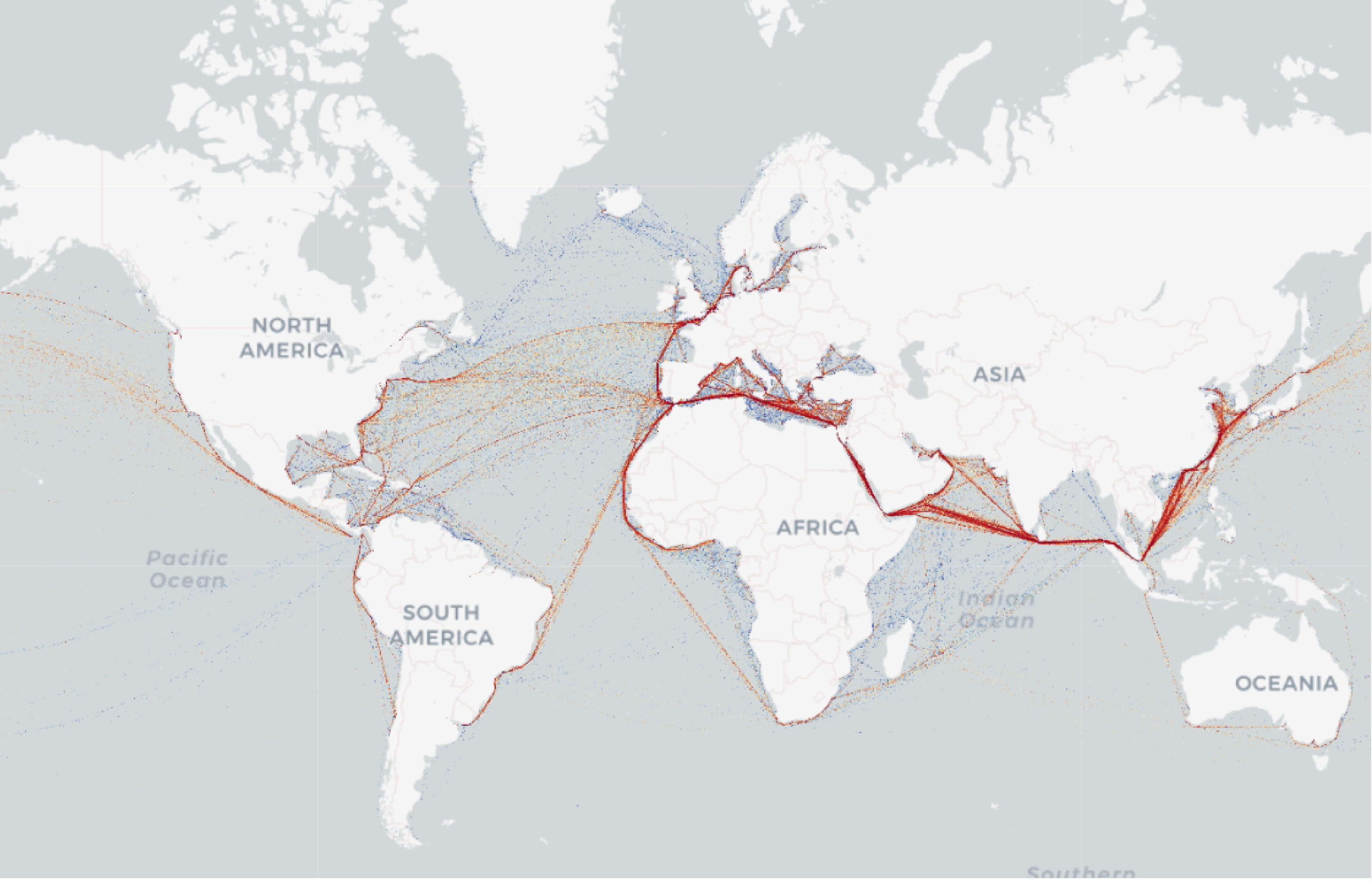

REPORT - May 2024

Europe-Asia Green Corridors

Case for Morocco as a green shipping H2 hub

Transport & Environment

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Executive summary

Endowed with rich solar and wind energy, Morocco has an ambitious green hydrogen strategy aiming to produce 0.67 million tonnes/year of green H2 by 2030. However, the production potential of currently announced projects would only reach 0.05 million tonnes/year, showing a discrepancy between the objectives and the current progress. Our research shows that ships sailing along the Moroccan Mediterranean coastline could be priority users of its green hydrogen production, as the sector will gradually need to switch to green e-fuels promoted by the EU and potentially forthcoming international IMO rules.

Major new bunkering hub between Europe and Asia

Our research found that of the 2348 trips between Europe and East Asia in 2019, two-thirds crossed the Strait of Gibraltar between Morocco and Spain. While the current technical autonomy allows ships to get away with limited bunkering stops , green policies forcing ships to rely more on lower energy density green e-fuels could change that bunkering dynamic. This represents an opportunity for Morocco to increase its role as a major bunkering hub, considering that green e-fuels are projected to make up 80% of energy consumption of ships sailing to and from the EU by 2050.

An opportunity for Morocco

Our analysis concluded that bunkering green e-fuels in Morocco could be a viable strategy for the majority of containerships to increase their operational autonomy when sailing between Western Europe and East Asia. Provided that the ships bunker once in East Asia, bunkering a second time in Morocco would allow most container ships to complete 26% more journeys when running on ammonia or 8% more journeys when running on e-methanol without the need to bunker anywhere else.

As the International Maritime Organisation (IMO) is in the process of agreeing new environmental rules for shipping, including alternative fuel mandates via a goal-based fuel standard (GFS), many countries in the region will be competing to attain a sizable share of the new fuels market. Active diplomatic engagement of Morocco in this process can further increase economic benefits for the Kingdom by ensuring that green hydrogen(-derived fuels) remain at the centre of IMO's environmental policies for shipping.

Sustainability remains key

While this potential geographical reshuffling of ship bunkering could result in big economic gains for countries such as Morocco, it will be essential to ensure that shipping's fuel transition does not compete with the needs of the local population, especially when it comes to investments in grid decarbonisation as well as limited fresh water supplies. While EU rules provide certain environmental safeguards for sustainable production of e-fuels, such as additionality of green electricity and limitations placed on fossil carbon feedstocks, it will be essential to apply a minimum of similar standards for e-fuel demands driven by the potential future IMO regulations, too.

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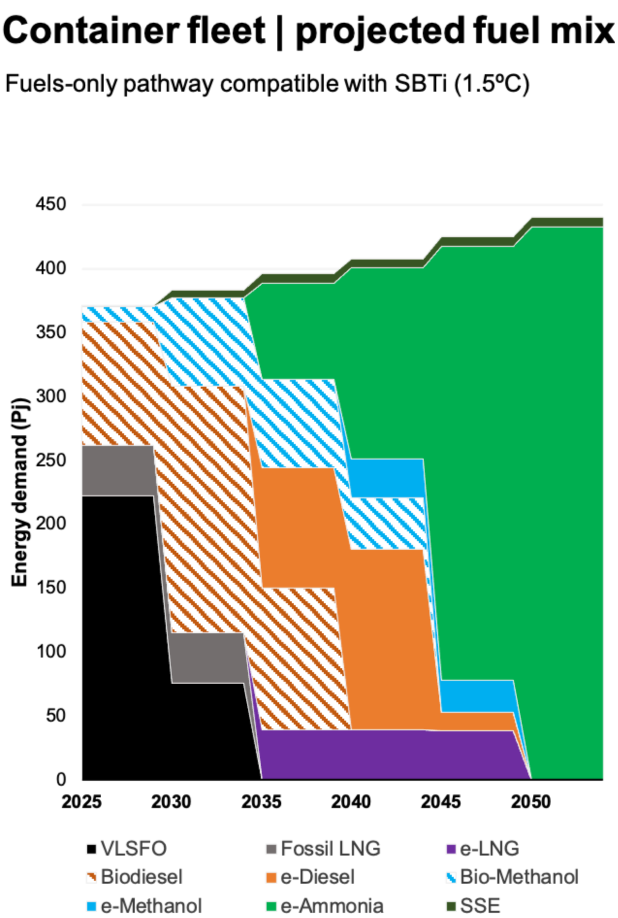
Section 1

1. Review of the geographic suitability of Morocco as a green fuel bunkering hub

Globally shipping consumes about 300 million tonnes of fossil fuels (primarily very low sulphur fuel oil (VLSFO)) every year, which represents about 3% of anthropogenic emissions[1]. Decarbonisation of the sector will require a huge shift in the energy system over the next 20-25 years. While technologies and alternative fuels to decarbonise shipping are coming of age, the development of supply chains and necessary land investments have been lagging behind.

This is principally because cleaner shipping fuels and technologies are more costly than their fossil alternatives. For as long as there is a lack of regulations either to completely bridge the price gap between fossil and green fuels or directly mandate the uptake of the latter, demand for these fuels will remain insignificant.

In the absence of effective and binding global rules, the EU has thankfully adopted a suite of shipping legislation as part of its fit-for-55 (FF55) climate and energy package. Europe will be the first continent to force shipping companies to use alternative marine fuels and pay for their carbon pollution. While the full impact of the FF55 package - the EU ETS and the FuelEU Maritime regulation - can only be assessed once these laws enter into force in 2024 and 2025, T&E's preliminary analysis has shown that FF55 will drive the uptake of alternative fuels. Initially LNG and biofuels will replace conventional fuels, but from 2030 onwards there will be widespread uptake of green e-fuels and direct electricity. The latter two are projected to make up close to 80% of energy consumption of ships sailing to and from the EU by 2050. A massive scale-up of green electricity and hydrogen production will be needed to meet the demand caused by the EU laws.



Source: T&E fuel optimisation model (2023). SBTi pathway, base-case.

Figure 1 | Projected EU container shipping fuel mix

[1] Faber, J., Kleijn, A., Hanayama, S., Zhang, S., Pereda, P., Comer, B., … Xing, H. (2020). Fourth IMO Greenhouse Gas Study.

An important part of the energy supply could be expected to come from **outside of Europe**. This means shipping decarbonisation offers unique opportunities and challenges to countries with abundant solar and wind potential, especially those located close to major shipping lanes.

The key question is how the development of the supply chain and deployment of green fuels could be practically operationalised in view of regulation-driven demand from ships that call at European ports. In this context, the development of green corridors for shipping between Europe, Africa and East Asia can provide public and private actors clarity on the development of green fuel supply and deployment.

According to UNCTAD, the Asia - Europe containerised cargo represents about 22% of global interregional trade, second only to the Asia Pacific - N. America corridor (26%).[2] Voyages between Asia and Europe through the Suez canal represent about two thirds of the fuel consumption of container ships calling at European ports.[3] This suggests that the Asia - Europe corridor is a primary candidate for alternative marine fuel supplies, demand for which will be generated by European legislation.

