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Decarbonization pathways in Brazilian maritime cabotage: A comparative analysis of very low sulfur fuel oil, marine diesel oil, and hydrogenated vegetable oil in carbon dioxide equivalent emissions

Gustavo Adolfo Alves da Costa[a,*], André Bergsten Mendes[a], Vanina Macowski Durski Silva[b]

[a] Department of Naval Architecture and Ocean Engineering, University of São Paulo, São Paulo, Brazil
[b] Department of Mobility Engineering, Federal University of Santa Catarina, Joinville, Brazil

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ABSTRACT

This study evaluates the decarbonization potential within Brazilian maritime cabotage by comparing carbon dioxide equivalent emissions from conventional fuels - specifically, Very Low Sulfur Fuel Oil and Marine Diesel Oil - with those from Hydrogenated Vegetable Oil. Utilizing a life cycle assessment approach alongside a mathematical model based on operational schedules from four leading Brazilian maritime cabotage companies in the container sector, this research quantifies the environmental benefits of switching fuels. The results demonstrate that transitioning to Hydrogenated Vegetable Oil could significantly reduce annual emissions, from 1395,466 tons of carbon dioxide equivalent to 343,950 tons, amounting to a 75.4 % decrease. This noticeable decrease underscores the critical importance and viability of incorporating hydrogenated vegetable oil into the maritime sector's fuel mix as part of Brazil's broader decarbonization strategy. This research highlights the need for strategic policy reforms and strengthened collaboration across sectors to advance Brazil's maritime sustainability efforts.

1. Introduction

1.1. Background on Brazilian cabotage container liner services

In Brazil, maritime cabotage is governed by Law 9432 from January 8, 1997 (Brazil, 1997). This law establishes the regulatory framework for cabotage navigation within Brazil, defining maritime cabotage as the transportation of goods or passengers between Brazilian ports or points within its territorial waters, including rivers and lakes. This legislation specifically reserves maritime cabotage operations for Brazilian shipping companies, mandating that only vessels registered under the Brazilian flag can engage in these activities. The law aims to protect and promote the national maritime industry by setting out registration, ownership, and crewing requirements for vessels, thereby fostering the development and competitiveness of Brazil's maritime sector. Additionally, it underscores the importance of safety and environmental standards in cabotage operations, aligning with national and international regulations to ensure the well-being of the public and the preservation of the environment. Law No. 9.432 also empowers the Brazilian maritime authority with regulatory and oversight responsibilities, while encouraging the modernization of the cabotage fleet through incentives such as tax benefits and financing options, aiming to upgrade and renew vessels for improved efficiency and sustainability in maritime transport.

In 2022 the Brazilian government amended the regulatory framework for cabotage maritime transport after publishing the Law 14301, known as BR do Mar Law (Brazil, 2022). This law represents a significant update to Brazil's regulatory framework for maritime transport, particularly enhancing the provisions related to cabotage. This law aims to modernize and streamline maritime cabotage operations in Brazil, introducing measures to boost efficiency, competitiveness, and sustainability within the sector. A key focus of the legislation is on facilitating the growth of the national maritime industry through the simplification of regulatory procedures and the promotion of investments in the cabotage fleet. The law encourages technological innovation and the adoption of environmentally sustainable practices by providing incentives for the use of cleaner fuels and more efficient vessels. It also seeks to expand the availability and reliability of cabotage services, aiming to make them a more attractive option for transporting goods and passengers across Brazil's vast coastal and inland waterways. By doing so, Law 14301 seeks not only to strengthen the domestic shipping industry but also to contribute to the reduction of Brazil's overall transport

* Correspondence to: Av. Prof. Mello Moraes 2231, Cidade Universitária, Butantã, São Paulo - SP, CEP 05508-030, Brazil.
E-mail address: costa@usp.br (G.A.A.d. Costa).

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emissions, aligning with broader environmental goals and commitments. This legislation underscores the Brazilian government's commitment to enhancing the role of maritime transport in the national logistics chain, recognizing its potential for economic development and environmental sustainability.

In the Brazilian maritime cabotage sector, four shipping lines offer container liner services: Aliança, Log-In, Mercosul Line, and Norcoast. Established in 1950, Aliança operates under A.P. Moller – Maersk, the world's second-largest shipping company. Log-In, originally founded as Docenave in 1962, became part of MSC, the global shipping leader, in 2022. Mercosul Line, created in 1996, was acquired by CMA CGM, the third-largest shipping company globally, in 2017. Lastly, Norcoast is a joint venture, with 50 % owned by Norsul, a Brazilian shipping company, and 50 % by Hapag Lloyd, the world's fifth-largest shipping company.

1.2. Importance of studying cabotage fuel consumption and carbon dioxide equivalent emissions

The study of fuel consumption and carbon dioxide equivalent emissions (CO_2eq) emissions in maritime cabotage is essential for several reasons. First, it helps identify opportunities to reduce greenhouse gas (GHG) emissions and mitigate climate change impacts Maritime cabotage has been found to be more energy-efficient and environmentally friendly compared to road transport, producing fewer CO_2eq emissions per ton of cargo transported.

Second, understanding the environmental performance of different shipping modes can inform policy decisions and promote the adoption of cleaner technologies and practices in the maritime industry (Eyring et al., 2005). The International Transport Forum (ITF) report on “Decarbonisation of Coastal Shipping and Multimodal Transport” provides several recommendations for decarbonizing maritime cabotage, including integrating it into national decarbonization strategies, supporting the sector’s decarbonization efforts by reducing investment uncertainty, harnessing the regional development potential of coastal shipping, and strengthening competition enforcement while leveraging maritime cabotage regulations (Decarbonisation, 2023).

Third, it contributes to the development of sustainable maritime transport strategies, addressing the economic, environmental, and social dimensions of sustainability. Lastly, it supports the International Maritime Organization’s (IMO) goal of reducing GHG emissions from international shipping by at least 50 % by 2050 compared to 2008 levels (IMO., 2020).

1.3. Biofuels production in Brazil

Brazil stands as a prominent figure in the global biofuels market, particularly in the production of biodiesel. The country’s biodiesel sector has experienced substantial growth, propelled by its abundant feedstock resources, supportive government policies, and a strong agricultural industry. As of recent years, Brazil has solidified its position as one of the world's leading biodiesel producers, with production capacities expanding significantly to meet both domestic and international demand. According to Brazilian National Agency for Petroleum, Natural Gas and Biofuels data for February 2024, there are 60 biodiesel production plants with a capacity of 40,501 m^3 per day. In 2023, the total biodiesel production was 8 million m^3 (Nacional do Petróleo, 2023a).

The foundation of Brazil's biodiesel production lies in its vast agricultural sector, which provides a rich source of feedstocks. In 2023, Soy oil was the main feedstock (70,2 %) followed by Other Fatty Materials (15,7 %), Beef Fat (7,3 %), Others (5,4 %) and Palm/Dendê and Sunflower oils (1.4 %). Included in the Others are Chicken and Pork Fat, Cotton, Corn and Rapeseed/Canola Oils and Used Cooking Oil (Nacional do Petróleo, 2023a).

On September 18, 2023, the Brazilian President presented the “Fuel of the Future” bill, PL 4516/2023 to the National Congress (Brazil, 2023a). This bill signifies Brazil’s preliminary efforts to decarbonize its energy matrix by achieving set greenhouse gas reduction targets in the upcoming years. The legislation provides a thorough perspective on the sustainability strategies being evaluated. It’s commendable to see the pronounced emphasis on promoting sustainable mobility with minimized carbon emissions. The proposed shift from fossil fuels to biofuels, given their organic attributes and diminished greenhouse gas emissions, stands out as a significant move. Highlighting initiatives like the National Program for Sustainable Aviation Fuel and the National Green Diesel Program indicates a deliberate approach to bolster sustainability in pivotal sectors.

