016.* URL: https://www.iemed.org/wp-content/uploads/2021/01/The-Economic-Impacts-of-the-New-Suez-Canal.pdf.

Kieler Institut für Weltwirtschaft (IfW Kiel). (2021). Suezkanal – wichtige Lebensader für deutsche Importe. URL: https://www.ifw-kiel.de/de/suezkanal-wichtige-lebensader-fuer-deutsche-importe/, checked on 7/31/2023.

Kim, J., Mohommad, A. (2022). Jobs Impact of Green Energy. *International Monetary Fund*, Working Paper. URL: https://www.imf.org/en/Publications/WP/Issues/2022/05/27/Jobs-Impact-of-Green-Energy-518411.

Lutmar, C. & Rubinovitz, Z. (2023). The Suez Canal: Past Lessons and Future Challenges. Springer International Publishing. URL: https://link.springer.com/book/10.1007/978-3-031-15670-0.

Maersk Mc-Kinney Møller Center (MMKMC). (2022). Preparing Container Vessels for Conversion to Green Fuels: A technical, environmental, and techno-economic analysis of the impacts of preparation and conversion. URL: https://safety4sea.com/wpcontent/uploads/2022/09/Center-for-Zero-Shipping-Preparing-Container-Vessels-forConversion-to-Green-Fuels-2022_09.pdf, last checked on 10/21/2022.

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. (ZCS). (2023). Recommendations for Design and Operation of Ammonia-Fueled Vessels Based on Multi-disciplinary Risk Analysis. URL: https://www.zerocarbonshipping.com/publications/recommendations-for-design-and-operation-of-ammonia-fueled-vessels-based-on-multi-disciplinary-risk-analysis, checked on 7/20/2023.

Mallouppas G. & Yfantis E.A. (2021). Decarbonization in Shipping Industry: A Review of Research, Technology Development, and Innovation Proposals. *Journal of Marine Science and Engineering* 9(4):415. URL: https://doi.org/10.3390/jmse9040415

MAN Energy Solutions. (2023). MAN B&W two-stroke engine operating on ammonia. URL: https://www.man-es.com/docs/default-source/document-sync/man-b-w-two-stroke-engine-operating-on-ammonia-eng.pdf?, checked on 8/3/2023.

Mandra, Jasmina O. (2022). WasteFuel, Averda to Produce Green Methanol for Shipping in the Middle East. *Offshore Energy*. URL: https://www.offshore-energy.biz/wastefuel-averda-to-produce-green-methanol-for-shipping-in-the-middle-east, published on 11/8/2022.

Manifold Times (MT). (2022). Shanghai plans hydrogen energy demonstration port project. URL: https://www.manifoldtimes.com/news/shanghai-plans-hydrogen-energy-demonstration-port-project/.

Marine Insight. (2022). Top 10 biggest LPG carriers. URL: https://www.marineinsight.com/types-of-ships/10-biggest-lpg-carriers/, retrieved 7/31/2023.

Maritime and Port Authority of Singapore (MPA). (2022a). Decarbonization Blue Print: working towards 2050. URL: https://www.mpa.gov.sg/docs/mpalibraries/mpa-documents-files/sustainability-office/mpa-decarb-blueprint-2050a.pdf.

Maritime and Port Authority of Singapore (MPA). (2022b). Revised Green Ship Programme under the Maritime Singapore Green Initiative. *Shipping Circular* No. 07/2021. URL: https://static1.squarespace.com/static/6155b5bdada6ea1708c2c74d/t/635762927bdad84d60d9d6a4/1666671251045/Maritime+and+Port+Authority+of+Singapore+Green+Ship+Program.pdf, published on 4/22/2022, checked on 7/31/2023.

Maritime and Port Authority of Singapore (MPA). (2023a). Total Cargo Throughput [Dataset]. URL: https://www.mpa.gov.sg/who-we-are/newsroom-resources/research-and-statistics/port-statistics, checked on 28.08.2023.

Maritime and Port Authority of Singapore (MPA). (2023b). Port dues tariff. URL: https://www.mpa.gov.sg/finance-e-services/tariff-fees-and-charges/ocean-going-vessels, retrieved 7/31/2023.

