COMPUTATIONAL TOOL FOR COMPARATIVE ANALYSIS OF DIESEL AND HVO USE IN PORT OPERATIONS: A CASE STUDY AT THE PORT OF ITAQUI

FERRAMENTA COMPUTACIONAL PARA ANÁLISE COMPARATIVA DO USO DE DIESEL E HVO EM OPERAÇÕES PORTUÁRIAS: ESTUDO DE CASO NO PORTO DO ITAQUI

HERRAMIENTA COMPUTACIONAL PARA EL ANÁLISIS COMPARATIVO DEL USO DE DIÉSEL Y HVO EN OPERACIONES PORTUARIAS: ESTUDIO DE CASO EN EL PUERTO DE ITAQUI

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ABSTRACT

Port decarbonization has gained increasing relevance in light of international targets for greenhouse gas (GHG) mitigation and regulatory pressures on maritime transport. The intensive use of diesel in vessels, equipment, and land vehicles generates significant CO_2 emissions and local air pollutants. Hydrotreated vegetable oil (HVO) stands out as a promising alternative, with lifecycle CO_2 emission reductions ranging from 60% to 95% and compatibility with existing infrastructure, although it faces cost barriers. This chapter presents a computational tool developed in Python using the Streamlit library to estimate emissions and perform an economic comparison between diesel and HVO, applied to the Port of Itaqui (MA) across five projected scenarios for the time horizons of 2025 and 2050. The results indicate that, with carbon pricing, HVO becomes economically competitive in the long term, constituting a relevant tool to support the port energy transition.

Keywords: Decarbonization. Ports. HVO. Carbon Credits.

RESUMO

A descarbonização portuária assume crescente relevância diante das metas internacionais de mitigação de gases de efeito estufa (GEE) e das pressões regulatórias sobre o transporte marítimo. O uso intensivo de diesel em embarcações, equipamentos e veículos terrestres gera emissões expressivas de CO_2 e poluentes atmosféricos locais. O óleo vegetal hidrotratado (HVO) destaca-se como alternativa promissora, com reduções de 60% a 95% nas emissões de CO_2 em ciclo de vida e compatibilidade com a infraestrutura existente, embora enfrente barreiras de custo. Este capítulo apresenta ferramenta computacional em Python utilizando a biblioteca Streamlit para estimativa de emissões e comparação econômica entre diesel e HVO, aplicada ao Porto do Itaqui (MA) em cinco cenários projetados para os horizontes temporais de 2025 e 2050. Os resultados indicam que, com a

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valorização do carbono, o HVO torna-se economicamente competitivo no longo prazo, constituindo instrumento relevante de apoio à transição energética portuária.

Palavras-chave: Descarbonização. Portos. HVO. Créditos de Carbono.

RESUMEN

La descarbonización portuaria adquiere una relevancia creciente frente a las metas internacionales de mitigación de gases de efecto invernadero (GEI) y las presiones regulatorias sobre el transporte marítimo. El uso intensivo de diésel en embarcaciones, equipos y vehículos terrestres genera emisiones significativas de CO_2 y contaminantes atmosféricos locales. El aceite vegetal hidrotratado (HVO) se destaca como una alternativa prometedora, con reducciones de entre el 60% y el 95% de las emisiones de CO_2 en su ciclo de vida y compatibilidad con la infraestructura existente, aunque enfrenta barreras de costo. Este capítulo presenta una herramienta computacional desarrollada en Python utilizando la biblioteca Streamlit para estimar emisiones y realizar una comparación económica entre diésel y HVO, aplicada al Puerto de Itaqui (MA) en cinco escenarios proyectados para los horizontes temporales de 2025 y 2050. Los resultados indican que, con la valorización del carbono, el HVO se vuelve económicamente competitivo a largo plazo, constituyendo una herramienta relevante de apoyo a la transición energética portuaria.

Palabras clave: Descarbonización. Puertos. HVO. Créditos de Carbono.