Hydrotreated Vegetable Oil (HVO) is emerging as a promising alternative in the biofuel market. Compatible with existing systems and derived from renewable sources like Brazilian soybean oil, HVO offers a high-quality, carbon-reducing potential that aligns with the IMO greenhouse gas emission reduction goals for 2050 (Cavalcanti et al., 2022; Cantarella et al., 2023; Müller-Casseres et al., 2021). Brazil’s commitment is further demonstrated through policies like RenovaBio, aiming to increase biofuel production and consumption to reduce the carbon intensity of transportation (Brazil, 2023b).

2. Objective of the study

The primary aim of this research is to conduct a detailed assessment of the carbon dioxide equivalent emissions associated with maritime cabotage in Brazil, specifically focusing on container services. This entails a comparative analysis between the emissions resulting from the consumption of traditional maritime fuels—Very Low Sulphur Fuel Oil (VLSFO) and Marine Diesel Oil (MDO)—and the emissions potential of Hydrogenated Vegetable Oil as an alternative fuel source. The core of this analysis is based on a hypothetical scenario where there is a 100 % replacement of VLSFO and MDO with HVO for the entire container service fleet engaged in Brazilian maritime cabotage. This approach aims to fully explore the emissions reduction capabilities of HVO in a direct comparison to the current standard maritime fuels. The decision to examine a complete substitution is driven by the need to understand the maximum potential impact of transitioning to a more sustainable fuel alternative on the maritime sector's carbon footprint. Derived from publicly available schedules disseminated by container shipping lines, this study's foundation enables a comprehensive evaluation of how a total shift to HVO could significantly alter CO_2eq emissions within the context of Brazil’s maritime cabotage operations.

3. Literature review

3.1. Container liner services

Container Liner Services are specialized maritime entities that focus on the conveyance of containers between a vast network of global ports and shipping routes. Their overarching objective is to ensure the efficient and dependable transportation of goods for their customers (Ducruet and Notteboom, 2012). A pivotal role in achieving this objective is the emphasis on service quality. In addition to service quality, another significant aspect of Container Liner Services is the adoption of yield management techniques. This involves the strategic allocation of container space, considering variables like perishability, fixed capacities, and unpredictable demand (Lin et al., 2020). Furthermore, liner shipping companies often forge strategic alliances and collaborations with fellow carriers. These alliances, which facilitate the sharing of ship capacities, allow companies to bolster their competitive stance in the market. Through the exchange of capacities and coordination of container routing, these entities can refine their network design, leading to heightened overall efficiency (Zheng et al., 2015). Merk et al (Merk et al., 2018). comment on the imperative of regular weekly services in liner shipping, driven by the industry’s high fixed-cost structure. Such regularity ensures a consistent flow of cargo, optimizing ship utilization and cost efficiency. Moreover, the reliability and frequency of such services have significant ramifications on supply chain management, influencing inventory management and planning for shippers (Zhang and Lam, 2015).

A container liner service proforma, used in the shipping industry, organizes data such as sailing schedules, vessel capacity, and cargo volume.

This proforma is foundational for the container liner schedule, which indicates planned vessel timings at various ports. The schedule, informed by the proforma, ensures efficient transportation, helping customers in shipment planning (Ducruet and Notteboom, 2012). The creation of the proforma and its schedules considers market needs, service quality, and operational constraints, and disruptions, such as port congestion, can affect schedules, necessitating recovery strategies (Notteboom, 2006). Collaborative agreements among shipping companies can further influence scheduling (Zhao et al., 2022). By utilizing these schedules, shippers can enhance supply chain efficiency (Lee et al., 2021). Overall, the development of a container liner service proforma and its relation to the published schedules involve considerations of market requirements, service quality, disruptions, collaborative agreements, and optimization, all aimed at providing efficient and reliable liner shipping services.

3.2. Use of alternative fuels for maritime decarbonization

The maritime sector is at the forefront of a sustainability revolution, with the exploration and integration of alternative fuels such as biofuels marking a significant step towards decarbonization. These alternative energy sources offer a viable pathway to reducing emissions, underpinning the industry's transition towards more environmentally responsible operations (Moshood, 2022). This shift, however, has challenges spanning economic, technological, and policy domains, necessitating a coordinated global approach to address marine environmental risks and ensure the successful adoption of clean energy solutions (Wang et al., 2023; Wang and Wright, 2021). The adoption of renewable marine fuels is gaining traction, supported by comprehensive roadmaps that underscore the importance of strategic pathways and policy measures for their integration (Harahap et al., 2023).

Academic research plays a crucial role in mapping the trajectory of alternative fuels in shipping, with studies highlighting both the technical and economic aspects of this transition. Public perception and international collaboration are pivotal, with countries like Brazil positioned to make substantial contributions to the global maritime decarbonization movement, thanks to its potential in producing alternative marine fuels (Zhang and Lam, 2015; Kołakowski et al., 2022).

Analytically, the shift towards alternative fuels presents both opportunities and challenges. Economically, it could lead to long-term cost savings, especially against the backdrop of fluctuating oil prices and the potential implementation of carbon pricing mechanisms (Wang and Wright, 2021). Technologically, it spurs the development of optimized engines and fuel systems, enhancing the sector's resilience by diversifying its energy mix (Müller-Casseres et al., 2021; Harahap et al., 2023). However, the environmental implications of alternative fuel spills, the need for substantial infrastructural investments to accommodate new fuel types, and the economic viability across their supply chains remain areas of active debate (Wang et al., 2023; Kouzelis et al., 2022).

In conclusion, the maritime sector's endeavor towards sustainable operations through alternative fuels is a complex interplay of opportunities and challenges. Brazil's potential for HVO production and its incorporation into maritime transportation exemplifies a model for sustainable maritime operations, highlighting the need for a comprehensive, collaborative approach to realize the sector's sustainability goals.

3.3. Well-to-wake emissions framework

In the context of maritime transportation, the assessment of CO_2eq emissions provides a holistic view of the environmental impact of shipping activities. CO_2eq emissions encompass not only carbon dioxide (CO_2) but also other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O), alongside particles like black carbon (BC), which have varying global warming potentials (GWPs). This comprehensive approach is crucial for accurately evaluating the climate implications of maritime transport and guiding policy decisions towards achieving global warming mitigation targets, such as those outlined in the Paris Agreement (Byahut et al., 2021).

The well-to-wake (WTW) emissions framework divides the life cycle of maritime fuels into two main phases: upstream (well-to-tank) and downstream (tank-to-wake). The upstream phase encompasses the extraction, production, and transportation of marine fuels to the point of use, while the downstream phase covers the combustion of these fuels in ship engines. By accounting for CO_2eq emissions across both phases, this framework ensures a complete assessment of the climate impact of maritime fuels, from their origin to their end use (Byahut et al., 2021; Comer and Osipova, 2021; Kramel et al., 2021).

The inclusion of methane and nitrous oxide in CO_2eq emissions is critical due to their potent global warming effects. Methane, for instance, has a GWP more than 25 times greater than CO_2 over a 100-year period, while nitrous oxide's GWP is about 298 times that of CO_2. Black carbon (BC), although not a greenhouse gas, significantly contributes to climate warming and is thus considered in the well-to-wake analysis. This approach ensures that all relevant climate pollutants are accounted for, providing a more accurate representation of the environmental impact of maritime transportation (Byahut et al., 2021).

The comprehensive assessment of well-to-wake CO_2eq emissions is crucial for shaping effective maritime transportation climate policies. This approach, which encompasses a broad spectrum of GHGs and particulates, enables policymakers to devise strategies that significantly reduce the shipping industry's climate impact. Key strategies include opting for less carbon-intensive fuels and adopting technologies and practices that lower emissions across the fuel life cycle. Such measures are essential for aligning the maritime sector with global climate objectives and promoting its sustainable development.

The well-to-wake framework is highlighted as a robust method for evaluating the climate impact of maritime transportation, offering a detailed understanding of the environmental effects of maritime fuels. This insight is fundamental for crafting policies and strategies aimed at the maritime sector's decarbonization and fulfilling international climate goals (Byahut et al., 2021; Comer and Osipova, 2021; Kramel et al., 2021).