Maritime Studies South Africa (MARITIMESA). (2023). *Maritime Economics.* URL: https://maritimesa.org, updated on 7/21/2023.

Martínez-Zarzoso, I. (2013). Alternative Sea Routes: What Effects on Maritime Trade? *SAIS Review of International Affairs* 33(2), 61-74. URL: https://doi.org/10.1353/sais.2013.0020.

Ministry of Foreign Affairs and Trade New Zealand (MFAT). (2021). The Importance of the Suez Canal to Global Trade. URL: https://www.mfat.govt.nz/assets/Trade/MFAT-Market-reports/The-Importance-of-the-Suez-Canal-to-Global-Trade-18-April-2021.pdf, published on 4/18/2021, checked on 7/31/2023.

Ministry of Transport of the Russian Federation. (2019). The General Scheme for Deployment of the Transport Logistics Centers Network (within the transportation part of the Federal Project 'Comprehensive Plan for the Modernization and Expansion of the Core Infrastructure up to 2024'). URL: http://mintrans.org/ftpgetfile.php?id=15, checked on 8/1/2023.

Mission Innovation. (2023). Green Shipping Corridor Route Tracker. URL: http://mission-innovation.net/missions/shipping/green-shipping-corridors/route-tracker/.

Moharram, N. A., Tarek, A., Gaber, M., & Bayoumi, S. (2022). Brief review on Egypt's renewable energy current status and future vision. *Energy Reports*, 8, 165-172.

Mondal M. A. H., Ringler C., Al-Riffai P., Eldidi H., Breisinger C., Wiebelt M. (2019). Long-term optimization of Egypt's power sector: Policy implications. *Energy 2019*;166:1063–73.

Morris, M., Kaplinsky, R., & Kaplan, D. (2012). "One thing leads to another"—Commodities, linkages and industrial development. *Resources Policy*, 37(4), 408-416. URL: https://doi.org/10.1016/j.resourpol.2012.06.008.

Moritz, M., Schönfisch, M., Schulte, S. (2023). Estimating global production and supply costs for green hydrogen and hydrogen-based green energy commodities. *International Journal of Hydrogen Energy* 48 (25), pp. 9139–9154. URL: https://doi.org/10.1016/j.ijhydene.2022.12.046.

Moses, J. W. (2021). Norwegian Local Content Policy. *Sovereign Wealth Funds, Local Content Policies and CSR: Developments in the Extractives Secto*r. 423-435. URL: http://dx.doi.org/10.1007/978-3-030-56092-8_24.

Namibian Ports Authority (NAMPORT). (2022). Integrated Annual Report 2022. URL: https://www.namport.com.na/files/files/Performance%20at%20a%20glance%20ended%2031%20March%202022.pdf.

Namibian Ports Authority (NAMPORT). (2023). Welcome to the Port of Walvis Bay. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_Outlook_Egypt_2018_En.pdf, checked on 7/31/2023.

NGHC. (2022). NEOM Green Hydrogen Company signs facility agreements. URL: https://www.nghc.com/nghc-facility-agreements/, published on 12/18/2022.

Notteboom, T., Haralambides, H. (2023). Seaports as green hydrogen hubs: advances, opportunities and challenges in Europe. Marit Econ Logist 25, 1–27 (2023). URL: https://doi.org/10.1057/s41278-023-00253-1.

Öko-Institute e.V. (2022). Hydrogen fact sheet – Gulf Cooperation Countries (GCC). URL: https://www.oeko.de/fileadmin/oekodoc/GIZ-SPIPA-hydrogen-factsheet-GCC.pdf.

Oeko-Institut, Agora Energiewende & Agora Industry. (2023). PTX Business Opportunity Analyser, Version 1.0.9. URL: https://www.agora-energiewende.de/en/publications/business-opportunity-analyser-boa, checked on: 09/13/2023.

Panama Canal Authority (ACP). (2022a). OP Notice to Shipping No. N-1-2022 – Vessel Requirements. URL: https://pancanal.com/wp-content/uploads/2022/03/N01-2022.pdf.

Panama Canal Authority (ACP). (2022b). Panama Canal Traffic – Fiscal Years 2020 Through 2022. URL: https://pancanal.com/wp-content/uploads/2022/10/Table01.pdf.