1 INTRODUCTION

The transition to low-carbon logistics chains occupies a central position in the international transport agenda, especially in sectors of high energy and emissive intensity, such as maritime transport and port operations (IEA, 2021; IMO, 2023). Ports, as strategic nodes of global supply chains, concentrate significant flows of cargo and energy, which translates into relevant emissions of greenhouse gases (GHG) and air pollutants, notably those associated with the consumption of diesel oil in vessels, tugboats, cargo handling equipment and land transport fleets (Di Majo, 2022; Pinto, Oliveira and Mendes, 2018).

In the Brazilian context, the normative framework aimed at climate mitigation and energy transition has progressively incorporated goals and instruments aimed at reducing emissions and expanding the use of low-carbon fuels. Examples of this movement are the National Policy on Climate Change (Brasil, 2009), the National Biofuels Policy, called RenovaBio (Brasil, 2017), and the National Green Diesel Program (Brasil, 2024). At the same time, the National Waterway Transportation Agency (ANTAQ) has promulgated guidelines and prepared diagnoses on the decarbonization of the port sector, emphasizing the need for sectoral emission inventories and the adoption of alternative fuels, among which HVO, low-emission hydrogen, and ammonia stand out (ANTAQ, 2023; 2024).

Among the technological routes available to replace fossil diesel, Hydrotreated Vegetable Oil (HVO) has stood out for providing reductions of 60% to 95% in CO_2 emissions throughout the life cycle, compared to fossil diesel, a variation that is conditioned by the raw materials used and the production processes adopted (Arvidsson et al., 2011; Menezes et al., 2022; Gomes et al., 2025). In addition, HVO has virtually zero sulfur and aromatic content, which favors the reduction of local pollutants without compromising compatibility with diesel engines and the existing supply infrastructure, factors that, together, tend to reduce the costs of technological transition (Szeto and Leung, 2022). Such attributes give HVO particular attractiveness for port applications, a context in which the full renewal of fleets or the replacement of infrastructure can imply high investment costs.

HVO production and distribution face obstacles related to its cost competitiveness against fossil diesel and the uncertainty that permeates carbon pricing instruments, such as regulated emissions markets and decarbonization credit mechanisms (Solakivi, Paimander and Ojala, 2022; Pereda et al., 2025). In this scenario, decisions regarding the adoption of alternative fuels cannot be based exclusively on the unit cost of fuel, but must incorporate variables such as avoided emissions and potential revenues from carbon credits and other economic mechanisms to induce decarbonization (Lee et al., 2024).

Although recent studies have advanced in the quantification of port emissions and evaluation of alternatives such as electrification and renewable fuels, critical gaps persist in the Brazilian context: absence of simple and configurable instruments for managers to simulate scenarios for replacing diesel with HVO considering carbon pricing; difficulty integrating GHG inventories, life cycle parameters and market prices into accessible operational tools without advanced programming; and lack of quantitative studies on conditions of economic competitiveness of HVO in specific ports. This article fills these gaps by developing a Python computational tool using the Streamlit decision support library, applied as a case study to the Port of Itaqui based on the inventory of 17,158 L diesel (EMAP, 2022), focusing on replicable land operations in other ports.

2 PORT DECARBONIZATION AND THE ROLE OF HVO

This section discusses the context of decarbonization in the port sector and the positioning of HVO among the main fuel alternatives for reducing greenhouse gas emissions, articulating the international and national regulatory framework with the specific operational demands of this sector.

2.1 PORTS, EMISSIONS, AND MITIGATION POLICIES

Seaports are highly complex socio-technical systems, responsible for the articulation between waterway and terrestrial infrastructures. Its configuration includes piers, mooring berths, specialized terminals, storage yards, road and rail accesses, as well as integrated logistics support areas (ANTAQ, 2022). The efficient operation of these facilities requires intensive energy consumption, mobilized by a heterogeneous set of equipment and vehicles, including port cranes, forklifts, internal handling trucks, backhoes, and maneuvering vessels (Pinto, Oliveira, and Mendes, 2018).