The WTW methodology incorporates the assessment of indirect land use change (ILUC) to evaluate the environmental impacts of biofuels and other renewable energy sources comprehensively. ILUC is a critical factor in Brazil's efforts to manage the environmental footprint of biofuel production. When agricultural land is diverted to biofuel crops, it can prompt the conversion of other land areas, potentially leading to significant ecological consequences, including biodiversity loss, soil degradation, water resource strain, and increased greenhouse gas emissions. For example, converting tropical forests into soy plantations for biofuel can release substantial amounts of carbon previously sequestered in the ecosystem.

Recognizing the challenges in quantifying and modeling ILUC due to the intricate nature of ecological systems and land use dynamics, Brazil has implemented RenovaBio, a targeted program to bolster biofuel production while mitigating its environmental impact. RenovaBio is a proactive measure that integrates ILUC considerations into national biofuel policy, setting forth certification standards for biofuel producers to ensure their operations do not inflict adverse environmental effects. The program mandates that producers demonstrate adherence to environmental criteria, thereby aligning biofuel production with broader climate objectives (Brazil, 2023b).

Additionally, RenovaBio strategically promotes the utilization of land that is already degraded or underused for biomass cultivation, thereby curtailing the likelihood of deforestation and environmental degradation linked to new biofuel crop areas. This approach exemplifies Brazil's commitment to reducing greenhouse gas emissions and enhancing the sustainability of its energy portfolio while addressing the potential indirect effects of land use change associated with biofuel production.

4. Methodology

The methodology to assess emissions from container liner services operated by Brazilian shipping companies is methodically outlined in five sequential phases:

a) Schedule Retrieval: Initially, the schedules of container liner services are sourced from the official websites of the Brazilian shipping companies. This step guarantees the utilization of up-to-date operational data for a comprehensive emission analysis.
b) Service Classification: Services are then classified, recognizing that operations may involve collaborations between several companies.
c) Fuel Consumption Calculations: The third phase involves calculating the total consumption of VLSFO and MDO. This calculation is based on actual navigational data between ports for VLSFO and MDO, along with the duration of stays in ports for estimating MDO usage.
d) CO_2eq Emissions Estimations for VLSFO and MDO: The carbon dioxide equivalent emissions for VLSFO and MDO are estimated using their WTW parameters.
e) CO_2eq Emissions Estimation for HVO: Similarly, CO_2eq emissions for HVO are estimated using its specific WTW parameters, allowing for a direct comparison of its environmental impact against traditional maritime fuels.

It's important to note that the analysis concentrates on emissions from vessel navigation and port stays, excluding emissions from container handling within port facilities. Given the limitations of publicly available schedules, which lack detailed operational data for precise fuel consumption estimates, the study employs certain assumptions to bridge these gaps:

- Considering the variability of currents that could either aid or obstruct vessel navigation in rivers and maritime routes, this methodology assumes that since services operate in a closed circuit, the effects of currents neutralize over a complete round voyage.
- As the distances between ports are based on the distances between Pilot Stations, not between container terminals, this study assumes a standard navigation duration of two hours at a speed of 10 knots for calculating VLSFO consumption during vessels' entry and exit through a port's access channels and during berthing and unberthing operations.

These methodological assumptions are critical for compensating the lack of detailed operational data and ensuring that the study's emission estimates remain both robust and reflective of actual maritime operations.

4.1. Data collection

The cabotage services names listed on the Brazilian shipping companies operating in the container liner services' websites are as follows:

(1) Aliança's service (Aliança, 2024) offerings showcase a clear alignment with certain Log-In services. Specifically, the ALCT 1 service is mirrored by Log-In's Manaus (SMN), while ALCT 3 and ALCT 4 find their counterparts in Log-In's Expresso Manaus - (SEA) and Shuttle Rio (SSR) respectively. It's noteworthy that ALCT 2 and ALCT 5 stand distinct without any direct equivalents in the other lines.
(2) Diving deeper into Log-In's portfolio (Services Schedule, 2024), the Atlântico Sul (SAS) stands out, as it finds a parallel in Mercosul Line's PLATA service. This connection underscores a shared service approach between the two lines. Additionally, Log-In's Feeder Shuttle (FSS) adds to its diverse service range.
(3) Mercosul Line's BRACO (Mercosul Line, 2024) emerges as a unique offering, standing independently without a direct match in Aliança or Log-In.
(4) Lastly, Norcoast Amazon service (Norcoast, 2024) also emerges as a unique offering, standing independently without a direct match in Aliança, Log-In or Mercosul Line.

Their published schedules provide data on ETA (Estimated Time of Arrival), ETB (Estimated Time of Berthing), and ETS (Estimated Time of Departure) for each port in the schedules and clearly indicate that all their routes adopt a circular pattern. In these routes, the journey begins and concludes at the same port, forming a complete loop (Kingsley, 2019). Some services have multiple calls in Santos and Rio de Janeiro to manage the feeder volume from long haul container services. Fig. 1 displays the cabotage map, highlighting the port names and codes referenced in this study and schedule data is presented in Annex I.

4.2. Calculation methods

There are two primary methodologies for measuring ship emissions: the fuel-based (top-down) approach and the activity-based (bottom-up) approach. The fuel-based method utilizes marine fuel consumption data combined with fuel-related emission factors, making it ideal when detailed ship movement information is lacking. On the other hand, the activity-based method demands comprehensive data on individual vessels' technical features and operations. Using this data, emissions from each ship can be determined and then combined to estimate the entire fleet's emissions (Czermański et al., 2021). This study uses the top-down reference method, considering both fuel consumption and specific emission rates for each fuel type.

The maritime industry has long recognized the critical importance of accurately estimating fuel consumption for operational efficiency and environmental sustainability. A pivotal aspect of this estimation lies in understanding the relationship between the power required by a ship to maintain a certain speed and the speed itself. This relationship, often described as cubic, significantly influences fuel consumption rates and, by extension, the operational costs and environmental impact of maritime operations. The cubic relationship between power and speed in ships is rooted in the principles of fluid dynamics and the resistance encountered by a vessel as it moves through water. As a ship increases its speed, the resistance it faces due to water friction, wave formation, and other factors increases exponentially. This resistance, particularly wave-making resistance, grows at a rate that is not linear but cubic with respect to the ship's speed. Consequently, the power required to overcome this resistance and maintain a higher speed increases in a cubic manner.

This study uses the VLSFO consumption calculation based on the work of Yao, Ng and Lee (Yao et al., 2012) that explored the correlation between bunker fuel consumption rate (F) and ship speed (V) across various container ship sizes based on real data obtained from a shipping company. They established an empirical model, $F = k_1V^3 + k_2$ to represent this relationship. In their model, 'F' represents the bunker fuel consumption rate in tons/day, 'V' indicates the ship speed in knots, and 'k_1' and 'k_2' are coefficients.

The coefficients 'k_1' and 'k_2' are derived from regression analysis of empirical data on fuel consumption and ship speed. The value of 'k_1' reflects the rate at which fuel consumption increases with speed, which is influenced by the type of engine, the hydrodynamic properties of the vessel, and other design factors. 'k_2', on the other hand, represents a baseline consumption rate that accounts for the fuel used at lower speeds or when the vessel is idling.

Based on their work and considering the average maritime cabotage fleet size in TEU, this study adopts the values of $k_1 = 0.006754$ and $k_2 = 37.23$.

The MDO consumption is based on data from a prominent Brazilian shipping company operating the cabotage container liner market, which states an average consumption of 3.5 tons/day during sea voyages and 5.0 tons/day while docked at ports.

The CO_2eq emission calculation uses the WTW parameters for VLSFO, MDO and HVO presented in Table 1.

