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The potential of Brazilian ports as renewable marine fuel bunkering hubs

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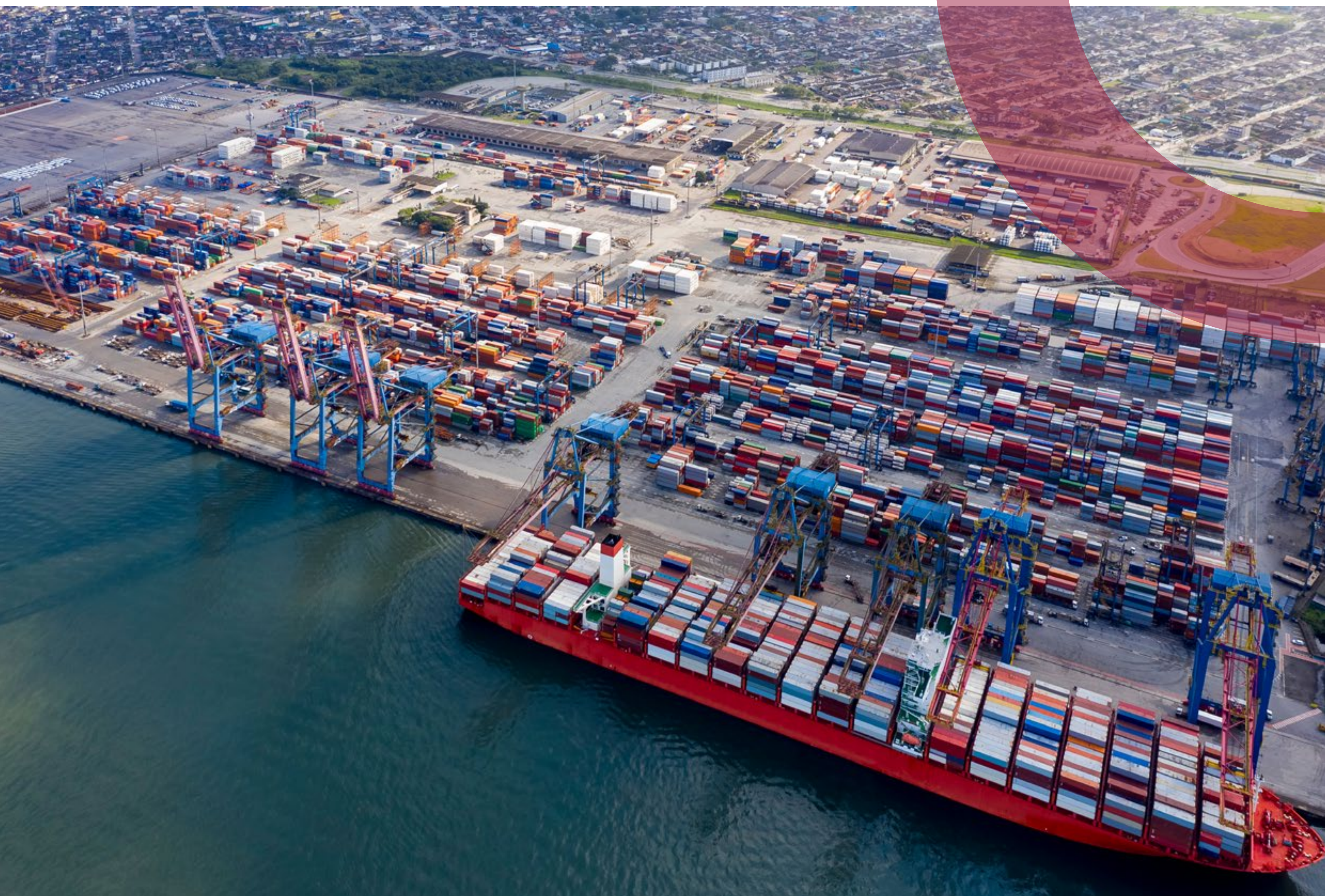

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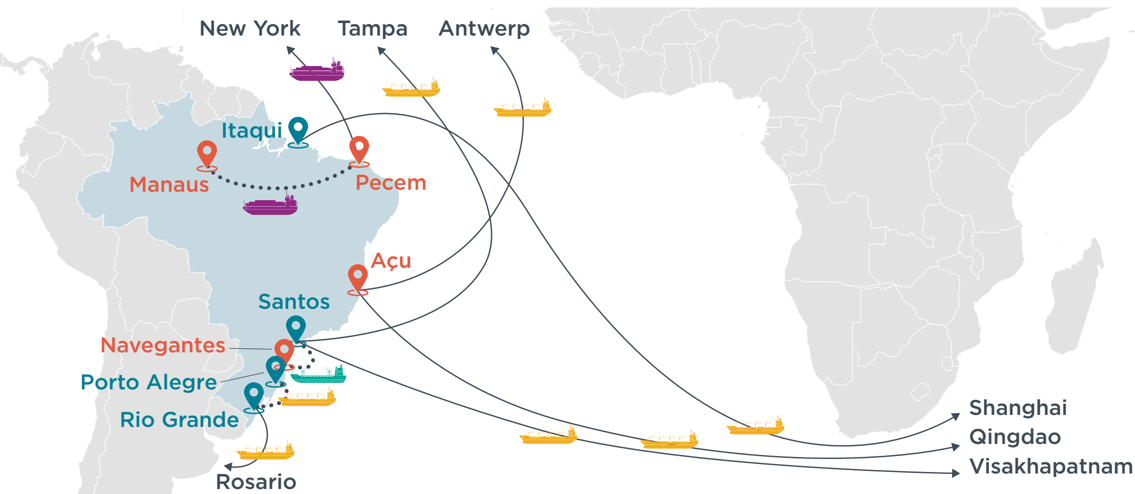
EXECUTIVE SUMMARY

Brazil's abundant renewable energy resources and location enable it to play a unique role in ramping up renewable fuel production for use in the maritime shipping sector. This study explores the potential of Brazilian ports to become key hubs for supplying renewable hydrogen and its derivatives, renewable ammonia and renewable methanol. We examine the best conditions for producing, and selling these renewable energy sources, their potential application in green shipping corridors, and the readiness of ports as determined by factors including existing infrastructure and logistical capacity. We also analyze existing ship traffic and estimate the potential bunkering demand for renewable marine fuels to support zero-emission vessels servicing international and domestic routes from selected ports. This helps provide a foundation for future investment and policy decisions aimed at developing green shipping infrastructure in Brazil.

Our port readiness assessment identified six Brazilian ports as candidate hubs for renewable marine fuel bunkering. Three are public ports—Santos, Rio Grande, and Itaqui—and three are privately owned ports—Pecem, Navegantes, and Porto do Açu. Among the 10 sample routes moving key commodities, including iron ore and container cargo, between the candidate ports and ports around the world, we estimated that five routes could be completed with direct use of renewable liquid hydrogen in a fuel cell without refueling en route. We found all routes could be completed without refueling if ships use renewable hydrogen-derived ammonia and methanol in internal combustion engines. To successfully complete all 10 routes, with at least one ship on each route, we need a total energy requirement of 1,785 tonnes of hydrogen if we consider the minimum consumption of renewable fuel across all routes. Conversely, if we look at the maximum consumption of renewable fuel for all 10 routes, the total energy requirement is 1,911 tonnes. This translates to a demand for renewable electricity of 82 to 92 GWh.

Figure ES1
Candidate ports as future renewable marine fuel bunkering hubs and sample routes



Route	Route port	Route type
Rio Grande - Porto Alegre	Rio Grande	Cabotage ·····
Itaqui - Shanghai	Itaqui	International ——
Rio Grande - Rosario	Rio Grande	International ——
Santos - Tampa	Santos	International ——
Santos - Visakhapatnam	Santos	International ——
Navegantes - Santos	Navegantes	Cabotage ·····
Pecem - Manaus	Pecem	Cabotage ·····
Pecem - New York	Pecem	International ——
Porto do Acu - Qingdao	Porto do Açu	International ——
Porto do Açu - Antwerp	Porto do Açu	International ——

Public port
Private port
General cargo ship
Container ship
Bulkcarrier ship

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Targeted investments in renewable energy production, storage, and bunkering facilities at these ports could accelerate establishing green shipping corridors. Supporting these would align with Brazil's goals for maritime decarbonization and leadership in the global green shipping transition.

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INTRODUCTION

The maritime shipping sector faces increasing pressure to decarbonize. This comes from various sources, including regulatory bodies like the International Maritime Organization (IMO) and growing global demand for sustainable practices from consumers, environmental organizations, and governments focused on mitigating climate change. While several alternative fuels and technologies have the potential to reduce shipping's carbon footprint, renewable hydrogen and its derivatives (e.g., ammonia and methanol) have emerged as promising candidates for achieving significant emission reductions. Brazil's abundant renewable energy resources and strategic location position it as a potential leader in the emerging market for such fuels.

The ICCT has conducted several studies regarding the potential demand for renewable hydrogen and its derivatives, and the opportunity to create green shipping corridors (Mao et al., 2020; Georgeff et al., 2020; Sturrup & Stolz, 2023; Mao et al., 2024; United States Maritime Administration, 2023). This report builds on that work and investigates the potential of ports in Brazil to serve as bunkering hubs for renewable hydrogen-derived fuels—including renewable hydrogen (RE-LH_2), renewable ammonia (RE-NH_3), and renewable methanol (RE-MeOH)—and the potential demand for such fuels in these ports. First, we introduce an analytical framework of port readiness that ranks the suitability of Brazil's ports for renewable hydrogen bunkering; this considers renewable energy potential, infrastructure, and logistical capacity. After that, we analyze shipping activity to, from, and between ports in Brazil to estimate the energy demand of ships based on their current fuel use. We then calculate the equivalent demand for renewable marine fuels if these same ships, with the same capacity and routes, were zero-emission vessels.

BACKGROUND

Despite the inherent energy efficiency of maritime shipping, which is driven by its high cargo capacity, it remains a substantial contributor to global anthropogenic carbon dioxide (CO_2) emissions due to its scale (Balcombe et al., 2019). A UN Trade and Development (2023) report stated that global CO_2 emissions from shipping reached 848 million tonnes in March 2023, a 20% increase from March 2013. To alleviate the climate impacts of shipping, the IMO adopted a strategy to reach net-zero greenhouse gas (GHG) emissions from shipping by or around 2050. The strategy also sets indicative checkpoints that call for reducing total GHG emissions by 20% (striving for 30%) by 2030 and 70% (striving for 80%) by 2040, both relative to 2008 levels (IMO, 2023). While the IMO has mandated several technical and operational energy efficiency measures for improving the energy efficiency of ships, the use of alternative fuels that can bring life-cycle GHG emissions to zero or near zero will be essential for reducing shipping emissions (Van Hoecke et al., 2021).