The use of fossil fuels, especially diesel oil, in the energy supply of these activities results in relevant emissions of carbon dioxide (CO_2) and air pollutants with local impact, such as particulate matter (PM), nitrogen oxides (NO_x) and sulfur oxides (SO_x). Such emissions simultaneously contribute to the worsening of climate change on a global scale and to the deterioration of air quality in urban areas adjacent to port complexes, with direct health implications for populations residing in these regions (Di Majo, 2022; CETESB, 2023).

In response to this scenario, international organizations have intensified regulatory efforts aimed at decarbonizing the sector. The International Maritime Organization (IMO), through its revised GHG Strategy, has established progressive emission reduction targets for shipping, with the aim of achieving net-zero emissions throughout the twenty-first century

(IMO, 2023). Such guidelines impose increasing pressures on port operators and shipowners, requiring the reorientation of their energy matrices towards lower carbon-intensity fuels.

At the national level, Brazil has a regulatory framework that progressively incorporates instruments to stimulate the energy transition in the transport sector. The National Policy on Climate Change (PNMC), instituted by Law No. 12,187/2009, establishes domestic commitments to reduce emissions and constitutes the central legal framework for sectoral decarbonization initiatives (BRASIL, 2009). The RenovaBio program, created by Law No. 13,576/2017, introduced a market mechanism based on decarbonization credits (CBIOs), encouraging the production and consumption of biofuels with lower carbon intensity in the life cycle (BRASIL, 2017). More recently, the National Green Diesel Program (BRASIL, 2024) has expanded the scope of these initiatives, creating specific regulatory and economic incentives for the replacement of fossil diesel with renewable alternatives compatible with existing infrastructure.

In the institutional scope of the port sector, studies coordinated by the National Waterway Transportation Agency (ANTAQ) have advanced in the formulation of decarbonization strategies, with an emphasis on the preparation of emission inventories and the evaluation of the technical and economic feasibility of alternative fuels (ANTAQ, 2023; ANTAQ, 2024). Such initiatives signal a movement towards the institutionalization of the climate agenda in the sector, although its effective operational implementation remains conditional on the availability of analytical tools capable of translating high-level guidelines into concrete management decisions.

In this context, the need for instruments that allow quantifying, in a systematic and comparative way, the impacts of different fuel options in terms of GHG emissions and economic viability is evident. It is precisely in this gap that the analysis of HVO as a promising alternative for the decarbonization of port operations is inserted, as developed in the following subsection.

2.2 HVO AS AN ALTERNATIVE TO FOSSIL DIESEL

Hydrotreated vegetable oil is a renewable fuel produced from raw materials of biogenic origin, such as vegetable oils and fats, through hydrotreating processes that remove oxygen and generate a compression-ignition engine fuel with similar or superior properties to fossil diesel (Kalnes, Marker and Shonnard, 2007; Art Fuels Forum, 2018). Life cycle assessment studies indicate that HVO can reduce between 60% and 95% of CO_2 emissions over the life cycle compared to diesel, depending on the feedstock and the technological route (Arvidsson et al., 2011; Menezes et al., 2022; Gomes et al., 2025).

In addition to the climatic advantages, HVO has low sulfur content, absence of aromatic compounds, and better combustion behavior, resulting in lower emissions of local pollutants such as NO_x, SO_x, and particulate matter, when compared to conventional diesel (Szeto and Leung, 2022; Shukla et al., 2023). A particularly relevant feature for port applications is HVO's high compatibility with existing diesel engines and with the storage and distribution infrastructure already in place, allowing its use in diesel blends or even as a total replacement without the need for large investments in adaptation (Szeto and Leung, 2022; Bodemer, 2023).

Despite these attributes, HVO still has higher direct costs than diesel in many markets, which limits its adoption at scale without carbon pricing mechanisms or specific economic incentives (Solakivi, Paimander and Ojala, 2022; Lee et al., 2024). Thus, the evaluation of its economic viability depends on models that integrate fuel prices, avoided emissions and revenues from carbon credits, such as the one proposed in this article.

3 METHODOLOGY

The methodology adopted in this work combines the formulation of a quantitative model for calculating emissions and costs with the development of an interactive computational tool that operationalizes this model for use by port managers.