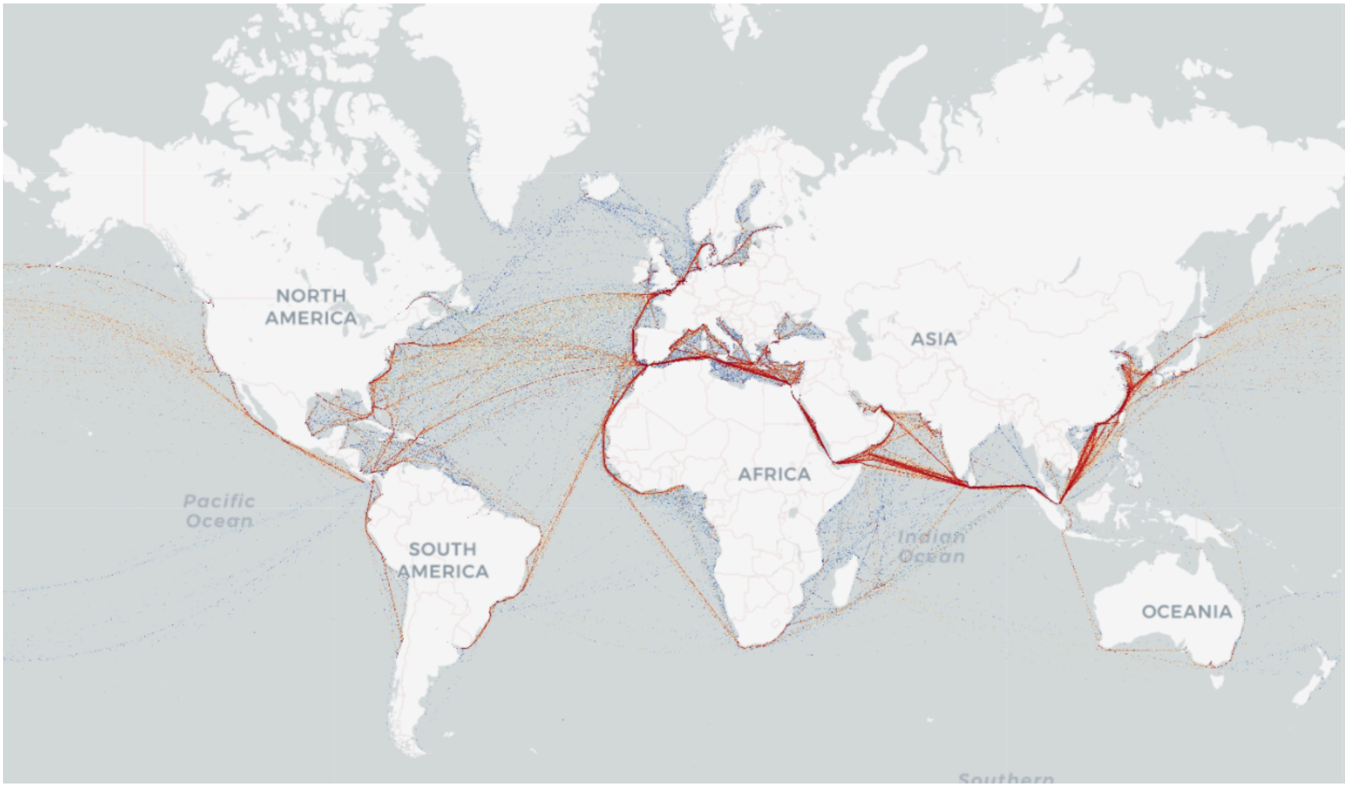


Figure 2 | MRV containers[4] fuel consumption map based on ship 2019 AIS analysis

For 2019, we have identified 465 container vessels performing 2348 individual end-to-end trips between the EU and East Asia (i.e. China, Japan and South Korea), consuming about 7.3 million tons of marine fuels, 2 Mt of which will be regulated by the EU laws. Ships on almost all end-to-end trips stopped at one or several ports along the way.

[2] UNCTAD (2022). Review of maritime transport 2022.
[3] Calculated by T&E using 2019 AIS data. East Asia corresponds to China, South Korea and Japan in this analysis.
[4] Containers calling at European ports at least once a year are covered by the EU's Monitoring, Reporting and Verification (MRV) Regulation

These end-to-end trips pass close to the North African coastline, which makes the region suitable for possible on-route bunkering of green electricity-based fuels that can be sustainably produced in the region (see section 4 below). This preliminary analysis concentrates on two possible factors that might make it attractive for container vessels to bunker in N. Africa:

- Operational/technical necessity to bunker more frequently;
- Cost-competitiveness of N. African supplies.

Definitions

It is important to clarify different expressions associated with vessel sailings as they have different practical and legal consequences. In this report, the words “end-to-end trip”, “voyage” and “trip leg” have different meanings.

For the purpose of this report, **end-to-end trip** means any journey between a port in Europe and a port in Asia, which represent the furthest extremes of the travel before the vessel turns around and sails in the opposite direction. For example, for a vessel starting off from Bremenhaven and sailing towards Asia, calling at multiple European, African and Asian ports along the way before reaching Xingang in China, Germany-China would constitute a single end-to-end trip.

Trip leg means the part of the journey between two bunkering/refuelling stops. For example, in the above-mentioned example, if a vessel bunkers only in Bremerhaven and Xingang, the trip will be considered to have only 1 leg. If the vessel also bunkers in Morocco, then we consider the trip having 2 legs, i.e. Germany-Morocco and Morocco-China (and in the opposite direction).

Voyage is legal terminology used by EU legislations, which denotes any journey between 2 ports of call where vessels carry out cargo or passenger operations regardless whether or not refuelling/resupplying actions take place. Based on this legal definition, an end-to-end trip may consist of multiple voyages. In order to avoid any confusion with the regulatory definitions, in this report we will avoid using the term voyage unless specifically referring to a meaning explained in this paragraph.

1.1 Operational/technical necessity to bunker more frequently

One of the key technical questions/concerns in shipping’s energy transition is the low volumetric energy densities of alternative fuels, which could have implications on the autonomy as well as the cargo capacity of vessels. T&E simulation based on existing vessel designs shows that while existing large (14,500-19,999 TEU) HFO/VLSFO vessels have an average 36,500 nm (~ 67,500 km) autonomy, running the same vessels on alternative marine fuels would significantly reduce their range (Fig. 3). This would range on average from ~6,500 nm

(12,000 km) for liquid H2 fuel cell propulsion to ~15,800 nm (30,000 km) for methanol-powered vessels.

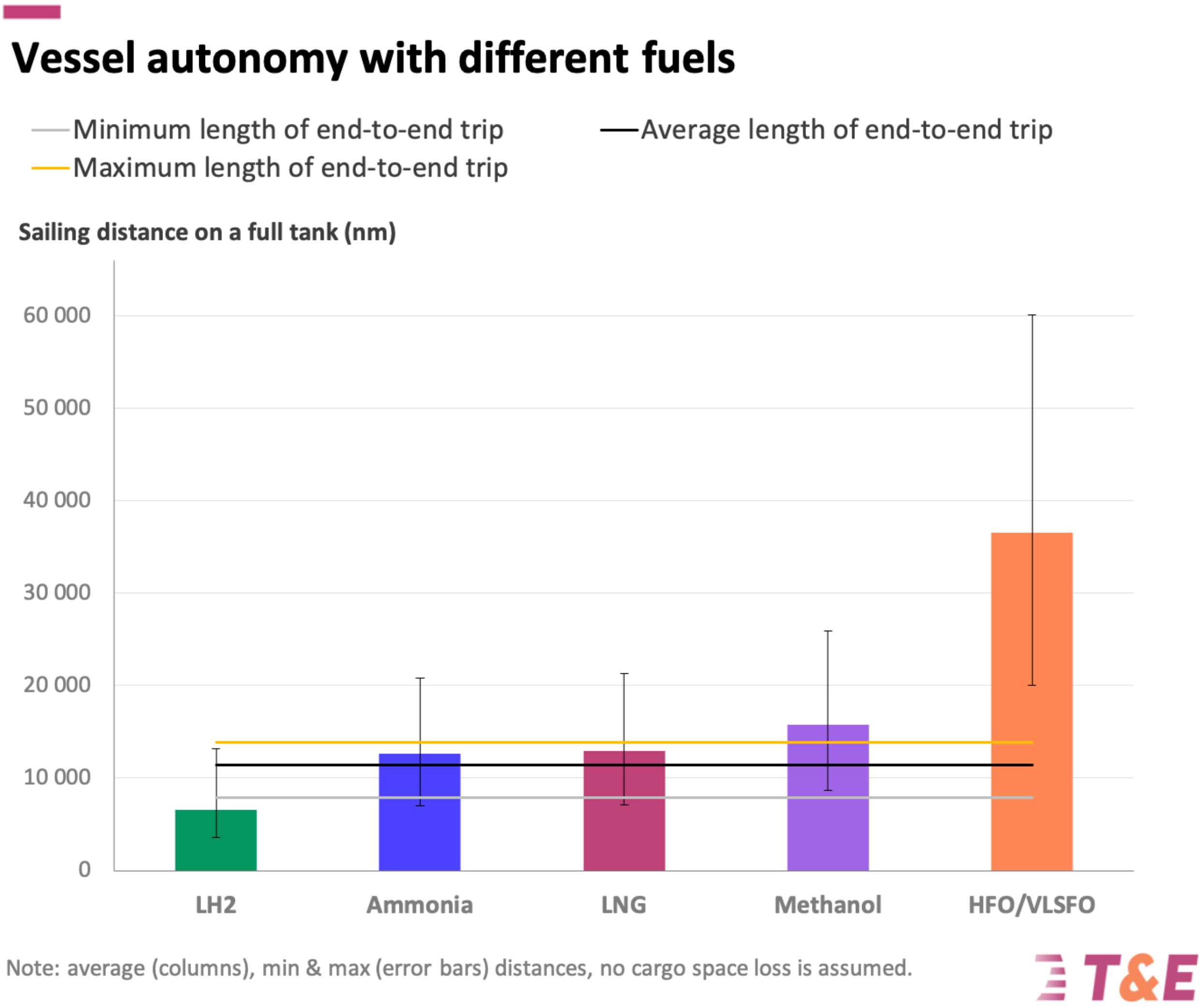


Figure 3 | Simulation of voyage autonomy of existing container vessel designs under different fuel options

It is important to point out that average simulated autonomy provides only a partial picture because the autonomy of existing vessels can vary significantly. For example, current HFO/VLSFO-powered large containerships of 14,500-19,999 TEU size can have autonomy ranging from ~20,000 nm (37,000 km) to ~60,000 nm (111,000 km). Using them as a baseline for simulation, e.g., ammonia-powered similar vessel designs would have an autonomy of between ~7,000 and ~20,000 nm. Vessels on the upper bound of this range could technically cover the longest trips these vessel sizes usually make on the E.Asia - Europe corridor (i.e. ~13,800 nm).

However, there are uncertainties in the strategies that ship operators might choose in dealing with technical autonomy limitations. Also existing bunkering patterns affected by cargo operations, alternative infrastructure availability and green fuel price considerations will probably also play an important role in deciding not only where to bunker but also which vessels to deploy on which routes. For that reason, at this stage, our simulation assumes no re-arrangement of current vessels on different routes and keeps them constant for the purpose of this analysis. This helps to have a better understanding and provides perhaps a more realistic (even if a bit conservative) view of challenges vessel operators might face if they choose one technology over the other. Based on this key assumption, we have simulated 2 main scenarios (Fig. 4):

A. Ships bunker only at the far ends of the Europe - East Asia corridor.
B. Ships bunker only in Morocco and at the Eastern end of the Europe - East Asia corridor.

Explored potential bunkering strategies

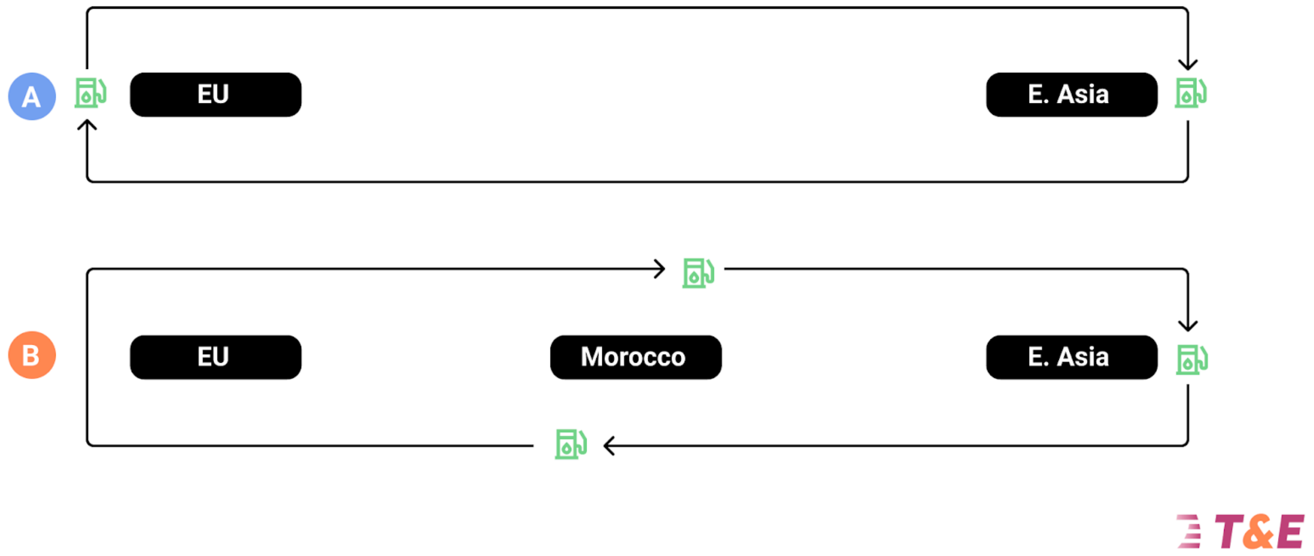


Figure 4 | Potential bunkering strategies explored in this analysis

Fig. 5 provides an example illustration of the concept on a single ship. The analysed vessel (EUROPE with ~8500 TEU capacity) travelled between Bremerhaven in Germany and Xingang in Eastern China in our analysed year (2019), while making a few port calls along the way.

