The potential of ports in developing Sustainable First Mover Initiatives

A tool for an inclusive shipping transition

LR
Environmental Defense Fund
ARUP

This report was prepared by the Environmental Defense Fund and the Lloyd's Register Maritime Decarbonisation Hub, in collaboration with Arup.

Lloyd's Register (LR) and the LR Maritime Decarbonisation Hub (MDH)

Lloyd's Register (LR) and Lloyd's Register Foundation through the LR Maritime Decarbonisation Hub, are enabling the delivery and operation of safe, technically feasible and commercially viable zero-emission shipping. Our research and partnerships with other forward-looking organisations bring together thought leaders and subject matter experts to create and share evidence, insight, and knowledge on shipping's energy transition to stakeholders across the industry. www.maritimedecarbonisationhub.org

Environmental Defense Fund

Guided by science and economics, Environmental Defense Fund (EDF) tackles our most urgent environmental challenges with practical solutions. EDF is one of the world's largest environmental organizations, with more than 2.5 million members and a staff of 700 scientists, economists, policy experts, and other professionals around the world.

Arup

Arup is a global independent firm of more than 15,000 designers, planners, engineers, architects, consultants and technical specialists, working across every aspect of today's built environment. The company was founded on the belief that the built environment has a central role in creating a safer, more sustainable planet. Together we help our clients solve their most complex challenges – turning exciting ideas into tangible reality as we strive to find a better way and shape a better world.

Please Contact

Dr Charlie McKinlay
LR MDH

Dana Rodriguez
EDF

Mark Button
Arup

Dr Carlo Raucci
LR MDH

Marie Hubatova
EDF

Executive Summary

The transition to electrofuels[1] is likely to change the fuel market landscape, creating new opportunities for developing countries. [1]

As global policies to advance the decarbonisation of shipping are to be implemented in the coming years, ports will play a critically important role this transition, as key hubs for transport and energy systems. Port areas are also home to large and diverse communities with their own unique local environmental impacts, utilizing ports as levers for shipping's transition can provide co-benefits to people and the environment. Stimulating the transition, first mover initiatives, such as green corridors or energy hubs, have been designed to play a key role in unlocking investments for the incubation and scale up of electrofuels and clean technologies. However, local socio-economic and environmental factors must be more intentionally considered in the development of these initiatives and if done right, inclusive and sustainable co-benefits for local communities and the environment may be achieved, while also delivering the emissions reductions, globally.

[1] Fuels made with renewable energy that have net-zero carbon emissions throughout their production process and output – such as e-hydrogen, e-ammonia, and e-methanol. Biofuels and their associated resource requirements are outside of the scope of this assessment.

The report introduces the concept of Sustainable First Mover Initiatives (SFMIs) which are aligned with the 1.5°C Paris Agreement climate target, delivering on social, economic, and environmental co-benefits, while fostering positive impacts on both the environment and port communities, especially those in Global South regions.

Environmental Defense Fund and Lloyd's Register Maritime Decarbonization Hub, in collaboration with Arup, are introducing a Sustainable First Mover Initiative identification tool to help shipping stakeholders make investment decisions with a more inclusive criteria for the sector's transition away from fossil fuels. Showcasing an opportunity to create a new, sustainable model for first movers that will work for shipping as well as port communities, the SFMI identification tool can offer shipping stakeholders[2] a way to assess a port's potential to produce and/or bunker electrofuels, while ensuring that local clean energy access, land suitability, and decarbonisation efforts are not undermined.

The tool was used to examine the Indo-Pacific region as a case study. The ports were then ranked to determine which had 'high' or 'promising' potential. Preliminary results demonstrate that several ports show a high potential to develop SFMIs in all scenarios. For example, preliminary results for ports that could produce and bunker electrofuels reveal that Jawaharlal Nehru Port Trust (JNPT) port in India and Chittagong port in Bangladesh performed well across all criteria and ranked as 'high potential'.

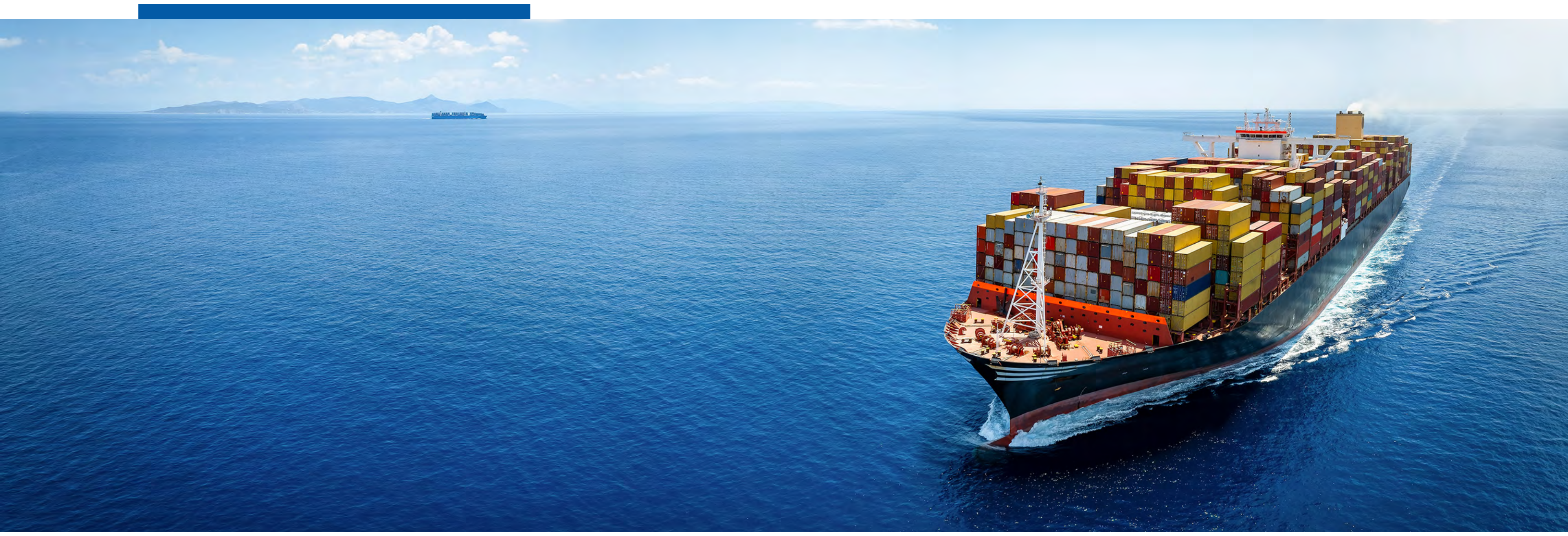
The tool can be customised according to stakeholders needs and goals dependent on scenario desirability; so long the research remains in line with the objectives and the purpose of the analysis.

This initial port assessment sets the scene for the second phase of this work that will lead to a more comprehensive port level analysis in partnership with local shipping stakeholders, to help better understand local needs and maximise the value offered by SFMIs.

[2] Shipping stakeholders include, but not limited to, port communities, ports, energy developers, fuel producers, investors, and governments.

Table of contents

Introduction



Maritime shipping occupies a central position in the global supply chain with nearly 100,000 commercial vessels moving 11 billion tons of goods each year, accounting for around 80% of global trade volume [2]. Responsible for approximately 3% of global Greenhouse Gas (GHG) emissions, the maritime industry is in the midst of a transformation as it responds to climate goals to decarbonise and contribute to the Paris Agreement target of 1.5°C [3]. Estimates show that decarbonising shipping will represent a more than $1 trillion investment opportunity for businesses and development, under the right rules and commercial environment [4]. Also, the transition to electrofuels[3] is likely to create new opportunities for Global South countries [5].

The recent agreement by the International Maritime Organization (IMO) to adopt the 2023 strategy on the reduction of GHG emissions gave way to strive for a 10% uptake of zero or near-zero greenhouse gas emission fuels and technology by 2030. This commitment is a crucial step toward the overarching goal of decarbonising the shipping industry by, or around, the year 2050,

[3] Fuels made with renewable energy that have net-zero carbon emissions throughout their production process and output – such as e-hydrogen, e-ammonia, and e-methanol. Biofuels and their associated resource requirements are outside of the scope of this assessment.

setting a clear direction for the shipping industry [1]. Voluntary first mover initiatives, such as green corridors and energy hubs, have kickstarted the maritime energy transition by signalling demand as well as showcasing potential for electrofuels and technologies [6]. However, to ensure they deliver to people and the environment, these initiatives must be designed in a way that is inclusive and sustainable. This report introduces the concept of 1.5°C Paris-aligned Sustainable First Mover Initiatives (SFMIs), that can allow the industry to transition away from fossil-based fuels in a manner that is inclusive and driven by wider social, economic, and environmental co-benefits.

Ports function as key hubs that bring together transport, communities, energy systems, and the environment, playing a role as facilitators and connectors for shipping decarbonisation. In this role, ports are very well positioned to drive the transition through SFMIs that deliver on co-benefits like improved air quality, economic resilience, and environmental sustainability.

The report presents the preliminary phase and results of a Sustainable First Mover Initiative identification tool that can be used to identify port locations that are most suitable to develop SFMIs. The tool can offer shipping stakeholders[4] a way to assess a port's potential to produce and/or bunker electrofuels, while ensuring that local clean energy access, land suitability, and decarbonisation efforts are not undermined. The results are meant to be used as a proof of concept to support the planning and development of potential SFMIs, through scenario generations, as well as being able to aid the process of stakeholder engagement.

[4] Shipping stakeholders include, but not limited to, port communities, ports, energy developers, investors, and governments.

An inclusive transition

Within its 2023 GHG Strategy, the IMO agreed that the maritime energy transition should be just and equitable [1][5]. However, it refrained from providing a definition as to its interpretation of a just and equitable transition. Initiatives delivering on the IMO's vision are widely interpreted as socio-economic focused, addressing impacts on countries and workforce. Examining the use of "just and equitable" terminology outside of the 2023 Strategy provides additional, albeit limited detail. UNCTAD adds that key elements that should be considered for shipping's transition include the need for a "environmentally effective, procedurally fair, socially just, globally equitable, and technologically inclusive" transition [7].

Current initiatives that address a 'Just and Equitable' transition for shipping consider three key elements. These include historic unequal contributions to the climate crisis, rich countries emitting higher-than-average amounts of GHGs, and disproportionately high climate mitigation and adaptation costs for small island developing states (SIDS) and least developed countries (LDCs) [7]. However,

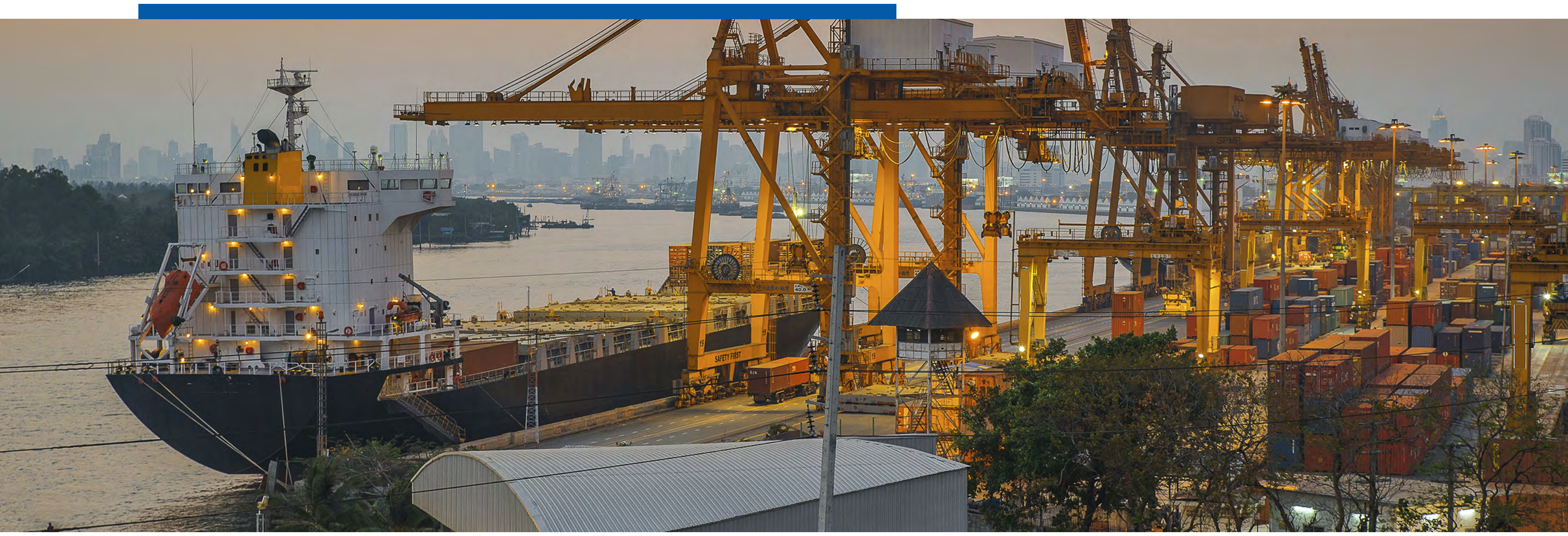
[5] "IMO remains committed to reducing GHG emissions from international shipping and, as a matter of urgency, aims to phase them out as soon as possible, while promoting, in the context of this Strategy, a just and equitable transition".

there is a need to expand beyond the macro-level impact and focus on the direct effects the shipping industry has on port-side communities, especially those in the Global South. To accelerate the transition, stakeholders must move together, and include both, currently underrepresented regions as well as communities, as part of the energy transition.