Park, N. K., Suh, S. C. (2019). Tendency toward Mega Containerships and the Constraints of Container Terminals. *Journal of Marine Science and Engineering* 7(5), 131. URL: https://doi.org/10.3390/jmse7050131.

Patonia, A. (2022). How Its War on Ukraine Killed Russia's Hydrogen Ambitions. German Marshall Funds of the United States. URL: https://www.gmfus.org/news/how-its-war-ukraine-killed-russias-hydrogen-ambitions.

Pestel, N. (2019). Employment effects of green energy policies. *IZA World of Labor.* URL: https://wol.iza.org/uploads/articles/519/pdfs/employment-effects-of-green-energy-policies.pdf.

Port of Rotterdam. (2021). Highlights Annual Report 2021. URL: https://reporting.portofrotterdam.com/FbContent.ashx/pub_1011/downloads/v230308134647/Highlights-annual-report-2022-Port-of-Rotterdam-Authority.pdf.

Port of Rotterdam. (2022a). Energiehafen Rotterdam: Wasserstoff, Energieunabhängikeit und Dekarbonisierung. URL: https://www.portofrotterdam.com/sites/default/files/2022-12/positionspapier-des-hafenbetrieb-zur-deutschen-nationalen-wasserstoffstrategie.pdf.

Port of Rotterdam. (2022b). Maritime and Port Authority of Singapore and Port of Rotterdam to establish world's longest Green and Digital Corridor for efficient and sustainable shipping. URL: https://www.portofrotterdam.com/en/news-and-press-releases/maritime-and-port-authority-of-singapore-and-port-of-rotterdam-to-establish, published on 8/2/ 2022.

Port of Rotterdam. (2022c). Highlights annual report 2022. URL: https://reporting.portofrotterdam.com/FbContent.ashx/pub_1011/downloads/v230308134647/Highlights-annual-report-2022-Port-of-Rotterdam-Authority.pdf.

Qatar Energy. (2022). QATARENERGY RENEWABLE SOLUTIONS & QAFCO LAUNCH THE WORLD'S LARGEST BLUE AMMONIA FACILITY. URL: https://www.qatarenergy.qa/en/MediaCenter/Pages/newsdetails.aspx?ItemId=3722, published on 8/31/2022.

Rahman, Noorul S. F. A., Saharuddin, A.H. & Roziah, Mohd R. (2014). Effect of the Northern Sea Route Opening to the Shipping Activities at Malacca Straits. *International Journal of E-Navigation and Maritime Economy* (1): 85–98. URL: https://doi.org/10.1016/j.enavi.2014.12.008.

Rystad Energy RenewableCube (n.d.). Announced green hydrogen projects in Egypt.

Salah, S. I., Eltaweel, M., & Abeykoon, C. (2022). Towards a sustainable energy future for Egypt: A systematic review of renewable energy sources, technologies, challenges, and recommendations. *Cleaner Engineering and Technology*, 8, 100497.

Shafran, Dmitry (2023): Capesize Bulk Carriers: A Complete Overview of Giant Ships. URL: https://maritimepage.com/capesize-bulk-carriers-a-complete-overview-of-giant-ships/, checked on 9/11/2023.

Shafran, Dmitry (2023): Capesize Bulk Carriers: A Complete Overview of Giant Ships. URL: https://maritimepage.com/capesize-bulk-carriers-a-complete-overview-of-giant-ships/, checked on 9/11/2023.

Shibhub. (2022). Top 50 seaports 2022. URL: https://www.shiphub.co/top-50-seaports-2022/, checked on 8/22/2023.

Søgaard, K., Blaxekjær, L., Krantz, R., Rud, S., Maver, T., Spiegelenberg, F. & Kirketerp-Møller, T. (2021). Report on Climate Commitments by Signatories to the Call to Action for Shipping Decarbonization. December 2021, Third Edition.

Staber, M. (2022). Ägypten erhöht Transitgebühren für Suezkanal kräftig. *tagesschau.de.* URL: https://www.tagesschau.de/wirtschaft/weltwirtschaft/suez-kanal-transitgebuehren-101.html, published on 9/18/2022, checked on 8/1/2023.