Our baseline simulation (i.e. scenario A) considers only end-to-end bunkering of this vessel in Europe and East Asia. With a high energy density of HFO/VLSFO and actual tank size of the vessel, only HFO and methanol could theoretically provide a full end-to-end trip autonomy without refuelling in the middle, respectively delivering about 247% and 107% of the energy needed on a "single tank". This is even considering an extra 20% fuel margin, which is the industry standard. The autonomy of ammonia and LNG won't be sufficient for such a long trip, unless there is an additional refuelling in Egypt (or elsewhere along the route). This makes a strong technical case for the need of a more frequent bunkering of vessels running on lower energy density fuels.

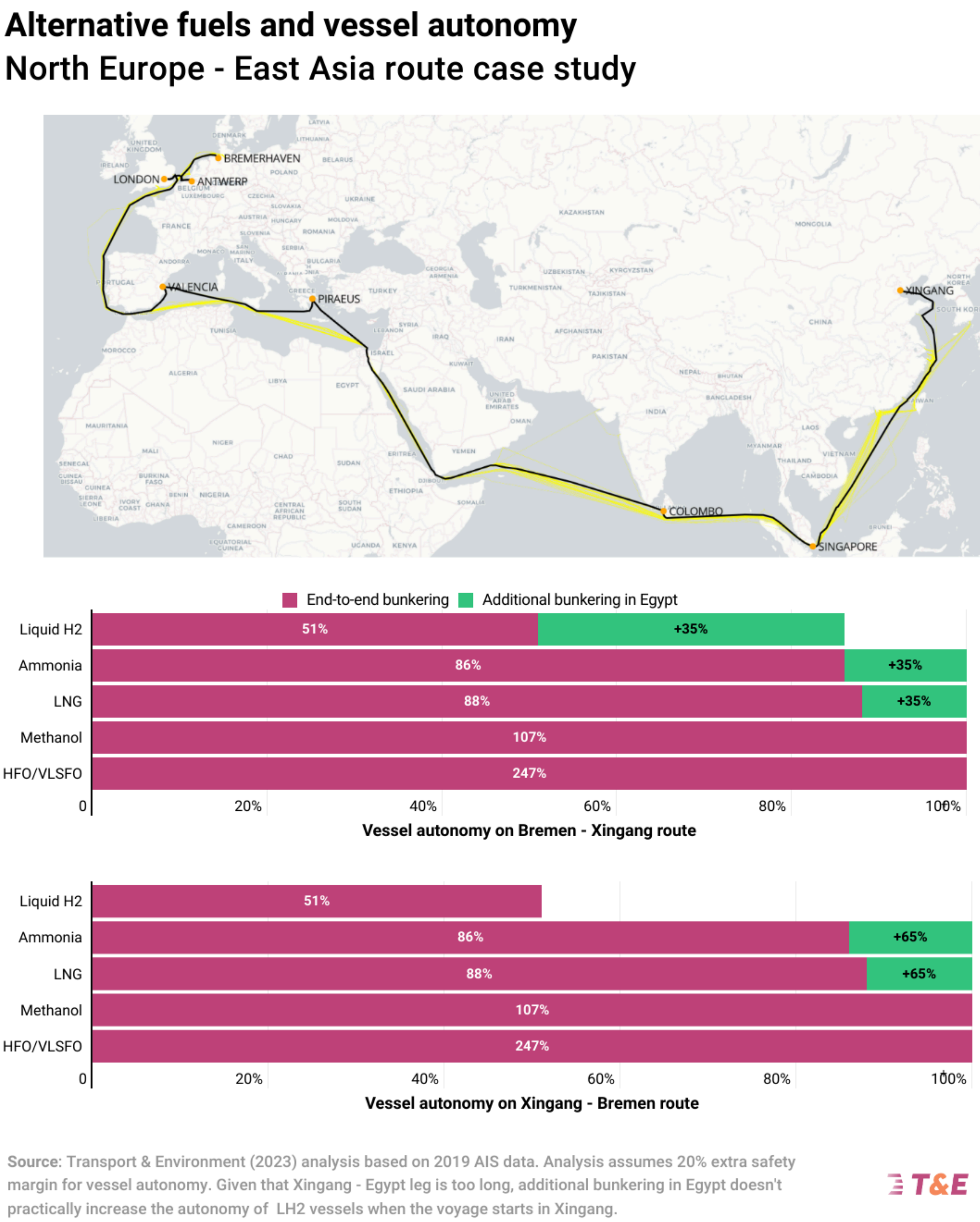


Figure 5 | Example voyage fuel autonomy of a representative ship on Germany-China route

We have simulated how many voyages would these vessels be able to complete if they were to hypothetically run on alternative propulsion systems, specifically liquid hydrogen, ammonia, LNG and methanol. In doing so, we use the same methodology as the ICCT study on liquid hydrogen propulsion on the East Asia - North America corridor and call the ability to complete end-to-end trips, i.e. the "attainment rate". The analysis concentrates on 2348 individual end-to-end trips by container ships with TEU capacity of up to 20 000 + TEU capacity.

Out of 2348 end-to-end trips between Europe and E.Asia (in both directions) in 2019, 1524 crossed the Strait of Gibraltar, which made them directly relevant for Morocco as a potential stopover point. Among these, 576 voyages from East Asia to Europe were directly followed by a return trip in the opposite direction. Together, these 1152 trips form the basis of this analysis.

The baseline simulation, i.e. ships bunkering only in (Western/Northern) Europe and E.Asia shows that the autonomy of alternative marine fuels would be significantly limited without additional/new bunkering along the route. Once baseline was set, we then proceeded to simulate scenario B (as defined in Fig. 4).

The analysis shows that stopping in Morocco for green fuel bunkering is a viable strategy for the majority of ships to reach full voyage autonomy. Even though replacing European bunkering with refuelling in Morocco doesn't allow ships to complete all the trips, it still significantly increases the attainment rates. By bunkering in Morocco (instead of Western/Northern Europe), ships running on ammonia, LNG and methanol would be able to complete 26%, 22% and 8% more trips, respectively (Fig. 6). This would be a significant boost to their operational autonomy even without compromising any on-board cargo space to store more green fuels with inferior energy density. This would also enable them access cheaper green e-fuels than is projected to be available in many parts of Europe.[5] Additional sensitivity analysis shows that switching a mere 2% of cargo space allows all ships doing such trips to complete their voyages if they stop in Morocco (except if they use liquid H2).

It is important to note that in our analysis, the E.Asia to Africa legs of the individual long-distance trips are always the limiting factors as they constitute the longest parts of the total journeys. This speaks to the likelihood of ships continuing to use Singapore as a major bunkering hub on routes between E.Asia and Europe (and on to the US). Analysis of this scenario remains beyond the scope of this report. However, T&E and Imal are in the process of acquiring more detailed global bunkering data (see section 2), which will enable us to perform these types of additional simulations in the future.

[5] This does not imply that bunkering in Morocco is the sole viable strategy or that T&E as an organisation favours bunkering in Morocco over, for instance, Spain. This analysis aims to highlight potential opportunities in the region, with the final outcomes depending on various factors, including the national governments' proactive efforts to prioritise hydrogen as a shipping fuel.

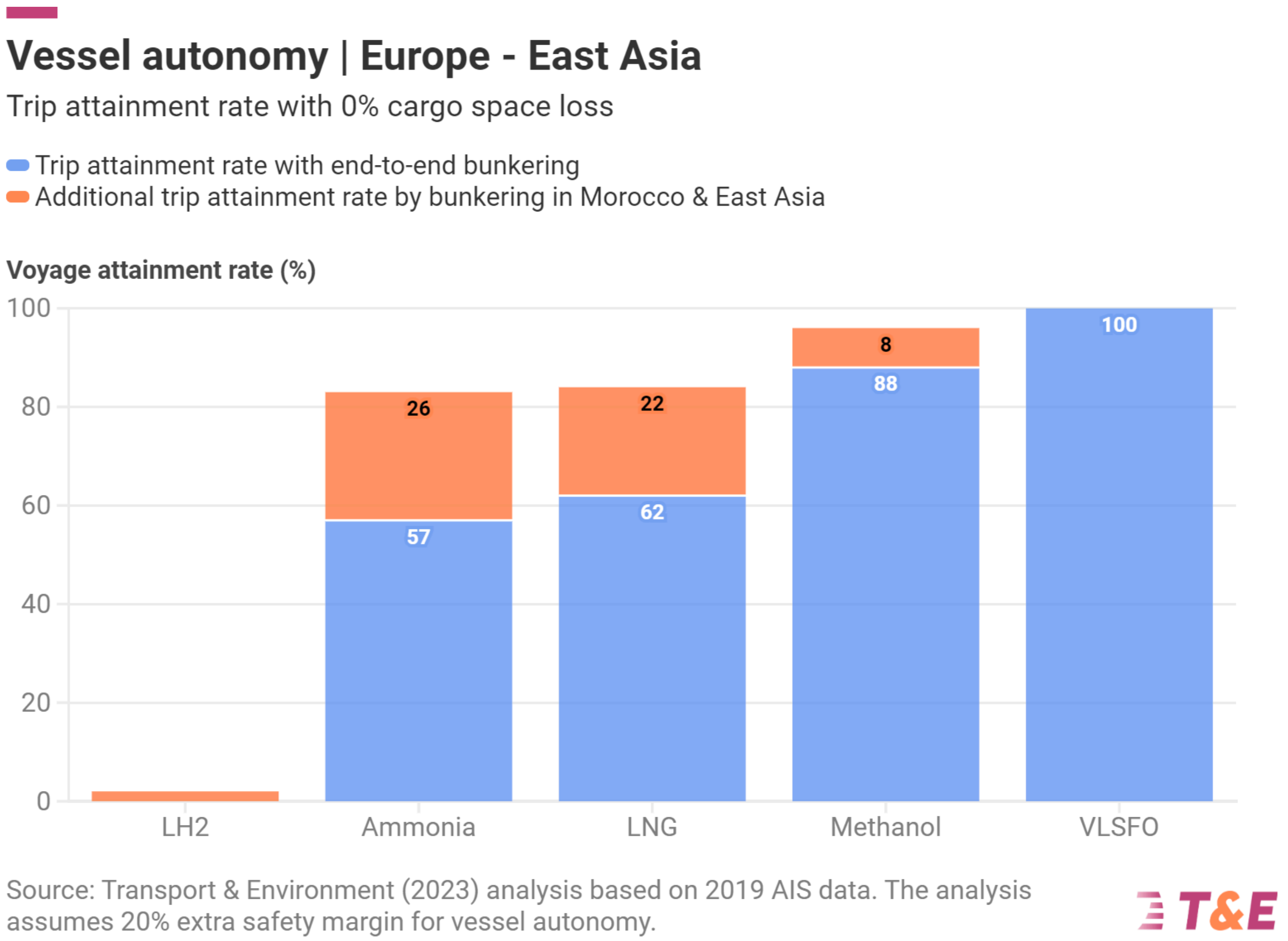


Figure 6 | Attainment rate of different trips under different propulsion options on East Asia - Europe corridor

1.2 Discussion

While this analysis provides some insight into a potential strategy, i.e. substituting European bunkering with refuelling in Morocco as a possible operational strategy to deal with low technical autonomy, there are many other strategies that shipping companies might choose, too.

For example, ships may choose to skip European or East Asian bunkering altogether and bunker only in the MENA region. This could potentially be justified by lower production costs of green hydrogen-based fuels in the MENA region (see sections 4 and 5 below) and the difficulty (or additional costs) associated with transporting low density alternatives fuels over long distances. Potential foregone revenues (i.e. opportunity costs) associated with more frequent bunkering without cargo operation will also be a key consideration for shipowners/operators when deciding where to bunker and how frequently.

Simulation of this and other strategies is beyond the scope of this analysis due to its heavy modelling needs. However, T&E and Imal can in the future explore building a tailor-made optimisation model to analyse this and other alternative strategies for bunkering low-density fuels by ships sailing along the African coast.