Electrofuels, also known as e-fuels or synthetic fuels, are one promising avenue for decarbonizing transport sectors that are difficult to electrify, like shipping. These fuels are produced by using renewable electricity to power water electrolysis and generate hydrogen. This renewable hydrogen is an e-fuel that can be used directly or be further processed to create other e-fuels. For example, renewable hydrogen can be combined with captured CO_2 through Fischer-Tropsch synthesis to produce liquid hydrocarbons such as e-diesel or e-methanol. Alternatively, it can react with nitrogen to produce e-ammonia. At present, the production of e-fuels is energy intensive and expensive, with costs significantly higher than fossil fuels. While technological advancements and economies of scale could reduce these costs in the future, achieving cost parity with fossil fuels is currently a challenge to widespread adoption (Carvalho et al., 2023; Zhou et al., 2022; Baldino & Searle, 2021; Mao et al., 2025).

Global hydrogen production reached 97 million tonnes in 2023, and just 0.1% of this was derived from electrolysis powered by renewable electricity (International Energy Agency, 2024). However, projected expansions of electrolyzer capacity suggest that by 2050, renewable hydrogen will potentially be 50%–65% of the total supply mix (Gulli et al., 2024). One study that estimated at-the-pump costs (including both fuel production and refueling costs) in the United States found that renewable hydrogen and most synthetic fuels were more than three times higher than traditional marine fuel but would likely become less costly over time (United States Maritime Administration, 2023). Producing renewable hydrogen at competitive costs depends on access to abundant, low-cost renewable power, and Brazil is exceptionally well-positioned to provide this due to its vast renewable energy resources and the anticipated growth of wind and solar-based electricity generation (International Renewable Energy Agency, 2022; Carvalho et al., 2023).

RENEWABLE ENERGY PRODUCTION AND POTENTIAL IN BRAZIL

Brazil's large landmass and diverse climate contribute to its high solar photovoltaic output, which is typically within the mid-range of 3.5–4.5 kWh/kWp.[1] Although not the highest globally, this range indicates substantial solar potential. In contrast, most countries in the European Union, except for those in Southern Europe, typically have a solar photovoltaic output below 3.5 kWh/kWp (Suri et al., 2020).

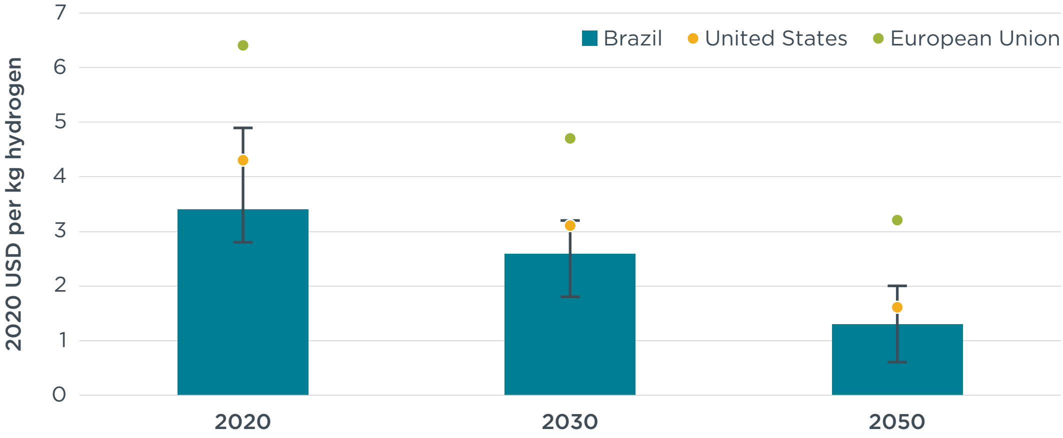
1 Essentially, kWh/kWp indicates how much energy in kilowatt-hours the solar photovoltaic system produces for each kilowatt of its peak capacity over a designated time frame, often a day or year. This helps assess the efficiency and effectiveness of solar energy systems in capturing and converting sunlight into electricity.

Beyond wind and solar, Brazil benefits from a well-established and extensive infrastructure for biofuel production. This network of pipelines, storage facilities, and distribution systems offers a considerable advantage for a potential transition to methanol production. As methanol is a promising hydrogen carrier, adapting this infrastructure could substantially reduce the capital costs associated with developing a hydrogen economy in Brazil.

In 2023, renewable feedstocks comprised approximately 89% of Brazil's domestic electricity supply, with hydropower making up 60%; that was followed by wind (14%), biofuels (8%), and solar photovoltaic generation at 7% (International Energy Agency, 2023; Silva et al., 2023; Ferreira et al., 2023; Khare et al., 2023; Empresa de Pesquisa Energética, 2024). A previous ICCT study projected that renewable hydrogen production would be cheaper in Brazil than in the European Union and the United States (Carvalho et al., 2023). This cost advantage, illustrated in Figure 1, is directly from Brazil's abundant and low-cost renewable energy resources.

Figure 1

Estimated production costs in the three major regions



Source: Carvalho et al. (2023)

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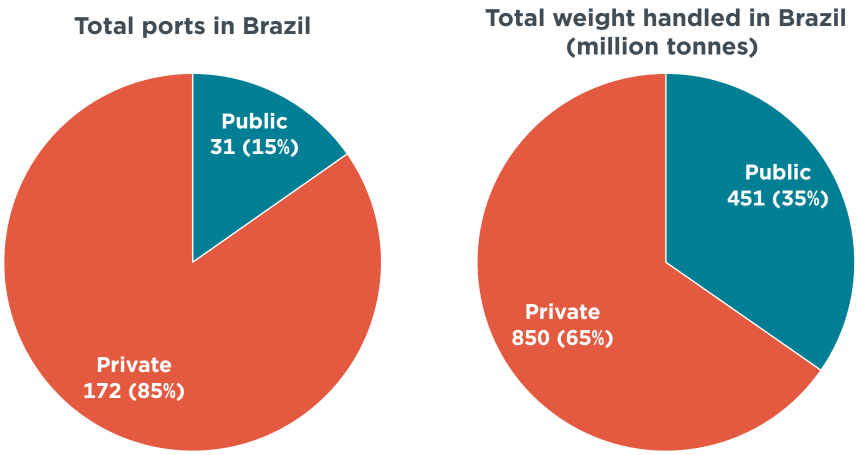
Brazil's nascent renewable hydrogen sector, with ongoing pilot projects, could reach production of 1 million tonnes annually by 2030 (Klevstrand, 2023). This is contingent on technological scale-up, infrastructure development, and cost parity with fossil fuels.

PORTS AND GREEN SHIPPING CORRIDORS

In Brazil, public ports are 15% of the total ports but handle 35% of the cargo by weight (Figure 2). Figure 3 highlights the geographic distribution of the 20 ports that moved the most cargo in 2023.

Figure 2

Cargo weight handled capacity by public and private ports in Brazil in 2023



Source: Agência Nacional de Transportes Aquaviários (ANTAQ2024)

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Figure 3

The 20 ports in Brazil that moved the most cargo in 2023

Source: ANTAQ (2024)

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Developing ports as hydrogen hubs involves integrating them into the entire hydrogen value chain, from production and storage to transportation, distribution, and bunkering (Fages et al., 2023). This requires substantial investment in production facilities (electrolyzers and e-fuel synthesis plants), storage, pipelines, and dedicated bunkering infrastructure.

Brazil has become a significant hub for planned renewable hydrogen projects, with announced investments reaching US$21 billion (roughly R$105 billion, based on early May 2025 exchange rates) designated for plant construction. These commitments, largely from private companies and consortia, are concentrated primarily at strategic ports in the northeast, such as Pecem (Ceara) and Suape (Pernambuco), and also at Porto de Açu in Rio de Janeiro (Aranha 2023). The concentration of investment in the northeast is strategically advantageous, as the region accounts for 82% of Brazil's solar and wind energy generation capacity (Carvalho et al., 2023).

Additionally, Brazil recently approved Law 15,097, which creates a comprehensive regulatory framework for offshore wind power. It is designed to facilitate and regulate auctions for and investment in the development of offshore wind projects, and is expected to establish clear guidelines and procedures (Lei No. 15.097, de 10 de janeiro, 2025). The new framework, coupled with existing and planned infrastructure, provides a strong foundation for developing hydrogen bunkering capabilities.

Green shipping corridors are defined as maritime routes established between two or more ports where zero-emission fuels are deployed (Maersk Mc-Kinney Møller Center for Zero Carbon Shipping, 2022; Global Maritime Forum, 2022). As of February 2024, there were 57 green shipping corridor initiatives operating globally (DNV, 2024). By concentrating efforts and resources on specific routes, stakeholders can accelerate the development of necessary bunkering infrastructure and stimulate demand for renewable shipping fuels. The focused nature of green shipping corridors simplifies stakeholder engagement and allows for targeted regulations (Mao et al., 2024).

METHODOLOGY

We employed a two-step approach to assess the potential of Brazilian ports to serve as renewable hydrogen bunkering hubs. On the supply side, we evaluated the readiness of ports to supply renewable liquefied hydrogen (RE-LH_2), renewable ammonia (RE-NH_3), and renewable methanol (RE-MeOH) by using a multifactor analytical framework that combines quantitative and qualitative criteria. On the demand side, we analyzed existing ship traffic and estimated the potential initial demand for bunkering renewable marine fuels within the context of green shipping corridors. This is a pre-feasibility study, and we screened initial port candidates that were then given further consideration.

PORT READINESS

There are many factors to consider when evaluating a port's readiness to develop bunkering capability for renewable marine fuel. After consulting experts from the maritime and ports industry, we decided on five criteria for our assessment when screening initial port candidates:[2]

1. Existing use of and potential access to renewable energy
2. Port capacity
3. Port infrastructure
4. Strategic location and connectivity
5. Commitment to decarbonization

Our primary data sources for information about ports were a public database from the Brazilian national waterway transportation agency, Agência Nacional de Transportes Aquaviários (ANTAQ), and the World Port Index. The former provides information on all public and private Brazilian ports (203 in total), including their location, cargo movement types, and import/export volumes (ANTAQ, 2024). The World Port Index provides information on a port's type, maximum draft, length, cargo facilities, and other characteristics (National Geospatial-Intelligence Agency, 2024). We also collected information from individual port websites about existing bunkering infrastructure, availability of land for expansion, and participation in the Port Decarbonization Alliance.[3] When information was missing, we consulted experts from Brazil's Ministry of Ports and Airports for insights.

For each criterion, we assigned each port a score of 1 to 5, with 5 indicating the highest ranking. We also created three weighting scenarios that we used to combine the scores of the five criteria for each port into a final score (see Appendix A for details).

Criterion 1: Existing use of and potential access to renewable energy

Because RE-LH_2, RE-NH_3, and RE-MeOH are produced using renewable electricity, one key factor in evaluating the readiness of a port is access to abundant renewable energy resources. Consistent with the approach taken by Mao et al. (2024), which assessed the same criteria for China's maritime sector, we only evaluated offshore wind resources near ports because (1) compared with solar, the land requirements for wind farms is much smaller, and (2) compared with electricity generated from remote wind farms, the cost of transporting electricity is minimal for fuel production at the port.