4.3. Mathematical model for emission calculation

The weekly CO_2eq emissions based published schedules by the Brazilian shipping company operating in the maritime cabotage container liner market are calculated using a Python code for the following math model that considers the calculation method presented before:

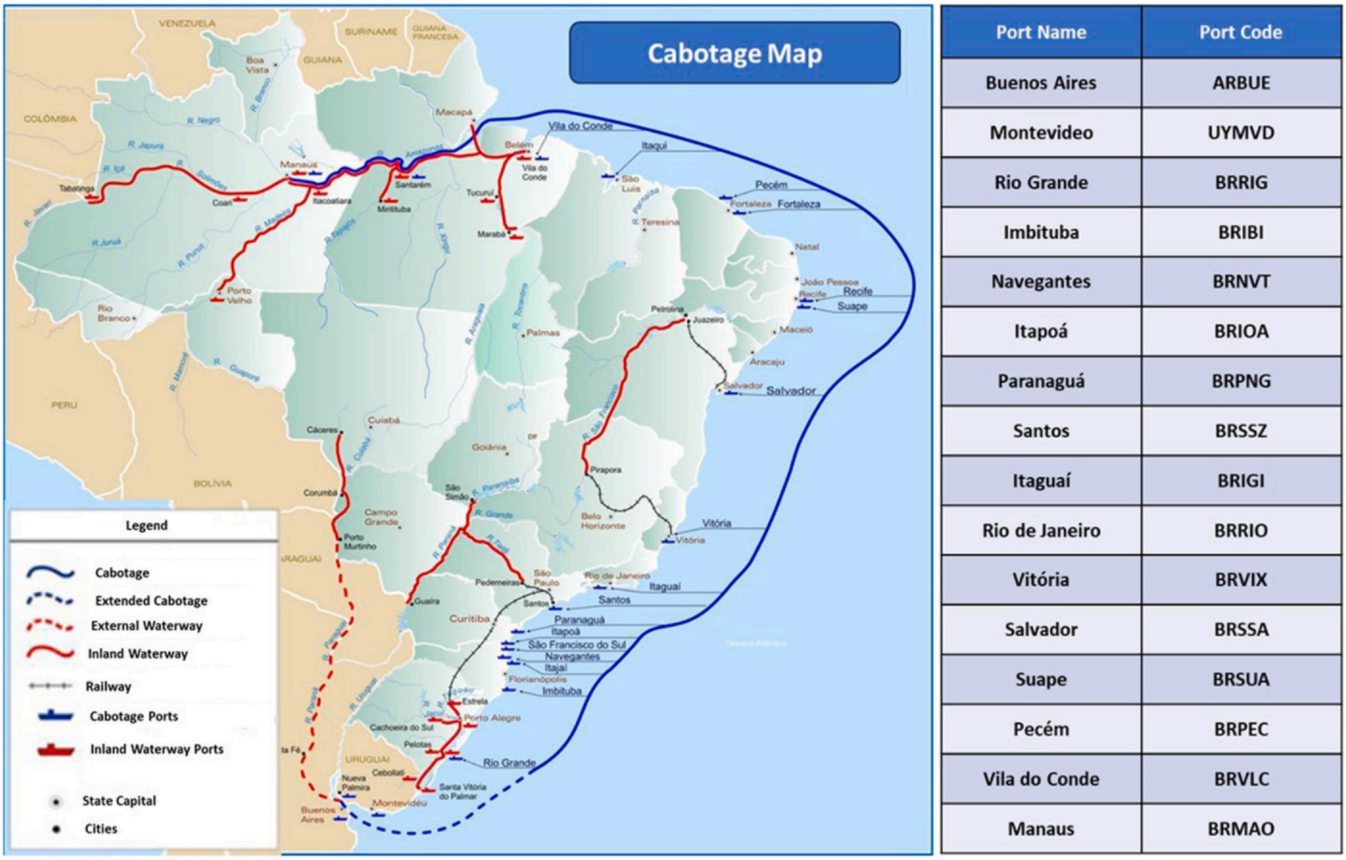

Fig. 1. Maritime Cabotage Map.
Authors.

Sets and Indices

S Set of cabotage services, indexed by s.

T Set of container terminals in the service loop for all cabotage service, indexed by t.

T_s Set of container terminals included in the service loop of each cabotage s, indexed by t ($T_s \subset T$). It is assumed that T_s lists the terminals in the order they are visited during the service loop. The last element in T_s, where the service ends, is a copy of the first terminal. This element will be referred to as e_s.

Variables

$ETA_{s,t}$ Estimated Time of Arrival at terminal t for service s.

$ETB_{s,t}$ Estimated Time of Berthing at terminal t for service s.

$ETS_{s,t}$ Estimated Time of Sailing from terminal t for service s.

$D_{s,t,t+1}$ Distance between terminal t and terminal $t+1$ for service s, measured in nautical miles (nm).

$TP_{s,t}$ Time spent in port at terminal t for service s, measured in days.

$TV_{s,t,t+1}$ Time spent in voyage between terminal t and terminal $t+1$ for service s, measured in days.

$S_{s,t,t+1}$: Vessel speed between terminal t and terminal $t+1$ for service s, measured in knots (kn).

$VLSFO_{s,t,t+1}$VLSFO consumption between terminal t and terminal $t+1$ for service s, measured in tons.

$MDO_{s,t}$: MDO consumption at terminal t for service s, measured in tons.

$MDO_{s,t,t+1}$MDO consumption between terminal t and terminal $t+1$ for service s, measured in tons.

Parameters

WTW_{VLSFO}Well-to-Wheel emission factor for fuel VLSFO, measured in gCO_2eq/MJ.

PCI_{VLSFO}Lower Heating Value for fuel VLSFO, measured in MJ/kg.

WTW_{MDO}Well-to-Wheel emission factor for fuel MDO, measured in g CO_2eq/MJ.

PCI_{MDO}Lower Heating Value for fuel MDO, measured in MJ/kg.

WTW_{HVO}Well-to-Wheel emission factor for fuel HVO, measured in g CO_2eq/MJ.

PCI_{HVO}Lower Heating Value for fuel HVO, measured in MJ/kg.

SCVessel speed in port for channel navigation, measured in kn.

Table 1
WTW and energy content parameters. Source: Authors.

Fuel	WTW (gCO_2e/MJ)	Energy Content (MJ/kg)	Source
HVO	23.7	37.68	EPE. 2023. Decarbonization of the Road Transport Sector - Carbon intensity of energy sources. Available in https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-708/NT-EPE-DPG-SDB-2022–03_Intensidade_de_carbono_Transporte_Rodoviario.pdf GREET. 2023. GREET® model: The Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model. Argonne National Laboratory. Available in https://greet.es.anl.gov/index.php.
VLSFO	96.7	42.2	IMO. 2020. Fourth IMO GHG Study 2020. Available in https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf.
MDO	93.8	42.7	IMO. 2020. Fourth IMO GHG Study 2020. Available in https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf.

TC Time spent in port for channel navigation, measured in hours.

Model equations

1. Time in Port (days)

$$TP_{s,t} = ETS_{s,t} - ETA_{s,t+1} \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{1}$$

2. Time in Voyage (days)

$$TV_{s,t,t+1} = ETA_{s,t+1} - ETS_{s,t} \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{2}$$

3. Speed (kn)

$$S_{s,t,t+1} = \frac{D_{s,t,t+1}}{24 \times TV_{s,t,t+1}} \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{3}$$

4. VLSFO Consumption (tons)

$$VLSFO_{s,t,t+1} = ((0.006754 \times S^3_{s,t,t+1} + 37.23) \times TV_{s,t,t+1}) + \left(\frac{0.006754 \times SC^3 + 37.23}{24} \times TC\right) \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{4}$$

5. MDO Consumption in Port (tons)

$$MDO^{P}_{s,t} = TP_{s,t} \times 5 \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{5}$$

6. MDO Consumption in Voyage (tons)

$$MDO^{V}_{s,t,t+1} = TV_{s,t,t+1} \times 3.\ 5 \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{6}$$

7. VLSFO Emission (t CO_2eq)

$$Emissions_{VLSFO,s,t,t+1} = \frac{VLSFO_{s,t,t+1} \times WTW_{VLSFO} \times PCI_{VLSFO}}{1000} \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{7}$$

8. MDO Emission at port (t CO_2eq)

$$Emissions^{P}_{MDO,s,t} = \frac{MDO^{P}_{s,t} \times WTW_{MDO} \times PCI_{MDO}}{1000} \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{8}$$