Stolz, B., Held, M., Georges, G., Boulouchos, K. (2022). Techno-economic analysis of renewable fuels for ships carrying bulk cargo in Europe. *Nature Energy* 7. URL: https://doi.org/10.1038/s41560-021-00957-9.

Suez Canal Authority (SCA). (2019a). About Suez Canal. URL: https://www.suezcanal.gov.eg/English/About/SuezCanal/Pages/AboutSuezCanal.aspx.

Suez Canal Authority (SCA). (2019b). Suez Canal Traffic Statistics: Annual Report 2019. URL: https://www.suezcanal.gov.eg/English/Downloads/DownloadsDocLibrary/Navigation%20Reports/Annual%20Reports%E2%80%8B%E2%80%8B%E2%80%8B/2019.pdf.

Suez Canal Authority (SCA). (2019c). Navigation Statistics: Monthly Number & Net Ton by Ship Type. URL: https://www.suezcanal.gov.eg/English/Navigation/Pages/NavigationStatistics.aspx.

Suez Canal Authority (SCA). (2020). Rules of Navigation. URL: https://www.suezcanal.gov.eg/FlipPDFDocuments/Rules%20of%20Navigation.pdf.

Suez Canal Authority (SCA). (2023a). Navigation statistics. URL: https://www.suezcanal.gov.eg/English/Navigation/Pages/NavigationStatistics.aspx, checked on 8/22/2023.

Suez Canal Authority (SCA). (2023b). Navigation Tolls. URL: https://www.suezcanal.gov.eg/English/Pages/default.aspx, checked on 8/22/2023.

Suez Canal Authority (SCA). (2023c). The Green Canal. URL: https://www.suezcanal.gov.eg/English/About/SuezCanal/Pages/greencanal.aspx, checked on 8/25/2023.

Suez Canal Authority (SCA). (2023d). Vessels Tolls Calculator. URL: https://www.suezcanal.gov.eg/English/Navigation/Tolls/Pages/TollsCalculator.aspx, retrieved 7/31/2023.

Suez Canal Authority (SCA). (n.d.) Media Center – Brochures: New Suez Canal. URL: https://www.suezcanal.gov.eg/English/MediaCenter/Brochures/New%20Suez%20Canal.pdf, checked on 8/31/2023.

Sustainable Development Strategy (SDS): Egypt Vision 2030. (2016). URL: https://arabdevelopmentportal.com/sites/default/files/publication/sds_egypt_vision_2030.pdf

UK Department of Transport. (2022). COP 26: Clydebank Declaration for green shipping corridors. Policy Paper. URL: https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors, updated on 4/13/2022.

UNCTAD. (2019). *Review of Maritime Transport 2019*, Chapter 3. URL: https://unctad.org/publication/review-maritime-transport-2019, retrieved 7/31/2023.

UNCTAD. (2022). *Review of Maritime Transport 2022.* URL: https://unctad.org/system/files/official-document/rmt2022_en.pdf.

UNCTAD. (2023). Port liner shipping connectivity index. URL: https://unctadstat.unctad.org/wds/TableViewer/tableView.aspx.

Vechkinzova, Elena, Larissa P., Steblyakova, Natalia, Roslyakova & Balnur Omarova. (2022). Prospects for the Development of Hydrogen Energy: Overview of Global Trends and the Russian Market State. *Energies* 15 (22): 8503. URL: https://doi.org/10.3390/en15228503.

VesselFinder. (2023). CARAVELLE, LPG Tanker - Details and current position - IMO 9722807. URL: https://www.vesselfinder.com/vessels/details/9722807, retrieved 7/31/2023.

Van Son, P. & Aruffo, C. (2023). Hydrogen developments and opportunities in the MENA region: Dii Desert Energy, World's first organization for energy from the deserts. *MENA Hydrogen Alliance*. URL: https://dii-desertenergy.org/wp-content/uploads/2023/05/2023_04_MENA_H2_developments.pdf.

Vukić, L. & Cerbán, M. (2022). Economic and environmental competitiveness of container shipping on alternative maritime routes in the Asia-Europe trade flow. *Maritime Transport Research* 3 (22): 100070. URL: https://doi.org/10.1016/j.martra.2022.100070.