3.1 GENERAL STRUCTURE OF THE VALUATION MODEL

The proposed evaluation model is deterministic, static and scenario-oriented, estimating, for each combination of parameters, three main sets of indicators: (i) direct cost of fueling diesel and HVO; (ii) CO_2 emissions associated with fuel consumption; and (iii) net cost after consideration of revenues from carbon credits. The approach is based on activity data (volume consumed) and emission factors, articulating environmental and economic dimensions in a simple and transparent structure (Arvidsson et al., 2011; Gomes et al., 2025; Lee et al., 2024).

As an empirical reference, the volume of diesel consumed by transport vehicles and a backhoe at the Port of Itaqui is used, according to the GHG emissions inventory prepared by the Maranhão Port Administration Company (EMAP, 2022). From this volume, different combinations of diesel and HVO use and different carbon price levels are simulated, for short and long-term horizons.

3.2 EMISSIONS AND COST CALCULATION MODEL

The model considers that the cost of filling up with each fuel is a function of the volume consumed and the unit price, while CO_2 emissions are derived from volume and average emission factors. The potential revenue from carbon credits is calculated from the emissions avoided in relation to a reference scenario with the exclusive use of diesel.

The main relationships can be summarized as follows:

- Fuel cost:
  $C_f = V_f \cdot P_f$which is the cost of fueling up with fuel (diesel or HVO), is the volume consumed and the price per liter.$C_f f V_f P_f$
- Diesel emissions:
  $E_d = V_d \cdot FE_d$which are the CO_2 emissions associated with diesel, the volume consumed and the average emission factor per litre.$E_d V_d FE_d$
- HVO emissions:
  $E_h = E_d \cdot (1 - R)$which are the emissions with HVO and is the percentage reduction of HVO emissions compared to fossil diesel.$E_h R$
- Avoided emissions:
  $E_{ev} = E_d - E_h$.
- Revenue from carbon credits:
  $R_c = E_{ev} \cdot P_c$ which is the price of carbon in monetary units per ton of CO_2.P_c
- Net cost:
  $C_{liq} = C_d + C_h - R_c$ where and are the costs of fueling diesel and HVO, respectively.$C_d C_h$

The values of emission factors, percentage reductions and prices of fuels and carbon credits were obtained in life cycle studies and economic analyses of alternative fuels, as well as on carbon credit market bases (Arvidsson et al., 2011; Solakivi, Paimander and Ojala, 2022; Gomes et al., 2025; Lee et al., 2024; Investing.com, 2025).

3.3 REQUIREMENTS AND DEVELOPMENT OF THE COMPUTATIONAL TOOL

To operationalize the model in an accessible way to port managers and technicians, a computational tool in Python language was developed, using a library for the construction of interactive panels, streamlit. The system was designed as a dashboard, in which the user enters fundamental parameters and obtains as output tables and graphs with costs, emissions and net costs for different scenarios.

The main requirements of the tool include: (i) simplicity of use, dispensing programming knowledge; (ii) flexibility, allowing the parameterization of diesel and HVO prices, carbon credit values, emission factors and percentage reductions; (iii) ability to simulate short- and long-term scenarios; and (iv) possibility of replication for different ports and sets of equipment. The choice of a monolithic architecture, without the need to connect to external databases, aims to facilitate deployment in diverse institutional contexts and minimize infrastructure dependencies.

From the point of view of data flow, the tool organizes the analysis into three stages: (i) input data entry; (ii) processing of emissions and cost equations; and (iii) presentation of results in tabular and graphic format. The following section presents the case study that illustrates the application of the tool.

4 CASE STUDY: PORT OF ITAQUI

The Port of Itaqui, located in São Luís (MA) and managed by the Maranhão Port Administration Company (EMAP), is a strategic public port in the Brazilian Central-North Corridor, specializing in the flow of grains (soybeans, corn), fuels, cellulose and mineral bulk. It has nine operational berths with depths of 12 to 19 meters, allowing the berthing of large ships, including specialized terminals such as Vale (Valemax, up to 400 thousand tons) and Tegram (grains, 500 thousand tons of storage).