In the meantime, however, the current scenarios modelled in this analysis provides good evidence into the technical needs of ships on Europe - E.Asia voyages to bunker more frequently than they might have in the past. In that regard, Morocco is well-positioned to supply (some) of the new green fuels due to their advantageous geographical location on the key shipping routes (see Appendix B for detailed breakdown of estimations in sections 1.1.1. and 1.1.2.).

Section 2

1. Review of the current port/bunkering infrastructure

Accessing historical fuel bunkering data is notoriously difficult because maritime nations do not publish data on marine fuels sold in their ports. Complete data is also not accessible through the UNFCCC national inventories as only developed nations and some Commonwealth of Independent States (for USSR) members appear to be providing international bunkers data (as memo item) in their UNFCCC reports.

Some ports do publish bunkering data, especially, Port of Antwerp, Port of Rotterdam and Port of Singapore. But data is not accessible in other ports/countries. After finalising all the quantitative analysis in this report, we have managed to eventually access marine fuel sales data per country, the breakdown of which can be found in figure 7 below. However, we are not able to re-do our analysis in section 1 with a new baseline. This can be further explored in the future.

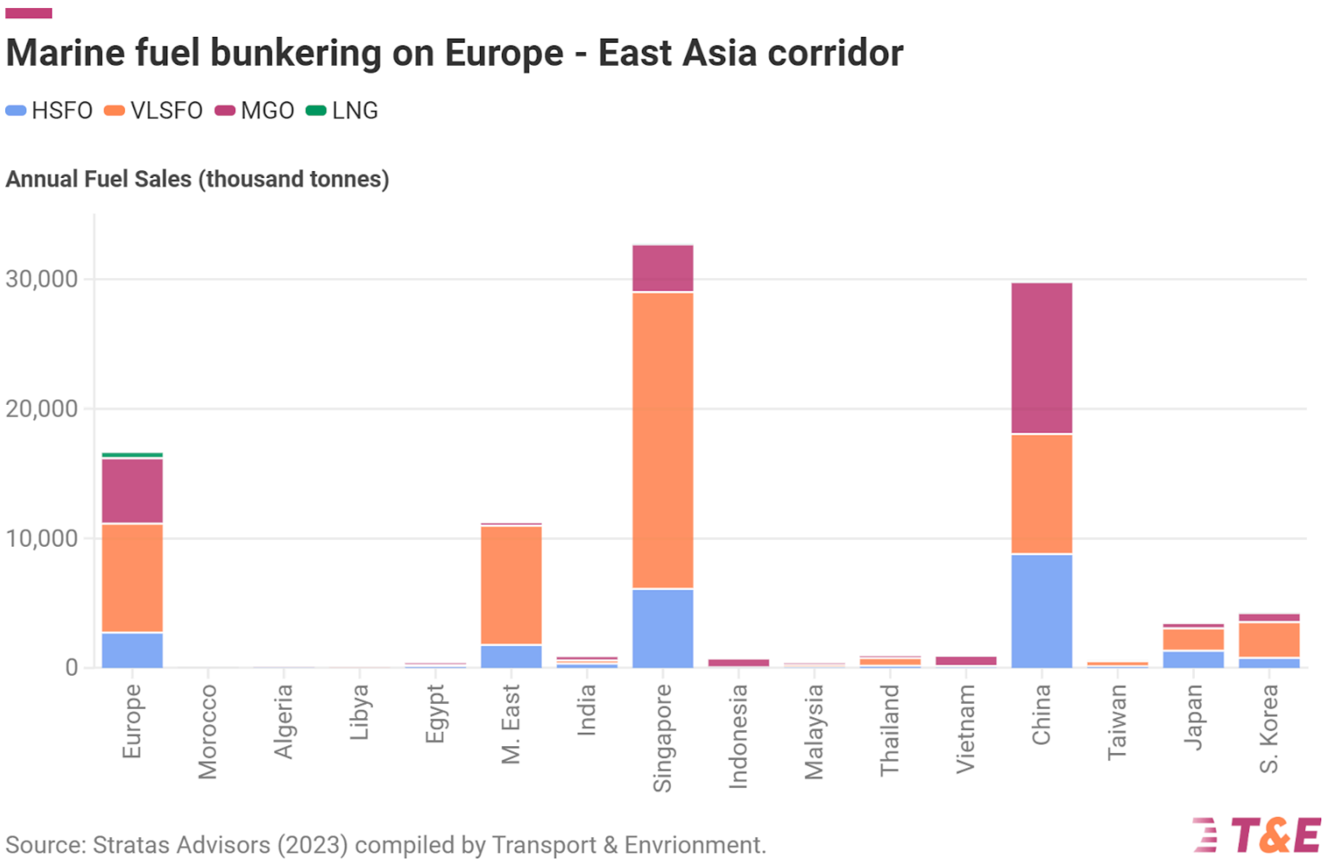


Figure 7 | Marine fuel sales to containerships on East Asia - Europe corridor

1. Review of the political and investment landscape

1.1 Political stability, H2 investor risks and economic policies

Economies in North Africa had traditionally been state-led, but by the 1990s, most countries had moved towards more open market economies. According to OECD, in Morocco, as well as in Tunisia, Jordan and Egypt, this process involved successive waves of reforms that removed important barriers to trade and investment. Both average GDP growth dropped to 1.6% between 2009 and 2011 and foreign direct investments (FDI) FDI plummeted, particularly in countries most affected by political upheavals (Egypt and Tunisia) or conflict (Libya). But instability or uncertainty tends to have a negative spill-over effect on trade and investment in the entire region and is not limited to countries directly affected.

Within the wider legislative framework for investment, a critical issue for foreign investors is the rules governing their market entry and operations. According to OECD, all governments in the MENA region impose some form of legal and/or regulatory restrictions on FDI, often in an effort to protect domestic industries or safeguard national security interests.[6] OECD tracks the openness of countries to investments using their Regulatory Restrictiveness Index (RRI), which is comparable to the World Bank's Doing Business indicator (DBI).

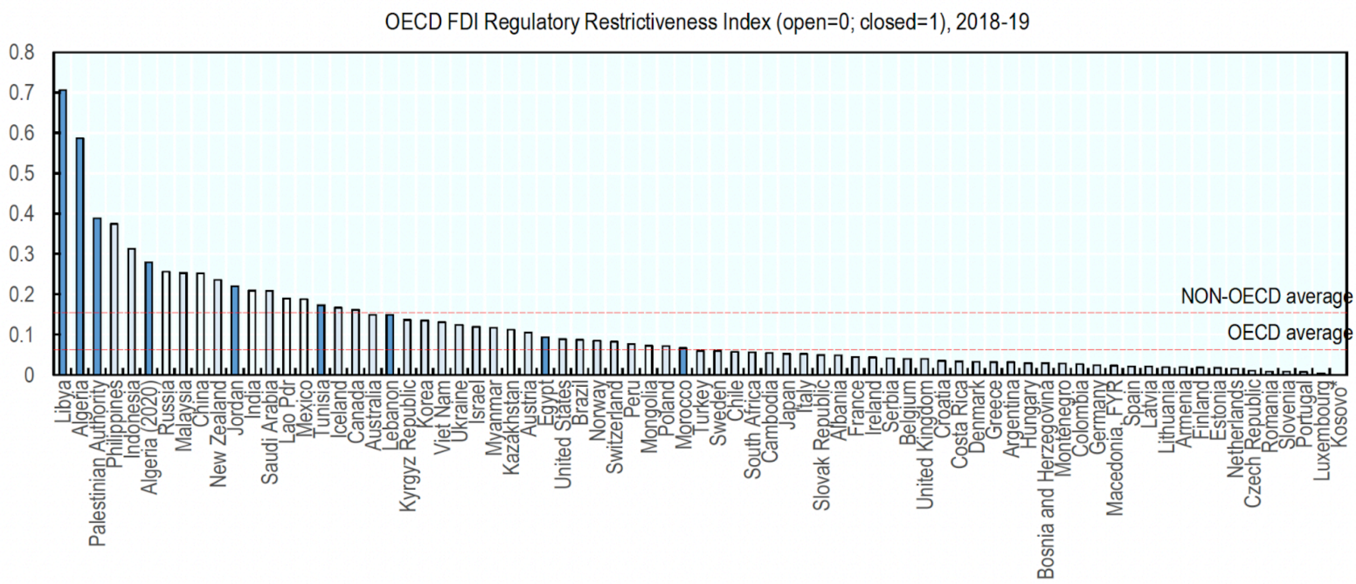


Figure 8 | OECD FDI Regulatory Restrictiveness Index (MENA 2019)

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6 In the opinion of the authors of this report, this does not necessarily mean that countries do not have legitimate reasons to protect domestic industries or safeguard national security interests. In fact similar decisions are taken by many developed OECD countries too; e.g. European countries limiting foreign investments in strategic port assets or higher import duties on clean technologies, e.g. batteries, electric vehicles or solar panels.

Based on statutory FDI restrictions (those explicit in regulations or laws), as of year-end 2019, OECD analyses that Morocco and Egypt are as liberal as OECD countries. Other regional countries, including Algeria and Libya are significantly more restrictive than OECD and non-OECD peers, while Tunisia imposes restrictions on FDIs close to the average non-OECD economy (see Fig. 8). It is essential, however, to stress that these are based on statutory requirements and might not reflect the practical implementation of the laws.

While many green hydrogen projects are in the pipeline in Africa, there is not a lot of investment history into this product. However, similarities and overlaps with renewable energy investments provide insight into the risks and barriers associated with large front-loaded and long-term investment projects. According to IRENA, at the macro level, chief among the risks that investors cite are:

- Political risks, such as political stability and the rule of law,
- Governance and safety issues,
- Off-taker risks, e.g. some power utilities in Africa are not financially sound, and
- Economic risks, including those linked to foreign exchange (incl. large currency fluctuations and currency inconvertibility).

While assessing these risks in detail remains beyond the scope of this analysis, some African countries have taken certain steps in mitigating investor risks.

Most of the regional countries have adopted investment laws, which can also be a way for host governments to signal expectations concerning responsible conduct by imposing certain investor obligations. For these reasons, the investment law is often the first point of reference for a potential investor, and MENA governments have expended considerable resources and political capital to periodically revise and update their investment laws. A common feature across MENA jurisdictions is the prominence of unified investment legislation, also called “omnibus investment laws”, framing both foreign and domestic investment under the same core provisions, underlined by a general principle of non-discrimination.

Morocco’s Investment Charter which treats domestic and foreign investors equally includes incentives when investing in strategic sectors such as renewable energy projects. The initiative encompasses subsidies and grants programmes that could cover up to 30% of investments (capped at 3 million dollars for renewable energy projects).[7] The initiative also contains a guarantee of free transfer of funds and gives foreign investors the freedom to transfer profits and capital. To further provide guidance and political clarity for investors, Morocco also developed a national Hydrogen Strategy over the past 3 years, which among others, set targets for H2 deployment in the coming decades.

Morocco has several “free zones” offering companies incentives such as tax breaks, subsidies, and reduced customs duties. These zones aim to attract investment by companies seeking to export products from Morocco. The government offers a VAT exemption for investors using and importing equipment goods, materials, and tools needed to achieve investment projects whose value is at least $20 million.

[7] AMDIE (2022). La Charte de l’investissement - un cadre transparent et lisible pour encourager l’acte d'investir. (Link).

