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Geo-Sciences

Inventory of Greenhouse Gas (GHG) emissions from the modal system on the port cargo route of Santa Catarina

Inventário de emissão de Gases de Efeito Estufa (GEE) do sistema modal na rota de cargas portuárias de Santa Catarina

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ABSTRACT

Climate change has intensified in recent decades due to the increase in the concentration of greenhouse gases (GHG) arising mainly from human activities. The transport sector is one of those responsible for the increase in these concentrations, due to the incomplete burning of fossil fuels in the use of different modals, such as road and railway. However, these modals are very important for the Brazilian production flow, product imports, as well as other human needs and development. Considering these facts, the present study inventoried the greenhouse gas emissions of the modal system on the port cargo route of Santa Catarina. With this purpose, movement data of Santa Catarina´s ports, road and railway modals data were used, referring to 2020 year. The data were analyzed using the Brazilian greenhouse gas protocol tool - GHG Protocol (Scope 1), 2022 version. In addition to the base data, five other scenarios were analyzed, considering different increments that encourage the railway use expansion as a strategy to reduce emissions. As a result, a reduction in carbon dioxide equivalent (CO_2e) emissions was observed when using the rail modal compared to the road modal, since, when comparing scenario 5 (50% rail + 50% road) with the current scenario (12.1% rail + 87.9% road), there is a 43% reduction in emissions from the road sector. Such findings make clear the importance of encouraging strategic planning and investments to promote intermodality and optimize logistical efficiency in Santa Catarina through the transport matrix diversification as a way of promoting sustainability.

Keywords: Greenhouse Gases; Transport modals; Port routes

RESUMO

As mudanças climáticas têm se intensificado nas últimas décadas em virtude do aumento da concentração de Gases de Efeito Estufa (GEE) oriundos, principalmente, de atividades antrópicas. O setor de transporte é um dos responsáveis pelo aumento destas concentrações em virtude da queima incompleta de combustíveis fósseis na utilização dos diferentes modais, como o rodoviário e ferroviário. No entanto, a importância destes para o escoamento da produção brasileira, importação de produtos, bem como demais necessidades humanas e o desenvolvimento é evidente. Diante disso, o presente estudo inventariou a emissão de gases de efeito estufa do sistema modal na rota de cargas portuárias de Santa Catarina. Para tanto, foram utilizados dados de movimentação para os portos catarinenses, para os modais rodoviário e ferroviário, referente ao ano de 2020 e analisados por meio da utilização da ferramenta do Protocolo Brasileiro de Gases de Efeito Estufa - GHG Protocol (Escopo 1), na versão 2022. Além dos dados base, foram analisados outros cinco cenários, considerando diferentes incrementos que incentivam a ampliação do uso de ferroviárias como estratégia na redução de emissões. Como resultado, observou-se uma redução nas emissões de dióxido de carbono equivalente (CO_2e) ao utilizar o modal ferroviário em comparação com o modal rodoviário, uma vez que, ao comparar o cenário 5 (50% ferroviário + 50% rodoviário) com o cenário atual (12,1% ferroviário + 87,9% rodoviário), há uma redução de 43% nas emissões do setor rodoviário. Tais constatações deixam claro a importância de incentivar o planejamento estratégico e investimentos para promover a intermodalidade e otimizar a eficiência logística em Santa Catarina, através da diversificação da matriz de transporte, como forma de promover a sustentabilidade.

Palavras-chave: Gases de Efeito Estufa; Modais de transporte; Rotas portuárias

1 INTRODUCTION

Greenhouse Gases (GHG) regulate the constant flow of solar energy that passes through the atmosphere in visible light and ultraviolet rays' form. Thus, part of this sun energy is absorbed and re-emitted by the Earth as an infrared (IR) wave spectrum. Some gases of the Earth's atmosphere have the property of absorbing and re-emitting part of this radiation in the IR, thus maintaining the Earth's temperature with a global average of approximately 15 °C. Without these gases, such as water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3), it is estimated that the earth would be 30 °C colder (Junges et al., 2018; Abreu, Albuquerque; Freitas, 2014; Le Treut et al., 2007).

Climate change, particularly concerning extreme weather phenomena, has intensified in recent decades due to the increased concentration of greenhouse gases (GHG) from anthropogenic activities. This has led to an acceleration of global warming, meaning that global temperatures are rising, and as a result, extreme weather events are occurring with greater frequency. Studies by the Intergovernmental Panel on Climate

Change (IPCC) currently show an increase in the global average temperature of 1.1 degrees Celsius above pre-industrial levels and project a rise in global temperatures of up to 1.5 ºC between 2030 and 2052. These factors are contributing to sea levels rise, regional and global temperature increase, heatwaves, species extinction, ecosystem impacts, irregular rainfall patterns, and other adverse effects arising from climate and environmental changes (IPCC, 2019; IPCC, 2021; IPCC, 2022; Mohammed et al., 2021; Yang et al., 2014).