As the adoption of electrofuels is expected to diffuse globally over time, considering the difference in capital resources, significant delays may arise between early and late electrofuel adopters. Failure to address these delays adequately could exacerbate inequality, resulting in additional costs and increased negative impacts for both businesses and local communities. Therefore, it is important to ensure that local port communities, especially in Global South regions, are included in the transition to electrofuels and considered a vital part of the transition [5].

Consequently, as the shipping industry begins to take concrete actions toward their climate commitment, it is essential to rapidly advance beyond initiatives built by players in developed economies and deliver meaningful improvements for people and the environment globally. An inclusive transition will entail the collaborative efforts by stakeholders from across the value chain, including governments, ship owners, fuel providers, ports, and port communities.

Sustainable First Mover Initiatives (SFMIs)



With close to 40% of the world's population living within 100km of the coast, and close to 80% of people living in developing economies [8], climate action is much more than just reducing GHG emissions; it is about the people whose livelihoods depend on limiting global warming to 1.5°C.

Driving the maritime energy transition, voluntary first mover initiatives, like the Clydebank Declaration for green shipping corridors and the Clean Energy Ministerial promoting energy hubs globally, are expected to signal demand for the production and scale up of electrofuels and technologies. While initiatives like these are striving to do their part in meeting shipping's climate target, they have been largely focused on the Global North, failing to fully deliver to regions in the Global South and engage all shipping stakeholders, including port communities.

Aiming to fill this gap, the report presents a tool that can be used to identify port locations that are most suitable to develop Sustainable First Mover Initiatives (SFMIs). The tool assesses port potential on the basis of specific co-benefits of renewable energy, air quality, local economy, land suitability, and ship traffic. SFMIs are therefore defined as a 1.5°C Paris aligned effort to decarbonise shipping, transitioning away from fossil fuels in a manner that is inclusive and driven by wider social, economic, and environmental factors.

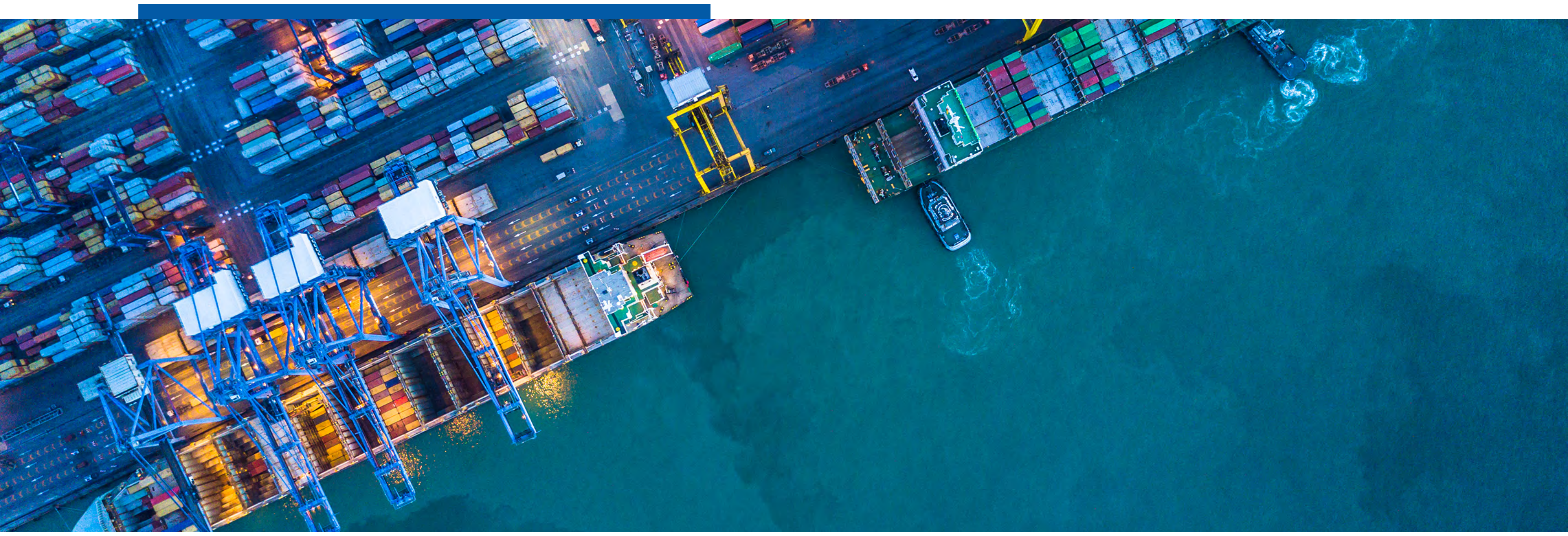
Driven by a port's role as a transport and energy hub as well as home to large and diverse communities, SFMIs can play an important role in the journey towards an inclusive shipping transition. SFMIs account for broader impacts on communities and the environment, truly ensuring that the transition is people centered. This means that communities affected by such initiatives can benefit from their implementation, rather than be put at risk [9].

The shift to electrofuel production can unlock investments and other socio-economic and environmental benefits, particularly in Global South regions where conditions for production of electrofuels may be more favourable and cost-effective due to a potential surplus of renewable energy [10]. By identifying the most suitable locations for SFMIs and supporting their development, those regions can boost their economies while decarbonising their maritime, and possibly other sectors as well. Today, more than 80% of clean energy investment is taking place in advanced economies and China [11]. A significant concessional finance[6] is needed to lower capital expenditure and mobilise private capital in lower income countries, where clean energy investment needs to increase nearly fivefold from the current level by 2030 to meet the needs of net zero by 2050 [11].

Subsequently, it is vital that future SFMIs focus on the Global South to ensure that the socio-economic and environmental benefits of a new market entry are not limited to advanced economies. An increased engagement among shipping stakeholders, including communities, at an early stage would be required to unlock port potential and economic opportunities. In addition, effective collaboration from the inception of an initiative would reduce the undesired impacts on the most vulnerable stakeholders, while assisting regulators in designing robust policy measures that address inequality more broadly.

[6] Concessional finance is below market rate finance provided by major financial institutions, such as development banks and multilateral funds, to developing countries to accelerate development objectives. https://www.worldbank.org/en/news/feature/2021/09/16/what-you-need-to-know-about-concessional-finance-for-climate-action

Ports as enablers



Ports sit at an epicentre enabling the energy transition on one end and playing a role as crucial gateways for international trade, transportation, and supply of goods on the other. At the same time ports have a long history of generating environmental externalities to port-side communities through their high contribution to GHG emissions and environmental pollution. Centring on the role a port can play in delivering co-benefits such as improved air quality, economic resilience, and environmental sustainability, they are crucial for fostering SFMIs.

Port infrastructure[7] is key to decarbonising the maritime industry [12]. However, acknowledging that the decarbonisation of the sector will highly depend on the development of electrofuels at or near ports, it is critical that ports, especially those in the Global South, are utilised as levers in enabling an inclusive maritime energy transition through SFMIs [12] [13].

For example, the production of hydrogen-derived fuels requires the development of a hydrogen supply chain. Such fuels could be most economical

[7] Recognizing the priority to tackle low-hanging fruits and delivering on immediate air quality needs, ports should initially electrify operations and provide shore power access prior to committing capital resources to develop additional renewable energy capacity [31].

in locations that have the optimal combination of untapped renewable potential, space for solar or wind farms, and access to water, along with the capability to export to large demand centres. By capitalising on the potential of ports to contribute to the development of SFMIs, new power nodes could arise in places that exploit these factors to become centres of hydrogen-derived fuel production and use [13].

SFMIs may involve one or more ports. Their development will require investments in climate resilient port infrastructure as well as fuel production and bunkering [12]. SFMIs can play a role in unlocking high impact investments[8] at ports, ensuring that the deployment of electrofuels and technologies do not result in unintended adverse impacts – environmentally, socially, or economically – on already burdened port adjacent communities.

It is important to highlight that the success of a SFMI will depend on the involvement of all key stakeholders across the entire shipping supply chain. Tools and frameworks, such as guidance reports, will provide necessary support to ports and other stakeholders as they commit to developing SFMIs, ensuring both their sustainability and accountability.

[8] With a clear intent for positive impact, a credible thesis of contribution, and for which there is a measurement system in place—criteria that together meet the definition of impact investment. https://documents1.worldbank.org/curated/en/644401628704547676/pdf/Investing-for-Impact-The-Global-Impact-Investing-Market-2020.pdf

A tool for a sustainable and inclusive transition

Environmental Defense Fund with the Lloyd's Register Maritime Decarbonisation Hub, in collaboration with Arup, partnered to develop a tool to identify port locations that are most suitable to be involved in SFMIs. Here "tool" refers to a methodology outline to assess the potential of ports for SFMIs, it has been demonstrated using a case study in the Indo-Pacifc region but could be applied to any given port or region. The Indo-Pacific was selected as there is a diverse mix of Global South and Global North countries, along with major shipping routes. A specific outline of the case study region is shown in the Appendix.

The report presents the preliminary phase and results of the application of the SFMI tool as well as the assessment methodology. This initial port assessment sets the scene for a secondary phase of this work that will lead to a more detailed port level analysis. The later selection and assessment of 10 ports will aim to understand local needs so that value[9] is targeted in Global South regions that have yet been considered. Some factors, such as political and regulatory landscape, are beyond the scope of this report.

[9] The 'value' of infrastructure can be defined as the perception of worth, or benefit, that accrues to stakeholders, communities, and other beneficiaries over time. https://www.arup.com/perspectives/publications/research/section/making-the-total-value-case-for-investment-in-infrastructure-and-the-built-environment

A multicriteria analysis to assess a ports' potential

A multicriteria analysis (MCA) allows decision makers to evaluate and compare various options, across multiple criteria and factors [14]. This structured approach enables a more comprehensive and balanced assessment by considering a range of criteria which can be assigned different weight.

It is important to note that the report represents a preliminary assessment of a port's potential. The listed indicators should not be considered exhaustive, a more detailed port-level analysis will take place in the next phase of this work.

This assessment focuses on the potential to produce and/or bunker electrofuels which are made with renewable energy and have net-zero carbon emissions throughout their lifecycle, such as e-hydrogen, e-ammonia, and e-methanol. Biofuels and their associated resource requirements are outside of the scope of this assessment.