4.1 CHARACTERIZATION AND INPUT DATA

The Port of Itaqui is an organized port located in São Luís (MA), with significant movement of grains, fuels, and other cargo, and with land operations that include internal transport vehicles and equipment such as backhoes (EMAP, 2022; ANTAQ, 2024). The port authority's GHG emissions inventory reports, for 2021, consumption of 17,158.30 liters of diesel in transport vehicles and a backhoe loader, with an average emission factor of 3.20 $kgCO_2$ per liter, considering data from literature and combustion stoichiometry (EMAP, 2022; CETESB, 2023).

This set of equipment was selected for the case study because it represents a relevant portion of the direct emissions associated with ground operations and because it has consolidated fuel consumption data. To simulate scenarios for the replacement of diesel by HVO, fuel price parameters and carbon credits were adopted based on recent market data and projections from prospective studies (Solakivi, Paimander and Ojala, 2022; Lee et al., 2024; Pereda et al., 2025).

4.2 CONSTRUCTION OF THE SCENARIOS

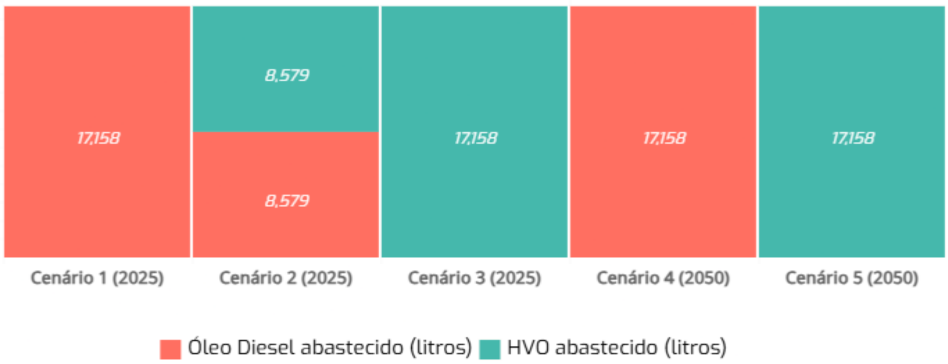
To answer the question of under what economic conditions the use of HVO can become competitive in relation to fossil diesel in the port's onshore operations, five base scenarios were defined, combining proportions of fuel use and time horizons. The scenarios were constructed in order to contrast short-term situations, with current HVO prices and carbon credits, and long-term scenarios with greater carbon valuation and technological advancement in the HVO chain, scenarios represented in Figure 1.

In the five scenarios, the years presented are equivalent to the diesel prices and carbon credits used for the calculation and are as follows:

1. Scenario 1 – Full use of diesel in 2025.
2. Scenario 2 – Partial replacement in 2025, with a 50% diesel and 50% HVO blend.
3. Scenario 3 – Total replacement of diesel by HVO in 2025.
4. Scenario 4 – Full use of diesel in 2050.
5. Scenario 5 – Total replacement of diesel by HVO in 2050.

Figure 1

Supply scenarios



Source: Prepared by the authors.

Fuel prices and carbon credit values were adopted as shown in Table 1, based on market data and projections for contexts of greater climate restriction (Solakivi, Paimander and Ojala, 2022; Lee et al., 2024; Pereda et al., 2025; Investing.com, 2025). The reduction in emissions associated with HVO was set at 85% for 2025 and 95% for 2050, reflecting expectations of improvements in the production chain, increased participation of sustainable raw materials, and technological gains (Arvidsson et al., 2011; Gomes et al., 2025; Solakivi, Paimander and Ojala, 2022).

Table 1

Parameters adopted for the scenarios

Variables	2025	2050
Diesel Cost (USD/l)	0,5	0,5
HVO Cost (USD/l)	1,75	≈ 1
Carbon credit value (USD/ton)	70,65	250 (Lee et al., 2024)
Reduction in CO_2 emissions from HVO compared to fossil diesel	85%	95%

Source: adapted from the authors.

Based on these parameters and the reference volume of 17,158.30 liters, the computational tool calculated, for each scenario, the total cost of supply, CO_2 emissions and the net cost after considering revenues from carbon credits. The following section presents and discusses the results obtained.