Although the greenhouse effect is a natural phenomenon responsible for keeping the Earth's temperature regular, the imbalance generated in recent decades causes an exponential increase of gases in specific atmosphere layers. The gases that most contribute to greenhouse effect phenomenon acceleration are: Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), Perfluorocarbons (PFC), Hydrofluorocarbons (HFC), Methane (CH_4), Tropospheric Ozone (O_3), Sulfur Hexafluoride (SF_6) (Mattei; Cunha, 2021; Oertel et al., 2016; Yang et al., 2014). It is noteworthy that some sectors are more representative in relation to GHG emissions, such as Energy, Industries, Agriculture, Transport, Civil Construction, among others (EPA, 2022).

The transport sector is one of the major contributors due to the incomplete fossil fuels burning. In 2016 it was responsible for 24% of global carbon dioxide emissions (Wang; Ge, 2019; EPA, 2022). The transportation sector accounted for approximately 11% of total GHG emissions in Brazil during 2021. Specifically, within the transportation sector in Brazil during the same period, 41% of the emissions were attributed to the truck fleet, and 31% to automobiles (Potenza et al., 2023).

The Southern of Brazil has the second largest road vehicle fleet in the country, representing 19.6% of the total, it also has the same position considering the number of trucks (CNT, 2022). The export and import of goods in Santa Catarina are divided into maritime (86%), air (2%) and road (12%) modals (FIESC, 2017). The maritime modal comprises the ports of Imbituba, Itajaí, São Francisco do Sul, Navegantes and Itapoá, which in 2019 were responsible for the movement of more than 46 million tons of goods, leading the ports of Itajaí and Itapoá to occupy significant positions in the Brazilian container handling ranking (FIESC, 2021).

The ports of Santa Catarina comprise one of the most important port complexes in South America, with expressive and diversified cargo movements. This diversification reflects a pulverized and dispersed economy among the various regions of the state. The food industry is the most expressive, driven by pig and chicken farming, followed by the textile and clothing sector (FIESC, 2017).

Transport infrastructure is a key factor for ports operation and, consequently, for their efficiency (Mafaldo, 2020). However, the production flow to the ports requires improvements in the existing infrastructure, as well as the creation of new scenarios, such as increasing the use of railways. Considering railways have greater cargo transport capacity, this change would reduce costs, time, and losses.

Vasques and Hoinaski (2021) developed the BRAVES software in their research, which uses a bottom-up approach to calculate Brazilian vehicular emissions, based on fleet characteristics, fuel consumption, vehicle wear and usage. In addition to exhaust emissions data, the software estimated pollutant emissions from various other sources, including fuel evaporation, tire and brake wear, soil resuspension, and others. The use of this software tool revealed a reduction in CO, NO_x, SO_2, and CO_2 equivalent emissions between 2013 and 2018, demonstrating the positive effects of Brazilian vehicle emission regulations. However, particulate matter and NMVOC emissions remain being two major challenges due to the lack of evaporative emission regulations.

Other researchers, such as Hoinaski et al. (2024), conducted studies on GHG emissions employing BRAIN, a comprehensive database that incorporates several emission inventories, meteorological data, and air quality information from Brazil. As part of their methodology, they used the WRF model for weather forecasting, SMOKE for processing and emissions, and CMAQ for air quality modeling. The results showed that BRAIN can reproduce seasonal variability and spatial patterns of pollutants, especially in urban regions and wildfires affected areas.

Loriato et al. (2018) used an integrated WRF-SMOKE-CMAQ modeling system to develop a high-resolution atmospheric emissions inventory for the Greater Vitória region. The experimental approach involved adapting an existing regional source inventory for SMOKE, making it possible to apply this inventory in regional air quality models, such as CMAQ. In particular, adjustments were made to resuspension emissions data, considering more realistic emission factors according to current levels of monitored PM_{10} particles. The results indicated that PM_{10} emissions from urban roads, especially due to resuspension, are substantial and should be considered in the official inventory, which should be improved to more accurately reflect the local situation.

The IPCC (2022) states that to stop global warming some changes need to be made, one of them is related to urban infrastructure, which includes the transport sector. A study carried out by the Industries Federation of Santa Catarina in 2021, demonstrates the need of increasing infrastructure for the state's ports. The necessity to increase the rail network on its territory was highlighted, as well as the interconnection of the existing network to the national system. The ports of Itajaí and Itapoá (of great representation and expressiveness nationally), for example, do not have an access through rail network, which means that the products arrive on the port only by road (FIESC, 2021).