2 The ICCT signed a memorandum of understanding with Brazil's Ministry of Ports and Airports and consulted with officials from the National Secretariat of Ports. These discussions involved experts responsible for port policy, regulation, management, and infrastructure planning.

3 The Brazilian Alliance for Port Decarbonization is a forum that promotes collaboration and knowledge sharing to accelerate the decarbonization of Brazil's port and maritime sectors. It gathers various stakeholders to implement strategic actions, facilitate debates, and develop effective decarbonization strategies.

This criterion includes both quantitative and qualitative considerations. Based on the *Statistical Yearbook of Electric Energy 2021* (Empresa de Pesquisa Energética, 2021; Brasil em Mapas, 2023), we established the dominant electricity source for each Brazilian state. If the Brazilian Electricity Regulatory Agency tracking system certified that a state's electricity generation is primarily from renewable sources—including hydropower, wind, and solar—we categorized the port in that state as having a "high" existing use of renewable energy. We utilized wind speed data to assess a port's potential to access offshore wind (World Bank, 2020). This quantitative indicator directly reflects the resource availability for offshore wind development. The top 10 highest-scoring ports on this criterion are presented in Table 1. Detailed results for the top 30 ports by this criterion are in Appendix C.

Table 1
Top 10 highest-scoring ports on Criterion 1

Port name	Port state	Existing use of renewable energy	Offshore wind speed (m/s)	Score
Guamare Oil Terminal	RN	High	>10	5
Pelotas	RS	High	>10	5
Porto Alegre	RS	High	>10	5
Rio Grande	RS	High	>10	5
Sao Francisco do Sul	SC	High	9	5
Imbituba	SC	High	8.75	5
Pecem	CE	High	8	4
Fortaleza	CE	High	7.75	4
Natal	RN	High	8	4
Antonina	PR	High	6	4

Criterion 2: Port capacity

This quantitative criterion assesses port capacity based on cargo throughput data from the ANTAQ database. Table 2 shows the top 10 Brazilian ports ranked by 2023 cargo throughput, their main cargo types, port type (public or private), and assigned scores. The scores reflect the relative capacity of each port, with a 5 indicating the highest capacity, and the remaining scores representing progressively lower capacity tiers based on the distribution of cargo volume. In Brazil, both public and private ports are highly active. The Port of Santos, the largest port, handled 166 million tonnes of cargo in 2023, including solid and liquid bulk, container cargo, and general cargo. Similarly, Porto do Açu is a major port specializing in dry bulk, breakbulk, and liquefied natural gas. Detailed results for the top 30 ports are in Appendix C.

Table 2
Top 10 highest-scoring ports on Criterion 2

Port name	Main cargo type	Total cargo throughput 2023 (million tonnes)	Type of port	Score
Santos	Bulk solid - Soybeans	166	Public	5
Ponta da Madeira	Bulk solid - Iron ores	166	Private	5
Porto do Açu	Bulk liquid and gaseous - Crude petroleum oils	84	Private	4
Tubarao	Bulk solid - Iron ores	76	Private	4
Paranagua	Bulk solid - Soybeans	66	Public	4
Angra dos Reis	Bulk liquid and gaseous - Crude petroleum oils	64	Private	4
Sao Sebastiao	Bulk liquid and gaseous - Petroleum oils	59	Private	4
Itaguai	Bulk solid - Iron ores	56	Public	4
Rio Grande	Bulk solid - Soybeans	40	Public	3
Vila do Conde	Bulk solid - Artificial corundum	38	Public	3

Criterion 3: Port infrastructure

For the qualitative criterion of port infrastructure, we focus on land and bunkering capability. A larger port has more potential to provide bunkering services as it can accommodate more and larger ships; additionally, a port that has access to land for potential future expansion has more potential to provide renewable marine fuel bunkering, as land is required to host facilities producing the fuel. Although there are currently no RE-LH_2, RE-NH_3, or RE-MeOH bunkering operations in Brazil, a port with existing bunkering facilities for traditional marine fuel has more potential than a port without. In Brazil, there are 18 ports that sell bunker fuel to ships, and they almost exclusively sell residual fuel and distillate fuel (see Appendix B for the list of bunker ports). The final scores of the top 10 ports are presented in Table 3. Scores for the top 30 ports are in Appendix C.

Table 3
Top 10 highest-scoring ports on Criterion 3

Port name	Area (million M^2)	Maximum draft	Existence of expansion area	Existence of bunkering facility	Score
Santos	7.9	15	Yes	Yes	5
Itaqui	2.6	23	Yes	Yes	5
Sao Sebastiao	0.4	23	Yes	Yes	4
Rio Grande	5.5	12.8	Yes	Yes	4
Suape	3.2	17.3	Yes	Yes	4
Paranagua	0.1	13.3	Yes	Yes	4
Salvador	0.3	14.7	Yes	Yes	4
Maceio	0.3	10.5	Yes	Yes	4
Recife	0.1	12	Yes	Yes	4
Angra dos Reis	0.1	9	Yes	Yes	4

Criterion 4: Strategic location and connectivity

Strategic location and connectivity are crucial factors in determining a port's suitability as a bunkering hub, as it indicates demand for bunkering. This demand is essential for achieving economies of scale that can offset the high investment cost of providing renewable marine fuel (United States Maritime Administration, 2023).

According to Carvalho and Costa (2024), Brazil's main trade partners include Argentina, China, Russia, and the United States. The main export products in terms of value are iron ore, soybeans, crude oil, and sugar. The main import products are higher-value-added commodities like automobile parts, telecommunications equipment, and natural gas. For domestic shipping, crude oil and its derivatives dominate the demand for transport services (Carvalho & Costa, 2024).

This criterion was evaluated based on a series of quantitative and qualitative factors. First, public ports, all managed by the Ministry of Ports and Airports, were regarded as more strategically significant than private ports due to their roles in national infrastructure. Second, ports with established shipping routes linked to major trade partners were deemed more strategically important. Third, connectivity, assessed by the number of connection routes for both international and cabotage voyages, was considered as it indicates the reach of economic impact. The scores are presented in Table 4, along with the main type of cargo involved in these routes. Results for the top 30 ports are in Appendix C.

Table 4
Top 10 highest-scoring ports on Criterion 4

Port name	Cabotage			International			Port type	Score
	Typical route (State)	Number of connection routes	Main type of cargo	Typical route (Country)	Number of connection routes	Main type of cargo		
Santos	RJ	15	Oil and derivatives	China	135	Soy	Public	5
Rio Grande	PE	14	Container	China	103	Soy	Public	5
Rio de Janeiro	SP	14	Oil and derivatives	United States	107	Container	Private	5
Itaqui	MA	13	Oil and derivatives	China	57	Soy	Public	5
Suape	SP	14	Oil and derivatives	United States	58	Petroleum oils	Public	5
Itaguai	CE	11	Container	China	73	Iron ores	Public	5
Imbituba	CE	10	Container	United States	53	Petroleum coke	Public	5
Fortaleza	CE	14	Oil and derivatives	Argentina	24	Wheat	Public	4
Vitoria	SC	13	Iron and steel	China	41	Cast Iron	Public	4
Navegantes	SC	11	Container	China	60	Container	Private	4

Criterion 5: Commitment to decarbonization

This criterion evaluates a port's commitment to proactively invest in decarbonization initiatives. We analyzed publicly available information, including port websites and news articles, according to three aspects: (1) projects under licensing for offshore wind complexes; (2) membership in the Brazilian Alliance for the Decarbonization of

Ports (ABDP); and (3) the incorporation of new energy generation sources into the respective port's strategic plan. This evaluation aimed to identify ports that are actively pursuing decarbonization strategies and demonstrating a commitment to sustainable port operations.

Each port was evaluated based on these three aspects; a score of 5 was awarded for "Yes" (aspect fulfilled) and a score of 1 for "No" (aspect not fulfilled). For criterion 5, the final score was determined by averaging the scores from three aspects. A port could only achieve a score of 5 if it met all aspects; lower scores indicated a decreasing level of commitment, with fewer aspects being fulfilled. Table 5 displays the scores of the top 10 ports based on this criterion, and results for the top 30 ports are in Appendix C.

Table 5
Top 10 highest-scoring ports on Criterion 5

Port name	Port region	Offshore wind projects under licensing	Membership at ABDP	Inclusion of renewable energy in the Strategic Plan	Score
Rio Grande	South	Yes	Yes	Yes	5
Rio de Janeiro	Southeast	Yes	Yes	Yes	5
Itaqui	Northeast	Yes	Yes	Yes	5
Itaguai	Northeast	Yes	Yes	Yes	5
Fortaleza	Northeast	Yes	Yes	Yes	5
Navegantes	South	Yes	Yes	Yes	5
Pecem	Northeast	Yes	Yes	Yes	5
Porto do Açu	Southeast	Yes	Yes	Yes	5
Angra dos Reis	Southeast	Yes	Yes	Yes	5
Santos	Southeast	No	Yes	Yes	4

Weighting scenarios

We assessed the five criteria via three weighting scenarios: equal weights, based on expert consultation, and preference for port infrastructure (Table 6). Full details are in Appendix A.

Scenario 1: Equal weights to all five criteria. This simplifies the evaluation by treating all factors with the same significance, but it may not accurately reflect the priorities of stakeholders or situations where some criteria might hold more importance than others.

Scenario 2: Based on expert consultation. Here weights are assigned based on insights and recommendations from industry experts and feedback from experts from Brazil's Ministry of Ports and Airports. This relies on the experience and knowledge of stakeholders who understand the ports' specific context and operational environments, and it aims to reflect a more nuanced understanding of which factors are most important when assessing the ports.

Scenario 3: Preference for port infrastructure. This highlights the importance of physical capabilities and logistics, which are usually the limiting factors for ports when considering green shipping initiatives.

Table 6
Weighting factors per scenario

Criteria	Scenario 1	Scenario 2	Scenario 3
C1: Existing use and potential access to renewable energy	20%	21%	17.5%
C2: Port capacity	20%	18%	17.5%
C3: Port infrastructure	20%	19%	30%
C4: Strategic location and connectivity	20%	23%	17.5%
C5: Commitment to decarbonization	20%	19%	17.5%

POTENTIAL DEMAND FOR RENEWABLE MARINE FUEL

We analyzed existing maritime traffic, route patterns, and energy consumption within the selected ports of interest using the ICCT Systematic Assessment of Vessel Emissions (SAVE) model (Mao et al., 2025). Based on trade route data, we identified specific routes or port-to-port pairs. To ensure a comprehensive evaluation, we included international and domestic routes connecting Brazil with major trading partners and covered the main cargo types being transported.