5 RESULTS

The results of the simulations allow to compare, for each scenario, the direct costs of supply, CO_2 emissions and the net costs after the internalization of carbon credits. In this section, the main findings and their interpretation for the management of port operations are presented.

5.1 DIRECT FUELING COSTS AND EMISSIONS

Table 2 summarizes the results for the five scenarios evaluated, considering the total consumption of 17,158.30 liters and the economic and environmental parameters previously defined.

Table 2

Scenarios of the replacement of Diesel by HVO

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Diesel oil filled (liters)	17.158,30	8.579,15	0	17.158,30	0
HVO fueled (liters)	0	8.579,15	17.158,30	0	17.158,30
Total Supply Amount (USD)	8.579,15	19.303,08	30.027,02	8.579,15	17.158,30
Value considering carbon credits (USD)	11.826,46	21.170,29	30.514,12	22.366,19	17.985,52
CO_2 emissions (ton)	45,96	26,43	6,89	45,96	2,29

Source: from the authors.

The results indicate that, in 2025, the scenarios with the introduction of HVO present direct supply costs significantly higher than the reference scenario with the exclusive use of diesel. On the other hand, substantial reductions in CO_2 emissions are observed: in the 50% blending scenario, emissions fall from 45.96 t to 26.43 t, while in the total replacement scenario in 2025 they reach 6.89 t, representing reductions of more than half compared to the exclusive use of diesel (Arvidsson et al., 2011; Gomes et al., 2025; EMAP, 2022).

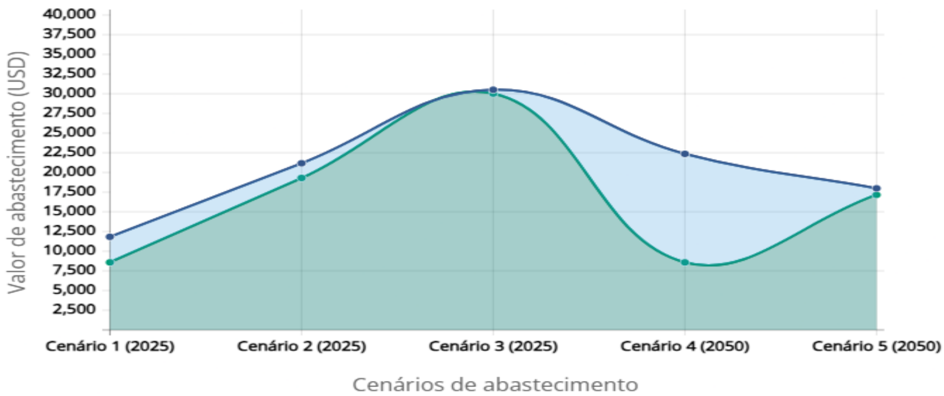
For 2050, even if the direct cost of diesel remains constant, the reduction of the price of HVO to 1.00 US$/L results in a total cost of fueling closer to diesel, while CO_2 emissions fall drastically to 2.29 t in the total replacement scenario, given the greater percentage reduction attributed to HVO (Gomes et al., 2025; Lee et al., 2024). These results reinforce the environmental potential of HVO, especially in long-term horizons with improvements in the production chain.

5.2 EFFECT OF CARBON CREDITS AND NET COST

When carbon credits are incorporated into the model, the economic comparison is altered, as part of the HVO cost differential is offset by revenues associated with avoided emissions. The representation of these scenarios is present in Figure 2.

Figure 2

Economic comparison between the scenarios of replacing diesel with HVO



Source: from the authors.

In 2025, even with the inclusion of carbon credit revenues, diesel remains more competitive in terms of net cost, although the difference is slightly reduced compared to the comparison based only on direct costs (Solakivi, Paimander and Ojala, 2022; Investing.com, 2025). However, the internalization of carbon credits makes the economic value of the avoided emissions more evident, especially in scenarios of total blending or substitution.