Considering these facts, it is important to evaluate and indicate different transport scenarios for the cargo flow to the ports of Santa Catarina, since, according to Marcilio, Rangel and Peixoto (2017) "the efficiency of the transport sector works as a mechanism to promote environmental sustainability by reducing carbon dioxide emissions".

Regarding that, the present study analyzed and compared GHG emissions from road and rail modal systems of Santa Catarina´s port cargo route, considering the current scenario for 2020 year and different proposed scenarios. There are few studies that demonstrate the importance of understanding the reality regarding GHG emissions in Santa Catarina, such as the research developed by Francisconi Junior et al. (2016), focused on the analysis of the main transportation modes. This study also contributes as a subsidy for decision-making regarding the expansion of the rail network, climate change and improvements in air quality, for example.

2 METODOLOGY

The present study was guided by the following steps: Proposition of less polluting scenarios for Santa Catarina´s ports and greenhouse gases (GHG) Inventory of current and future demands.

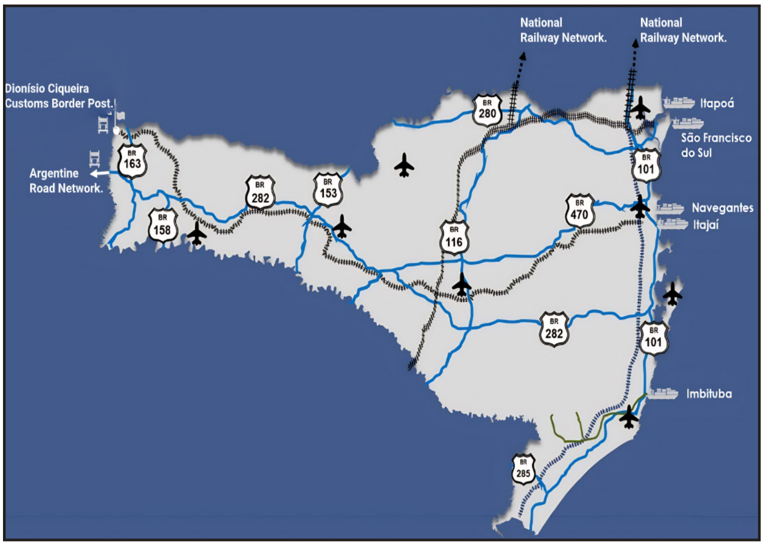
2.1 Characterization of the Study Area

The current study analyzes greenhouse gas emissions related to the flow of port cargo in Santa Catarina state. Import and export activities occur at the ports of Itapoá, São Francisco do Sul, Itajaí, Navegantes, and Imbituba.

Only the road and rail routes of port cargo were considered as the study area. Figure 1 shows the location of the main highways in Santa Catarina. The state has a road network of 2,606 kilometers of federal highways and 8,345 kilometers of state highways, according to FIESC (2019).

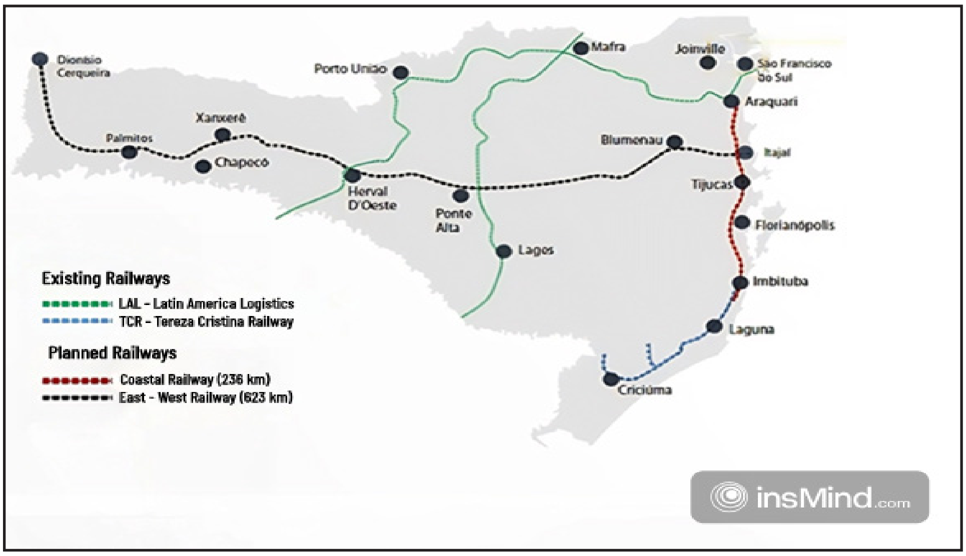
Regarding railways, there are 764 km in operation currently which are connected to the Port of São Francisco do Sul, in addition to the Teresa Cristina Railway, which extends for 164 kilometers. There are two projects to expand this mode of transportation, known as the East-West Corridor and the Coastal Railway. Figure 2 outlines the existing railways as well as the planned expansion projects used as the study area.