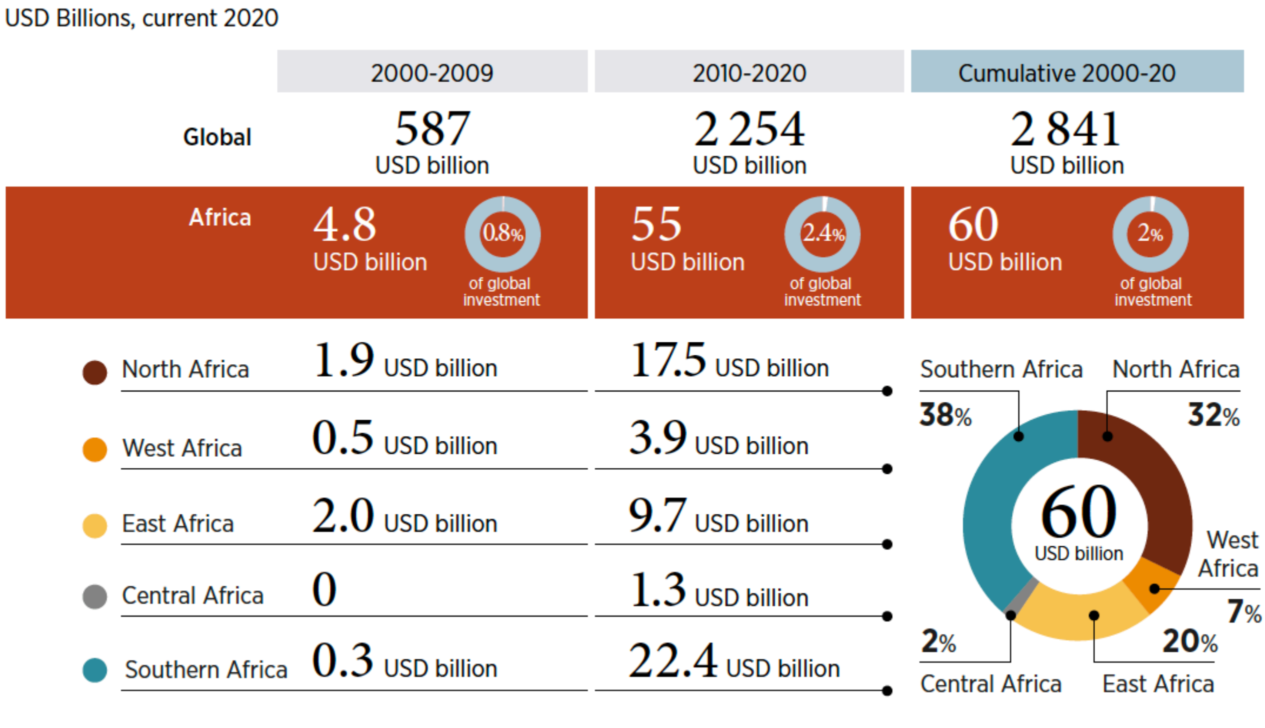
Since 2014, Morocco has lifted most subsidies for fossil fuels, although the government reinstituted a diesel fuel subsidy for transportation providers in 2022. While Morocco currently does not offer decarbonisation incentives, Morocco's Low Carbon Strategy 2050, submitted at the end of 2021 to the United Nations, calls for the establishment of a carbon tax system and incentive tools to support Morocco's decarbonation transition.

1.2 Investment landscape

Africa received $109 billion in investments between 2000 and 2020, most of which is public financing. The largest investments came from China (51% of the total), the International Bank for Reconstruction and Development (14%) and the Islamic Development Bank. Around $60 billion of the total investment was in renewable energy (Fig. 9).

Most of these investments tend to go to economies with relatively advanced green policies, regulatory and investment frameworks and sound macroeconomic conditions. The top five recipients – South Africa, Egypt, Nigeria, Morocco and Kenya – receive more than half of all renewable investments.

North Africa received the second largest investments in renewable energy in Africa, just behind Southern Africa. Cumulative investments between 2000-2020 reached $19.4 billion, most of it coming in the last decade. Most of these investments concentrated in Morocco (USD 9.5 billion) and Egypt (USD 8.2 billion).



Source: BNEF (2021c).
Note: BNEF data exclude investments in large hydropower (i.e. greater than 50 megawatts).

Figure 9 | Overall renewable energy investment in Africa (2000-2020), IRENA, 2022

In terms of financing instruments, debt continues to be the most favoured public financing instrument across Africa. It made up 88% of all public financing in 2010-2020, followed by grants, at 10%.

Share of renewables has been steadily increasing among energy investments in the past few years, mostly concentrated in solar (PV and thermal) (67.5%) and wind (32%), with the remainder going to bioenergy and small hydropower.

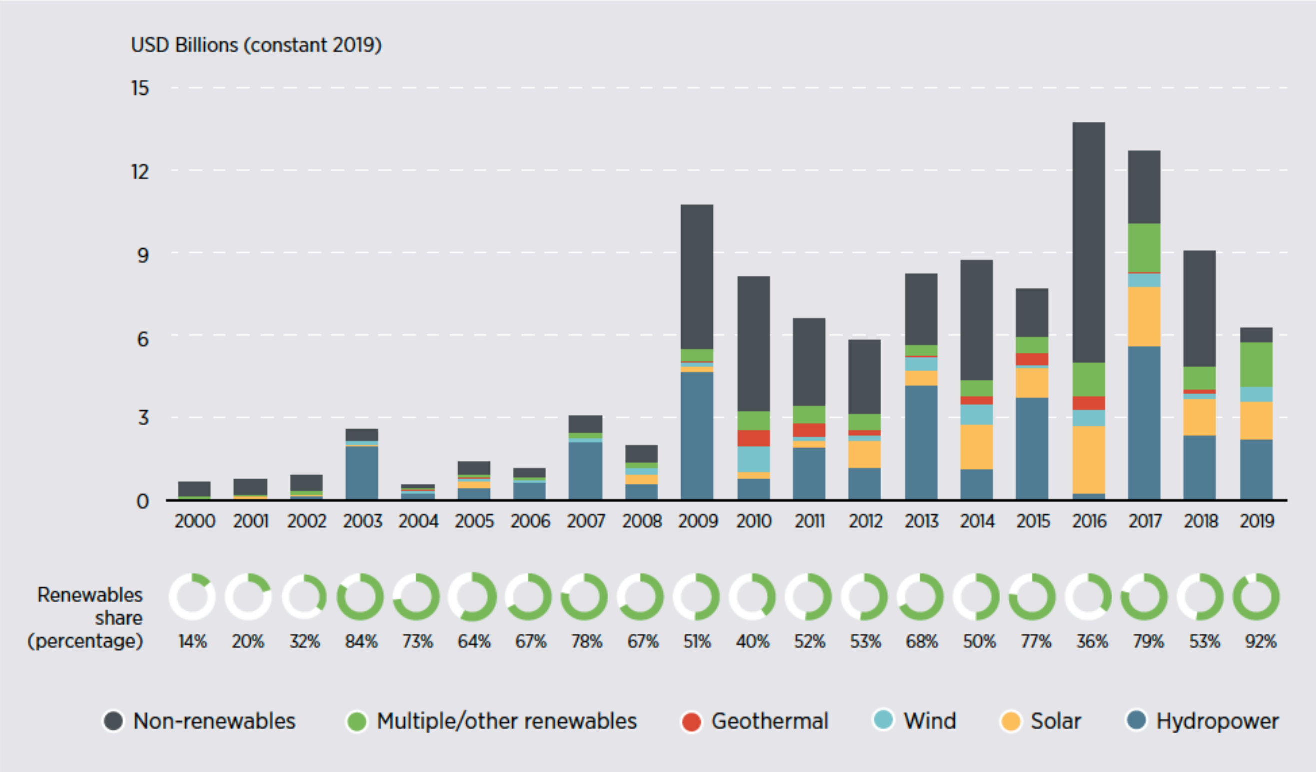


Figure 10 | Breakdown of energy investment in Africa (2000-2020), IRENA, 2022

Section 4

1. Review of the renewable potential and local needs

North Africa is one of the regions in the world best endowed with scalable renewable energy, especially solar and wind. The region's annual average solar irradiation is very high, at around 2,200 kilowatt hours per square metre, while wind speeds average a high 7 metres per second.

Assuming a land-utilisation factor of 1% for solar and wind, IRENA estimates the technical installable capacities at 2,792 gigawatts (GW) for solar and 223 GW for wind.

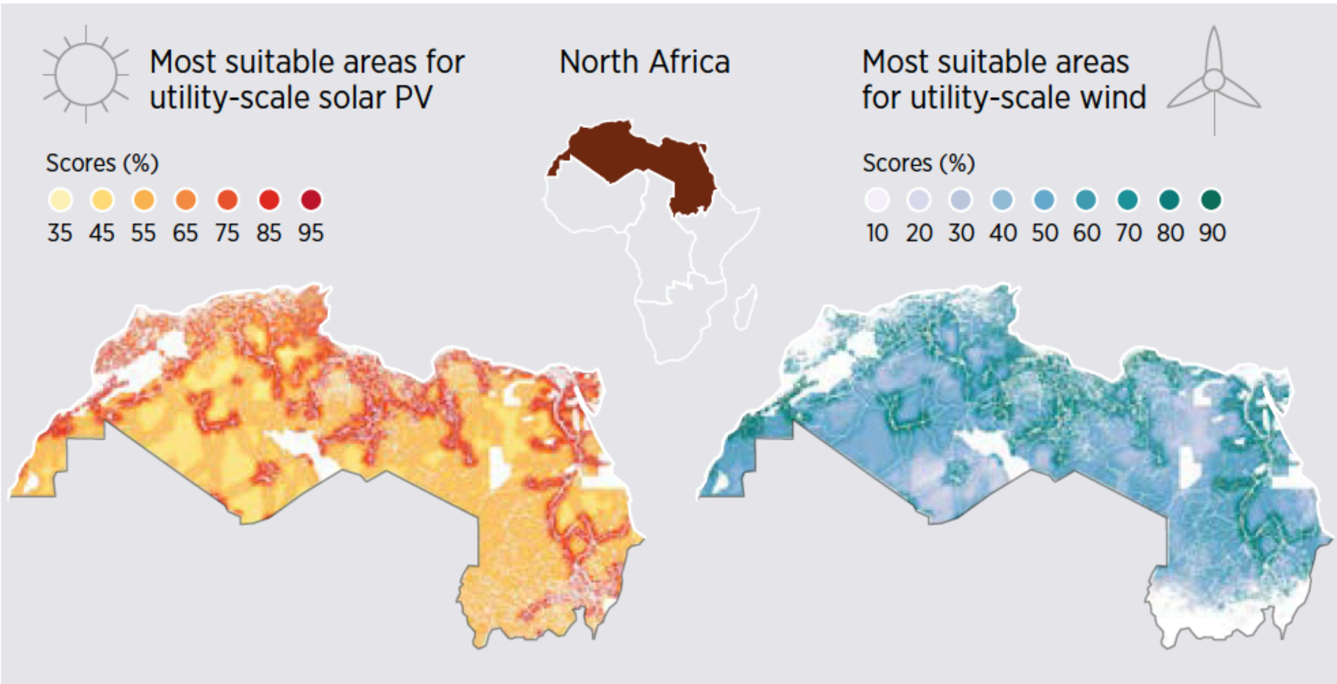


Figure 11 | Solar and wind resources in North Africa (IRENA, 2022)

Tapping into these resources in a cost-effective manner can provide sustainable and scalable energy for the Europe-Asia shipping corridor, but also create huge economic benefits for the region. In doing so, it is essential to bear in mind that N. African countries still need to decarbonise their domestic economy as most countries still rely on fossil fuels to power their grid.

Among the six North African countries, only Morocco, along with Sudan, have a considerable penetration of renewables to their grid. Close to 40% of Morocco's energy capacity is derived from renewables (solar, wind and hydro), while for Egypt this figure stands at only around 15% (Fig. 12).

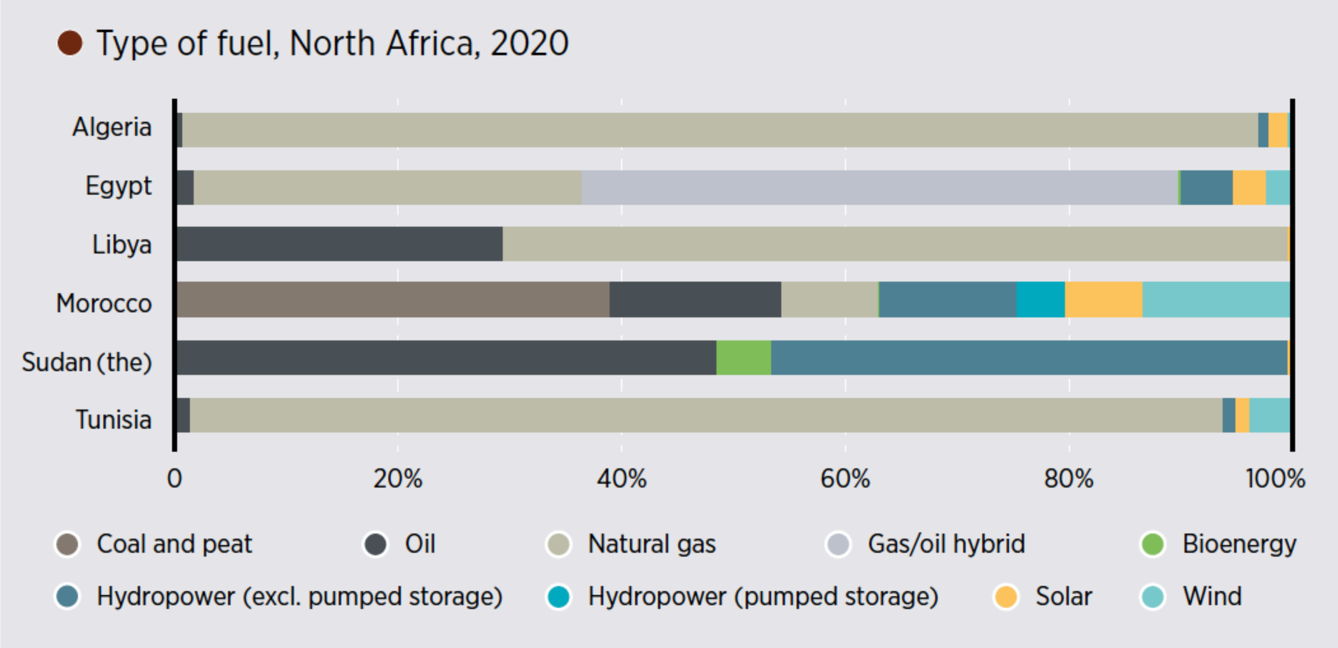


Figure 12 | Electricity grid mix of North African countries (IRENA, 2022)

This raises a legitimate question: if (European) shipping taps into African renewable energy before the local economies had a chance to decarbonise, would it place an unnecessary burden/hurdle on these countries? Some civil society organisations have called for caution raising concerns over possible neo-colonialism.