Weldegiorgis, F. S., Dietsche, E., Franks D. M., Cust, J., Ahmad S. (2022). Mining and linkages for economic transformation: Revealing multi-stakeholder perspectives through Q-methodology. *The Extractive Industries and Society* 12. URL: https://doi.org/10.1016/j.exis.2022.101174.

Wissner, N., Healy, S., Cames, M., Sutter, J. (2023). Methanol as a marine fuel - Advantages and limitations. URL: https://www.oeko.de/fileadmin/oekodoc/Methanol-as-a-marine-fuel.pdf, checked 8/31/2023.

World Shipping Council. N.d. The Top 50 Container Ports. Top 50 Ports — World Shipping Council. URL: https://www.worldshipping.org/top-50-ports, retrieved 8/22/2023.

World Trade Organization (WTO). (2013). World Trade Report 2013. URL: https://www.wto.org/english/res_e/booksp_e/wtr13-2c_e.pdf.

World Trade Organization (WTO). (2020). An economic analysis of the US-China trade conflict. Staff Working Paper ERSD-2020-04. URL: https://www.wto.org/english/res_e/reser_e/ersd202004_e.htm, checked on 8/31/2023.

World Trade Organization (WTO). (2023). Understanding the WTO: Principles of the trading system. URL: https://www.wto.org/english/thewto_e/whatis_e/tif_e/understanding_e.pdf, checked on 8/31/2023.

Zaher, M.A., Elbarbary, S., El-Shahat A., Mesbah H., Embaby, A. (2018). Geothermal resources in Egypt integrated with GIS-based analysis, *Journal of Volcanology and Geothermal Research* 365 (1-12). URL: https://doi.org/10.1016/j.jvolgeores.2018.09.013.

Glossary

Ports

A seaport is a complex of berths for seagoing vessels which, as a junction between inland and maritime traffic and transport, has the necessary facilities for the transshipment, storage, arrival, and departure of goods as well as for the traffic and handling of seagoing vessels and inland means of transport. Typical harbor services include the provision of fuel, called bunkering (Dorsch, 2021).

Ships

Ships can be classified by their size and their purpose. The size of cargo ships is generally classified by the largest waterway these ships can pass. Ships of the Panamax-class are the largest ships that can pass the Panama Canal. Suezmax-Class ships are the largest ships that can pass the Suez Canal. Capesize-class ships are too large for both canals and must take the cape route around Africa (Cape of Good Hope) or South America (Cape Horn) (Dorsch, 2021).

Table 10: *Selected shipping classes and their size*

Class	Length [m]	Width [m]	Depth [m]
Panamax	294	32.3	12
Neopanamax	366	51.3	15.2
Suezmax	400	77.5	20.1
Capesize	too large for the Panama and the Suez Canal		

Source: *ACP, 2022a; Dorsch, 2021; SCA, 2020*

In terms of purpose, cargo ships can be classified into three categories:

- **Container carriers** are specialized ships to transport containers. The size of containers is internationally normed, and the capacity of a container carrier is measured in twenty-foot equivalent (TEU), which refers to the volume of one container.
- **Bulk carriers** transport dry or wet bulk. Dry bulk carriers transport cargo that can be handled by conveyor systems, chutes, grabs, or skips (e.g., ore, coal, grain, minerals). Neo Bulk carriers transport bulk from individual pieces (e.g., wood, pig iron, steel). Wet bulk carriers transport liquids or liquefied gases (e.g., crude oil, petroleum products, LNG, Liquefied Petroleum Gas (LPG), and Chemicals). Bulk carriers generally charge and discharge cargo at specific terminals.
- **Special purpose carriers** are specialized in transporting certain goods. Examples are heavy-duty carriers, refrigerated cargo carriers, or RoRo (Roll-on Roll-off) carriers. In RoRo carriers, the cargo can be brought on board on its own wheels, as with car ferries (Dorsch, 2021).
- **Chokepoints,** in the sense of navigation, are narrow waterways that are difficult to navigate around. These can be natural, like straits, or artificial, like canals, and are a sensible concern in global trade as they can easily be blocked. In the case of the Suez Canal and the Panama Canal, which are artificial waterways connecting two seas/oceans, canal infrastructure ensures the transit of vessels. Ports are located on both sides of the canal.