9. MDO Emission in voyage (t CO_2eq)

$$Emissions^{V}_{MDO,s,t,t+1} = \frac{MDO^{V}_{s,t,t+1} \times WTW_{MDO} \times PCI_{MDO}}{1000} \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{9}$$

10. Total Emissions for All Services (t CO_2eq)

$$Total\ Emissions = \sum_{s\in S}\sum_{t\in T_s} Emissions_{VLSFO,s,t,t+1} + \sum_{s\in S}\left(\sum_{t\in T_s} Emissions^{P}_{MDO,s,t} + \sum_{t\in T_s} Emissions^{V}_{MDO,s,t,t+1}\right) \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{10}$$

11. Energy Generated by MDO at Port (MJ)

$$Energy^{P}_{MDO,s,t} = MDO^{P}_{s,t} \times PCI_{MDO} \times 1000 \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{11}$$

12. Energy Generated by MDO in Voyage (MJ)

$$Energy^{V}_{MDO,s,t,t+1} = MDO^{V}_{s,t,t+1} \times PCI_{MDO} \times 1000 \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{12}$$

13. Energy Generated by VLSFO (MJ)

$$Energy_{VLSFO,s,t,t+1} = VLSFO_{s,t,t+1} \times PCI_{VLSFO} \times 1000 \ \forall\ s, \forall\ t \in T_s \setminus \{e_s\} \tag{13}$$

14. Total Energy Generated (MJ)

$$Total\ Energy = \sum_{s\in S}\sum_{t\in T_s\setminus\{e_s\}} Energy_{VLSFO,s,t,t+1} + \sum_{s\in S}\left(\sum_{t\in T_s\setminus\{e_s\}} Energy^{P}_{MDO,s,t} + \sum_{t\in T_s\setminus\{e_s\}} Energy^{V}_{MDO,s,t,t+1}\right) \tag{14}$$

15. HVO Emissions (t CO_2eq)

$$Emissions_{HVO} = \frac{Total\ Energy \times WTW_{HVO}}{1000000} \tag{15}$$

In essence, the model calculates the energy consumption for VLSFO and MDO based on projected consumptions in tons. Using their respective WTW emission factors, it then determines their CO_2eq emissions. For the transition to HVO, the model combines the energy consumptions of VLSFO and MDO and applies the HVO WTW emission factor to estimate its emissions. The schedules data is presented in Annex 1.

5. Results

In the domain of Brazilian maritime cabotage, container liner services that include the Port of Manaus within their operational itineraries exhibit the most substantial CO_2eq emissions when utilizing VLSFO and MDO. Specifically, the service LG SEA - AL ALCT 3 is responsible for emissions amounting to 5668.9 tons, constituting 17.4 % of the total, followed by NC Manaus with emissions of 5339.0 tons (16.4 %), ML Braco with 5322.9 tons (16.3 %), and AL ALCT 1 - LG SMN at 5224.4 tons (16 %).

A second echelon comprises services traversing routes from the South to the Northeast of Brazil; LG SAS - ML Plata and AL ALCT 2, emitting 4629.7 tons (14.2 %) and 3755.1 tons (11.5 %) respectively. The final category includes what are commonly referred to as “Feeder Services”, such as AL ALCT 5 with 1089.2 tons (3.3 %), LG SSR- AL ALCT 4 with 942.9 tons (2.9 %), and LG FSS with 628.0 tons (1.9 %).

In aggregate, Brazilian maritime cabotage container liner services consume 7288.1 tons of VLSFO and 713.9 tons of MDO per week, resulting on an emission of 32,600.2 t CO_2eq per week, or 1695,211 t CO_2eq per year.

The environmental implications of such emissions are profound. However, the introduction of HVO as an alternative fuel led to a 75,4 % reduction in annual emissions, from 1695,211 to 416,602 t CO_2eq, underscoring the potential of sustainable fuels in reshaping the maritime cabotage footprint. A table of the calculation result by service can be found in Annex II, while Fig. 2 illustrates the emission results for the maritime cabotage services. This transition not only signifies a move towards greener cabotage operations but also emphasizes the industry's commitment to combating climate change and reducing its carbon footprint.

The annual energy produced through the consumption of VLSFO and MDO is calculated at 17,578,156,936 Megajoules (MJ). Utilizing the energy content of HVO, which is 37.68 MJ/kg as indicated in Table 1, the yearly demand for HVO is estimated to be 467,504,174 kg. Given HVO's density of 778 kg per liter (Hydrogenated vegetable oil HVO, 2020), this translates to a requirement of approximately 599,364,325 liters of HVO annually.

6. Discussion

In a broader view, the maritime cabotage services in Brazil have contributed to a decline in GHG emissions by promoting the modal shift from road transportation to maritime cabotage. This transition is underscored by the steady increase in container throughput observed over the last 15 years (Brazilian Association of Cabotage Shipowners,). The potential for even greater emission reductions exists, particularly by substituting VLSFO and MDO with HVO, a fuel already being produced in Brazil. Considering that HVO can be produced from Used Cooking Oil (UCO), it emerges as a promising sustainable alternative fuel, effectively contributing to the energy

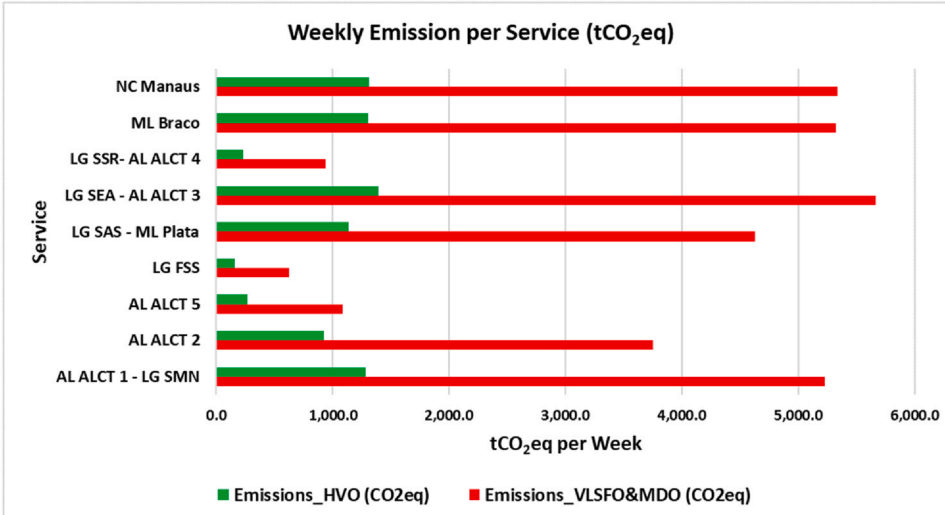

Fig. 2. Weekly tCO_2eq emissions per service.
Authors.

transition. With cooking oil consumption estimated at 3 billion liters in Brazil (Descarte, 2023) and according to the National Agency for Petroleum, Natural Gas and Biofuels, 127 million liters of UCO was used to produce biodiesel (Nacional do Petróleo, 2023a), representing less than 5 % of recycling in 2023. Utilizing UCO for HVO production addresses both the demand for cleaner fuels and the issue of waste management. A demand for 600 million liters of HVO, capable of replacing conventional maritime cabotage fuels MDO and VLSFO in Brazil, can be met by recycling 20 % of UCO. This strategy notably mitigates the indirect land use change impacts by repurposing waste, thus reducing deforestation and carbon emissions associated with new agricultural land. Moreover, it exemplifies the principles of the circular economy by transforming waste into energy, enhancing resource efficiency, and minimizing environmental pollution.

Given this, it's crucial to examine the Brazilian Government's strategies aimed at reducing GHG emissions in domestic transportation.