Once the routes of interest were established, we selected sample ships that operate on those routes. Employing methodologies developed by Mao et al. (2024), we evaluated only the fuel demand for a selected group of zero-emission vessels deployed on key trade routes connecting candidate ports. After the ships of interest were established, we used the SAVE model to estimate the energy demand at ports by assuming all ships bunkered enough fuel to support at least the next voyage before departure. We then converted that energy to equivalent renewable marine fuel using Equation 1.

$$V_{fuel\_need\_i} = \frac{E_{required\_i}}{VD_{fuel} \times \eta_{fuel}} \times fuel\ margin \qquad (1)$$

Where:

$V_{fuel\_need\_i}$ is the fuel system volume needed to provide enough energy to complete leg *i*, in m^3

$E_{required\_i}$ is the energy output required to complete leg *i*, in kWh (from the SAVE model)

VD_{fuel} is the volumetric density of the fuel system, in kWh/m^3 (see Table 7)

η_{fuel} is the efficiency of converting the respective fuel into energy:

LH_2: 54% (fuel-cell based)

MeOH: 50% (ICE-based)

NH_3: 50% (ICE-based)

fuel margin is a factor of 1.2, assuming all ships carry more fuel than the minimum required onboard

Table 7
Fuel characteristics

Fuel	Density (kg/m³)[a]	Energy density (kWh/kg)	Volumetric density (kWh/m³)[b]
RE-LH_2	40	33.3	1,332
RE-NH_3	602	5.2	3,112
RE-MeOH	790	5.5	4,369

[a] These are system-wide assumptions from Mao et al. (2024)
[b] Volumetric density is derived via the multiplication of density (kg/m³) and energy density (kWh/kg)

The total mass of e-fuel required was estimated using Equation 2, based on the calculated fuel system volume and the density of the e-fuel.

$$m_{fuel} = \frac{\frac{E_{required\_i}}{ED_{fuel} \times \eta_{fuel}} \times fuel\ margin}{1{,}000} \quad (2)$$

Where:

m_{fuel} is the total mass of considered e-fuels (in tonnes)

ED_{fuel} is the energy density of e-fuels

As RE-LH_2, RE-NH_3, and RE-MeOH have lower energy density than traditional marine fuel, it is possible that a ship will not be able to fulfil its original voyage if it switches to these fuel options and would need to refuel along the way. We evaluated the technological feasibility using Equation 3.

$$N_{refuel\_i} = \frac{V_{fuel\_need\_i}}{V_{fuel\_capacity\_I}} \quad (3)$$

Where:

$V_{\_fuel\_capacity\_I}$ is the available space for fuel, in the fuel system on board ship I, in m^3

N_{refuel_i} is the number of times a ship will have to refuel on a single leg *i*

Only if the refueling stops of a particular fuel option are zero is the fuel considered feasible. If multiple fuel options were feasible for a ship for the selected route, we kept all options. As a result, when calculating the underlying demand for renewable hydrogen (Equation 4), we provided a range rather than a single value.

$$m\_H2\_implied = m\_fuel \times \left(\frac{LHV\_fuel}{\eta \times LHV\_H2}\right) \quad (4)$$

Where:

m_H2_implied is the implied mass of hydrogen required for MeOH and NH_3 production

LHV is the lower heating value of fuel. For H_2,120 MJ/kg; MeOH, 19.9MJ/kg; and NH_3, 18.6 MJ/kg), from IMO (2022) and IMO (2024)

η is the conversion efficiency. For MeOH, 79%, and NH_3, 84%, from Brynolf et al. (2018) and Moritz et al. (2023)

Finally, we converted the implied demand for renewable hydrogen into demand for renewable electricity and compared that with existing renewable electricity power generated by wind energy in Brazil (International Energy Agency, 2023). This step completed the screening for the feasibility of port candidates as future bunkering hubs for renewable marine fuel.

RESULTS AND DISCUSSION

PORT READINESS

The final scores and rankings for Brazilian ports are presented in Table 8 under the three weighting scenarios. Public and private ports are treated separately because they have different business models and thus different decision-making processes. This also ensures they are represented equally in our analysis. The different weighting scenarios resulted in only a minor difference in the final ranking, and the top three ports (highlighted in grey) of each group are the top three for all scenarios.

Table 8

Final scores of port readiness, top 10 private and top 10 public ports

Private ports								
Port name	**Criterion 1**	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**	**Weighting scenario 1**	**Weighting scenario 2**	**Weighting scenario 3**
Pecem	4.5	3.0	3.3	3.8	5.0	3.9	3.9	3.8
Navegantes	4.0	3.0	2.8	4.0	5.0	3.8	3.8	3.6
Porto do Açu	2.5	4.0	3.0	3.5	5.0	3.6	3.6	3.5
Angra dos Reis	2.5	4.0	3.5	3.3	5.0	3.6	3.7	3.6
Sao Sebastiao	4.0	4.0	4.3	3.0	2.3	3.5	3.5	3.6
Ponta da Madeira	2.5	5.0	3.3	2.8	3.7	3.4	3.4	3.4
Itapoá	4.5	3.0	1.8	4.0	3.7	3.4	3.4	3.2
Tubarao	3.0	4.0	3.0	3.0	3.7	3.3	3.3	3.3
Guamare Oil Terminal	5.0	2.0	2.5	3.3	3.7	3.3	3.3	3.2
Praia Mole	3.0	3.0	3.3	3.3	3.7	3.2	3.2	3.2
Public ports								
Port Name	**Criterion 1**	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**	**Weighting scenario 1**	**Weighting scenario 2**	**Weighting scenario 3**
Santos	4.0	5.0	4.5	5.0	3.7	4.4	4.4	4.4
Rio Grande	5.0	3.0	4.3	4.8	5.0	4.4	4.4	4.4
Itaqui	2.5	3.0	4.5	4.5	5.0	3.9	3.9	4.0
Itaguai	2.5	4.0	3.3	4.5	5.0	3.8	3.9	3.8
Fortaleza	4.5	2.0	2.8	4.3	5.0	3.8	3.7	3.6
Sao Francisco do Sul	5.0	3.0	3.0	3.8	3.7	3.7	3.7	3.6
Imbituba	5.0	2.0	3.0	4.5	3.7	3.7	3.6	3.6
Rio de Janeiro	2.5	3.0	2.8	4.8	5.0	3.6	3.6	3.5
Paranagua	4.0	4.0	3.8	3.5	2.3	3.5	3.5	3.5
Suape	2.5	3.0	4.0	4.5	2.0	3.2	3.2	3.3

Note: The shading highlights the top three ports, which are also the top in all weighting scenarios.

Five of the top six ports (three each for private and public ports) have high scores for Criterion 5: commitment to decarbonization. The only exception is Santos, which is the largest and one of Brazil's most connected and strategically important ports. The score for Santos is primarily because no existing or planned offshore wind projects exist, and that is the primary source of renewable energy considered for renewable hydrogen production in this study. Porto do Açu and Itaqui both had mid-range scores for access to renewable energy (Criterion 1), but they scored higher in other criteria. Scores for Criterion 3 show that, compared with public ports, most private ports have insufficient infrastructure to be ready for renewable marine fuel bunkering. Finally, according to scores under Criterion 4, public ports appear to be more connected and have a strategic advantage over private ports. While private ports are subject to regulation, the Brazilian Ministry of Ports and Airports has more direct influence over public ports due to its role in their administration, planning, and the nature of public port management. We selected six ports, the top three of each type, as initial candidate ports for future renewable marine fuel bunkering hubs: Pecem, Navegantes, Porto do Açu, Santos, Rio Grande, and Itaqui.

BUNKERING DEMAND ANALYSIS

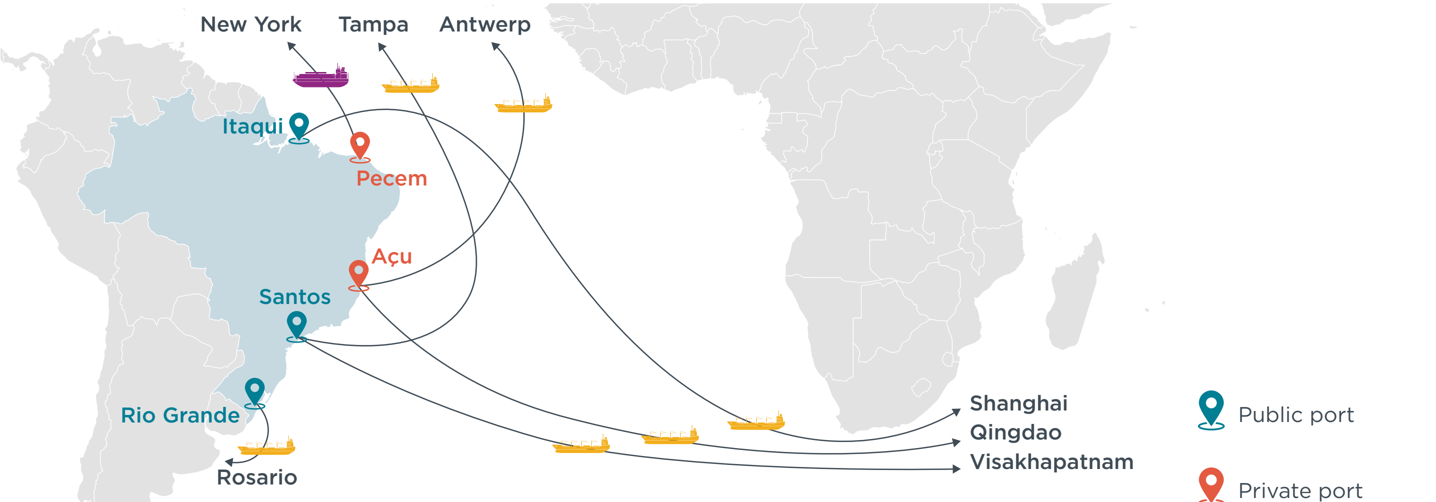
Route selection and energy demand

In Criterion 4: Strategic location and connectivity, key routes and commodity types were identified for each port (Table 4). Based on that and ship traffic patterns in and out of Brazilian ports enabled by our SAVE model, we selected 10 routes connecting the six candidate ports as candidate routes (Table 9). This selection covers both international (Figure 4) and cabotage voyages (Figure 5) of ships that move the top-traded commodity types in Brazil and routes that connect to Brazil's largest trading partners.