While this debate is important to avoid repeating historical mistakes, sound policy designs could help mitigate some of these concerns in practical terms. It is important to note that given the magnitude of Africa's renewable potential, it is not the physical limitations of solar and wind power that raises the concern. Africa has in theory enough sustainable energy to decarbonise its economies many times over. While relatively limited compared to the size of the exporting countries, such projects could have high impacts on local ecosystems and compete with current land uses.

We would argue that the competition is rather on the access to land, water and financial resources. Despite new solar and wind installations becoming increasingly cheaper than fossil alternatives, about 570 million of Africa's 1.3 billion population still doesn't have access to electricity; and countries that do have 100% electricity coverage still require significant new investments to roll out renewable energy and upgrade their grids. Therefore, it is essential to avoid European shipping competing with local populations over public financing for green H2(-based fuels) production in African countries.

The good news is that Europe has already developed sustainability and additionality rules for green H2-based fuels, a.k.a. renewable fuels of non-biological origin (RFNBOs). These rules ensure that RFNBOs deliver at least 70% WtW emissions reductions, are additional to the needs of the general economy and the source of electricity is traceable thanks to the required temporal and geographical correlations between green H2 and renewable electricity productions. Importantly, the EU rules require that renewable electricity to be used by H2 producers "*does not receive financial support*", which will ensure that H2/RFNBO production does not compete with local electricity grid for renewable subsidies.

The benefit of these rules is that they apply not only RFNBOs produced on European soil, but also those imported from third countries, as well as those bunkered by ships elsewhere and used on voyages to and from Europe. The latter means that if a shipping company wants to bunker green e-ammonia or e-methanol in Egypt and use that fuel in order to comply with the newly adopted EU shipping laws (ETS and FuelEU Maritime), these fuels will need to comply with the EU's RFNBO rules in order to be eligible. Otherwise, they will be considered as high emitting as their fossil equivalents (i.e. grey ammonia and grey methanol) despite being considerably more expensive. Stringent verification and implementation of this rule will be of key importance and needs to be prioritised by the EU and the future global IMO certification schemes.

Despite the climate and additionality rules around the production of RFNBOs, the EU doesn't require respect of human rights and the Free Prior and Informed Consent (FPIC) of local communities to ensure there is real public acceptance of these projects in the country of production. And the rules do not cover crucial environmental impacts such as land use, water use or impacts on biodiversity. These will need to be taken into account if we want to ensure that RFNBO production in these countries do not create more damages. It is also essential that EU certification rules are properly enforced in Africa in order to ensure their positive effect. However, given the less than ideal implementation of the EU certification rules in relation to biofuels production in third countries, especially in South East Asia and Latin America, vigilance is warranted for H2 certification, too.

As a minimum, we thus recommend to respect the principle of Free, Prior & Informed Consent from local population and Indigenous Peoples and to ensure a real benefit for local populations by creating synergies with local grid decarbonisation and energy access.[8]

[8] More details and recommendations are available in a T&E briefing. (Link).

Section 5

1. Review of the current and planned H2 projects

Morocco has big ambitions to become an African green hydrogen hub and its strategic geographical proximity to Europe further enhances its export potential. Country's Green Hydrogen Production Plan, initiated in 2020, aims to establish 4GW of green hydrogen capacity by 2030.

The strategy strongly supports the local production of ammonia, an industry where Morocco has so far relied on imported ammonia to meet its agricultural needs.

The country aims to produce 0.67 Mt/year of hydrogen by 2030, with 0.22 Mt/year to be exported to the EU. However, the current announced projects only amount to 0.05 Mt/year showing a significant deficit between announcements and progress (Fig. 13).[9]

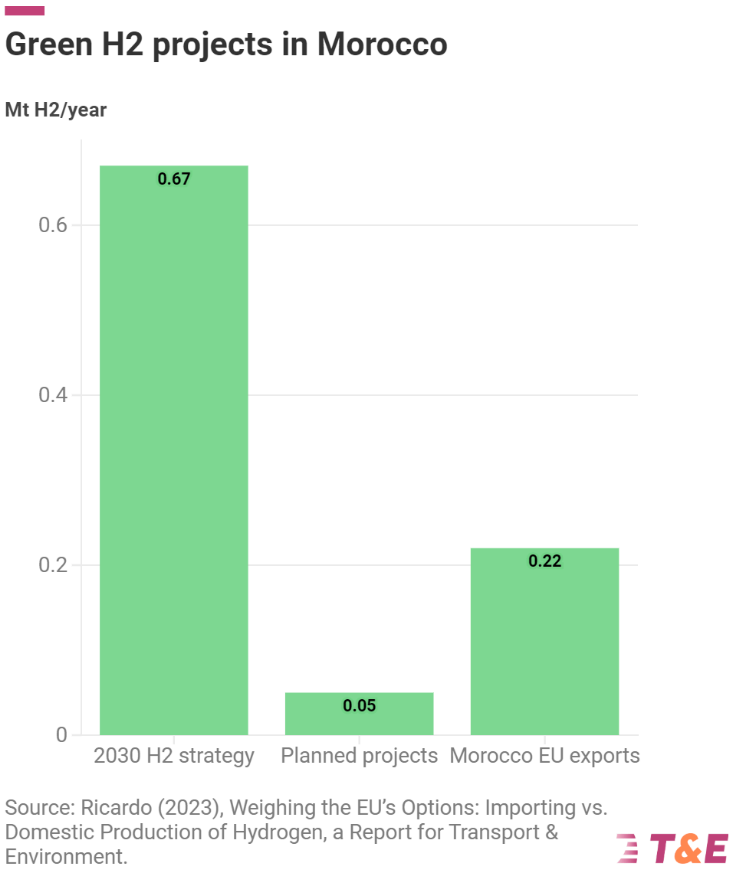


Figure 13 | Green H2 strategy target (2030) and planned projects

The hydrogen strategy considers 3 phases of development:[10]

- 2020-2030: The short term considers the local use as a raw material and exports to targeted countries. The development is based on pilot projects using government and international financial support. The government expects higher costs of production during this phase.
- 2030-2040: The medium-term explores the opportunities to reduce production costs and local usage of green hydrogen in the electricity sector.

[9] Ricardo (2023). Weighing the EU's Options: Importing vs. Domestic Production of Hydrogen, a Report for Transport & Environment (Link)
[10] Green Hydrogen Organisation (2022). Green hydrogen vision. (Link).

- 2040-2050: In the long term, the roadmap is aiming to improve the business case for green hydrogen at the world level. It includes expansion of usage to the heat production sector for residential and urban mobility usage, including heavy vehicles and aviation.

Hydrogen exports to the EU can be done both by pipelines (e.g. refurbished Maghreb gas pipeline)[11] or by ships (most likely in the form of H2 derivatives).

In 2023, Morocco's state-owned chemical company OCP announced an investment of USD 7 billion in an ammonia plant that uses renewable-based hydrogen.[12] The plant will start producing 200,000 metric tons of ammonia annually by 2026. It will increase that output to 1 million metric tons by 2027 and 3 million by 2032.[13]

Furthermore, the Moroccan government signed within the German Moroccan Energy Partnership (PARMA) an active partnership to advance green hydrogen, and is developing a roadmap for 2050 to develop the green industry in Morocco. In June 2020, the Germany-Morocco Hydrogen Agreement was signed in Berlin for the joint development of the production of green hydrogen for its use in Morocco and Germany. An investment of €300 million has already been pledged, allowing Germany to source green hydrogen from Morocco in the future.[14]

Total Energies is also targeting to set up a plant with a green hydrogen and ammonia production capacity of 10 GW of solar and wind electricity in the Guelmim-Oued Noun of Morocco starting 2027. Total Energies plans to invest $10.69 billion (about €9.4 billion) in this project with an active phase starting in 2025 and first production by 2027 despite some concerns that the government might not be fully committed to the idea.[15]

1.1 Carbon feedstock for e-fuels

According to the IEA hydrogen database, Morocco does not have any announced carbon-containing e-fuel projects. But some companies are already exploring the possibility thereof, especially for e-methanol and e-kerosene, both requiring a carbon feedstock.

Morocco is a significant emitter of GHG with over 66 Mt CO2e in 2020, the majority of which comes from the power sector still largely reliant on oil and coal. The main industry in Morocco produces phosphate and involves both the mining of phosphate rock and its processing. These activities are not typically large emitters, which indicates low potential for capturing industrial emissions for use as carbon feedstock. Also, given the timeline and sustainability restrictions on fossil CO2 source under the EU legislation, it is unlikely that these CO2 can be used for green e-fuel production eligible for shipping under the EU law.

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[11] Morocco World News (2023). Spain, Italy, Morocco Partner on Green Hydrogen Export Venture. (Link).
[12] Atalayar (2023). OCP and Morocco commit to renewable energies. (Link).
[13] Global Business Outlook (2023). Go Green with GBO: Morocco's OCP to invest USD 7 Billion in an ammonia factory. (Link).
[14] Green Hydrogen Organisation (2022). Green hydrogen vision. (Link).
[15] H2 Energy News (2023). Total Energies Invests in Large Wind and Solar Project in Morocco. (Link).

Morocco has opportunities for biogenic carbon sources with a remarkably high potential for use of biomass such as sugar cane and other agricultural waste or wood chips. Currently biofuels and waste biomass contribute to 6% in the total energy mix. So, combination of direct air capture with (limited) biogenic CO2 may work to provide a sustainable source for e-fuel production in the country.[16]

1.2 Impact on the scarcity of water resources

About 80% to 95% of water resources in Morocco are directed toward agriculture with approximately 40% of this deriving from groundwater sources. The country has a fresh water deficit and climate change induced warming is predicted to intensify this deficit further. Contamination is an additional stressor to the nation's groundwater, due to seawater intrusion and nitrate pollution from fertilisers and sewage. Lastly, water resource availability across Morocco is coming under pressure due to the pressure created on such systems from expanding populations and corresponding economic development.[17]

This puts the emphasis on the need for the development of seawater desalination plants, which some studies have concluded that the impact on the final cost of green hydrogen might be negligible (representing 0.12%-0.35% of the net present costs).[18] Morocco plans to build 8 new desalination plants in total powered by renewables, adding to an existing 12 that operate on fossil fuels. It aims to produce 1.3 billion cubic metres of fresh water from desalination by 2035.[19]

Supply Scenario	**Km^2 required**		**Water Required Mt/y**
100% Solar + Electrolysis plant	162.22	Equivalent to 15,020 football fields	4.4-6.6
100% Wind + Electrolysis plant	1116.37	Equivalent to 103,368 football fields	

[16] Ricardo (2023). Weighing the EU's Options: Importing vs. Domestic Production of Hydrogen, a Report for Transport & Environment. (Link)
[17] Ricardo (2023). Weighing the EU's Options: Importing vs. Domestic Production of Hydrogen, a Report for Transport & Environment. (Link)
[18] Ourya, I. et al. (2023). *Assessment of green hydrogen production in Morocco, using hybrid renewable sources (PV and wind)*, International Journal of Hydrogen Energy, ISSN 0360-3199. (Link).
[19] Morocco to launch tender for 250 mln cubic metre desalination plant - Minister, Reuters, 12 October 2023. (Link).