Figure 1 – Main highways of Santa Catarina



Source: FIESC (2022)

Figure 2 – Layout of existing railways, as well as railways in expansion projects



Source: FIESC (2019)

2.2 Scenarios proposition for Santa Catarina's ports

Scenarios proposition was based on the current diagnosis of Santa Catarina modal system regarding port routes, in order to carry out an analysis of GHG emissions scenarios' impacts. Only scenarios involving road and rail modals were considered. Data from the Railway Sector Yearbook, as well as the study of "Santa Catarina in data

(2017)" were considered as a basis for the approach of a realistic proposition, with scenarios that can effectively be achieved (FIESC, 2017).

The Yearbook of the Railway Sector, available by the National Land Transport Agency (Agência Nacional de Transportes Terrestres - ANTT), presents data referring to the provision of public rail cargo transport services. Origin-Destination cargo transport data was used for 2020 year, considering cargo of several states' origin but destinated to Santa Catarina. This resulted in a total movement of 6,282,599 UT (Useful Tons) to Santa Catarina. Comparing this with the total amount of cargo handled in Santa Catarina´s ports of approximately 51,810,776 UT in 2020, the railway modal was responsible for 12.1%.

Different increments were considered for the scenarios' elaboration (Chart 1) taking into account that with the expansion of the rail modal, which would be preferred instead of the road modal, then reducing the road use. Besides this, as this study aimed to analyze the cargo routes that are destined to ports, it was considered that even if there are other transport modes such as cabotage and air transport, for example, at some point roads will be used.

The state has 1365 km of railways currently, future projects described in the study "Santa Catarina in data (2017)" would add 852 km of railways to the state, which would result in 2217 km, which represents 62.4% growth (FIESC, 2017, p. 41). Considering this data, when the expansion projects is implemented, rail transport will be responsible for 50% of port cargo transport (Scenario 5).

The increments were estimated, randomly, for the gradual reduction of road transport throughout each proposed scenario, so in scenario 5 both modals would be responsible for 50% of representativeness (Chart 1).

Chart 1 – Proposed scenarios considering railway and road modals to Santa Catarina

Modal/ Scenario	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Railway	12.10%	15.00%	20.00%	27.00%	35.00%	50.00%
Road	87.90%	85.00%	80.00%	73.00%	65.00%	50.00%
Railway increment	--	23.97%	65.29%	123.14%	189.26%	313.22%

Source: Authors (2024)

In order to assess each scenario impact on greenhouse gas emissions, GHG Protocol (Scope 1) tool was used to enable the comparison. Then, a GHG inventory was carried out and finally the results were compared.

2.3 Greenhouse Gas Inventory (GHG) of current and future demands

The GHG Inventory was conducted using the Brazilian greenhouse gas protocol tool - GHG Protocol, 2022 version. The tool was developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBSCD), compatible with ISO 14064 standard, and with the calculation methodologies of the Intergovernmental Panel on Climate Change (IPCC). For Brazil, this tool was adapted to the national reality by the Center for Sustainability Studies of Getúlio Vargas Foundation (Centro de Estudos em Sustentabilidade da Fundação Getúlio Vargas - GVces), the Environment Ministry (Ministério do Meio Ambiente - MMA) and the Brazilian Business Council for Sustainable Development (Conselho Empresarial Brasileiro para o Desenvolvimento Sustentável - CEBDS) (FGV, 2009).

The GHG Protocol methodology establishes stages for the inventory elaboration, divided into Scopes 1, 2 and 3. In this study, only Scope 1 (direct emissions) was considered, focusing on the calculation tool referring to mobile fossil burning. Data from railway and road modals with cargo handled in Santa Catarina´s ports in 2020 were considered.

Data related to quantity, profile and productive sector transported through the ports were collected from the National Waterway Transport Agency (Agência Nacional de Transportes Aquaviários - ANTAQ) available in Waterway Statistics 2.1.4 (ANTAQ, 2023). This information guided the calculations of the trucks and locomotives needed number and fuel consumption in the year (road and rail). These calculated data were inserted in the GHG Protocol tool enabling GHG emissions analysis.