Assessment criteria

The SFMI identification tool uses following five criteria with underlying indicators:

Potential to deliver a surplus of renewable energy near ports

Shipping traffic at the port and in the surrounding sea area

Land suitability near the port

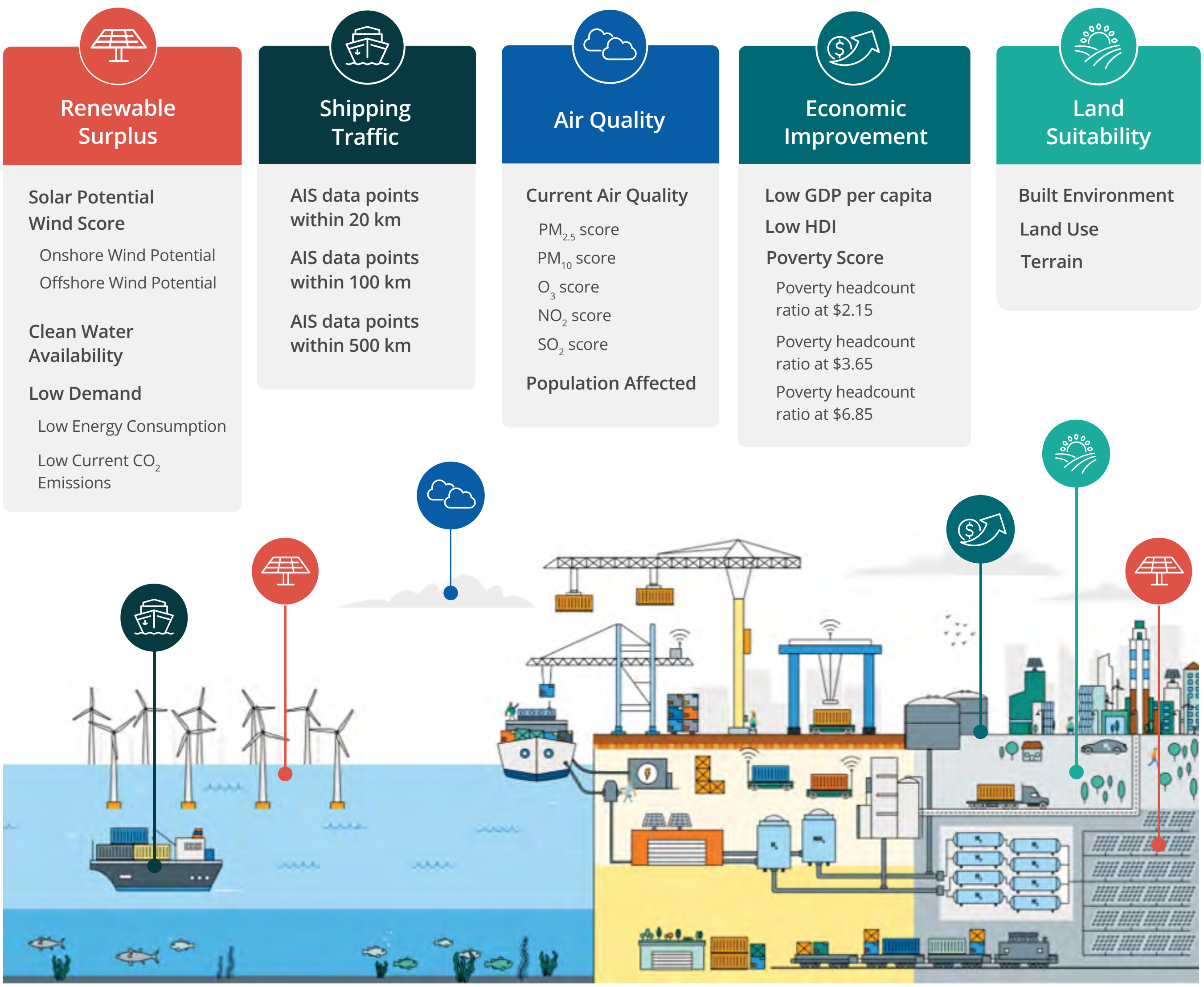
Potential improvement in air quality

Potential improvement to local economies

The port potential (port-score) is assessed by assigning a weighted score to each port. The port-score is based on the criteria-score and the weight assigned to the criteria in each scenario. The port-score categorises ports with 'high potential' or 'promising potential' in developing SFMIs in the near future. Ports above the third quartile are considered 'high potential', whereas ports between the second and third quartiles are considered 'promising potential'.

FIGURE 1
The SFMI identification tool uses five criteria with underlying indicators.

The following sections further elaborate on these criteria. Detailed methods used to calculate a score for each of them, along with the corresponding data sources are provided in the Appendix.



ARUP GRAPHIC

POTENTIAL TO DELIVER A SURPLUS OF RENEWABLE ENERGY NEAR PORTS

This criterion combines indicators measuring the potential surplus of renewable energy with indicators measuring water availability in each port and its surrounding area.

The production of electrofuels must not undermine local electricity access and power potential or existing decarbonisation efforts. Moreover, it is essential that SFMIs operate with a strict additionality principle[10], such that they lead to emissions reductions or avoidance exceeding those that would have occurred in their absence, especially in regions currently facing financial or other challenges.

The use of surplus renewable energy must ensure that there is water to be exploited without harming local population and the environment. For instance, producing electrofuels in water-stressed areas risks increasing water scarcity and creating conflicts over water resources. Any proposal to build desalination plants in water-stressed areas needs to prioritise basic water needs of the local population beyond the production of electrolysis for fuels and must not have negative environmental implications. Ultimately, any negative externalities to both the environment and the people must be accounted for and prevented.

LAND SUITABILITY

This criterion accounts for land use, biodiversity and protected areas, terrain, as well as built environment within a 100km-radius of the port.

There are several types of land cover that would not be considered suitable for the installation of renewable energy production infrastructure, electrofuel production sites, or bunkering facilities. These include forestry, wetlands, and crop lands. Protected areas are also excluded from the suitable land.

SHIPPING TRAFFIC AT PORT AND IN THE SURROUNDING SEA AREA

Examining Automatic Identification System (AIS) vessels' activities at varying distances from each port, this criterion not only gauges the potential fuel

[10] It pertains to the notion that interventions are deemed "additional" if they lead to emissions reductions or avoidance exceeding those that would have occurred in the absence of the project's implementation, where the financial incentives provided by the project are the primary drivers for the changes in land use or management practices. https://www.nature4justice.earth/climate-justice-additionality-defined/#:~:text=It%20pertains%20to%20the%20notion,changes%20in%20land%20use%20or

demand at a port, but also assesses its connectivity with other ports in the region.

SFMIs are likely to involve one or more ports. Examining the volumes and traffic at port and in the surrounding area is one way to measure a port's potential for emissions reductions, regardless of its potential to be a fuel exporter or a bunkering hub.

POTENTIAL IMPROVEMENT TO AIR QUALITY

This criterion combines indicators measuring clean air quality with indicators measuring the population affected in each port and its surrounding area.

In areas with poor air quality, SFMIs that reduce local GHG emissions from ships and improve air quality by offering shore-power, electrifying operations, and ultimately encouraging ships to move to alternative fuels can bring significant environmental and health benefits. This criterion captures the potential improvement of air quality and the corresponding population that would benefit from it compared to the current level.

POTENTIAL IMPROVEMENT TO LOCAL ECONOMIES

This criterion combines indicators measuring the poverty score, GDP per capita and Human Development Index (HDI) for each port and its surrounding area.

Electrofuel production in resource-rich locations needs to create value for the local economies. Any fuel production or bunkering activities, particularly in Global South regions, need to be carefully planned, regulated, and implemented to ensure local job creation and population protection. Subsequently, a port's involvement in a SFMI, whether it is for bunkering or production, can mean a potential improvement in local poverty, GDP and HDI.

Definition of the scenarios

The criteria described in the previous section are not necessarily of equal importance. To help capture the different potential weighing options, three basic scenarios were developed. The underlined factors and further weighing systems used to calculate a score for each of these criteria in each of the scenarios are provided in the Appendix.

Scenario A: Ports exploring both fuel production and bunkering

Scenario B: Ports mainly exploring fuel exports

Scenario C: Ports mainly exploring fuel imports and bunkering

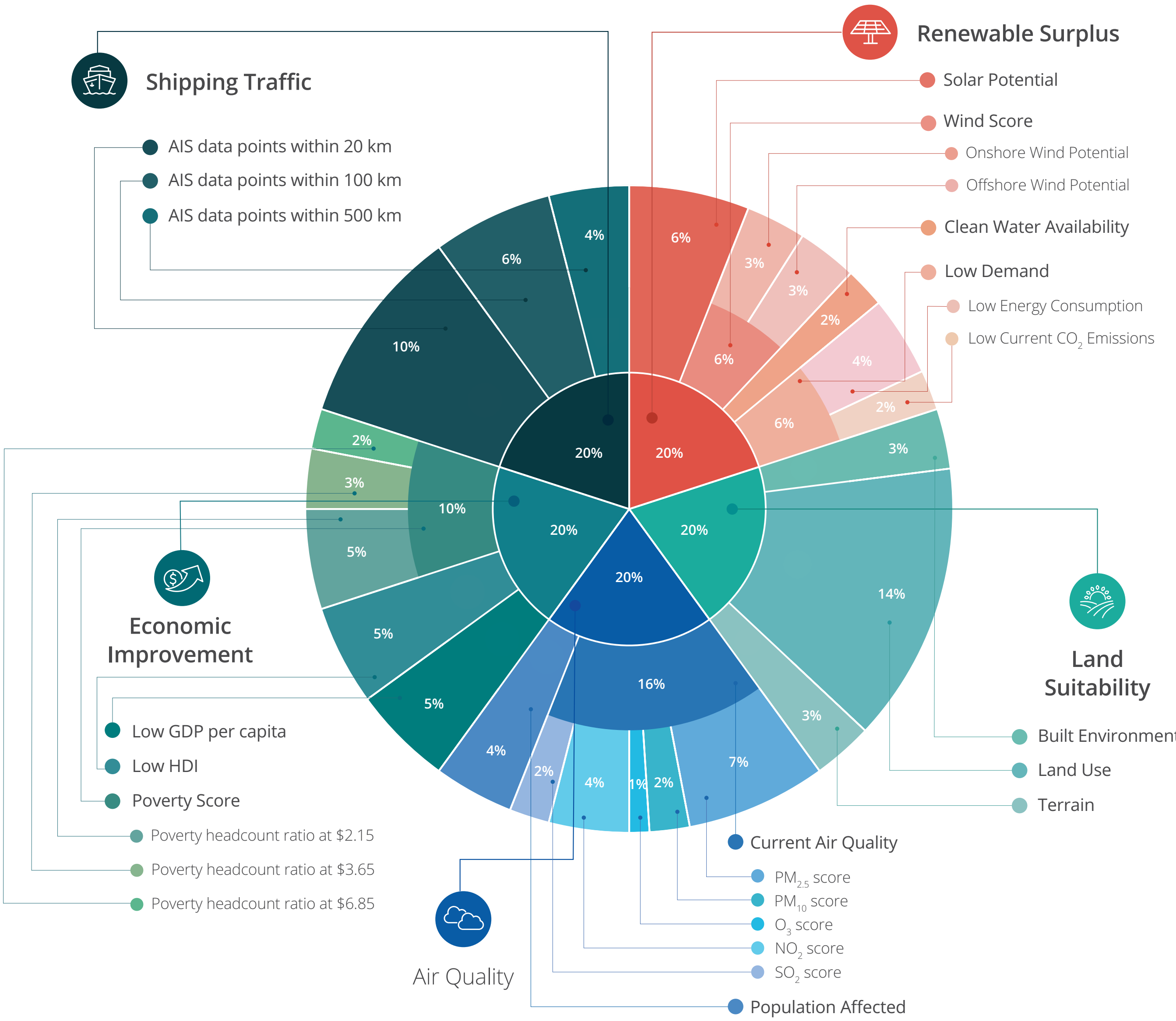


FIGURE 2
Criteria weightings for Scenario A: Ports exploring both fuel production and bunkering.

For Scenario A, the focus is on ports that are well-suited to develop SFMIs and unlock investments in fuel production and bunkering. There are five equally weighted criteria, with each representing 20% of the port-score. Figure 2, shows the full distribution of weightings for the MCA analysis for this scenario.