7. Conclusion

During the webinar "Recommendations to Develop a Brazilian Maritime National Action Plan" organized by the Instituto Clima e Sociedade in August 2022, stakeholders from the maritime sector concurred on several critical actions for decarbonizing maritime activities in Brazil. These actions include incentivizing the use of alternative fuels, setting energy efficiency standards for the fleet, and enhancing infrastructure for emerging fuel technologies (Carvalho, 2023). The discussion underscored the urgent need for national policies to establish a clear direction for maritime decarbonization. Although various initiatives are underway that contribute to emissions reduction, a firm commitment from the government remains pivotal for delineating a comprehensive decarbonization path for the maritime industry. Successful decarbonization requires collective action from government bodies, the private sector, civil society, and academia (Carvalho, 2023).

However, despite Brazil's engagement with the International Transport Forum and its pledge towards sustainable transport, the "Fuel of the Future" bill notably lacks provisions for the decarbonization of maritime transport, including maritime cabotage. This gap is particularly striking given the recognized potential of maritime cabotage in mitigating GHG emissions using alternative fuels as HVO. The absence of targeted strategies or measures for maritime decarbonization in this legislation points to a significant oversight. It reflects a disconnect in Brazil's efforts to integrate and capitalize on maritime transportation's contribution to the country's overarching goals for reducing its transportation sector's environmental impact, despite international recommendations and sustainability goals.

Future work

Building upon the findings of this study, two key areas are outlined for future research that promise to deepen the understanding of sustainable transport solutions and the potential of alternative fuels in mitigating environmental impacts:

- Advocating for Maritime Cabotage through Emission Assessments: Future research should focus on evaluating maritime cabotage's emissions compared to road transport, encompassing not only direct ship emissions but also those from port operations and the entire maritime cabotage logistics chain. This comprehensive analysis aims to highlight maritime cabotage's environmental benefits over road transport, providing strong evidence to support its promotion. Such findings are crucial for guiding policy and infrastructure decisions to prioritize maritime cabotage as a sustainable transport solution, effectively contributing to the sector's overall reduction in environmental impact.
- Potential of UCO in HVO Production for Maritime Cabotage: There is a significant opportunity to explore the feasibility of utilizing UCO as a primary feedstock for HVO production, specifically tailored for the maritime cabotage sector in Brazil. Investigating UCO's availability, scalability of processing technologies, and the environmental and economic impacts of such a production pathway could uncover valuable data. This research could validate UCO's role in promoting a circular economy while assessing its capability to meet the fuel demands of Brazil's maritime cabotage industry sustainably.

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CRediT authorship contribution statement

Gustavo Adolfo Alves Costa: Writing – original draft, Methodology, Formal analysis, Conceptualization. **André Bergsten Mendes:** Writing – review & editing, Validation, Supervision, Formal analysis. **Vanina Macowski Durski Silva:** Writing – review & editing, Visualization, Validation, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ANNEX I Schedule Data

Service	Port	Terminal	ETA	ETB	ETS	Distance (nm)
AL ALCT 1 - LG SMN	BRSSZ	Santos Brasil	02/02/2024 13:00	02/02/2024 13:00	02/03/2024 19:00	5.0
AL ALCT 1 - LG SMN	BRSSZ	BTP	02/04/2024 00:01	02/04/2024 00:01	02/04/2024 18:00	191
AL ALCT 1 - LG SMN	BRIGI	Sepetiba Tecon	02/05/2024 06:00	02/05/2024 06:00	02/05/2024 18:00	813
AL ALCT 1 - LG SMN	BRSSA	Tecon Salvador	02/08/2024 04:00	02/08/2024 04:00	02/08/2024 19:00	375
AL ALCT 1 - LG SMN	BRSUA	Tecon Suape	02/10/2024 05:00	02/10/2024 05:00	02/10/2024 21:00	478
AL ALCT 1 - LG SMN	BRPEC	APM Terminals	02/12/2024 06:00	02/12/2024 06:00	02/12/2024 19:00	1569
AL ALCT 1 - LG SMN	BRMAO	Porto Chibatão	02/17/2024 12:00	02/17/2024 12:00	02/20/2024 16:00	1569
AL ALCT 1 - LG SMN	BRPEC	APM Terminals	02/24/2024 15:00	02/24/2024 15:00	02/25/2024 02:00	478
AL ALCT 1 - LG SMN	BRSUA	Tecon Suape	02/26/2024 07:00	02/26/2024 07:00	02/26/2024 19:00	1259
AL ALCT 1 - LG SMN	BRSSZ	Santos Brasil	03/01/2024 13:00	03/01/2024 13:00	03/02/2024 19:00	
AL ALCT 2	BRIOA	Itapoa Terminais	02/09/2024 13:00	02/09/2024 13:00	02/10/2024 07:00	461
AL ALCT 2	BRRIG	Tecon Rio Grande	02/11/2024 17:00	02/11/2024 17:00	02/12/2024 12:00	321
AL ALCT 2	BRIBI	Tecon Imbituba	02/14/2024 07:00	02/14/2024 07:00	02/16/2024 03:00	1496
AL ALCT 2	BRSUA	Tecon Suape	02/20/2024 15:00	02/20/2024 15:00	02/21/2024 05:00	478
AL ALCT 2	BRPEC	APM Terminals	02/22/2024 10:00	02/22/2024 10:00	02/23/2024 09:00	853
AL ALCT 2	BRSSA	Tecon Salvador	02/25/2024 14:00	02/25/2024 14:00	02/26/2024 07:00	942
AL ALCT 2	BRSSZ	Santos Brasil	02/29/2024 01:00	02/29/2024 01:00	02/29/2024 19:00	192
AL ALCT 2	BRIOA	Itapoa Terminais	01/03/2024 13:00	01/03/2024 13:00	02/03/2024 07:00	
LG SEA - AL ALCT 3	BRSSZ	DPW Santos	02/02/2024 13:00	02/03/2024 14:00	02/04/2024 07:00	5
LG SEA - AL ALCT 3	BRSSZ	Santos Brasil	02/04/2024 13:00	02/04/2024 13:00	02/04/2024 23:00	226
LG SEA - AL ALCT 3	BRNVT	Portonave	02/05/2024 19:00	02/05/2024 20:00	02/06/2024 10:00	104
LG SEA - AL ALCT 3	BRPNG	TCP	02/06/2024 20:00	02/06/2024 20:00	02/07/2024 06:00	1072
LG SEA - AL ALCT 3	BRSSA	Tecon Salvador	02/10/2024 16:00	02/10/2024 17:00	02/10/2024 23:00	375
LG SEA - AL ALCT 3	BRSUA	Tecon Suape	02/12/2024 18:00	02/12/2024 19:00	02/13/2024 03:00	478
LG SEA - AL ALCT 3	BRPEC	APM Terminals	02/15/2024 01:00	02/15/2024 02:00	02/15/2024 09:00	1569
LG SEA - AL ALCT 3	BRMAO	Porto Chibatão	02/20/2024 18:00	02/20/2024 19:00	02/22/2024 20:00	3300
LG SEA - AL ALCT 3	BRSSZ	DPW Santos	01/03/2024 13:00	02/03/2024 14:00	03/03/2024 07:00	
LG SSR- AL ALCT 4	BRSSZ	DPW Santos	02/14/2024 08:00	02/14/2024 08:00	02/14/2024 16:00	5
LG SSR- AL ALCT 4	BRSSZ	Santos Brasil	02/14/2024 19:00	02/14/2024 19:00	02/15/2024 11:00	219
LG SSR- AL ALCT 4	BRRIO	ICSTI	02/16/2024 07:00	02/16/2024 07:00	02/16/2024 15:00	1
LG SSR- AL ALCT 4	BRRIO	Multi	02/16/2024 18:00	02/16/2024 18:00	02/17/2024 01:00	281
LG SSR- AL ALCT 4	BRVIX	TVV	02/18/2024 02:00	02/18/2024 02:00	02/19/2024 08:00	480
LG SSR- AL ALCT 4	BRSSZ	DPW Santos	02/21/2024 08:00	02/21/2024 08:00	02/21/2024 16:00	