The equations used to perform the necessary conversions were:

$$Qc = \frac{Qct\,2020}{Ccargo} \quad (1)$$

where:
Qc= Truck number;
Qct2020 = Amount of transported cargo in 2020 (ton) through road modal;
Ccargo = Cargo capacity of each truck (ton).

$$Cc = \frac{Dp}{Em}\, x\, Qc \quad (2)$$

where:
Cc = Fuel consumpsion (l);
Dp = Travelled distance (km);
Em = Engine efficiency (km/l);
Qc = Truck number.

$$EL = \left(\frac{Vc}{Cc}\right) \quad (3)$$

where:
EL = Locomotive efficiency (km/l);
Vc = Considered speed to railway modal (km/h);
Cc = Fuel consumption in gear 4 (l/h);

$$NV = \left(\frac{Qctt\,2020}{Ccargotv}\right) \quad (4)$$

where:
NV = Wagons number;
Qctt2020 = Amount of transported cargo in 2020 (ton) through rail modal;
Ccargotv = Cargo capacity of each wagon (ton).

$$QVL = \frac{\left(\frac{Qctt\,2020}{Ccargotv}\right)}{52{,}5\,wagons} \quad (5)$$

where:
QVL = Number of locomotive trips;
Qctt2020 = Amount of transported cargo in 2020 (ton) through rail modal;
Ccargotv = Cargo capacity of each wagon (ton);

Considered characteristics and results obtained through equations 1 to 6, for rail and road modals are presented in Chart 2. To estimate the amount of cargo transported in 2020, data from ANTAQ's Waterway Statistics 2.1.4 were used, along with the proposed scenarios. Using these data, it was possible to calculate the number of trucks needed by considering the load capacity of each type of truck, as determined by Equation 1.

Fuel consumption, which is crucial for analyzing the environmental impact of the different transport modes, was calculated using Equation 2. This calculation took into account a travel distance of 623 km and engine efficiency, as specified in Chart 2, along with the previously calculated number of trucks.

Similarly, data for the railway modal were analyzed, considering the representativeness of each scenario as shown in Chart 1. After calculating the percentage related to rail transport, these data were used to determine the number of wagons needed to meet demand using Equation 4. The number of trips with locomotives was then calculated using Equation 5, and the necessary fuel consumption was estimated using Equation 6.

To estimate greenhouse gas (GHG) emissions for each scenario, the GHG Protocol Program Spreadsheet was used, focusing on the mobile combustion tab of Scope 1. Fuel consumption data, fuel type, and cargo type were input into the spreadsheet to perform the conversions into emissions of fossil CO2 (t), CH4 (t), N2O emissions (t), total emissions (tCO2e), and biogenic CO2 (t).

Chart 2 – Considered characteristics and results obtained for railway and road modals

Characteristics	**Railway**	**Road**			
		Containerized Cargo	**Solid Bulk**	**Liquid and Gaseous Bulk**	**General Cargo**
Model	ES43BBi	Iveco Stralis NR 410	Volvo	Scania	Mercedes
Engine Type	GEVO V12	NR 410	D12 Liters	R 540	MB OM 926 LA
Consumption in gear 4	Notch 4 312.7 l/h	-	-	-	-
Fuel consumption	0.08 km/l (Equation 3)	6.0 km/l	2.2 km/l	3.9 km/ l	3.5 km/l
Fuel type	Diesel (13 % of biodiesel)				

Chart 2 – Considered characteristics and results obtained for railway and road modals

(conclusion)

Characteristics	Railway	Road			
		Containerized Cargo	Solid Bulk	Liquid and Gaseous Bulk	General Cargo
Considered Amount of transported cargo	76 tons per wagon	28.5 ton	34 ton	32 ton	18.5 ton
Considered Speed	25 km/h	80 km/h			
Characteristics	105 wagons with 2	--	--	--	--
Average travelled distance	623 km (Extension of East – West railway)				

Source: Sanches, 2022; Cabral, 2010; Cassane, 2020; Canal Dana, 2020; Mercedes Benz, 2019; Guia Marítimo, 2022; Brasil, 2021; SCPAR, 2021; NSC, 2022; LOGWEB, 2018; FġESC, 2017

3 RESULTS AND DISCUSSION

Fuel consumption (Chart 3) was calculated as outlined in the methodological procedures, for a distance of 623 km, considering engine efficiency and the previously calculated number of trucks.

Chart 3 – Road modal fuel consumption (l), calculated from data on the amount of cargo transported in 2020, for all analyzed scenarios