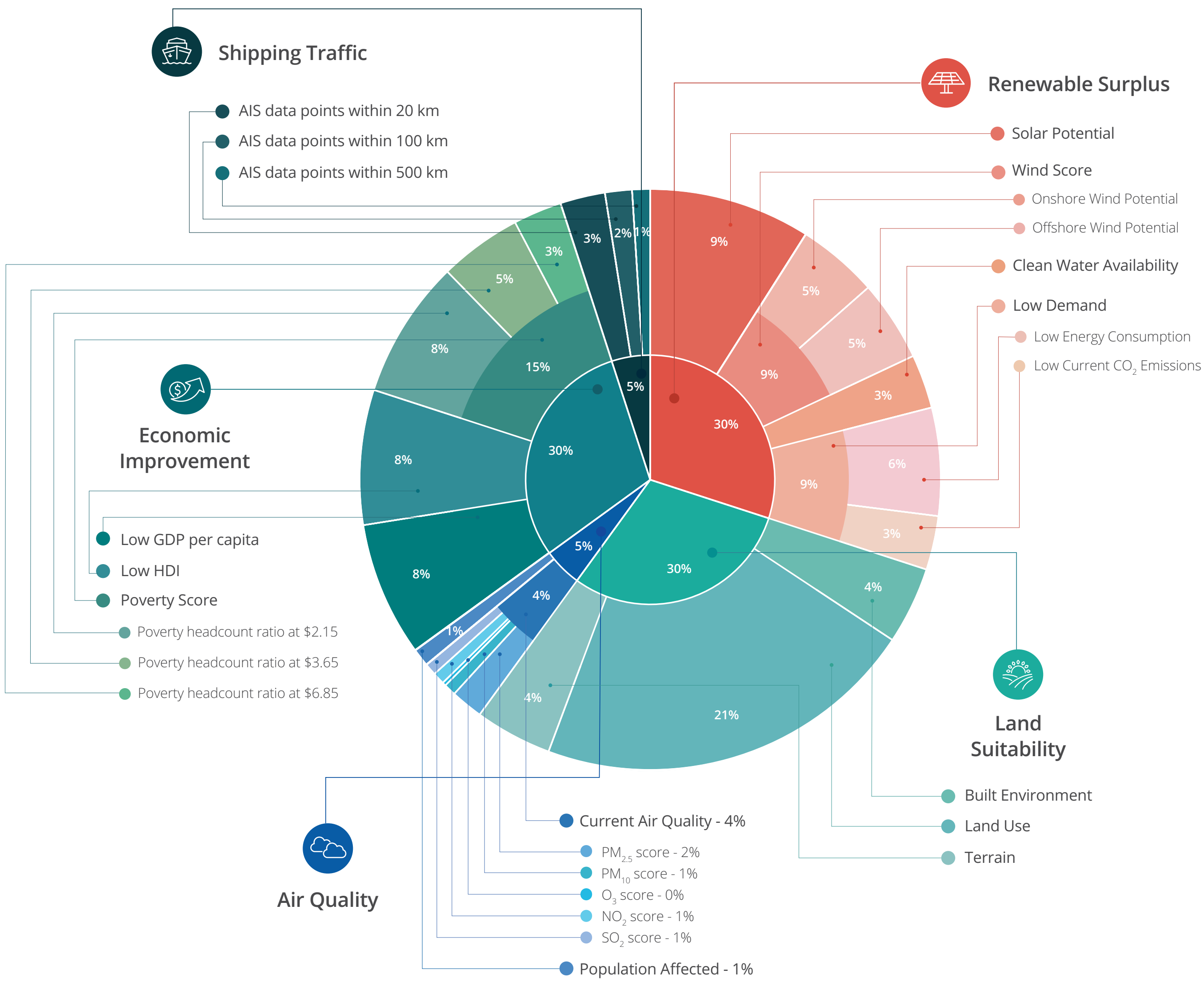


FIGURE 3
Criteria weightings for Scenario B: Ports mainly exploring fuel exports.

Scenario B targets ports that are best positioned to develop SFMIs and unlock investments in fuel production and export activities. In this case, the criteria assessing the sustainable use of renewable energy and improvements to local economies are given more weight than the other criteria.

The weighting is applied as shown in Figure 3 (30% for potential surplus of renewable energy, 30 percent for land suitability, 30% for economic improvement, 5% for shipping traffic, and 5% for improvement in air quality).

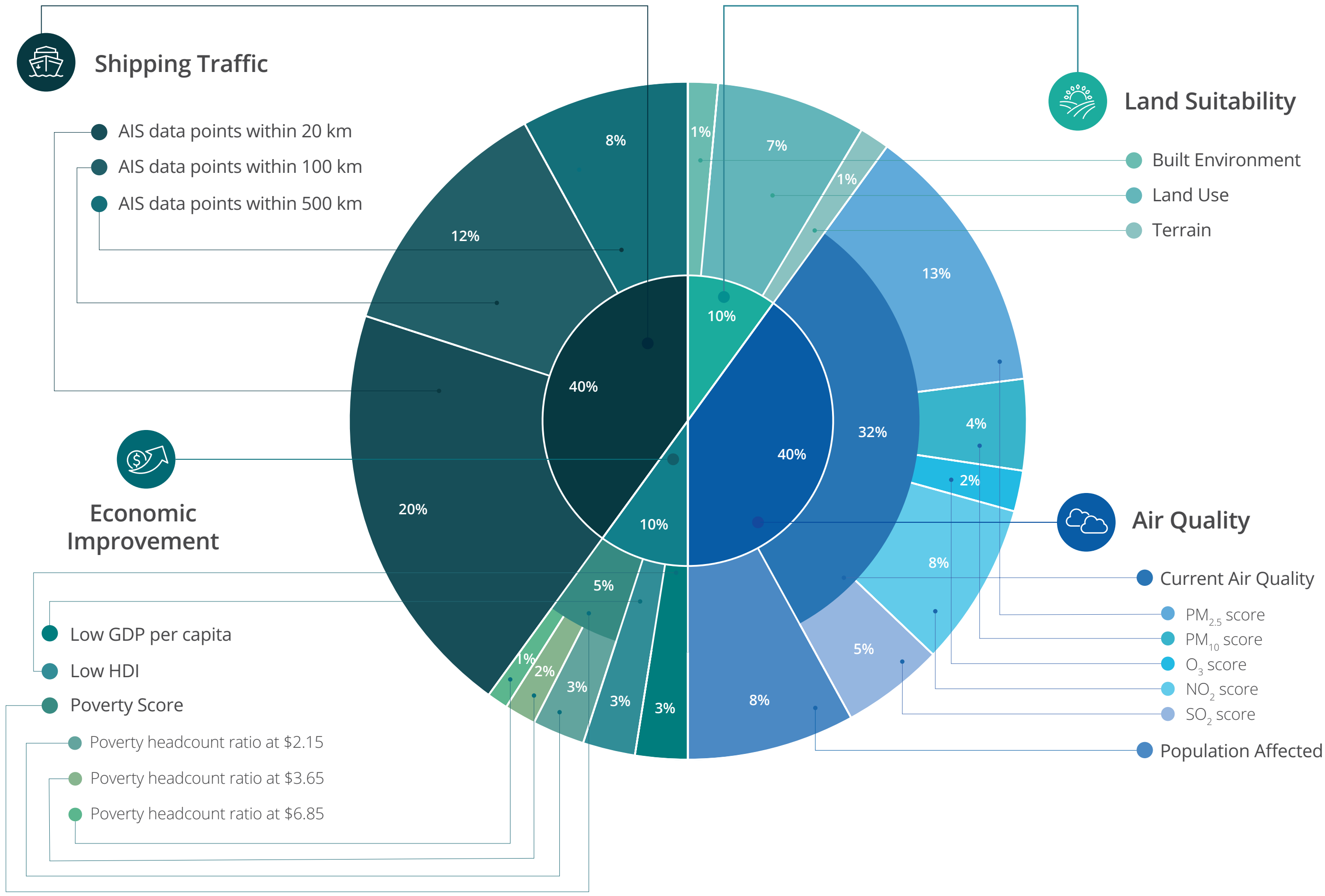


FIGURE 4

Criteria weightings for Scenario C: Ports mainly exploring fuel imports and bunkering.

For Scenario C, the emphasis is on ports that are ideally situated to develop SFMIs and unlock investments in fuel imports and bunkering activities. The criteria related to shipping traffic and air quality are more important than the other criteria.

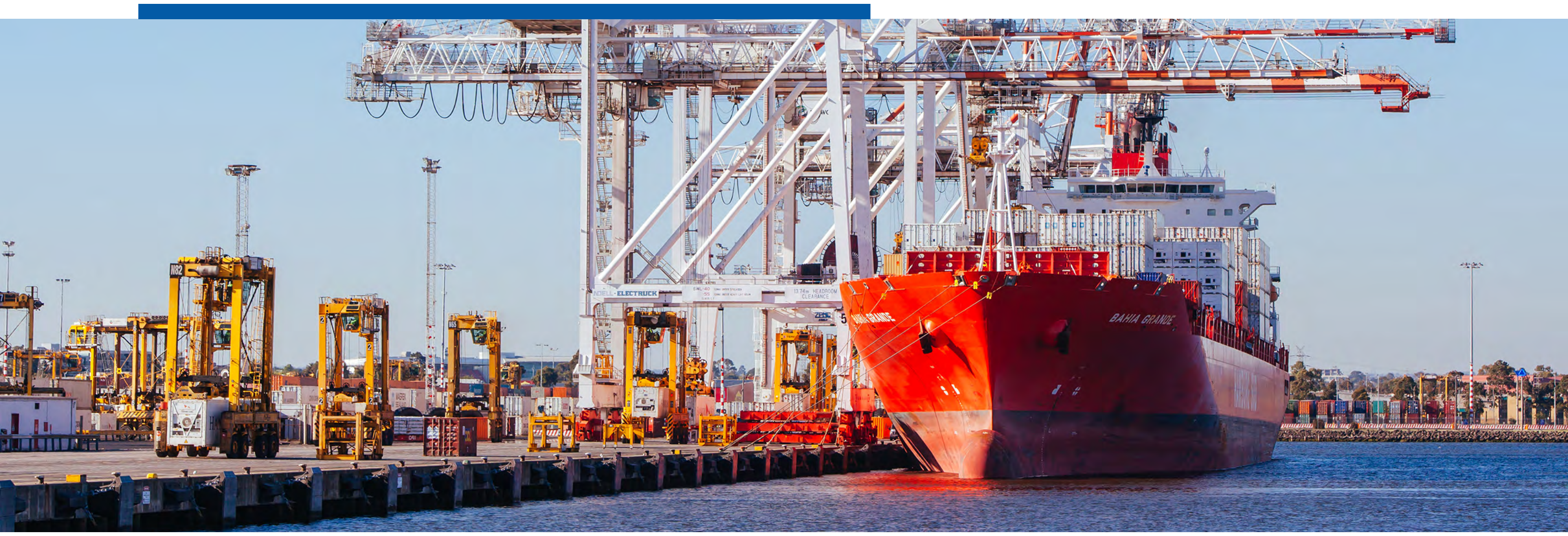
The weightage is applied as shown in Figure 4 (10% for land suitability, 40% for improvement to air quality, 40% for shipping traffic, and 10%t for improvement to local economies). For this scenario, the potential to produce renewable energy is irrelevant as there is no localised production.

The criteria mentioned above are utilised to calculate a weighted score for each port in each scenario. Based on this weighted score, ports are automatically categorised as having 'high' or 'promising' potential.

To deliver an objective scoring system, a score is calculated for each of the five criteria categories based on a series of data inputs. For example, the "Potential to deliver a surplus of renewable energy near ports" metric is calculated based on weighted scores for localised solar potential, wind potential, water availability, and low current energy demand. A full breakdown of the specific scoring system is available in the Appendix. Criteria have been normalised at each level to avoid scores being dominated by any heavily skewed criteria.

The weighting systems can be subject to the stakeholders that use this tool, therefore, the one presented in this analysis is a possible weighting system based on the reasons described above. This is not meant to be exhaustive or the only one that can be applied. Other weightings could be considered but shall remain in line with the objectives and the purpose of this analysis.

Preliminary results for Indo-Pacific region



Scenario A: Ports exploring both fuel production and bunkering

Scenario A indicates ports that are well-suited to become a clean electrofuels hub that incorporates both local production and bunkering. Ports are grouped into categories representing different levels of potential. The top 25% of ports have been classified as "high potential" and the following 25% classified as "promising potential", for this scenario these equated to scores over 1.83 and 1.51 respectively. Results are shown in Figure 5 and the individual results of the assessment can be found in the Appendix.