ANNEX I – Schedule Data – continuation

Service	Port	Terminal	ETA	ETB	ETS	Distance (nm)
AL ALCT 5	BRPEC	APM Terminals	02/07/2024 01:00	02/07/2024 01:00	02/08/2024 00:01	696
AL ALCT 5	BRSSZ	Santos Brasil	02/10/2024 01:00	02/10/2024 01:00	02/12/2024 01:00	696
AL ALCT 5	BRPEC	APM Terminals	02/14/2024 01:00	02/14/2024 01:00	02/15/2024 00:01	
LG FSS	BRRIO	Multi	02/02/2024 13:00	02/02/2024 13:00	02/04/2024 13:00	281
LG FSS	BRVIX	TVV	02/05/2024 07:00	02/06/2024 07:00	02/07/2024 19:00	281
LG FSS	BRRIO	Multi	02/09/2024 13:00	02/09/2024 13:00	02/11/2043 13:00	
LG SAS - ML Plata	ARBUE	DPW Buenos Aires	02/11/2024 11:00	02/11/2024 23:00	02/13/2024 01:00	129
LG SAS - ML Plata	UYMVD	Montecon	02/13/2024 18:00	02/13/2024 19:30	02/14/2024 06:30	332
LG SAS - ML Plata	BRRIG	Tecon Rio Grande	02/15/2024 17:00	02/15/2024 19:00	02/16/2024 09:00	410
LG SAS - ML Plata	BRNVT	Portonave	02/18/2024 12:00	02/18/2024 13:00	02/19/2024 06:00	226
LG SAS - ML Plata	BRSSZ	DPW Santos	02/20/2024 00:01	02/20/2024 01:00	02/20/2024 10:00	1259
LG SAS - ML Plata	BRSUA	Tecon Suape	02/24/2024 21:00	02/24/2024 22:00	02/25/2024 16:00	478
LG SAS - ML Plata	BRPEC	APM Terminals	02/27/2024 06:00	02/27/2024 08:00	02/27/2024 21:00	853
LG SAS - ML Plata	BRSSA	Tecon Salvador	03/01/2024 05:00	03/01/2024 06:00	03/02/2024 01:00	942
LG SAS - ML Plata	BRSSZ	DPW Santos	03/05/2024 09:00	03/05/2024 11:00	03/06/2024 01:00	226
LG SAS - ML Plata	BRNVT	Portonave	03/06/2024 23:00	03/07/2024 01:00	03/07/2024 13:00	782
LG SAS - ML Plata	ARBUE	DPW Buenos Aires	03/10/2024 11:00	03/10/2024 23:00	03/12/2024 01:00	
ML Braco	BRSSZ	DPW Santos	02/14/2024 06:00	02/14/2024 06:00	02/15/2024 08:00	192
ML Braco	BRIOA	Itapoa Terminais	02/16/2024 06:00	02/16/2024 06:00	02/16/2024 20:00	380
ML Braco	BRRIO	ICSTI	02/18/2024 06:00	02/18/2024 06:00	02/18/2024 16:00	1061
ML Braco	BRSUA	Tecon Suape	02/22/2024 02:00	02/22/2024 02:00	02/22/2024 17:00	478
ML Braco	BRPEC	APM Terminals	02/24/2024 06:00	02/24/2024 06:00	02/24/2024 14:00	1569
ML Braco	BRMAO	Porto Chibatão	02/29/2024 19:00	02/29/2024 19:00	03/02/2024 23:00	2045
ML Braco	BRSUA	Tecon Suape	03/08/2024 19:00	03/08/2024 19:00	03/09/2024 09:00	1259
ML Braco	BRSSZ	DPW Santos	03/13/2024 06:00	03/13/2024 06:00	03/14/2024 08:00	
NC Manaus	BRSSZ	Santos Brasil	05/02/2024 23:00	06/02/2024 01:00	07/02/2024 01:00	167
NC Manaus	BRPNG	TCP	07/02/2024 16:00	07/02/2024 23:00	08/02/2024 12:00	1388
NC Manaus	BRSUA	Tecon Suape	12/02/2024 06:00	12/02/2024 08:00	12/02/2024 21:00	478
NC Manaus	BRPEC	APM Terminals	14/02/2024 06:00	14/02/2024 08:00	14/02/2024 21:00	1569
NC Manaus	BRMAO	Super Terminais	19/02/2024 07:00	19/02/2024 19:00	21/02/2024 08:00	1569
NC Manaus	BRPEC	APM Terminals	25/02/2024 15:00	25/02/2024 17:00	26/02/2024 04:00	478
NC Manaus	BRSUA	Tecon Suape	28/02/2024 06:00	28/02/2024 08:00	29/02/2024 02:00	1259
NC Manaus	BRSSZ	Santos Brasil	04/03/2024 23:00	05/03/2024 01:00	06/03/2024 01:00	

ANNEX II – Calculation Result

						Consumption (tons)		Emissions (t CO2eq)		Energy (MJ)			
Service	**Terminal**	**Distance (nm)**	**Time_Port (day)**	**Time_Voyage (day)**	**Speed (kn)**	**VLSFO**	**MDO**	**VLSFO**	**MDO**	**MDO**	**VLSFO**	**Total**	**Emissions_HVO (t CO2eq)**
AL ALCT 1 - LG SMN	Santos Brasil	5	1.3	0.2	1.0	11.4	7.0	46.7	28.0	298,114.2	483,140.8	781,255.0	18.5
AL ALCT 1 - LG SMN	BTP	191	0.7	0.5	15.9	35.9	5.5	146.5	22.0	234,701.7	1514,875.4	1749,577.1	41.5
AL ALCT 1 - LG SMN	Sepetiba Tecon	813	0.5	2.4	14.0	138.6	11.0	565.6	43.9	467,920.8	5848,562.8	6316,483.6	149.7
AL ALCT 1 - LG SMN	Tecon Salvador	375	0.6	1.4	11.0	69.2	8.1	282.6	32.4	345,158.3	2922,159.7	3267,318.0	77.4
AL ALCT 1 - LG SMN	Tecon Suape	478	0.7	1.4	14.5	83.1	8.1	339.0	32.6	347,827.1	3505,965.1	3853,792.2	91.3
AL ALCT 1 - LG SMN	APM Terminals	1569	0.5	4.7	13.9	264.1	19.2	1077.7	76.9	819,306.3	11,144,281.1	11,963,587.4	283.5
AL ALCT 1 - LG SMN	Porto Chibatão	1569	3.2	4.0	16.5	271.5	29.7	1107.8	118.9	1267,656.3	11,456,214.4	12,723,870.6	301.6
AL ALCT 1 - LG SMN	APM Terminals	478	0.5	1.2	16.5	85.2	6.5	347.7	26.1	278,439.6	3595,329.7	3873,769.3	91.8
AL ALCT 1 - LG SMN	Tecon Suape	1259	0.5	3.8	14.0	212.6	15.6	867.6	62.6	667,187.5	8972,190.6	9639,378.1	228.5
AL ALCT 1 - LG SMN	Santos Brasil												
AL ALCT 2	Itapoa Terminais	461	0.8	1.4	13.6	80.3	8.7	327.5	34.9	371,845.8	3386,895.3	3758,741.2	89.1
AL ALCT 2	Tecon Rio Grande	321	0.8	1.8	7.5	75.4	10.2	307.7	41.0	436,785.4	3182,017.4	3618,802.8	85.8
AL ALCT 2	Tecon Imbituba	1496	1.8	4.5	13.9	252.0	24.9	1028.3	99.8	1063,941.7	10,633,517.0	11,697,458.6	277.2
AL ALCT 2	Tecon Suape	478	0.6	1.2	16.5	85.2	7.1	347.7	28.6	305,127.1	3595,329.7	3900,456.8	92.4
AL ALCT 2	APM Terminals	853	1.0	2.2	16.1	148.1	12.5	604.2	50.1	534,639.6	6248,165.3	6782,804.9	160.8
AL ALCT 2	Tecon Salvador	942	0.7	2.8	14.3	160.1	13.2	653.1	52.7	562,216.7	6754,128.2	7316,344.9	173.4
AL ALCT 2	Santos Brasil	192	0.8	0.8	10.7	37.7	6.4	154.0	25.5	272,212.5	1592,437.0	1864,649.5	44.2
AL ALCT 2	Itapoa Terminais												
LG SEA - AL ALCT 3	DPW Santos	5	1.8	0.3	0.8	13.0	9.6	52.9	38.6	410,987.5	547,494.8	958,482.3	22.7
LG SEA - AL ALCT 3	Santos Brasil	226	0.4	0.8	11.3	42.8	5.0	174.7	20.0	213,500.0	1806,642.7	2020,142.7	47.9
LG SEA - AL ALCT 3	Portonave	104	0.6	0.4	10.4	22.3	4.6	91.2	18.4	195,708.3	942,891.0	1138,599.3	27.0
LG SEA - AL ALCT 3	TCP	1072	0.4	3.4	13.1	182.4	14.0	744.4	56.2	599,579.2	7698,422.3	8298,001.5	196.7
LG SEA - AL ALCT 3	Tecon Salvador	375	0.3	1.8	8.7	78.4	7.7	319.9	31.0	330,035.4	3308,278.4	3638,313.8	86.2
LG SEA - AL ALCT 3	Tecon Suape	478	0.4	1.9	10.4	89.5	8.6	365.4	34.4	366,508.3	3778,921.0	4145,429.3	98.2
LG SEA - AL ALCT 3	APM Terminals	1569	0.3	5.4	12.2	269.1	20.5	1098.1	82.0	874,460.4	11,355,831.7	12,230,292.1	289.9
LG SEA - AL ALCT 3	Porto Chibatão	3300	2.1	7.7	17.8	586.1	37.4	2391.9	149.8	1596,802.1	24,735,118.6	26,331,920.6	624.1
LG SEA - AL ALCT 3	DPW Santos												
LG SSR- AL ALCT 4	DPW Santos	5	0.3	0.1	1.7	8.3	2.1	34.0	8.4	89,847.9	351,230.3	441,078.2	10.5
LG SSR- AL ALCT 4	Santos Brasil	219	0.7	0.8	11.0	42.1	6.3	171.7	25.0	266,875.0	1775,774.1	2042,649.1	48.4
LG SSR- AL ALCT 4	ICTSI	1	0.3	0.1	0.3	8.3	2.1	33.9	8.4	89,847.9	351,066.6	440,914.6	10.4
LG SSR- AL ALCT 4	Multi	281	0.3	1.0	11.2	52.4	5.1	214.0	20.4	217,947.9	2212,846.4	2430,794.3	57.6
LG SSR- AL ALCT 4	TVV	480	1.3	2.0	10.0	91.6	13.3	373.9	53.1	565,775.0	3866,926.7	4432,701.7	105.1
LG SSR- AL ALCT 4	DPW Santos												