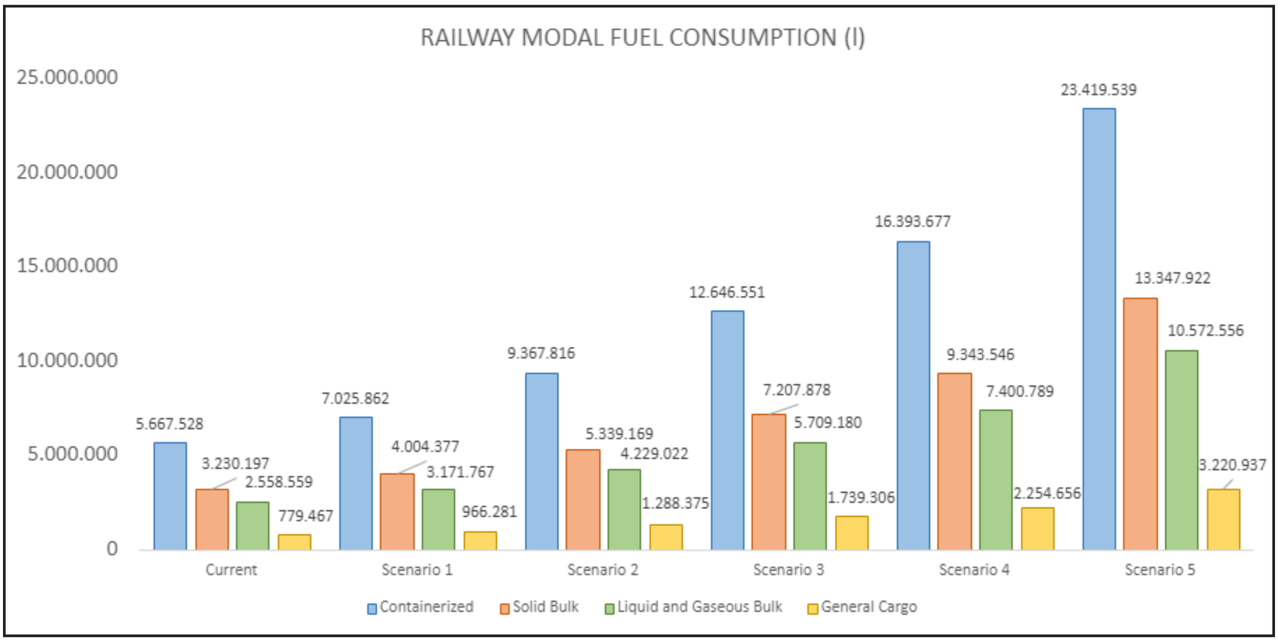
Cargo type	ROAD MODAL FUEL CONSUMPTION (l)					
	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Containerized	76.853.559	74.318.004	69.946.357	63.826.050	56.831.415	43.716.473
Solid Bulk	100.136.827	96.833.109	91.137.044	83.162.553	74.048.848	56.960.653
Liquid and Gaseous Bulk	47.538.684	45.970.286	43.266.152	39.480.364	35.153.748	27.041.345
General Cargo	27.914.140	26.993.196	25.405.361	23.182.392	20.641.856	15.878.350

Source: Authors (2024)

Similarly, data were calculated for the rail transport modal, taking into account the representativeness of each scenario. After determining the percentage corresponding to rail transport, the required number of wagons, the number of locomotive trips, and the necessary fuel consumption were calculated. The results for each rail transport scenario are presented in Figure 3.

In order to favor comparisons, only the total emissions (tCO_2e) for both modals were considered. It is observed in Chart 4 that for the road modal, the solid bulk cargo is responsible for the largest percentage of emissions in all scenarios (39.6%). It can be explained by the load capacity of the truck needed to this type of transport, as well as its lowest efficiency among the four types of cargo considered. Containerized cargo ranks the second place in emissions (30.4%), despite having the largest volume handled in the Santa Catarina´s ports in 2020. This rank can also be explained by the truck´s characteristics. In the sequence of total emissions (tCO_2e) follow the liquid and gaseous bulk (18.8%) and general cargo (11.1%), respectively.

Figure 3 – Railway modal fuel consumption (l), calculated from data on the amount of cargo transported in 2020, for all analyzed scenarios



Source: Authors (2024)

Regarding the rail modal, it was considered that each wagon can carry up to 76 tons (Chart 2). The transport data were proportional, where types of cargo with greater movement in 2020 presented the highest result of total emissions (tCO_2e), summarizing, containerized cargo (46.3%), solid bulk (26.4%), liquid and gaseous bulk (20.9%) and general (6.3%).

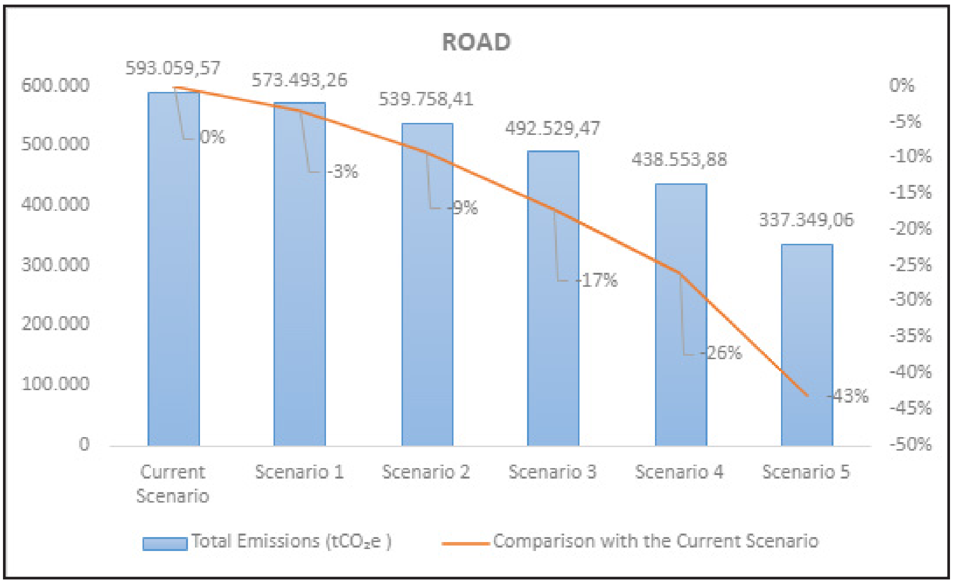
Chart 4 – Total emissions (tCO_2e) for road and railway modals