This scenario aims to identify the ports with ideal conditions in all five criteria. Among the high and promising ports, there are a few that show a good combination across all criteria such as: Jawaharlal Nehru Port Trust (JNPT) and Mumbai ports in India, Khawr Khasab port in Oman, Chittagong port in Bangladesh, Shanghai and Tianjin Xin Gang ports in China. It is important to note that not many ports will score high in each criterion as it difficult to find ideal conditions.

However, even if some ports have very good scores in one or a few criteria, they may still be classified as high or promising if the lower scores are balanced by

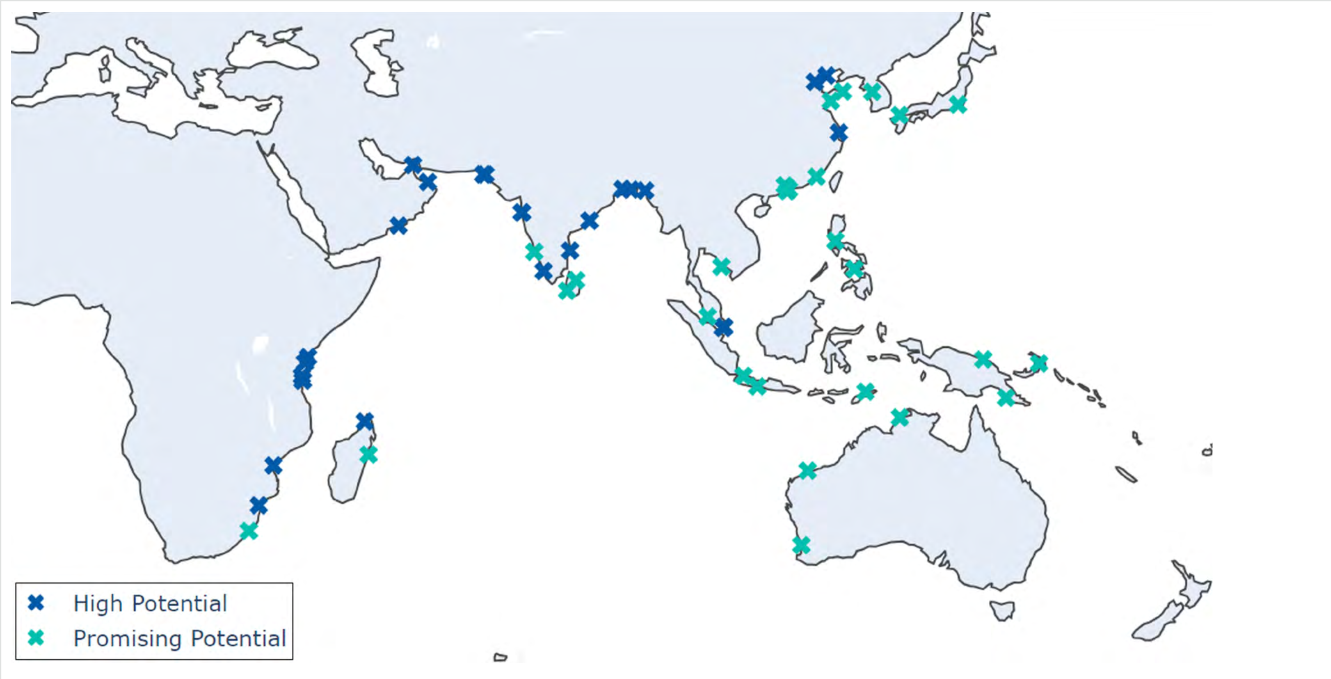


FIGURE 5
Visualisation of results for Scenario A. Ports above the third quartile are considered 'high potential', whereas ports between the second and third quartiles are considered 'promising potential'.

one or more very high scores. Among those ports, for example, there are ports in Pakistan such as Muhamamad Bin Qasim and Karachi, and ports in Oman such as Mina Raysut, Mina Al Fahl, and other ports such as Beira in Mozambique, Johor in Malaysia, Antsohim Bondrona in Madagascar, and Mombasa and Malindi in Kenya.

Another example is Singapore, which is classified as high potential despite its low scores in land suitability and relative economic improvement which are balanced by high scores in shipping traffic and relative improvement in air quality.

Scenario B: Ports mainly exploring fuel exports

Scenario B indicates which ports are strong candidates to produce electrofuels but may not necessarily have high local shipping demand, instead focusing on exports. The results are shown in Figure 6. For this scenario, ports required scores over 2.19 and 1.87 to be classified as "high potential" or "promising potential" respectively.

Results from this scenario show that Antsohim Bondrona in Madagascar and Beira in Mozambique could be particularly suited

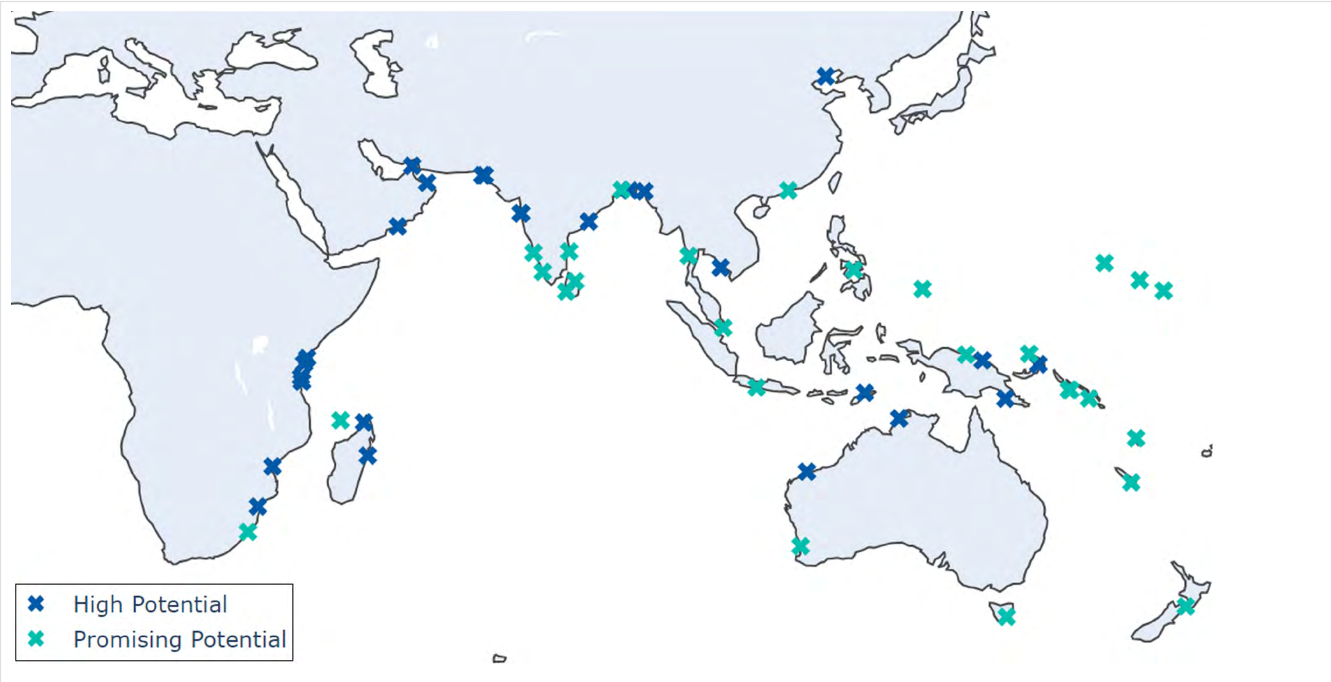


FIGURE 6
Visualisation of results for Scenario B. Ports above the third quartile are considered 'high potential', whereas ports between the second and third quartiles are considered 'promising potential'.

to explore fuel production and export. Land suitability results for the latter are visualised in the Appendix.

Madagascar presents a distinctive scenario due to its extensive forest coverage (44% of the island [15]) and unique biodiversity. While it is evident that some ports, such as Toamasina, are not viable candidates for electrofuel production, the case of Antsohim Bondrona, if proven suitable, underscores the importance of conducting analyses on a port-specific basis rather than applying a nationwide perspective. This emphasises the value of assessing individual ports independently, revealing nuanced insights that may be obscured when considering the entire country as a uniform entity.

Antsohim Bondrona scores highly for land suitability, however it is noteworthy that the current assessment includes land types like pastures, which introduces a potential risk of indirect Land Use Change (iLUC). For example, if the infrastructure for electrofuel production is established on pasture or rangeland, there is a likelihood that agricultural activities may need to relocate, possibly to areas with more "valuable" land cover.

Therefore, while Antsohim Bondrona shows promise in the initial assessment, it is imperative to emphasise that further investigation is required during the second phase of the project. This additional scrutiny aims to ensure that the chosen location does not result in any negative impacts, either direct or indirect, on the surrounding environment.

There are, however, many other ports with high potential in Scenario B, including Malindi and Mombasa in Kenya, JNPT and Mumbai in India, Mjimwema in Tanzania, Mongla in Bangladesh, Mina Raysut and Mina Al Fahl in Oman. The individual results of the assessment can be found in the Appendix.

Another example are the ports of Darwin and Dampier in Australia. Analysing the five criteria categories shows that these ports score very highly for renewable energy potential and land suitability, which balanced out their low potential for economic improvement.

Scenario C: Ports mainly exploring fuel imports and bunkering

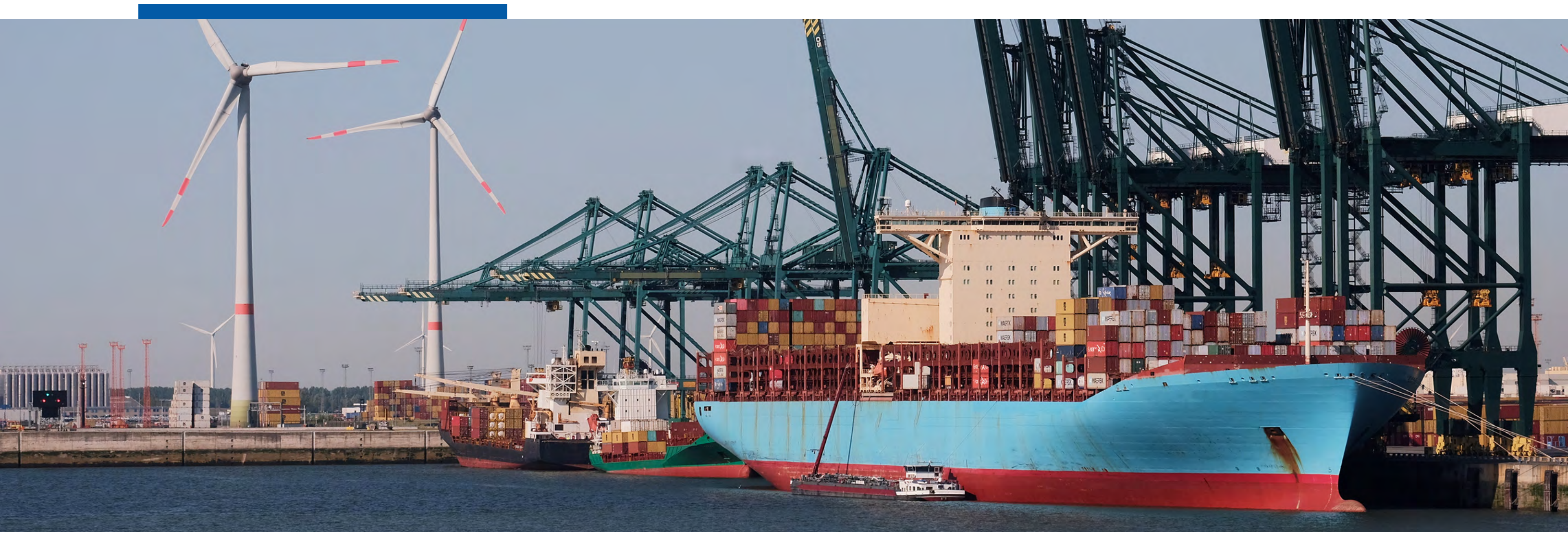
Scenario C indicates the suitability of ports to provide electrofuel storage and bunkering facilities, although this fuel may be imported rather than produced locally. A map of high and promising potential is shown in Figure 7. For this scenario, ports required scores over 1.33 and 0.91 to be classified as "high potential" or "promising potential" respectively.