List of abbreviations

CBAM	Carbon Border Adjustment Mechanism
EU	European Union
GWP20	Global Warming Potential over 20 years
GSC	Green Shipping Corridors
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
ICE	Internal Combustion Engine
IMO	International Maritime Organization
LOI	Letter of Interest
LNG	Liquified Natural Gas
MGO	Marine Gas Oil
MOU	Memorandum of Understanding
MENA	Middle East and North Africa
MPA	Maritime and Port Authority of Singapore
PV	Photovoltaic
RoRo carriers	Roll-on Roll-off carriers
SCA	Suez Canal Authority
UAE	United Arab Emirates
TEU	Twenty-foot Equivalent
ULCC	Ultra Large Crude Carriers
VLCC	Very Large Crude Carriers
VLSFO	Very low sulfur fuel oil
WACC	Weighted Average Cost of Capital

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Appendix

Appendix

Table 11: *Calculation of the costs of an additional bunkering stop for a container carrier in Egypt and calculation of the transport cost of ammonia from Egypt to Germany (referring to Chapter 3.3)*

	Assumptions		
Parameter	**Unit**	**Value**	**Source**
Ship name	[-]	ECO VLGC Caravelle	VesselFinder, 2023
Travel Speed	[km/h]	21	Marineinsight, 2022
Fuel tank size	[m³]	84,000	Marineinsight, 2022
Deadweight tonnage	[t]	54,566	Marineinsight, 2022
Gross tonnage	[t]	47,379	Marineinsight, 2022
Net tonnage	[t]	14,200	Based on Benelux Overseas, 2017
Charter costs	[$/d]	50,000	Moritz et al., 2023
Fueling Cost	[$/d]	3,000	MPA, 2023B
Port Cost	[$/d]	124,400	Al-Breiki & Bicer, 2020
Insurance cost	[$/d]	4,400	Al-Breiki & Bicer, 2020
Maintenance Cost	[$/d]	11,500	Al-Breiki & Bicer, 2020
Crew cost	[$/d]	3,800	Al-Breiki & Bicer, 2020
Fuel consumption (approx.)	[t/h]	5	Based on Fan et al., 2017
Fuel needed	[t]	960	Based on Fan et al., 2017
Transported fuel (cargo only)	[t]	56,328	
Passage costs Suez Canal	[$]	131,700	SCA, 2023d
Costs of an additional bunkering stop in Egypt			
Time needed (Waiting, Bunkering, Berthing)[a]	[d]	3	UNCTAD, 2019; Based on Park & Suh, 2019
Charter costs	[$/MWh]	0.50	Own calculations
Fueling Cost[a]	[$/MWh]	0.01	Own calculations
Port Cost[a]	[$/MWh]	0.42	Own calculations
Insurance cost	[$/MWh]	0.04	Own calculations
Maintenance Cost	[$/MWh]	0.12	Own calculations
Crew cost	[$/MWh]	0.04	Own calculations
Sum	***[$/MWh]***	***1.13***	
Costs of transporting Ammonia from Egypt to Germany			
Travel time (one-way)	[d]	13	Own calculations
Port Stop in Egypt[b]	[d]	3	UNCTAD, 2019; Based on Park & Suh, 2019
Port Stop in Germany[b]	[d]	3	UNCTAD, 2019; Based on Park & Suh, 2019
Charter costs	[$/MWh]	2.19	Own calculations
Insurance cost	[$/MWh]	5.44	Own calculations
Maintenance Cost	[$/MWh]	0.19	Own calculations
Crew cost	[$/MWh]	0.50	Own calculations
Fuel cost	[$/MWh]	12.43	Own calculations
Cost of Port Stop in Egypt	[$/MWh]	1.13	Own calculations
Cost of Port Stop in Germany	[$/MWh]	1.13	Own calculations
Passage costs Suez Canal	[$/MWh]	0.44	Own calculations
Sum	***[$/MWh]***	***23.46***	

Note: **a** Fueling and Port Costs only apply to berthing time of one day. **b** Berthing time was estimated to be one day, based on UNCTAD (2019). Waiting time was estimated based on Park & Suh (2019) and own estimates to be two days.