By 2050, the combination of higher percentage reduction in emissions, higher carbon price, and falling cost of HVO substantially changes the net cost hierarchy. In this horizon, the scenario with total substitution by HVO has a lower net cost than the scenario of exclusive use of diesel, indicating that biofuel can become not only environmentally superior, but also economically more attractive, when considering the climate externalities internalized via carbon credits (Lee et al., 2024; Pereda et al., 2025; Solakivi, Paimander and Ojala, 2022).

5.3 IMPLICATIONS FOR PORT MANAGEMENT

The results suggest that the economic competitiveness of HVO in inland port operations is strongly dependent on the carbon price trajectory and technological advances in the fuel production chain. In stricter regulatory contexts, with high carbon prices and policies to encourage renewable fuels, HVO tends to become an attractive alternative from an economic and environmental point of view (IEA, 2021; ANTAQ, 2024; Lee et al., 2024). On the other hand, in low-carbon pricing environments, HVO adoption depends on corporate decarbonization strategies, additional policies to support or reputational benefits, and reduce regulatory risk.

From an operational point of view, the computational tool presented offers a practical way to explore these relationships, allowing managers to evaluate different combinations of parameters and identify conditions under which partial or total replacement by HVO becomes feasible. By facilitating scenario simulation, the instrument contributes to the planning of the port energy transition, while it can be adapted to other ports with adjustments to consumption and price data.

6 METHODOLOGICAL AND PRACTICAL CONTRIBUTION

The main contribution of this work lies in the integration, in an accessible tool, of a simple quantitative model of emissions and costs with an interactive interface that allows port managers to test fuel substitution scenarios without the need for advanced programming knowledge. This approach responds to the gap identified in the literature and practice, where many analyses remain restricted to academic studies or specialized consultancies.

By operationalizing the model in a configurable dashboard, the study brings together concepts of life cycle assessment, carbon pricing, and analysis of scenarios of daily port management, favoring the incorporation of environmental variables in investment and operation decisions. This characteristic is particularly relevant in a scenario of intensifying regulatory requirements and corporate decarbonization goals (IEA, 2021; ANTAQ, 2023; ANTAQ, 2024).

Despite the advances, the study has limitations that should be considered in the interpretation of the results. First, the analysis focused on a specific set of equipment from a single port, which restricts the generalization of the results to other operational and geographical contexts. Second, supply infrastructure costs, operational adaptations, or uncertainties related to future HVO availability and input pricing dynamics, which may be relevant to long-term investment decisions, were not included (Solakivi, Paimander and Ojala, 2022; Pereda et al., 2025).

Another limitation is the absence of systematic analysis of the sensitivity of the results in relation to the main variables of the model, such as fuel prices, emission factors, carbon credit values, and reduction percentages attributed to HVO. Although the tool allows changing these parameters, the present article did not explore, in detail, the joint variation of multiple variables nor did it apply risk analysis techniques or probabilistic scenarios.

7 CONCLUSIONS

This paper presented the development and application of a computational decision support tool for comparative analysis of diesel and HVO use scenarios in onshore port operations, with a case study in the Port of Itaqui. The model integrates estimates of CO_2 emissions, fueling costs and revenues from carbon credits, allowing the environmental and economic impacts of fuel substitution to be evaluated in an integrated manner over short and long-term horizons.

The simulations indicated that, in 2025, the scenarios with the introduction of HVO present direct costs and net costs higher than the exclusive use of diesel, although with significant reductions in CO_2 emissions. By 2050, the combination of greater carbon valuation, reduced HVO cost, and increased percentage reduction in emissions changes the net cost hierarchy, making HVO potentially competitive or more economically advantageous, while enabling substantial emission reductions (Lee et al., 2024; Pereda et al., 2025; Solakivi, Paimander and Ojala, 2022).

From the point of view of transport engineering and port management, the proposed tool is a practical tool to support decision-making in the energy transition, by allowing managers to explore scenarios of partial or total replacement of diesel by HVO under different carbon price conditions. Despite the limitations regarding geographic scope, the absence of infrastructure costs, and the lack of systematic sensitivity analysis, the study offers a methodological and computational basis that can be expanded to broader contexts.

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