Results indicate that a smaller number of ports appear to be strong candidates for this category. Three ports appear to have ideal conditions under this scenario, and they are all within 25 km of each other namely: Keppel, Jurong Island, both in Singapore, and Johor in Malaysia. This can be easily explained by the relatively high score they have on the shipping traffic criteria. This also shows why the region is dominated by a few ports for bunkering activities. Nevertheless, the results can still show the potential of other ports considering that shipping traffic for bunkering could change in the future.

FIGURE 7
Visualisation of results for Scenario C. Ports above the third quartile are considered 'high potential', whereas ports between the second and third quartiles are considered 'promising potential'.

Amongst the high potential and promising potential ports, there are JNPT and Mumbai in India, Muhamamad Bin Qasim and Karachi in Pakistan, Shanghai and Tianjin Xin Gang in China, and Khawr Khasab and Mina al Fahl in Oman. The individual results of the assessment can be found in the Appendix.

Conclusion



All in all, the shipping's transition to electrofuels is likely to change the fuel market landscape, creating new and progressive opportunities for developing countries [5]. As the industry aims to meet the IMO's targets and reach net zero by or close to the year 2050, it must do so in a way that is inclusive and sustainable. Through the implementation of Sustainable First Mover Initiatives (SFMIs), there is an opportunity for future initiatives to deliver co-benefits for regions in the Global South, transitioning away from fossil fuels and aligned to the 1.5°C climate target.

Ports as transport and energy hubs can play a crucial role in driving an inclusive maritime energy transition. By fostering SFMIs and delivering co-benefits such as air quality, economic resilience, and environmental sustainability, ports can unlock high impact investments in electrofuel production or distribution infrastructure.

This report presents the methodology and preliminary results of a Sustainable First Mover identification tool that can be used to identify and prioritise port locations that have high potential in developing SFMIs. The underlying approach of this tool explores how shipping stakeholders can evaluate results considering co-benefits, while offering inclusive solutions that deliver benefits to both the environment and the local communities. This tool uses a multicriteria analysis to determine the potential for ports to successfully foster SFMIs. The Indo-Pacific region was chosen as a case study. In this instance, this tool uses five criteria that have been weighted in different way under three scenarios:

Scenario A: Ports exploring both fuel production and bunkering	**Scenario B:** Ports mainly exploring fuel exports	**Scenario C:** Ports mainly exploring fuel imports and bunkering

The weighting systems can vary based on the stakeholders utilising this tool, however, under these circumstances a number of ports show a 'high potential' to develop SFMIs in all scenarios. For example, preliminary results for ports that could produce and bunker electrofuels reveal that Jawaharlal Nehru Port Trust (JNPT) port in India and Chittagong port in Bangladesh performed well across all criteria and ranked as 'high potential'. The complete results provided in the Appendix serve as a good starting point to further assess this tool's outcomes.

This initial port assessment sets the scene for the next phase of this work that will lead to a more comprehensive port level analysis in partnership with local shipping stakeholders and will include the selection and assessment of 10 ports to help better understand local needs and maximise the value offered by SFMIs.

Call to action

There are several key recommendations that can be derived from these results:

- Stakeholders interested in initiating a SFMI must consider the wider benefits of an inclusive representation of various types of ports and stakeholders, especially if located in Global South regions. The inclusion of these wider benefits can identify ports that may otherwise not be in the spotlight for this type of initiatives.

- Shipping's decarbonisation does not happen in isolation and a wider range of potential impacts should be considered. Interested parties can use this tool to further explore the current region of interest (Indo-Pacific) or apply it to other areas.

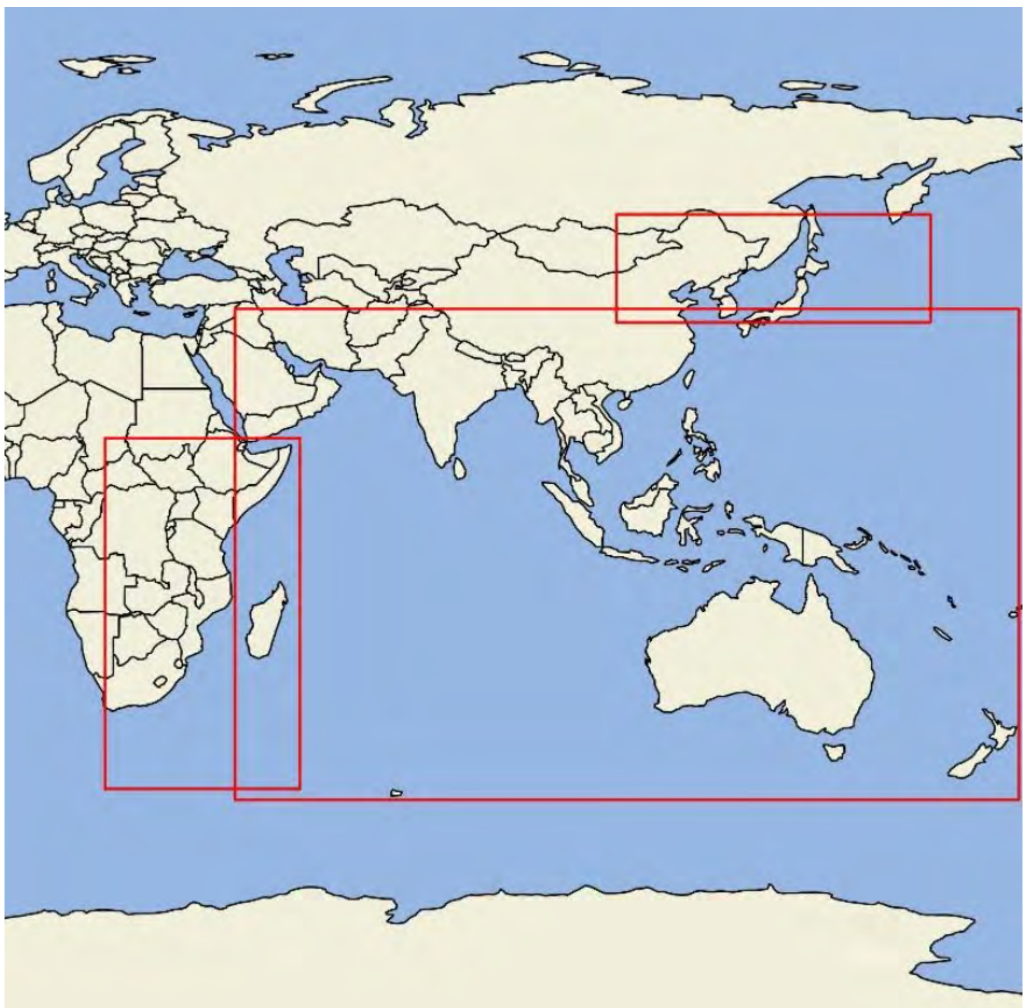
- Financial institutions and governments can use this tool to better understand where to maximise impact of their investments and meet not only climate goals but also improve other environmental indicators together with well-being of local communities. The next phase of this project aims to create case studies for a deep dive into specific ports and explore further details in the assessment of the pre-defined criteria. This follow-up stage will be done in partnership with local stakeholders to ensure as realistic reflection of the ports conditions as possible.

Appendix

Identify the region

At the initial stage, the Indo-Pacific Region (the area that encompass the Indian Ocean and Oceania) was selected as there is a strong mix of Global South and Global North countries, along with major shipping routes. It was necessary to specifically define the region, as shown in Figure 8, where ports within any of the 3 rectangular regions were deemed within scope. The use of three outlines were aimed to prevent the unnecessary division of countries where possible.

FIGURE 8
Sea region defined for case study, all ports that lie within any of the three rectangles.



Divide into ports (narrow to approximately 100)

The next stage required a high-level algorithm to identify approximately 100 ports for further examination. This was conducted in two phases, firstly to assign a target for the number of ports per country, secondly to specifically identify which ports have been selected.

A comprehensive list of all countries within the defined region was complied. Those countries were subject to an initial screening, which removed some countries due to pre-defined criteria (for example political instability). A total of 918 ports then remained in the region across 44 countries. These were cut to 100 ports by establishing a minimum of 1 port per country, then allocating the remaining ports based on land mass.

Then, specific ports for each country were selected. For example, the target for India was to include 9 out of 45 ports, however the selection of which specific ports was non-trivial. An iterative approach was taken, adding ports to the "in scope" list until the target number of ports for each country was achieved (or was at least two less than the target). The ports were added based on the following order:

- All ports with bunkering facilities
- All ports classified as "Large"
- All ports classified as "Medium"
- All ports classified as "Small"
- All ports classified as "Very Small"

On some occasions, multiple ports fell under the same category. For example, Singapore has two "Large" ports with bunkering facilities, therefore both were included, whereas the original target was only one. This trend in the algorithm yielded a total of 108 ports, up from the original target of 100. The full breakdown of ports per country is shown in Table 1, as well as visualization shown in Figure 9.

It is acknowledged that this method for filtering data may have resulted in the exclusion of ports that could be strong candidates. This particular case study covered a very large area, selecting a smaller region for analysis would facilitate a more comprehensive assessment of medium and small sizes ports

TABLE 1

Breakdown of 108 ports by country following the initial screening.

Country	Total Ports In Region	Final Ports In Scope	Country	Total Ports In Region	Final Ports In Scope
Australia	66	12	**Maldives**	1	1
Bangladesh	2	2	**Malaysia**	35	2
Brunei Darussalam	5	2	**Mozambique**	11	2
China	68	10	**New Caledonia**	3	1
Christmas Island	1	1	**Nauru**	1	1
Micronesia, Federated States of	4	1	**New Zealand**	22	2
Guam	1	1	**Oman**	6	3
Hong Kong	1	1	**Papua New Guinea**	22	5
Indonesia	123	2	**Philippines**	70	2
India	45	7	**Pakistan**	3	2
Japan	163	11	**Palau**	1	1
Kenya	4	2	**Reunion**	4	2
Cambodia	2	1	**Solomon Islands**	6	3
Kiribati	1	1	**Seychelles**	1	1
Comoros	4	1	**Singapore**	5	2
South Korea	16	2	**Thailand**	21	1
Sri Lanka	4	3	**Timor-Leste (East Timor)**	1	1
Madagascar	13	2	**Taiwan**	8	1
Marshall Islands	3	3	**Tanzania**	8	3
Myanmar (Burma)	6	1	**Vietnam**	16	1
Macau SAR China	1	1	**Vanuatu**	3	2
Mauritius	2	1	**South Africa**	6	1

FIGURE 9
All 108 ports included in the case study.

Multicriteria analysis (MCA): Define criteria

An objective of the MCA was to deliver an inclusive and fair assessment. To achieve this, a diverse range of criteria were required. A full breakdown of the data sources used is shown in Table 2. Port-specific data sources were used where possible, the exceptions being for: basic water access; gross domestic product (GDP) per capita; Human Development Index (HDI). The assumption has been made that these metrics do not tend to vary considerably within nations, and therefore the adoption of country average data was acceptable.

Port specific data were used due to significant fluctuation from one port to another. For example, the solar potential in Australia ranged from a high of 5.38 kWh/kWp in Dampier (ranked 2nd out of 108 ports) to a low of 3.73 kWh/kWp in Hobart (ranked 90th out of 108 ports). Hence, this justifies the value of a port-specific assessment model rather than a country-wide one.

All datasets shown in Table 2 were normalised based on the maximum value to give a score between 0 and 5.

TABLE 2
Breakdown of all datasets used for the MCA analysis.