Figure 14 | Land and water requirement for planned projects assuming solar and wind energy supply[20]

Using saltwater with desalination as an alternative to fresh water may pose financial and environmental challenges for hydrogen projects. If brine from desalination is disposed into the ocean it may pose risks to aquatic life due to high salt concentrations. It is heavier than seawater if undiluted and it tends to settle towards the bottom suffocating animals on the seafloor. Although plants can use strategies to minimise these impacts such as disposing brine where strong currents help to disperse it or mixing brine into the ocean with multiple waste outlets.[21]

1.3 EU export potential

In order to contribute to internal deliberations on the potential and desirability of green H2(-based fuels) imports from third countries, T&E commissioned a study with Ricardo (2023), which has been quoted extensively throughout section 5 in this report. The Ricardo study analysed 6 potential non-EU countries, specifically, Chile, Namibia, Norway, Egypt, Morocco and Oman. The selection of these countries was made with the needs of the current project (i.e. green shipping corridors) in mind as well.

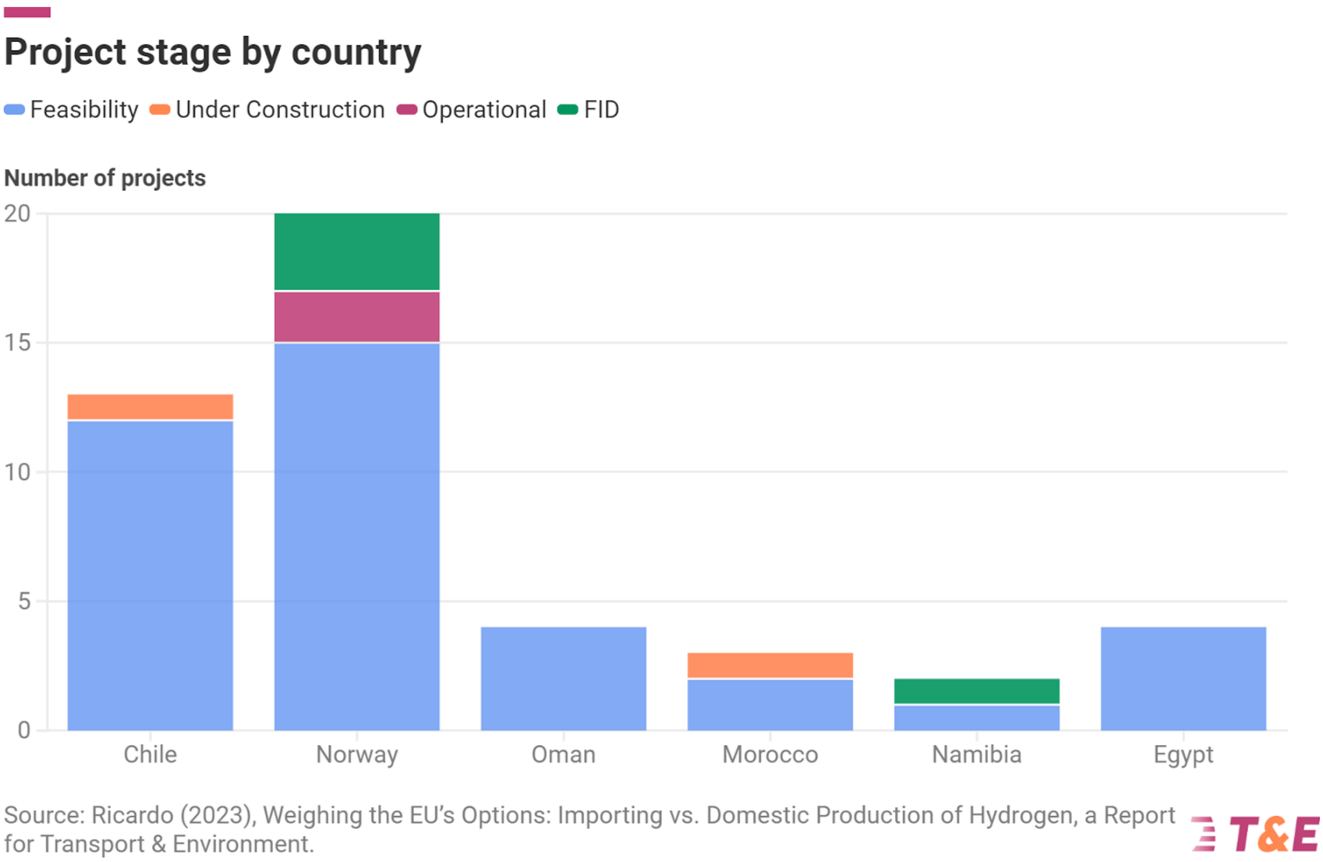

Figure 15 | Volume of projects at various stages in each country

[20] Ricardo (2023). Weighing the EU's Options: Importing vs. Domestic Production of Hydrogen, a Report for Transport & Environment. (Link).

[21] Scientific American (2019). Slaking the World's Thirst with Seawater Dumps Toxic Brine in Oceans. (Link).

According to the Ricardo study, among the 6 countries analysed, the three countries with the largest national hydrogen strategies are Chile, Namibia, and Oman. When considering planned projects, the three countries with the largest cumulative production are Chile, Oman, and Norway. Lastly, the countries with the largest anticipated exports to the EU are Chile, Oman, and Namibia. Based on production capacity for EU export, the most promising export nations appear to be Chile, Oman, Namibia and Norway.[22] From the identified projects, over 80% were at the feasibility stage.

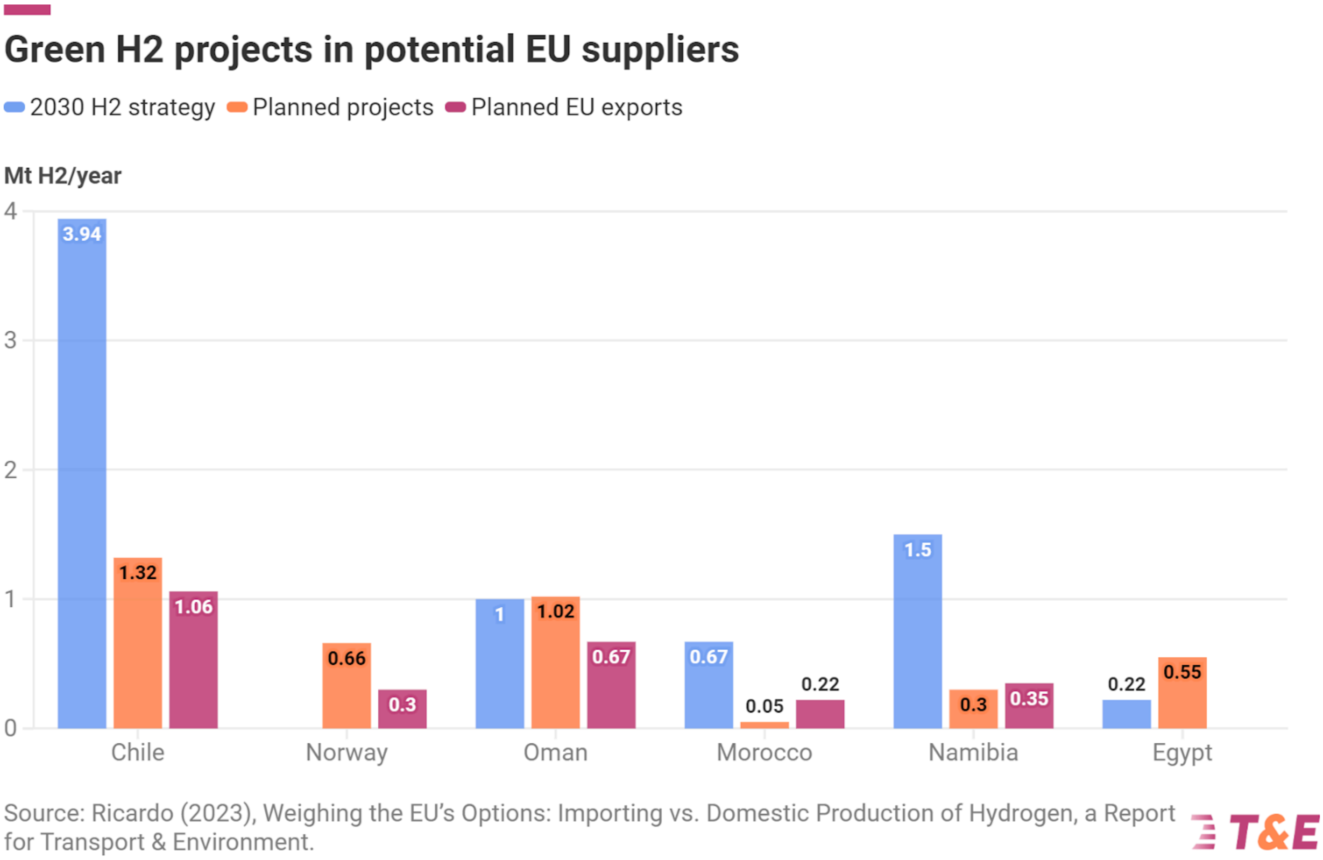

Figure 16 | Volume of projects at various stages in each of the chosen countries[23]

Figure 16 shows that a potential 2.61 Mt/year of hydrogen could be exported to the EU for the 6 countries discussed, which is significantly below the 10 Mt/year ambition which the EU's REPowerEU strategy aims to achieve by 2030.[24] It is possible/likely that other exporting countries in North Africa, North America, the Middle East, and Sub-Saharan Africa will contribute to deliver the remaining amount. Other projects may reach FID, increasing the potential supply to the EU, though this is uncertain and some projects will undoubtedly fail to reach the production stage. REPowerEU does not specify which specific sectors should be using imported green H2(-based fuels), which leaves the possibility for the maritime (and aviation) sector(s) to be significant (despite not a majority) users of this energy.

[22] Ricardo (2023). Weighing the EU's Options: Importing vs. Domestic Production of Hydrogen, a Report for Transport & Environment. (Link).
[23] Ricardo (2023). Weighing the EU's Options: Importing vs. Domestic Production of Hydrogen, a Report for Transport & Environment. (Link).
[24] The EU's RePowerEU strategy, adopted in 2022 following the Russian invasion of Ukraine, aims to increase the consumption of green hydrogen in Europe with 10Mt being locally produced and 10Mt imported.

Conclusions

This analysis showed that bunkering ships with green H2(-based) fuels on the East Asia - Europe shipping corridor could help improve their autonomy, which would otherwise be significantly constrained by the low (volumetric) energy density of alternative marine fuels.

While this analysis provides some insight only into 1 potential strategy, substituting European bunkering with refuelling in Morocco for end-to-end Europe-E. Asia journeys, there are many other strategies that shipping companies might choose to deal with inferior technical autonomies that alternative green fuels provide.

For example, ships may choose to skip European or East Asian bunkering altogether and bunker only in the MENA region. This could potentially be justified by lower production costs of green hydrogen-based fuels in the MENA region and the difficulty (or additional costs) associated with transporting low density alternatives fuels over long distances. Potential foregone revenues (i.e. opportunity costs) associated with more frequent bunkering without cargo operation will also be a key consideration for shipowners/operators when deciding where to bunker and how frequently. Simulation of this and other strategies is beyond the scope of this analysis due to its heavy modelling needs, which can be explored in the future .

A high-level desk research also concluded that Morocco is currently viewed as a prime location for the production of green H2. The country appears to be well advanced in terms of implementing market reforms to attract foreign investments. Morocco has also set up an ambitious national hydrogen strategy and plans to export locally produced hydrogen to the EU and world markets.

There are considerable concerns about the impact of the hydrogen economy on the local environment, access to scarce water resources and potential competition for domestic grid decarbonisation. While European renewable energy legislation provides some safeguards for the additionality of renewables investment for hydrogen production (including vis-à-vis imports from Africa or elsewhere), prudence is warranted not least to ensure that European sustainability rules are upheld. Morocco has a significant coastline, which makes it suitable for the development of water desalination plants for hydrogen electrolysis and avoiding competition with land-based fresh water. However, extra efforts will need to be made to ensure that salt brine from the desalination process is well disposed of in order to reduce the impact on marine biodiversity and coastal ecosystems.