Table 9
Route selection for bunkering demand analysis

Port	Route	Route type	Ship class
Santos	Santos – Tampa (U.S.)	International	Bulk carrier
Santos	Santos – Visakhapatnam (India)	International	Bulk carrier
Porto do Açu	Porto do Açu – Qingdao (China)	International	Bulk carrier
Porto do Açu	Porto do Açu – Antwerp (Belgium)	International	Bulk carrier
Pecem	Pecem – New York (U.S.)	International	Container
Itaqui	Itaqui – Shanghai (China)	International	Bulk carrier
Rio Grande	Rio Grande – Rosario (Argentina)	International	Bulk carrier
Rio Grande	Rio Grande – Porto Alegre	Cabotage	Bulk carrier
Navegantes	Navegantes – Santos	Cabotage	General cargo
Pecem	Pecem – Manaus	Cabotage	Container

Figure 4
International routes considered in the study



Route	Route port	Route type
Itaqui - Shanghai	Itaqui	International
Rio Grande - Rosario	Rio Grande	International
Santos - Tampa	Santos	International
Santos - Visakhapatnam	Santos	International
Pecem - New York	Pecem	International
Porto do Açu - Qingdao	Porto do Açu	International
Porto do Açu - Antwerp	Porto do Açu	International

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Figure 5
Brazilian cabotage routes considered in the study

Route	Route port
Rio Grande - Porto Alegre	Rio Grande
Navegantes - Santos	Navegantes
Pecem - Manaus	Pecem

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We selected one sample ship for each chosen route as the hypothetical first-deployed zero-emission vessel to bunker renewable marine fuel at the screened candidate ports. Table 10 provides an overview of their fuel consumption and associated CO_2 emissions for one trip on these routes.

Table 10
Operational CO_2 emissions and fuel consumption volumes for selected maritime routes

Route	Ship class	Distance (nm)	Deadweight tonnage	Fuel consumption (tonnes)	CO_2 emissions (tonnes)	Annual efficiency ratio (g CO_2/ dwt-nm)
Santos – Tampa	Bulk carrier	5,420	40,261	232	723	3.3
Pecem – New York	Container	3,300	83,557	459	1,432	5.2
Porto do Açu – Qingdao	Bulk carrier	10,064	176,330	1,062	3,307	1.9
Porto do Açu – Antwerp	Bulk carrier	5,162	31,837	351	1,085	6.7
Santos – Visakhapatnam	Bulk carrier	8,568	82,997	632	1,969	2.8
Itaqui – Shanghai	Bulk carrier	12,141	324,272	1,466	4,564	1.2
Rio Grande – Rosario	Bulk carrier	1,131	35,956	79	247	6.1
Navegantes – Santos	General cargo	226	62,014	21	65	4.6
Pecem – Manaus	Container	1,542	37,968	137	425	7.3
Porto Alegre – Rio Grande	Bulk carrier	158	45,601	11	35	4.8
Total		**47,712**	**920,723**	**4,449**	**13,862**	

In total, the 10 sample ships consumed 4,449 tonnes of fuel and that resulted in 13,862 tonnes of CO_2 emissions. The longest route analyzed, Itaqui–Shanghai, spans over 12,000 nautical miles. The routes to China and India (Porto do Açu–Qingdao, Itaqui–Shanghai, and Santos–Visakhapatnam), primarily serviced by bulk carriers transporting commodities like iron ore, exhibited relatively low annual efficiency ratios (AER), a metric used to measure carbon intensity. These routes averaged less than 3 g CO_2/dwt-nm, which aligns with the understanding that bulk carriers are generally more efficient (Mao et al., 2025). In contrast, other routes showed higher carbon intensity. The Porto do Açu–Antwerp route, also operated by a bulk carrier, had an AER of 6.7 g CO_2/dwt-nm. Furthermore, the Brazilian cabotage routes analyzed (Navegantes–Santos, Pecem–Manaus, and Porto Alegre–Rio Grande) generally displayed higher AER values, likely reflecting the impact of shorter distances and the use of smaller, potentially less efficient vessels. The Pecem–Manaus container route had the highest AER of 7.3 g CO_2/dwt-nm.

BUNKERING DEMAND AND IMPLIED DEMAND FOR RENEWABLE ELECTRICITY

Regarding the technological feasibility of replacing existing fuel requirements with the alternatives, our results in Figure 6 show that using RE-LH_2 without refueling stops is feasible on the five shortest routes, including three cabotage routes (Navegantes–Santos, Pecem–Manaus, and Porto Alegre–Rio Grande) and two international routes (Pecem–New York and Rio Grande–Rosario). For the other international routes requiring refueling stops, if powered by RE-LH_2, all five routes would need one refueling stop. Figures 7 and 8 show that both RE-NH_3 and RE-MeOH consistently offer higher feasibility across all routes, with no refueling stops needed for any of the analyzed routes.