Category	Data	Category	Source
Renewable Surplus	Solar Potential	Port specific	[16]
	Wind Potential (both onshore and offshore)	Port specific	[17]
	Basic Water Access	Country average	[18]
	Energy Demand	Country average of consumption per capita x Local Population	[19] [20]
	CO_2 emissions	Country average for CO_2 per capita x Local Population	[21] [20]
	Land Suitability	Local Population	Arup internal database
Air Quality	Air Quality (NO_2, $PM_{2.5}$, O_3)	Port specific	[22]
	PM_{10}	Port specific	[23]
	SO_2	Port specific	[24]
	Population/Population Density	Port specific	[20]
Economic	GDP per capita	Country average	[25]
	Human Development Index (HDI)	Country average	[26]
	Poverty headcount ratio at $2.15	Regional	[27]
	Poverty headcount ratio at $3.65	Regional	[27]
	Poverty headcount ratio at $6.85	Regional	[27]
Shipipng Traffic	AIS data points within 20 km	Port specific	LR internal database
	AIS data points within 100 km	Port specific	LR internal database
	AIS data points within 500 km	Port specific	LR internal database

One of the challenges of this study was attaining comprehensive datasets, this can particularly be attributed to the large number of developing nations and small island states within this study. An illustrative instance involves air quality metrics which, in several of the datasets, contained gaps, potentially caused by a lack of measurement equipment in port areas.

For occurrences where there were gaps in data, the weightings of the available data were scaled up to still provide a normalised score for air quality out of five.

This method is reinforced by the strong correlation between these data entries, for example nitrogen dioxide (NO_2) has a correlation coefficient of 0.57, 0.54 and 0.2 for O_3, $PM_{2.5}$, and PM_{10} respectively.

A further data gap was evident in the poverty headcount ratio, which contained entries for 88 of the 108 ports. This was managed by scaling up the GDP and HDI metrics. Then, the remaining datasets used covered all ports.

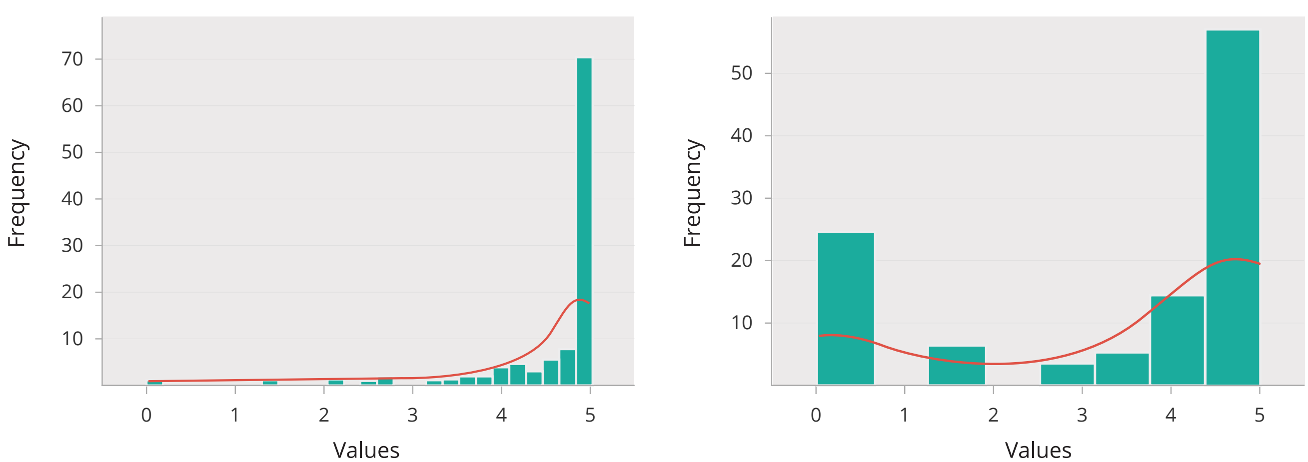
Adjustments for outliers

As shown in Table 2, both the energy demand and carbon dioxide (CO_2) emissions data were based on per capita scores and multiplied by the local population score. However, this approach leads to a strong positive skew of the population data with a maximum value of 25.4 million (Manila, Philippines) which is significantly higher than the mean of 2.5 million. Hence, the resulting score for low energy demand was significantly skewed, as shown on the left-hand side of Figure 10.

This resulted in 70 ports being assigned a score of 4.8 or more out of 5 for low energy demand, which made it difficult to differential between these ports. To manage this, any port in the 20th percentile for high energy consumption was assigned a score of 0, then the remaining ports were renormalised. The resulting spread of scores are shown on the right-hand side of Figure 10, which shows a more balanced spread of results.

The same method was applied for total CO_2 emissions.

FIGURE 10
Score for low energy demand before the removal of outliers (left) and afterwards (right)



Land suitability scoring

The land suitability scoring system was determined using data from Arup's internal system, with a final score being delivered based on weighted scores for local infrastructure (14.3%), current land use (71.4%), and slope (14.3%). To assess these factors, scores were assigned for each hexagon with 100 km of each port. The fifth highest scoring port was Beira, Mozambique, results for this port are in Figure 11.

FIGURE 11
Land suitability scores for Beira, Mozambique. Clockwise from the top-left: infrastructure; current land use; slope; final land suitability score. Scores are represented on a scale with green being highest and red the lowest.

Multicriteria analysis (MCA): Weighting the criteria

The full distribution of weightings for the MCA analysis were shown in Figure 2 (in the main body of the report) for Scenario A. This includes the weightings for the lower levels of the analysis. Generally, the approach taken was to weigh the criteria evenly unless there was justification for differentiation. For example, for the Renewable Surplus score, Clear Water Availability was weighted slightly lower than the other criteria due to the argument that desalination of water before electrofuel production is a viable option. Hence, high clean water access is beneficial but may not be an absolute necessity.

The Air Quality metrics were based on the WHO's AQG levels for the daily maximum limit of each of these pollutants. For example, the maximum limit of $PM_{2.5}$ is three times smaller than PM_{10}, therefore it has been weighted three times higher in the MCA analysis, as shown in Table 3.

TABLE 3
Pollutant weighting based on the World Health Organization's Air Quality Guideline levels [28]

Pollutant	AQC levels (WHO)	Weighting (/1)
$PM_{2.5}$	15	0.41
PM_{10}	45	0.14
O_3	100	0.06
NO_2	25	0.24
SO_2	40	0.15

For scenarios B and C, the weighting for each of the five criteria categories was changed but the underlying weighting for other criteria within each of these categories did not change, as was shown in Figures 3 and 4.

Results: Breakdown by scenario

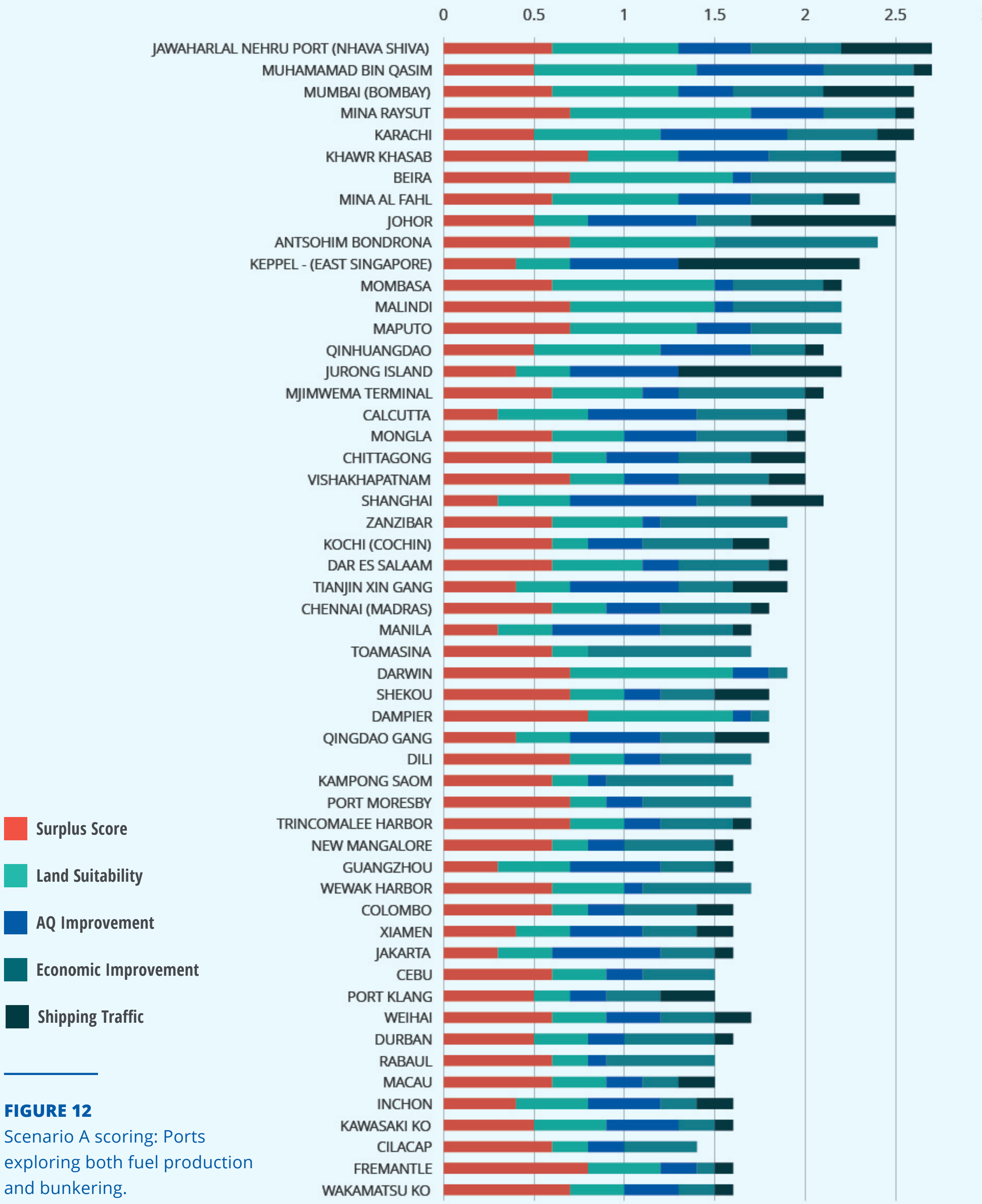


FIGURE 12

Scenario A scoring: Ports exploring both fuel production and bunkering.