Finally, it will also be key to promote viable sustainable standards at the IMO level. This could be achieved via the GFS which will be essential to generate a greater demand for green hydrogen-based fuels shipping, but also ensure that their climate advantages are clearly delimited.

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12. UNCTAD (2022). Review of maritime transport 2022. (Link).

13. Scientific American (2019). Slaking the World's Thirst with Seawater Dumps Toxic Brine in Oceans. (Link).

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Appendix A - Methodology

A.1. Ship fuel consumption calculation and voyage allocation

We analysed containerships of more than 5000 GT which stopped in at least one of the European countries that were part of EU's Monitoring, Reporting and Verification (MRV) system in 2019. We followed the bottom-up methodology presented at p.40 of the Fourth IMO Greenhouse Gas (GHG) study[25] to calculate ship fuel consumption using automatic identification system (AIS) data. AIS messages are sent by ships at regular intervals during their operation and contain information such as timestamp, geographical position, speed over ground (SOG) and draught of the vessel. The AIS data was obtained from ExactEarth, pre-treated by UMAS and the ICCT, and provided to T&E. We purchased ship technical specifications from IHS Markit and Clarksons and pre-processed them to fill in the data gaps. We then followed the following steps:

- Detection of port stops
- Assignment of operational phases
- Allocation of voyages to trips touching European ports
- Calculation of hourly vessel energy consumption and emissions.

As explained above, **voyage** is legal terminology used by EU legislations, which denotes any journey between 2 ports of call where vessels carry out cargo or passenger operations regardless whether or not refuelling/resupplying actions take place.

A.2 Identification of end-to-end trips

To analyse the establishment of green corridors, we wrote an algorithm to extract from the list of voyages all **end-to-end** trips between Europe and three East-Asia (i.e. China, Japan and South Korea). End-to-end trips are defined as journeys between a port in Europe and a port in East-Asia, which represent the furthest extremes of the travel before the vessel turns around and sails in the opposite direction. For example, for a vessel starting off from Bremenhaven and selling towards Asia, calling at multiple European, African and Asian ports along the way before reaching Xingang in China, Germany-China would constitute a single end-to-end trip. A few trips were filtered out from the database because the AIS was of insufficient quality, leading to

[25] Faber, J., Kleijn, A., Hanayama, S., Zhang, S., Pereda, P., Comer, B., … Xing, H. (2020). *Fourth IMO Greenhouse Gas Study*. Retrieved from https://docs.imo.org/Shared/Download.aspx?did=125134

incorrect trip distances for example. We calculated trip distance, trip duration, ship energy output and fuel consumption for each trip.

A.3. Calculation of metrics for different fuel bunkering strategies

For the bunkering scenarios, we calculated metrics (trip distance, trip duration, ship energy output and fuel consumption) for each leg using AIS to determine when the ship passed by Morocco. We assumed an extra 50 nm distance to sail in order to reach Tangier Med port.

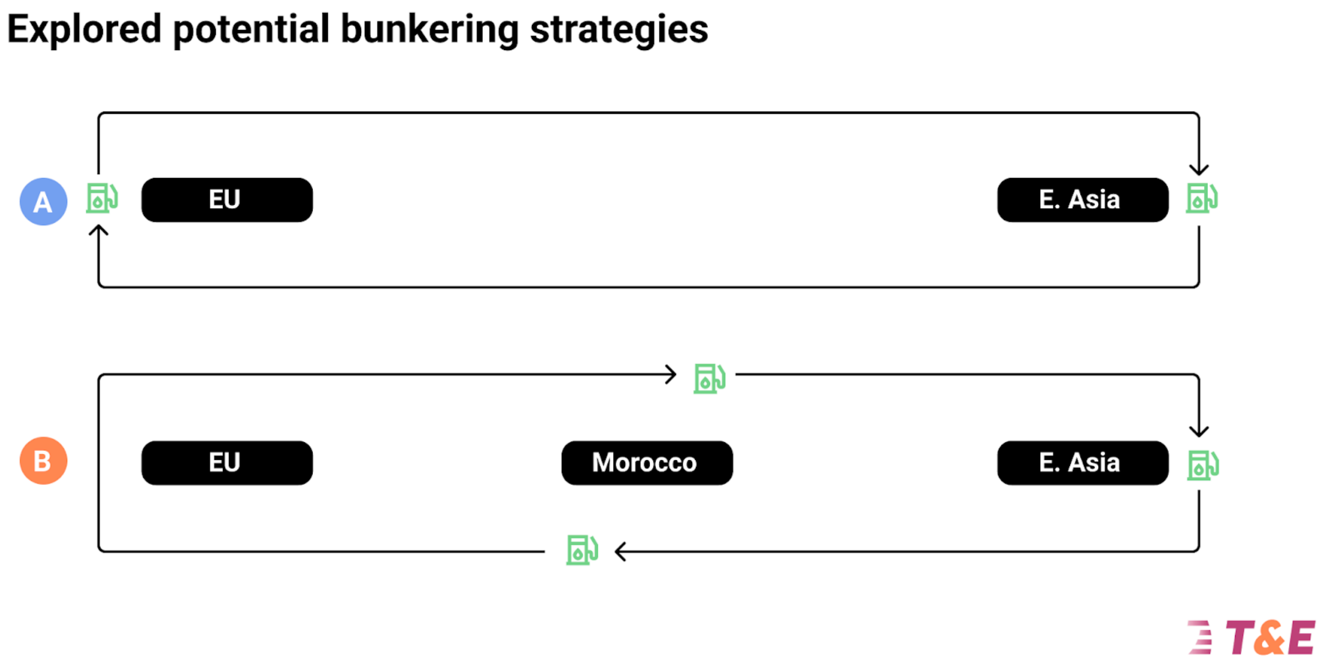

Figure A.1 | Potential bunkering strategies explored in this analysis

We then estimated the autonomy of ships if they ran on alternative marine fuels, and whether they would be able to complete their trips in the different scenarios shown in Fig. A.1. To calculate autonomy and leg attainment, we followed the same methodology as the ICCT in their paper on the use of liquid hydrogen in the U.S.–China container shipping corridor.[26] For liquid hydrogen, we used fuel system and engine characteristics from that publication. For HFO, LNG, methanol and ammonia, we assumed engines of equal size and efficiency, and we used fuel system energy densities shown in Table A.1. For all fuels, we assumed a sea margin of 20% of extra fuel. To calculate cargo space replacement, we used the ship capacity in TEU and assumed one TEU is equivalent to 38m.3

Table A.1 | Fuel system volumetric energy density

Fuel	Fuel system volumetric energy density (GJ/m^3)	Note/source

[26] Georgeff, E. (2020), *Liquid hydrogen refueling infrastructure to support a zero-emission U.S.–China container shipping corridor*, ICCT.

HFO	36.6	DNV - “Maritime Forecast to 2050 - Energy Transition Outlook 2021”, figure 6.2. Assumes volumetric energy density of the fuel system is roughly the same as that of the fuel itself.
Methanol	15.8	
LNG	13.0	DNV - “Maritime Forecast to 2050 - Energy Transition Outlook 2019”, figure 3.4.
NH3	11.3	

Appendix B: Breakdown of voyage data and autonomy simulations

Table B.1 | Breakdown of result for Morocco case study

Ship size bin	No. of Voyages	Length of the longest leg			Autonomy with 0% cargo space substitution			Trip attainment rate (%) with no cargo space loss		Autonomy with 2% cargo space substitution			Container space loss if 2% cargo space is substituted for fuel carriage			Trip attainment rate (%) with 2% cargo space loss	
		Min (nm)	Mean (nm)	Max (nm)	Min (nm)	Mean (nm)	Max (nm)	Only end-to-end bunkering	Additional bunkering in Morocco	Min (nm)	Mean (nm)	Max (nm)	Min (no. of TEU)	Mean (no. of TEU)	Max (no. of TEU)	Only end-to-end bunkering	Additional bunkering in Morocco
Liquid H2 (LH2)																	
3,000-4,999	17	9,220	9,345	9,479	4,382	6,275	7,226	0	0	6,778	8,792	10,153	91	95	100	0	29
5,000-7,999	9	9,276	9,399	10,008	5,998	7,021	8,166	0	0	8,476	9,874	11,232	101	109	135	11	77
8,000-11,999	46	8,738	10,055	11,254	3,727	6,595	8,521	0	0	6,584	9,627	12,656	162	182	233	8	41
12,000-14,499	164	8,408	9,458	11,067	4,493	6,411	10,185	0	1	7,908	10,721	19,272	248	274	287	34	79
14,500-19,999	206	8,395	9,772	11,002	3,695	6,086	10,105	0	2	6,707	10,602	16,412	291	348	397	27	57
20,000-+	134	8,342	9,945	11,457	3,466	6,025	11,912	0	4	6,949	11,181	21,875	401	413	475	31	65
Total/average	576							0	2							27	63
Ammonia (NH3)																	
3,000-4,999	17	9,220	9,345	9,479	8,575	10,515	11,792	41	82	14,071	16,200	18,265	91	95	100	100	100
5,000-7,999	9	9,276	9,399	10,008	10,372	11,740	13,917	55	100	15,985	18,138	20,138	101	109	135	100	100
8,000-11,999	46	8738	10055	11254	6978	11433	15076	52	58	14058	18228	24172	162	182	233	100	100
12,000-14,499	164	8,408	9,458	11,067	8,618	11,920	20,835	62	92	15,836	22,058	41,955	248	274	287	100	100
14,500-19,999	206	8,395	9,772	11,002	7,074	11,926	17,952	56	83	15,198	22,784	31,982	291	348	397	100	100
20,000-+	134	8,342	9,945	11,457	6,234	12,109	21,894	54	79	14,718	24,672	44,058	401	413	475	100	100
Total/average	576							57	83							100	100
LNG																	
3,000-4,999	17	9,220	9,345	9,479	8,777	10,763	12,071	41	82	14,404	16,582	18,696	91	95	100	100	100
5,000-7,999	9	9,276	9,399	10,008	10,617	12,017	14,245	77	100	16,362	18,566	20,613	101	109	135	100	100
8,000-11,999	46	8,738	10,055	11,254	7,143	11,703	15,432	56	58	14,390	18,659	24,743	162	182	233	100	100
12,000-14,499	164	8,408	9,458	11,067	8,821	12,201	21,327	68	94	16,210	22,579	42,946	248	274	287	100	100
14,500-19,999	206	8,395	9,772	11,002	7,241	12,208	18,376	60	85	15,557	23,322	32,737	291	348	397	100	100
20,000-+	134	8342	9945	11457	6381	12395	22411	60	79	15066	25255	45099	401	413	475	100	100
Total/average	576							62	84							100	100
Methanol (CH3OH)																	
3,000-4,999	17	9,220	9,345	9,479	10,668	13,081	14,671	94	100	17,506	20,154	22,723	91	95	100	100	100
5,000-7,999	9	9,276	9,399	10,008	12,904	14,605	17,314	100	100	19,887	22,565	25,053	101	109	135	100	100
8,000-11,999	46	8,738	10,055	11,254	8,681	14,224	18,756	71	97	17,490	22,678	30,073	162	182	233	100	100
12,000-14,499	164	8,408	9,458	11,067	10,721	14,829	25,921	97	100	19,702	27,442	52,195	248	274	287	100	100
14,500-19,999	206	8,395	9,772	11,002	8,801	14,837	22,334	89	94	18,908	28,345	39,788	291	348	397	100	100
20,000-+	134	8,342	9,945	11,457	7,756	15,065	27,238	82	92	18,311	30,694	54,813	401	413	475	100	100
Total/average	576							89	96							100	100
HFO/VLSFO																	
3,000-4,999	17	9220	9345	9479	24711	30302	33984	100	100	40552	46686	52637	91	95	100	100	100
5,000-7,999	9	9,276	9,399	10,008	29,892	33,832	40,106	100	100	46,066	52,271	58,034	101	109	135	100	100

8,000-11,999	46	8,738	10,055	11,254	20,109	32,949	43,448	100	100	40,514	52,532	69,662	162	182	233	100	100
12,000-14,499	164	8,408	9,458	11,067	24,835	34,351	60,044	100	100	45,638	63,568	120,908	248	274	287	100	100
14,500-19,999	206	8,395	9,772	11,002	20,387	34,369	51,735	100	100	43,800	65,661	92,168	291	348	397	100	100
20,000-+	134	8,342	9,945	11,457	17,965	34,897	63,096	100	100	42,417	71,102	126,972	401	413	475	100	100
Total/average	576							100	100							100	100