ANNEX II – Calculation Result - continuation

						Consumption (tons)		Emissions (tCO2eq)		Energy (MJ)			
Service	Terminal	Distance (nm)	Time_Port (day)	Time_Voyage (day)	Speed (kn)	VLSFO	MDO	VLSFO	MDO	MDO	VLSFO	Total	Emissions_HVO (t CO2eq)
AL ALCT 5	APM Terminals	696	1.0	2.0	14.2	119.2	11.9	486.4	47.8	509,775.7	5030,018.6	5539,794.3	131.3
AL ALCT 5	Santos Brasil	696	2.0	2.0	14.5	119.3	17.0	486.9	68.1	725,900.0	5034,719.9	5760,619.9	136.5
AL ALCT 5	APM Terminals												
LG FSS	Multi	281	2.0	0.8	15.6	50.9	12.6	207.5	50.6	539,087.5	2146,279.3	2685,366.8	63.6
LG FSS	TVV	281	2.5	1.8	6.7	72.4	18.6	295.3	74.6	795,287.5	3053,489.2	3848,776.7	91.2
LG FSS	Multi												
LG SAS - ML Plata	DPW Buenos Aires	129	1.6	0.7	7.6	32.1	10.4	131.1	41.6	443,902.1	1355,757.0	1799,659.1	42.7
LG SAS - ML Plata	Montecon	332	0.5	1.4	9.6	65.8	7.6	268.7	30.6	326,032.3	2778,264.2	3104,296.5	73.6
LG SAS - ML Plata	Tecon Rio Grande	410	0.7	2.1	8.0	90.2	10.8	368.2	43.1	459,914.6	3807,960.5	4267,875.0	101.1
LG SAS - ML Plata	Portonave	226	0.8	0.8	12.5	41.6	6.4	169.8	25.5	272,316.3	1756,414.7	2028,731.0	48.1
LG SAS - ML Plata	DPW Santos	1259	0.4	4.5	11.8	218.7	17.7	892.5	70.8	755,108.0	9229,198.7	9984,306.7	236.6
LG SAS - ML Plata	Tecon Suape	478	0.8	1.6	12.6	83.9	9.5	342.4	38.0	405,650.0	3540,473.4	3946,123.4	93.5
LG SAS - ML Plata	APM Terminals	853	0.6	2.3	15.2	146.2	11.3	596.7	45.2	482,154.2	6170,945.2	6653,099.4	157.7
LG SAS - ML Plata	Tecon Salvador	942	0.8	3.3	11.8	164.5	15.8	671.4	63.4	676,083.3	6942,779.9	7618,863.3	180.6
LG SAS - ML Plata	DPW Santos	226	0.7	0.9	10.3	44.5	6.5	181.6	26.2	279,329.2	1878,089.5	2157,418.7	51.1
LG SAS - ML Plata	Portonave	782	0.6	2.9	11.2	139.7	13.1	570.2	52.6	560,437.5	5896,077.6	6456,515.1	153.0
LG SAS - ML Plata	DPW Buenos Aires												
ML Braco	DPW Santos	192	1.1	0.9	8.7	41.9	8.6	171.0	34.5	368,287.5	1768,525.9	2136,813.4	50.6
ML Braco	Itapoa Teminais	380	0.6	1.4	11.2	69.8	7.9	284.7	31.5	336,262.5	2944,119.9	3280,382.4	77.7
ML Braco	ICSTI	1061	0.4	3.4	12.9	180.9	14.0	738.0	56.2	599,579.2	7632,128.3	8231,707.5	195.1
ML Braco	Tecon Suape	478	0.6	1.5	12.9	83.5	8.5	340.8	34.1	363,839.6	3524,218.7	3888,058.3	92.1
ML Braco	APM Terminals	1569	0.3	5.2	12.6	267.1	19.9	1090.1	79.7	849,552.1	11,273,216.7	12,122,768.8	287.3
ML Braco	Porto Chibatão	2045	2.2	5.8	14.6	343.6	31.3	1402.3	125.2	1334,375.0	14,501,327.5	15,835,702.5	375.3
ML Braco	Tecon Suape	1259	0.6	3.9	13.5	212.9	16.5	868.6	66.0	703,660.4	8982,857.9	9686,518.3	229.6
ML Braco	DPW Santos												
NC Manaus	Santos Brasil	167	1.1	0.6	11.1	32.8	7.6	133.7	30.5	324,697.9	1382,445.1	1707,143.0	40.5
NC Manaus	TCP	1388	0.8	3.8	15.4	236.2	17.3	963.8	69.3	738,354.2	9966,862.4	10,705,216.5	253.7
NC Manaus	Tecon Suape	478	0.6	1.4	14.5	83.1	7.9	339.0	31.8	338,931.3	3505,965.1	3844,896.4	91.1
NC Manaus	APM Terminals	1569	0.6	4.4	14.8	264.8	18.6	1080.7	74.4	793,508.3	11,176,164.4	11,969,672.7	283.7
NC Manaus	Super Terminais	1569	2.0	4.3	15.2	265.9	25.2	1085.1	101.0	1077,285.4	11,221,051.2	12,298,336.6	291.5
NC Manaus	APM Terminals	478	0.5	2.1	9.6	93.5	10.0	381.6	40.1	427,000.0	3946,621.7	4373,621.7	103.7
NC Manaus	Tecon Suape	1259	0.8	4.9	10.8	226.2	21.2	923.0	85.0	906,485.4	9545,100.5	10,451,585.9	247.7
NC Manaus	Santos Brasil												

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