Figure 6

Estimated required versus available LH_2 by route

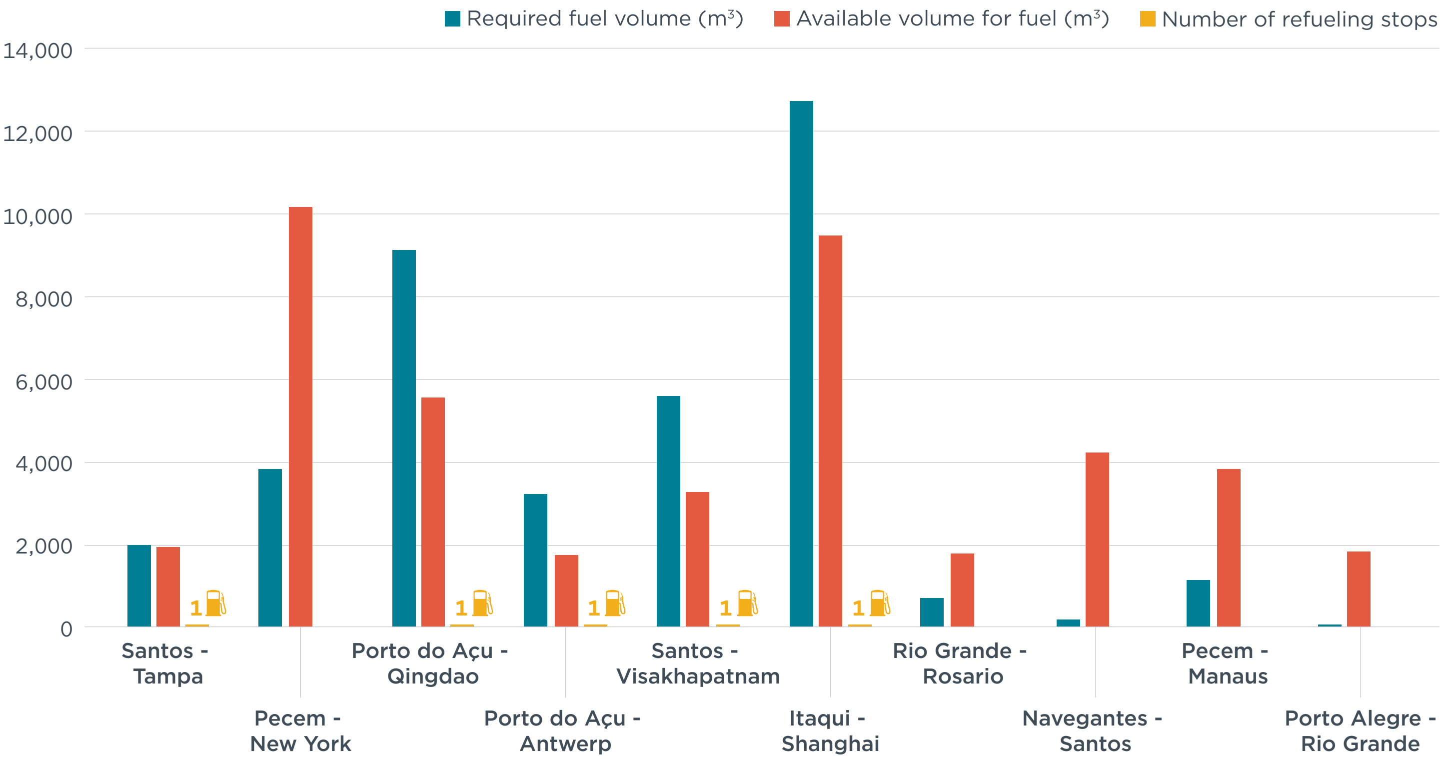

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Figure 7

Estimated required versus available NH_3 by route

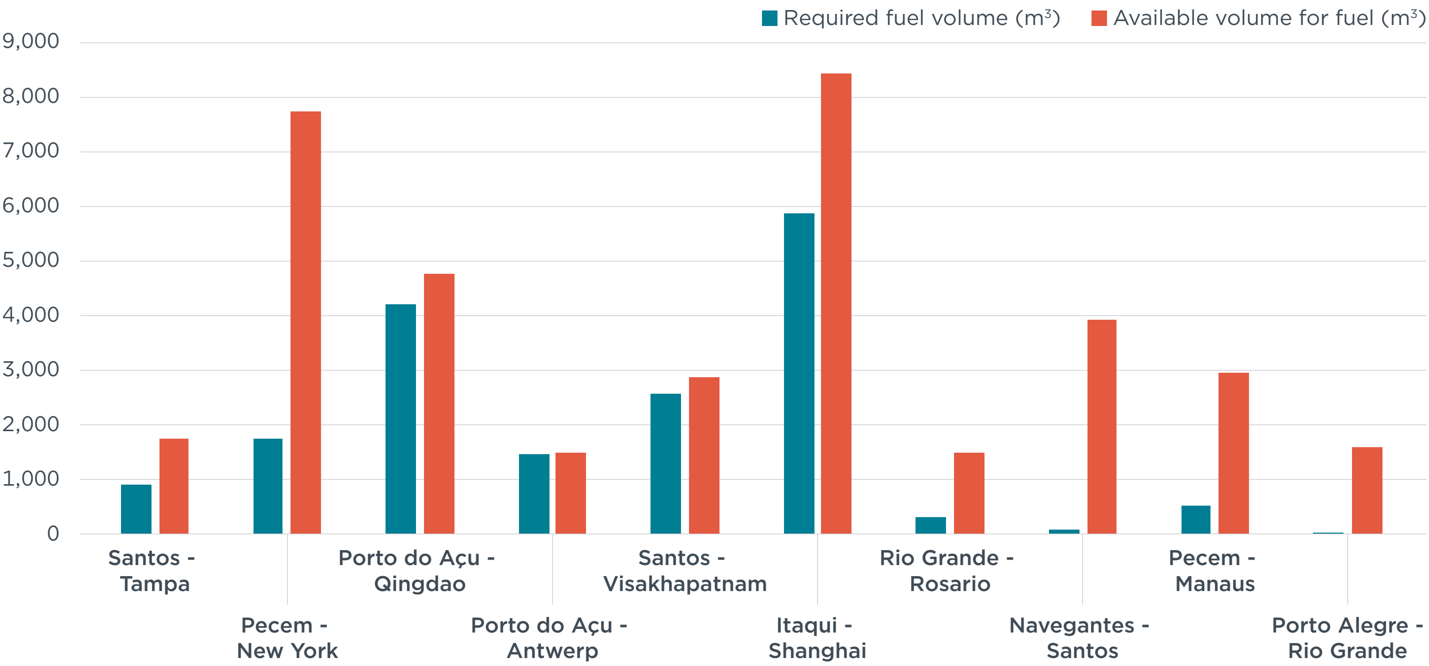

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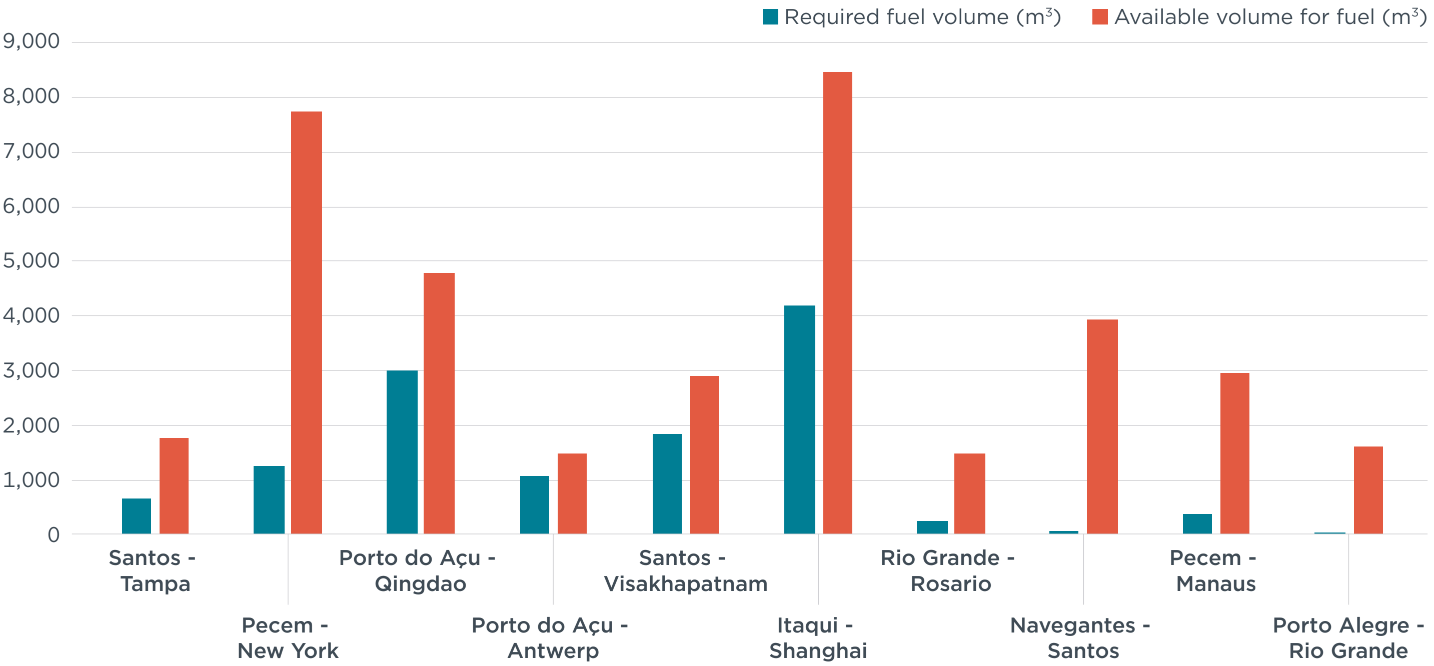
Figure 8
Estimated required versus available MeOH by route



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Given that RE-NH_3 and RE-MeOH are produced from RE-LH_2, we converted the estimated demand for these fuel options and calculated the implied demand for RE-LH_2 (Table 11) for routes where RE-NH3 or RE-MeOH were identified as feasible fuel options. For routes where more than one fuel option is feasible, we present the range of implied RE-LH_2 demand. Subsequently, we estimated the corresponding demand for renewable electricity required for RE-LH_2 production (Table 11). While the direct use of RE-LH_2 is energetically more efficient due to the energy loss inherent in its conversion to RE-NH_3 or RE-MeOH, the technological feasibility of RE-LH_2 is not guaranteed on longer routes because of the large volumes of it required. Additionally, although RE-NH_3 requires less hydrogen input than RE-MeOH, its technical readiness for maritime application is currently lower. Across all analyzed routes, meeting the fuel demands would require 1,785–1,910 tonnes of hydrogen (regardless of the specific renewable marine fuel utilized), and that translates to a renewable electricity demand of 82–92 GWh. To put this into context, a 1 MW electrolyzer can produce about 500 kg of renewable hydrogen per day (Zhou & Searle, 2022) and the biggest electrolyzer being built has a capacity of 4 GW (International Energy Agency, n.d.). This total demand represents a small fraction (less than 1%) of Brazil's projected annual renewable hydrogen production of 1 million tonnes by 2030 (Klevstrand, 2023).

Table 11

Implied demand for renewable hydrogen and renewable electricity from selected routes connecting candidate Brazil ports

Route	Implied demand for RE-LH_2 (tonnes)				Implied demand for renewable electricity (GWh)
	RE-LH_2	RE-NH_3	RE-MeOH	Total	Total
Santos – Tampa		98	105	98–105	4.7–5
Pecem – New York	142	183	196	142–196	7–9
Porto do Acu – Qingdao		425	455	425–455	20–22
Porto do Acu – Antwerp		140	150	140-150	6.7–7
Santos – Visakhapatnam		253	271	253–271	12–13
Itaqui – Shanghai		586	627	586–627	28–30
Rio Grande – Rosario	25	32	34	25–34	1–2
Navegantes – Santos	6	8	9	6–9	0.3–0.4
Pecem – Manaus	42	55	58	42–58	2–3
Rio Grande – Porto Alegre	3	4	5	3–5	0.2
Total	219	1,785	1,911	1,785–1,911	82–92

Note: Blank cells represent routes where that fuel option was not feasible.

In Table 12, we aggregated the demand for renewable hydrogen from all routes connecting each candidate port at the port level. Itaqui shows the highest demand of 586–627 tonnes of RE-LH_2 and 28–30 GWh of renewable electricity from a single route, and it is followed by Porto do Acu with 565–605 tonnes of RE-LH_2 (27–29 GWh) across its two analyzed routes. Santos, with routes served by bulk carriers and container ships, has a demand of 351–376 tonnes of RE-LH_2 (17–18 GWh). Pecem, which services container and general cargo ships, has a demand of 184–254 tonnes of RE-LH_2 (9–12 GWh). Rio Grande, which is served by bulk carriers, has a demand of 28–39 tonnes of RE-LH_2 (1.2–2 GWh). Navegantes, which has a general cargo route, has a demand of 6–9 tonnes of RE-LH_2 (0.3–0.4 GWh). Public ports (highlighted in grey in Table 12) would account for around 43% of the total demand for RE-LH_2. This demand estimate only reflects the demand for one trip on each route, and that could be substantially scaled up with the implementation of green shipping corridors.

Table 12

Total demand for renewable hydrogen and renewable electricity at candidate ports

Port	Number of routes analyzed	Demand for RE-LH2 (tonnes)	Demand for renewable electricity (GWh)
Santos	2	351-376	17-18
Itaqui	1	586-627	28–30
Rio Grande	2	28–39	1.2-2
Porto do Acu	2	565–605	27–29
Pecem	2	184–254	9–12
Navegantes	1	6–9	0.3–0.4
Total	10	1,720–1,911	82–92

Note: Public ports are highlighted in grey.

CONCLUSION

This pre-feasibility analysis explored the potential of Brazilian ports to serve as bunkering hubs for renewable marine fuels. We first screened ports based on a multifactor analytical framework for port readiness and then quantified potential bunkering demand for renewable marine fuels at these ports.

We identified six candidate ports: three public (Santos, Itaqui, and Rio Grande) and three private (Porto do Açu, Pecem, and Navegantes) for further assessment. Santos, the largest port in Latin America, ranked high in four out of the five criteria assessed for readiness, though it had only a moderate level of commitment to decarbonization due to a lack of ongoing or planned offshore wind projects. Porto do Açu and Itaqui scored high on all criteria except for access to potential offshore wind energy. Public ports generally scored higher than private ports, especially for their infrastructure, strategic location, and connectivity. On a scale of 1 to 5, the six candidates chosen for further assessment had weighted scores that ranged from 3.5 to 4.4.

Based on 2023 ship traffic, we identified 10 routes connecting the six candidates to both the domestic market and key international markets. In 2023, sample vessels on these routes were estimated to consume over 4,449 tonnes of fuel and emit approximately 13,862 tonnes of CO_2 on one trip. Operational efficiency varies by route, and routes with higher efficiency could be prioritized when deploying zero-emission vessels, considering the potential fuel consumption savings.

We considered RE-LH_2, RE-NH_3, and RE-MeOH as alternative fuels that could be bunkered in these ports. While the direct utilization of RE-LH_2 was found to be feasible for only half of the routes, RE-NH_3 and RE-MeOH were feasible on all routes without requiring an additional refueling stop. In total, we estimated that to replace fossil fuel consumed on the sample routes and trips, approximately 1,785–1,910 tonnes of renewable hydrogen would be needed to produce the various types of end-use renewable marine fuels, which implies demand for 82–92 GWh of renewable electricity generated by offshore wind facilities. To provide context, in 2023, the Itaipu hydroelectric power plant, the largest in Brazil, generated approximately 83,000 GWh of electricity (Itaipu Binacional, 2023). Thus, the 82–92 GWh demand represents roughly 0.1% of Itaipu's annual energy production. Although this demand represents only 0.2% of the planned production of renewable hydrogen in Brazil, it could quickly scale up once bunkering services at ports are established. In a follow-up study, we intend to quantify that scaled demand for renewable marine fuel in Brazil and explore the potential economic and climate benefits.

Nevertheless, realizing the full potential of these renewable fuel alternatives requires substantial investments and collaborative efforts from all stakeholders involved, including port authorities, shipping companies, and government agencies. Initiatives such as the Brazil–Norway agreement to establish sustainable maritime corridors are addressing the need for comprehensive studies to develop green shipping corridors (Machado, 2025). Furthermore, on February 19, 2025, Brazil and Portugal signed a memorandum of understanding focused on the development of ports in both countries, and it explicitly includes the development of green shipping corridors (Ministerio dos Portos e Aeroportos, 2025). These agreements reinforce the growing international commitment to fostering sustainable maritime practices and underscore the importance of bilateral partnerships in accelerating the transition to cleaner shipping.