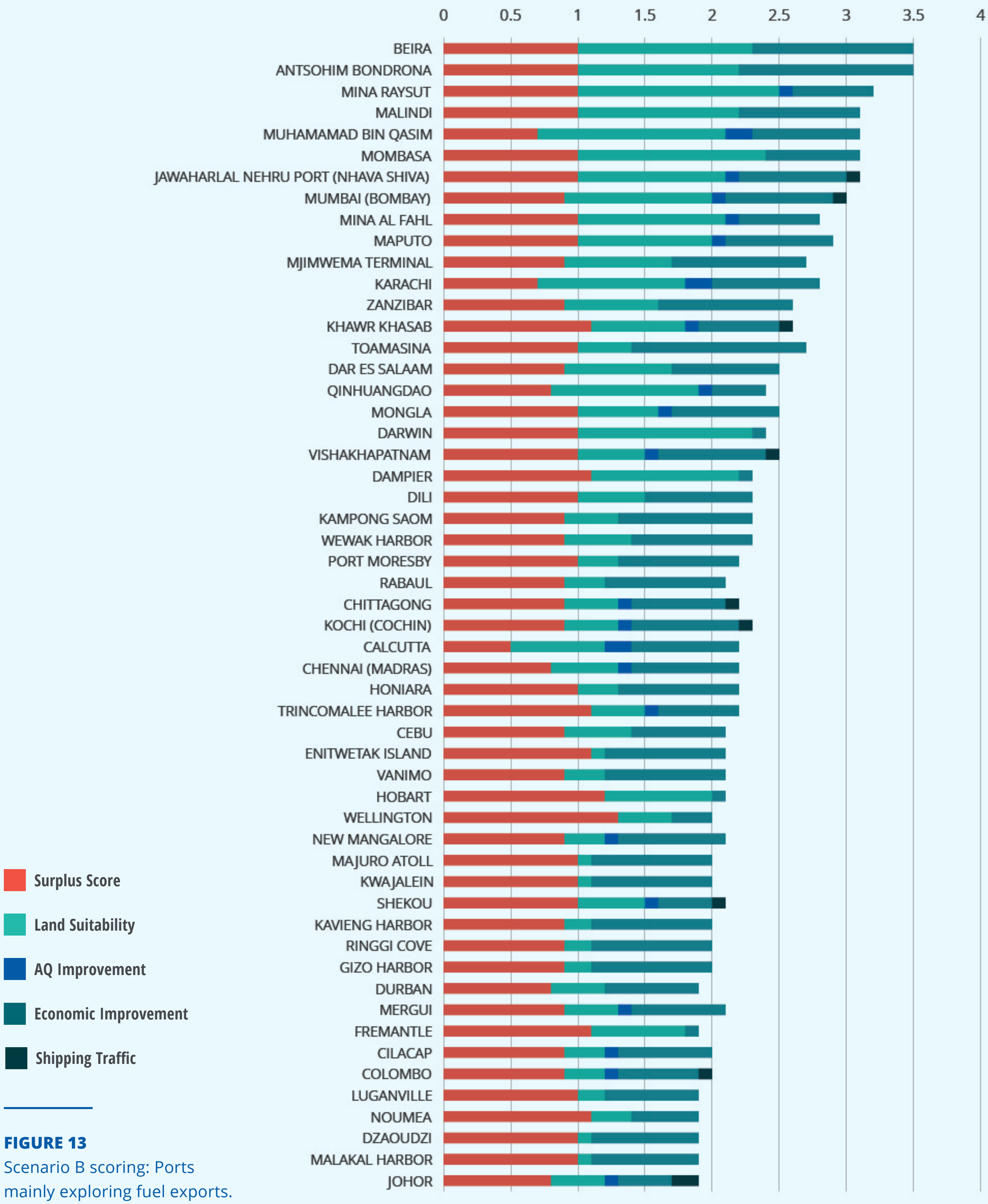


FIGURE 13
Scenario B scoring: Ports mainly exploring fuel exports.

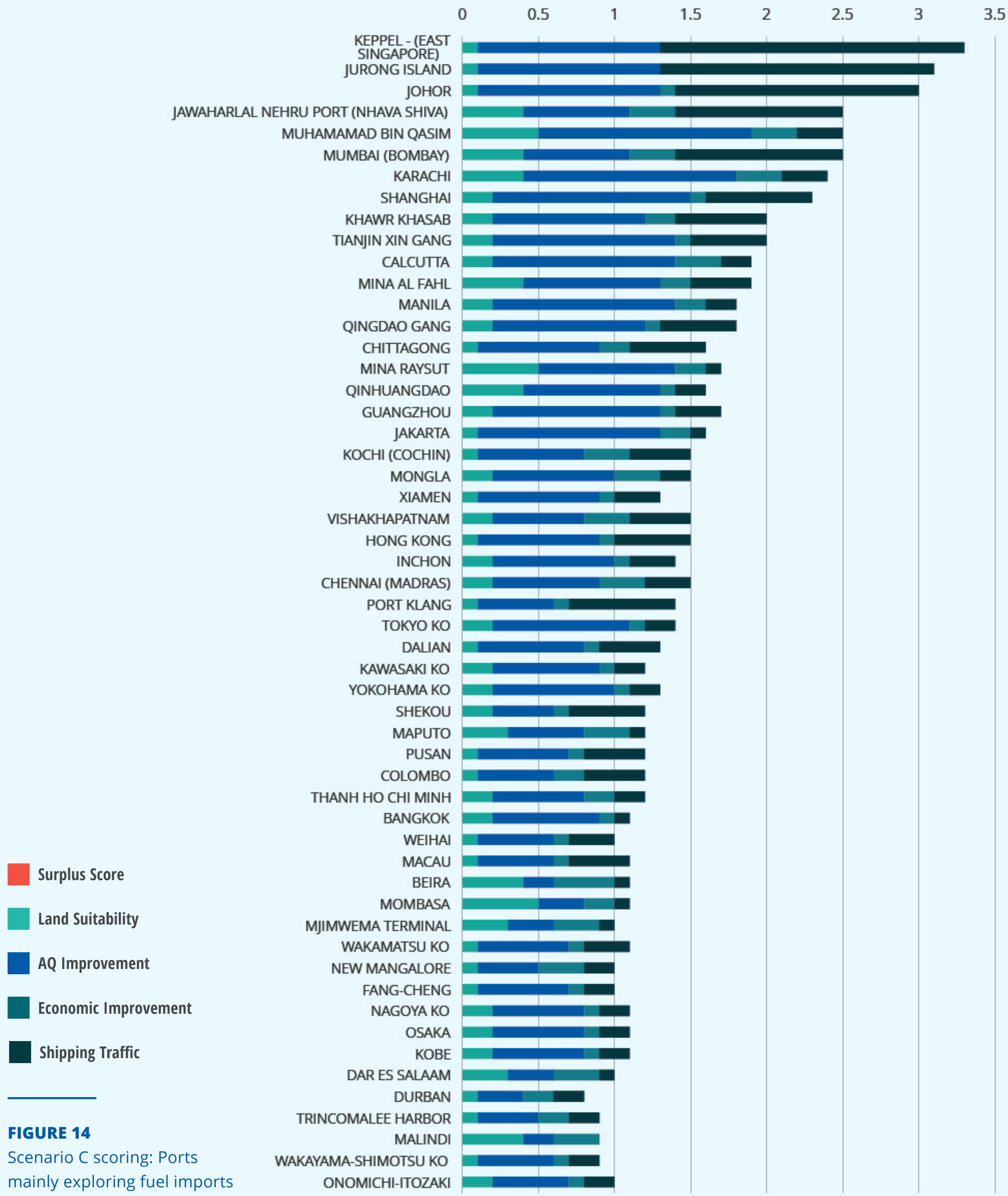


FIGURE 14
Scenario C scoring: Ports mainly exploring fuel imports and bunkering.

References

[1] International Maritime Organization (IMO), "IMO Strategy on Reduction of GHG Emissions From Ships," 2023. [Online]. Available: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf.

[2] United Nations Conference on Trade and Development (UNCTAD), "Review of Maritime Transport," 2023. [Online]. Available: https://www.un-ilibrary.org/content/books/9789213584569.

[3] International Maritime Organization (IMO), "Fourth Greenhouse Gas Study," 2020. [Online]. Available: https://www.imo.org/en/ourwork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx.

[4] Global Maritime Forum, "The scale of investment needed to decarbonize international shipping [Online]," 2020. [Online]. Available: https://www.globalmaritimeforum.org/content/2020/01/Getting-to-Zero-Coalition_Insight-brief_Scale-of-investment.pdf.

[5] The World Bank Blogs, "Zero-carbon shipping: A sea of opportunities for developing countries, [Online]," 2021. [Online]. Available: https://blogs.worldbank.org/climatechange/zero-carbon-shipping-sea-opportunities-developing-countries.

[6] Lloyd's Register Maritime Decarbonisation Hub, "First movers in shipping's decarbonisation. A framework for getting started," 2021. [Online]. Available: https://www.lr.org/en/knowledge/research-reports/first-movers-in-shippings-decarbonisation/.

[7] United Nations Conference on Trade and Development (UNCTAD), "Why should we talk about a 'just and equitable' transition for shipping?'," 2022. [Online]. Available: https://unctad.org/news/why-should-we-talk-about-just-and-equitable-transition-shipping#:~:.

[8] United Nations Environment Programme (UNEP), "The UNEP Environmental Data Explorer, as compiled from UNEP/DEWA/GRID-Geneva," 2014. [Online]. Available: http://geodata.grid.unep.ch..

[9] Environmental Defense Fund (EDF), "Making clean ports a reality across the country. How EDF's work on ports has scaled up and influenced industry-wide change.," 2018. [Online]. Available: https://www.edf.org/climate/making-clean-ports-reality-across-country.

[10] Environmental Defense Fund (EDF), "Electrofuels for shipping How synthetic fuels from renewable electricity could unlock sustainable investment in countries like Chile.," 2019. [Online]. Available: https://www.edfeurope.org/news/2019/10/12/electrofuels-shipping#:~:text=Electrofuels%20for%20Shipping%2C%20produced%20by,namely%20ammonia%2C%20hydrogen%20and%20methanol.

[11] IEA, "Net Zero Roadmap: A Global Pathway to Keep the 1.5C Goal in Reach," Internation Energy Agency, 2023. [Online]. Available: https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach .

[12] United Nations Conference on Trade and Development (UNCTAD), "Climate-resilience of seaports: Adequate finance is critical for developing countries but remains a major challenge. Policy Brief 103.," 2022. [Online]. Available: https://unctad.org/publication/climate-resilience-seaports-adequate-finance-critical-developing-countries-remains.

[13] IRENA, "A pathway to decarbonize the shipping sector by 2050," 2021. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf .

[14] United Nations Framework Convention on Climate Change (UNFCCC), "Multicriteria Analysis (MCA)," 2023. [Online]. Available: https://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/multicriteria_analysis__mca_pdf.pdf .

[15] Organisation for Economic Co-operation and Development, "Land cover in countries and regions," OECD.Stat, 2019. [Online]. Available: https://stats.oecd.org/Index.aspx?DataSetCode=LAND_COVER.

[16] Global Solar Atlas 2.0, "Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP)," 2019. [Online]. Available: https://globalsolaratlas.info.

[17] Global Wind Atlas 3.0, "Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using fundi," 2019. [Online]. Available: https://globalwindatlas.info.

[18] Unicef, "Drinking water, sanitation and hygiene (WASH) estimates," JMP, July 2023. [Online]. Available: https://data.unicef.org/topic/water-and-sanitation/drinking-water/.

[19] U.S. Energy Information Administration (EIA), "Energy Institute Statistical Review of World Energy," 2023. [Online]. Available: https://ourworldindata.org/grapher/per-capita-energy-use.

[20] City Population, "Population statistics for countries, administrative divisions, cities, urban areas and agglomerations – interactive maps and charts," 2022. [Online]. Available: https://www.citypopulation.de/.

[21] H. Ritchie, M. Roser and P. Rosado, "CO_2 and Greenhouse Gas Emissions," OurWorldInData.org, 2020. [Online]. Available: https://ourworldindata.org/co2-and-greenhouse-gas-emissions.

[22] Milken Institute School of Public Health, "Urban Air Quality Explorer," The George Washington University, HAQAST, 2019. [Online]. Available: https://urbanairquality.online/.

[23] World Health Organisation, "WHO Ambient Air Quality Database (Update 2023)," 2023. [Online]. Available: https://www.who.int/publications/m/item/who-ambient-air-quality-database-(update-2023).

[24] W. Aas, A. Mortier, V. Bowersox, R. Cherian, G. Faluvegi, H. Fagerli, J. Hand, Z. Klimont, C. Galy-Lacaux, C. M. Lehmann, C. Lund Myhre, G. Myhre, D. Olivié, K. Sato and J. Quaas, "Trends in atmospheric sulfur components from the major regional monitoring network including results from six global atmospheric transport models, 1990-2015," Actris Data Centre, 2018. [Online]. Available: https://doi.org/10.21336/GEN.2.

[25] The World Bank, "GDP per capita (current US$) - World Bank Gender Data Portal," 2022. [Online]. Available: https://genderdata.worldbank.org/indicators/ny-gdp-pcap-cd/.

[26] United Nations Development Programme, "Human Development Index (HDI)," 2022. [Online]. Available: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI.

[27] The World Bank, "Global Subnational Poverty Atlas (GSAP): Subnational poverty and inequality database," 2023. [Online]. Available: https://datacatalog.worldbank.org/search/dataset/0042041/Global-Subnational-Poverty-Atlas--GSAP-.

[28] World Health Organization (WHO) , "WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.," Geneva, 2021.

[29] International Council for Clean Transportation (ICCT), "Electrifying ports to reduce diesel pollution from ships and trucks and benefit public health: Case studies of the Port of Seattle and the Port of New York and New Jersey," 2023. [Online]. Available: https://theicct.org/wp-content/uploads/2023/02/Ports-electrification_wp_final2.pdf.

This report was prepared by the Environmental Defense Fund
and the Lloyd's Register Maritime Decarbonisation Hub
in collaboration with Arup.

LR Environmental Defense Fund ARUP