Cargo type	Current Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	%
ROAD MODAL TOTAL EMISSIONS (tCO_2e)							
Containerized	180,550.47	174,593.74	164,323.52	149,945.21	133,512.86	102,702.20	30.44%
Solid Bulk	235,249.37	227,488.01	214,106.36	195,372.06	195,372.06	133,816.48	39.67%
Liquid and gaseous Bulk	111,681.64	107,997.04	101,644.27	92,750.40	82,585.97	63,527.67	18.83%
General	65,578.11	63,414.55	59,684.29	54,461.91	48,493.48	37,302.68	11.06%
Total	593,059.57	573,493.26	539,758.41	492,529.47	438,553.88	337,349.06	100.00%
RAILWAY MODAL TOTAL EMISSIONS (tCO_2e)							
Containerized	13,314.61	16,505.71	22,007.61	29,710.28	38,513.33	55,019.04	46.32%
Solid Bulk	7,588.64	9,407.40	12,543.20	16,933.32	21,950.60	31,358.00	26.40%
Liquid and gaseous Bulk	6,010.77	7,451.37	9,935.15	13,412.46	17,386.52	24,837.89	20.91%
General	1,831.19	2,270.06	3,026.75	4,086.12	5,296.82	7,566.88	6.37%
Total	28,745.35	35,634.44	47,512.78	64,142.12	83,147.21	118,781.67	100.00%
TOTAL EMISSIONS FOR ROAD AND RAILWAY MODALS (tCO_2e)							
Total	621,804.92	609,127.7	587,271.1	556,671.5	521,701.0	456,130.73	-

Source: Authors (2024)

By comparing the total emissions (tCO_2e) of each scenario of the road modal to the current scenario, a reduction is observed, and in this case the sum of emissions by type of cargo was considered (Figure 4). As there is a reduction in emissions, due to the decrease in the use of this modal, there is a reduction of up to 43% in GHG emissions, when comparing scenario 5 with the current one.

Figure 4 – Total emissions (tCO_2e) for road modal in each scenario and the reduction of emissions

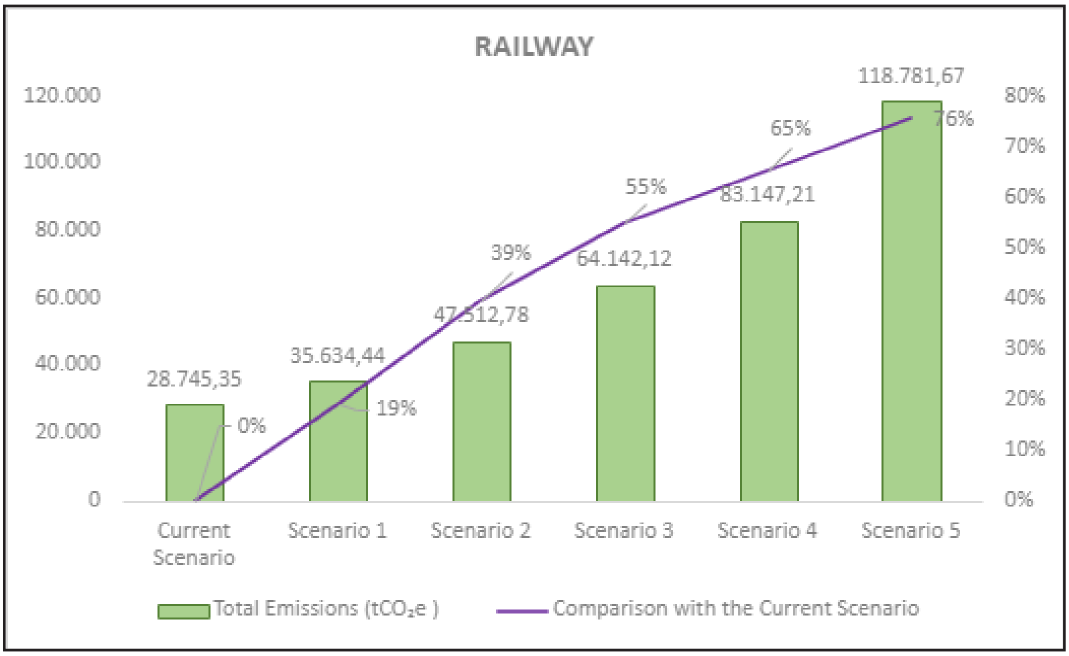


Source: Authors (2024)