REFERENCES

Agência Nacional de Transportes Aquaviários. (2024). *Estatístico aquaviário.* https://web3.antaq.gov.br/ea/sense/index.html#

Aranha, C. (2023, July 21). Brazilian ports get ready for energy transition with green hydrogen. *CZ Insights*. https://www.czapp.com/analyst-insights/brazilian-ports-get-ready-for-energy-transition-with-green-hydrogen/

Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., & Staffell, I. (2019). How to decarbonise international shipping: Options for fuels, technologies and policies. *Energy Conversion and Management, 182*(February), 72–88. https://doi.org/10.1016/j.enconman.2018.12.080

Baldino, C., & Searle, S. (2021, June 14). GO big or GO home with e-fuels and hydrogen. *International Council on Clean Transportation Staff Blog.* https://theicct.org/go-big-or-go-home-with-e-fuels-and-hydrogen/

Brasil em Mapas. (2023). Main source of electricity in each Brazilian state. https://brasilemapas.wordpress.com/2023/02/26/principal-fonte-de-energia-de-cada-estado-do-brasil/

Brynolf, S., Taljegard, M., Grahn, M., & Hannsson, J. (2018). Electrofuels for the transport sector: A review of production costs. *Renewable and Sustainable Energy Reviews 81*(January):1887–1905. https://doi.org/10.1016/j.rser.2017.05.288

Carvalho, F., Osipova, L., & Zhou, Y. (2023). *Life-cycle greenhouse gas emissions of hydrogen as a marine fuel and cost of producing green hydrogen in Brazil*. International Council on Clean Transportation. https://theicct.org/publication/maritime-brazil-hydrogen-costs-mar23/

Carvalho, F., & Costa, G. (2024). *Coastal shipping in Brazil in 2021*. International Council on Clean Transportation. https://theicct.org/publication/coastal-shipping-in-brazil-in-2021-mar24/

DNV. (2024, March 25). Key considerations for establishing a green shipping corridor. *Maritime Impact*. https://www.dnv.com/expert-story/maritime-impact/key-considerations-for-establishing-a-green-shipping-corridor/

Empresa de Pesquisa Energética. (2021). *Anuário estatístico de energia elétrica*. Ministério de Minas e Energia. https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-160/topico-168/Anu%C3%A1rio_2021.pdf

Empresa de Pesquisa Energética. (2024). *Summary report 2024*. https://www.epe.gov.br/sites-en/publicacoes-dados-abertos/publicacoes/PublishingImages/Paginas/Forms/Publicaes/Summary%20Report%202024.pdf

National Geospatial-Intelligence Agency. (2024). *World Port Index* [Dataset]. https://fgmod.nga.mil/apps/WPI-Viewer/

Fages, E., Weichenhain, U., Schillaci, G., & Audouin, C. (2023, September 12). Ports and green hydrogen: Match made in heaven? *Roland Berger*. https://www.rolandberger.com/en/Insights/Publications/Ports-and-green-hydrogen-Match-made-in-heaven.html

Ferreira, M., Santos, J., Da Silva, L., Abrahao, R., Gomes, F., & Braz, H. (2023). A new index to evaluate renewable energy potential: A case study on solar, wind and hybrid generation in northeast Brazil. *Renewable Energy 217*(November): 119182. https://doi.org/10.1016/j.renene.2023.119182

Georgeff, E., Mao, X., Rutherford, D., *Liquid hydrogen refueling infrastructure to support a zero-emission U.S.–China container shipping corridor.* International Council on Clean Transportation. https://theicct.org/publication/liquid-hydrogen-refueling-infrastructure-to-support-a-zero-emission-u-s-china-container-shipping-corridor/

Global Maritime Forum. (2022). *Green corridors: Definitions and approaches*. https://globalmaritimeforum.org/insight/green-corridors-definitions-and-approaches/

Gulli, C., Heid, B., Noffsinger, J., Waardenburg, M, & Wilthaner, M. (2024). *Global energy perspective 2023: Hydrogen outlook*. McKinsey & Company. https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2023-hydrogen-outlook

International Energy Agency. (n.d.). *Electrolysers*. Accessed March 27, 2025, https://www.iea.org/energy-system/low-emission-fuels/electrolysers

International Energy Agency. (2023). *Brazil - Sources of electricity generation*. https://www.iea.org/countries/brazil/electricity

International Energy Agency. (2024). *Global hydrogen review 2024*. https://iea.blob.core.windows.net/assets/89c1e382-dc59-46ca-aa47-9f7d41531ab5/GlobalHydrogenReview2024.pdf

International Maritime Organization. (2022). Resolution MEPC.364(79) 2022 guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships. https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.364%2879%29.pdf

International Maritime Organization. (2023). Resolution MEPC.377(80) 2023 IMO strategy on reduction of GHG emissions from ships. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf

International Maritime Organization. (2024). Resolution MEPC.391(81) 2024 guidelines on life cycle GHG intesity of marine fuels (2024 LCA guidelines). https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.391(81).pdf

International Renewable Energy Agency. (2022). *Geopolitics of the energy transformation: The hydrogen factor*. https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen

Itaipu Binacional. (2023). *Produção ano a ano*. https://www.itaipu.gov.br/energia/producao-ano-ano

Khare, V., Jain, A,, & Bhuiyan, M. (2023). Perspective of renewable energy in the BRICS country. *e-Prime - Advances in Electrical Engineering, Electronics and Energy 5*(September): 100250. https://doi.org/10.1016/j.prime.2023.100250

Klevstrand, A. (2023, February 17). Which ten countries will be the biggest producers of green hydrogen in 2030? *Hydrogen Insight*. https://www.hydrogeninsight.com/production/exclusive-which-ten-countries-will-be-the-biggest-producers-of-green-hydrogen-in-2030-/2-1-1405571

Machado, N. (2025, February 27). Brasil tenta entrar na rota dos corredores marítimos sustentáveis [Brazil tries to join the route of sustainable maritime corridors]. *Eixos*. https://eixos.com.br/newsletters/dialogos-da-transicao/brasil-tenta-entrar-na-rota-dos-corredores-maritimos-sustentaveis/

Maersk Mc-Kinney Møller Center for Zero Carbon Shipping. (2022). *Green corridors: Feasibility phase blueprint*. https://cms.zerocarbonshipping.com/media/uploads/documents/220929_Green-Corridors_Feasibility-Blueprint.pdf

Mao, X., Meng, Z., Comer, B., & Decker, T. 2025. *Greenhouse gas emissions and air pollution from global shipping, 2016–2023*. International Council on Clean Transportation. https://theicct.org/publication/greenhouse-gas-emissions-and-air-pollution-from-global-shipping-2016-2023-apr25/

Mao, X., Meng, Z., Osipova, L., Comer, B., Cho, H., & Sturrup, E. (2025). *Systematic Assessment of Vessel Emissions (SAVE) V2025.03.1 Documentation*. International Council on Clean Transportation. https://theicct.github.io/SAVE-doc/

Mao, X., Rutherford, D., Osipova, L., & Comer, B. (2020). *Refueling assessment of a zero-emission container corridor between China and the United States: Could hydrogen replace fossil fuels?* International Council on Clean Transportation. https://theicct.org/publication/refueling-assessment-of-a-zero-emission-container-corridor-between-china-and-the-united-states-could-hydrogen-replace-fossil-fuels/

Mao, X., Zhou, Y., Meng, Z., & Cho, H.. (2024). *Green shipping corridors: Screening first mover candidates for China's coastal shipping based on energy use and technological feasibility*. International Council on Clean Transportation. https://theicct.org/publication/green-shipping-corridors-for-chinas-coastal-shipping-aug24/

Ministerio dos Portos e Aeroportos. (2025, February 19). *Ministro Silvio Costa Filho assina memorando de entendimento com governo Português para desenvolvimento de portos nos dois países* [Minister Silvio Costa Filho signs memorandum of understanding with the Portuguese government for the development of ports in both countries] [Press release]. https://www.gov.br/portos-e-aeroportos/pt-br/assuntos/noticias/2025/02/ministro-silvio-costa-filho-assina-memorando-de-entendimento-com-governo-portugues-para-desenvolvimento-de-portos-nos-dois-paises

Moritz, M., Schönfisch, M., & Schulte, S. (2023). Estimating global production and supply costs for green hydrogen and hydrogen-based green energy commodities. *International Journal of Hydrogen Energy 48*(25): 9139–54. https://doi.org/10.1016/j.ijhydene.2022.12.046

Lei No. 15.097, de 10 de janeiro de 2025, https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2025/lei/l15097.htm

Silva, D. D., Cardoso, E.M., Basquerotto, C., Pereira, J.A., Turra, A.E., & Feldhaus, J. (2023). Outlook on the Brazilian scenario of floating photovoltaic solar energy. *Energy Reports, 10*(November), 4429–4435. https://doi.org/10.1016/j.egyr.2023.11.004

Sturrup, E., & Stolz, D. (2023). *Jones Act shipping case studies: Feasibility of U.S. domestic green corridors with hydrogen and wind assist*. International Council on Clean Transportation. https://theicct.org/publication/jones-act-shipping-case-studies-dec23/

Suri, M., Betak, J., Rosina, K., Chrkavy, D., Suriova, N., Cebecauer, T., Caltik, M., & Erdelyi, B. (2020). *Global photovoltaic power potential by country*. Energy Sector Management Assistance Program and World Bank Group. http://documents.worldbank.org/curated/en/466331592817725242

United States Maritime Administration. (2023). *Feasibility study of future energy options for Great Lakes shipping*. International Council on Clean Transportation. https://theicct.org/publication/feasibility-study-of-future-energy-options-for-great-lakes-shipping-march24/

UN Trade and Development. (2023). *Review of maritime transport 2023*. https://unctad.org/publication/review-maritime-transport-2023

Van Hoecke, L., Laffineur, L., Campe, R., Perreault, P., Verbruggen, S., & Lenaerts, S. (2021). Challenges in the use of hydrogen for maritime applications. *Energy & Environmental Science, 14*(2), 815–43. https://doi.org/10.1039/D0EE01545H

World Bank. (2020). *Offshore wind technical potential in Brazil*. https://documents1.worldbank.org/curated/en/902341586847107376/pdf/Technical-Potential-for-Offshore-Wind-in-Brazil-Map.pdf

Zhou, Y., & Searle, S. (2022). *Cost of renewable hydrogen produced onsite at hydrogen refueling stations in Europe*. International Council on Clean Transportation. https://theicct.org/publication/fuels-eu-onsite-hydro-cost-feb22/

Zhou, Y., Searle, S., & Pavlenko, N. (2022). *Current and future cost of e-kerosene in the United States and Europe*. International Council on Clean Transportation. https://theicct.org/publication/fuels-us-eu-cost-ekerosene-mar22/

APPENDIX A. WEIGHTING SCENARIOS

Table A1
Weight assignment to each of the five criteria in Scenario 2, based on equal weights

Criteria	Weight
Existing and potential use of Renewable energy	20%
Port capacity	20%
Port infrastructure	20%
Strategic location and connectivity	20%
Commitment to decarbonization	20%

Table A2
Weight assignment to each of the five criteria in Scenario 1, based on expert consultation

Criteria	Weight
Existing and potential use of Renewable energy	21%
Port capacity	18%
Port infrastructure	19%
Strategic location and connectivity	23%
Commitment to decarbonization	19%

Table A3
Weight assignment to each of the five criteria in Scenario 3, based on port infrastructure preference

Criteria	Weight
Existing and potential use of Renewable energy	17.5%
Port capacity	17.5%
Port infrastructure	30.0%
Strategic location and connectivity	17.5%
Commitment to decarbonization	17.5%

APPENDIX B. BUNKERING PORTS IN BRAZIL

Table B1
Bunkering services at Brazilian ports

Port name	Bunkering availability
Angra dos Reis	HSFO, MGO, VLSFO
Belem	HSFO, MGO, VLSFO
Fortaleza	HSFO, MGO, VLSFO
Itaqui	HSFO, MGO, VLSFO
Maceio	HSFO, MGO, VLSFO
Manaus	HSFO, MGO, VLSFO
Niteroi	HSFO, MGO, VLSFO
Santos	HSFO, MGO, VLSFO
Sao Sebastiao	HSFO, MGO, VLSFO
Tubarao	HSFO, MGO, VLSFO
Vila do Conde	HSFO, MGO, VLSFO
Paranagua	HSFO, MGO, VLSFO, IFO 180, IFO 380
Recife	HSFO, MGO, VLSFO, IFO 180, IFO 380
Rio de Janeiro	HSFO, MGO, VLSFO, IFO 180, IFO 380
Rio Grande	HSFO, MGO, VLSFO, IFO 180, IFO 380
Salvador	HSFO, MGO, VLSFO, IFO 180, IFO 380
Madre de Deus	MGO
Suape	MGO, VLSFO

Notes: HSFO = high-sulfur fuel oil; MGO = marine gas oil; VLSFO = very-low sulfur fuel oil; IFO = intermediate fuel oil

APPENDIX C. CRITERIA SCORES FOR TOP 30 PORTS

Table C1

Criterion 1: Existing and potential use of renewable energy, top 30 ports

Port name	Main source of energy It is renewable	Offshore wind speed (m/s)	Score
Rio Grande	High availability	>10	5,0
Sao Francisco do Sul	High availability	9	5,0
Imbituba	High availability	8,75	5,0
Guamare Oil Terminal	High availability	>10	5,0
Pelotas	High availability	>10	5,0
Porto Alegre	High availability	>10	5,0
Pecem	High availability	8	4,5
Fortaleza	High availability	7,75	4,5
Itapoa	High availability	6,5	4,5
Salvador	High availability	6,5	4,5
Natal	High availability	8	4,5
Santos	High availability	6	4,0
Navegantes	High availability	6	4,0
Sao Sebastiao	High availability	6	4,0
Paranagua	High availability	6	4,0
Itajai	High availability	6	4,0
Maceio	High availability	6	4,0
Belem	High availability	5,75	4,0
Vila do Conde	High availability	5,75	4,0
Madre de Deus	High availability	6	4,0
Aratu	High availability	6	4,0
Antonina	High availability	6	4,0
Ilheus	High availability	6	4,0
Santana	High availability	4	3,5
Trombetas	High availability	3	3,5
Santarem	High availability	3	3,5
Juruti	High availability	3	3,5
Corumba	High availability	2,5	3,5
Praia Mole	Low availability	8,3	3,0
Tubarao	Low availability	8,3	3,0
Vitoria	Low availability	8,3	3,0

Table C2

Criterion 2: Port capacity in 2023, top 30 ports

Port name	Total cargo in 2023 (Tonnes)	Score
Santos	166,377,121	5.0
Ponta da Madeira	166,334,878	5.0
Porto do Açu	84,155,255	4.0
Tubarao	75,996,732	4.0
Paranagua	66,451,870	4.0
Angra dos Reis	64,472,457	4.0
Sao Sebastiao	58,525,636	4.0
Itaguai	55,777,025	4.0
Rio Grande	40,133,860	3.0
Vila do Conde	38,344,468	3.0
Pecem	37,999,283	3.0
Itaqui	36,329,965	3.0
Sepetiba	35,874,166	3.0
Rio de Janeiro	27,921,197	3.0
Sao Francisco do Sul	27,490,404	3.0
Suape	24,015,152	3.0
Madre de Deus	23,982,481	3.0
Praia Mole	17,857,712	3.0
Santarem	16,452,458	3.0
Navegantes	14,235,009	3.0
Trombetas	12,606,492	3.0
Itapoa	11,726,201	3.0
Ponta Ubu	9,310,956	2.0
Imbituba	7,696,745	2.0
Vitoria	7,488,179	2.0
Aratu	7,216,498	2.0
Juruti	5,689,731	2.0
Manaus	5,626,181	2.0
Salvador	5,430,185	2.0
Belem	5,184,679	2.0

Table C3

Criterion 3: Port infrastructure, top 30 ports

Port name	Maximum draft	Area [million m2]	Existence of expansion area	Bunkering availability	Score
Santos	7.94	15.0	Available	Available	5
Itaqui	2.68	23.0	Available	Available	5
Sao Sebastiao	0.40	23.0	Available	Available	4
Rio Grande	5.56	12.8	Available	Available	4
Suape	3.23	17.3	Available	Available	4
Paranagua	0.17	13.3	Available	Available	4
Salvador	0.36	14.7	Available	Available	4
Maceio	0.33	10.5	Available	Available	4
Recife	0.11	12.0	Available	Available	4
Angra dos Reis	0.12	9.0	Available	Available	4
Vila do Conde	3.75	22.0	Not available	Available	4
Manaus	0.09	11.5	Available	Available	4
Belem	0.33	7.9	Available	Available	4
Ponta da Madeira	0.60	25.0	Available	Not available	3
Itaguaí	7.20	18.5	Available	Not available	3
Pecem	1.90	15.2	Available	Not available	3
Praia Mole	1.13	17.0	Available	Not available	3
Niteroi	0.03	7.0	Available	Available	3
Porto do Açu	0.09	21.7	Available	Not available	3
Tubarao	0.01	23.3	Not available	Available	3
Sao Francisco do Sul	1.20	12.8	Available	Not available	3
Imbituba	1.55	13.5	Available	Not available	3
Aratu	4.00	14.8	Available	Not available	3
Sepetiba	10.00	19.8	Not available	Not available	3
Rio de Janeiro	0.21	14.2	Not available	Available	3
Madre de Deus	0.22	14.0	Not available	Available	3
Navegantes	0.40	11.0	Available	Not available	3
Trombetas	0.11	11.6	Available	Not available	3
Fortaleza	0.32	11.0	Not available	Available	3
Barra dos Coqueiros	2.00	9.5	Available	Not available	3

Table C4

Criterion 4: Role in major trade routes and connectivity score in 2023, top 30 ports

Port Name	Number of cabotage state connection routes	Number of countries involved in international routes	Port type	Score
Santos	15	135	Public	5.0
Rio Grande	14	103	Public	4.8
Rio de Janeiro	14	107	Public	4.8
Itaqui	13	57	Public	4.5
Suape	14	58	Public	4.5
Itaguaí	11	73	Public	4.5
Imbituba	10	53	Public	4.5
Fortaleza	14	24	Public	4.3
Vitoria	13	41	Public	4.3
Navegantes	11	60	Private	4.0
Itapoa	11	80	Private	4.0
Itajai	9	14	Public	3.8
Salvador	12	117	Public	3.8
Pecem	12	36	Private	3.8
Sao Francisco do Sul	5	37	Public	3.8
Paranagua	14	85	Public	3.5
Recife	4	15	Public	3.5
Vila do Conde	12	78	Public	3.5
Porto do Açu	7	30	Private	3.5
Santana	1	23	Public	3.5
Porto Alegre	3	13	Public	3.5
Maceio	10	28	Public	3.3
Angra dos Reis	8	18	Private	3.3
Belem	11	22	Public	3.3
Praia Mole	3	32	Private	3.3
Aratu	13	43	Public	3.3
Madre de Deus	13	25	Public	3.3
Guamare Oil Terminal	9	7	Private	3.3
Natal	2	13	Public	3.3
Sao Sebastiao	16	26	Private	3.0

Table C5

Criterion 5: Commitment to decarbonization and score, top 30 ports

Port name	Projects under licensing - Offshore wind complexes	Part of the Brazilian Alliance for the Decarbonization of Ports	Use of new sources of energy generation in port strategic plan	Score
Rio Grande	Yes	Yes	Yes	5.0
Rio de Janeiro	Yes	Yes	Yes	5.0
Itaqui	Yes	Yes	Yes	5.0
Itaguai	Yes	Yes	Yes	5.0
Fortaleza	Yes	Yes	Yes	5.0
Navegantes	Yes	Yes	Yes	5.0
Pecem	Yes	Yes	Yes	5.0
Porto do Açu	Yes	Yes	Yes	5.0
Angra dos Reis	Yes	Yes	Yes	5.0
Santos	Not	Yes	Yes	3.7
Imbituba	Yes	Yes	Not	3.7
Vitoria	Yes	Yes	Not	3.7
Itapoa	Yes	Not	Yes	3.7
Itajai	Yes	Yes	Not	3.7
Sao Francisco do Sul	Yes	Yes	Not	3.7
Porto Alegre	Yes	Yes	Not	3.7
Praia Mole	Yes	Yes	Not	3.7
Guamare Oil Terminal	Yes	Yes	Not	3.7
Niteroi	Yes	Yes	Not	3.7
Tubarao	Yes	Yes	Not	3.7
Pelotas	Yes	Yes	Not	3.7
Ponta da Madeira	Yes	Yes	Not	3.7
Sepetiba	Yes	Not	Yes	3.7
Paranagua	Not	Yes	Not	2.3
Santana	Yes	Not	Not	2.3
Maceio	Not	Yes	Not	2.3
Belem	Not	Yes	Not	2.3
Madre de Deus	Not	Yes	Not	2.3
Natal	Yes	Not	Not	2.3

APPENDIX D. DETAILED RESULTS OF FEASIBILITY ON THE 10 SELECTED ROUTES

Table D1

Technological feasibility of using renewable marine fuel to power selected routes

Route	Required fuel volume (m3)			Available volume for fuel (m3)			Number of refueling stops		
	LH2	NH3	MeOH	LH2	NH3	MeOH	LH2	NH3	MeOH
Santos - Tampa	1,971	911	649	1,952	1,758	1,758	1	0	0
Pecem - New York	3,817	1,764	1,257	10,174	7,752	7,752	0	0	0
Porto do Açu - Qingdao	9,124	4,217	3,005	5,570	4,787	4,787	1	0	0
Porto do Açu - Antwerp	3,210	1,484	1,057	1,750	1,487	1,487	1	0	0
Santos - Visakhapatnam	5,586	2,582	1,839	3,272	2,890	2,890	1	0	0
Itaqui – Shanghai	12,718	5,878	4,188	9,474	8,456	8,456	1	0	0
Rio Grande-Rosario	717	332	236	1,767	1,492	1,492	0	0	0
Navegantes- Santos	184	85	60	4,221	3,924	3,924	0	0	0
Pecem - Manaus	1,133	524	373	3,842	2,950	2,950	0	0	0
Porto Alegre - Rio Grande	77	36	25	1,842	1,605	1,605	0	0	0

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