This comparison was also carried out for the rail modal, taking into account the sum of total emissions (tCO_2e) of all types of cargo for each scenario (Figure 5). In this case, with the increase in the railways use there was an increase in emissions by 76% in scenario 5, observing that, the use of the railway would be approximately 313.2% higher than in the current scenario.

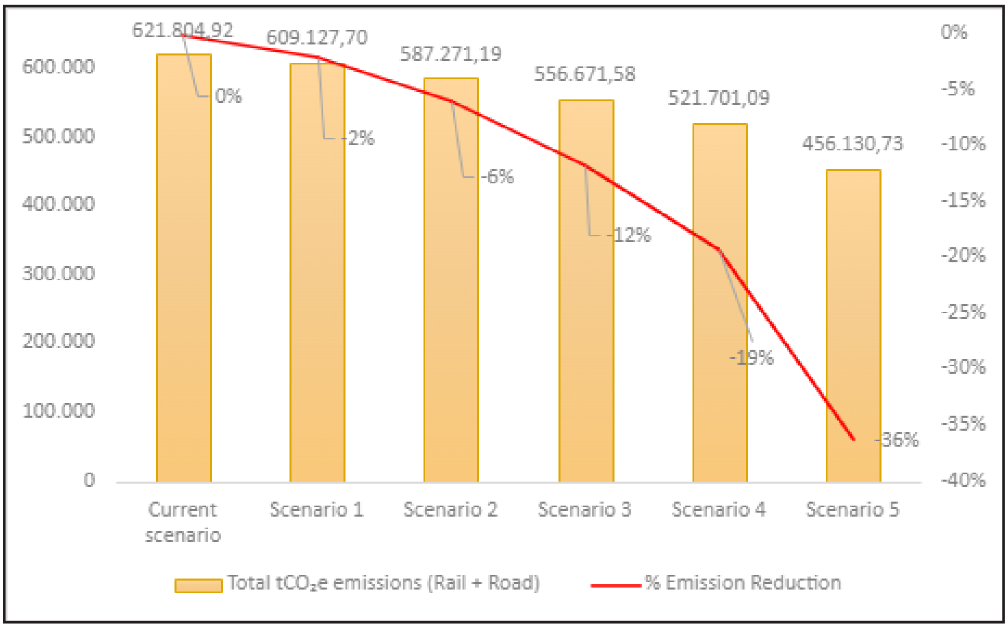
However, even this number seems to be high, the total emissions would be 118,781.67 tCO_2e for scenario 5 of the rail modal. In the road modal, the total emission in this scenario, is 337,349.06 tCO_2e. Therefore, even if in this scenario the representation of transport is 50% for both modes, the total amount of emissions is evidently higher in the road modal, since the load capacity of trucks is smaller and more trips are necessary, compared to rail.

Figure 5 – Total emissions (tCO_2e) for railway modal in each scenario



Source: Authors (2024)

Figure 6 – Total emissions (tCO_2e) considering the sum of emissions from railway and road modals



Source: Authors (2024)

The result of the total emissions for each scenario considering the sum of emissions from railway and road modals, are presented in Figure 6. Significant reductions in total emissions can be observed, reaching up to 36% in scenario 5, and this total represents 165,674.19 tCO_2e compared to the current scenario. The mentioned emissions reductions refer to the proposed implementations to increase the use of the rail modal and the reduction in the road modal use.

It is worth noting that the industrial profile of regions and cities has a direct influence on emissions. Thus, more industrialized regions tend to carry out more port movements for the commercialization of products. However, Santa Catarina needs infrastructure improvements and the expansion of other modals use, which would bring great benefits in relation to total emissions, as well as improvements to the traffic of other vehicles on the roads, since the flow of vehicles tends to decrease with the use of railways.

In Santa Catarina, FIESC has the House of Transport and Logistics Matters, in order to assess the conditions of the state transport infrastructure. This is responsible for preparing several technical studies on the subject that provide the basis for requesting investments increase to the transport sector. In several studies provided by the agency, the topic is related to "Promote planning and investments aiming intermodality and logistical efficiency, diversifying Santa Catarina´s transport matrix" (FIESC, 2021).

The state has a very dispersed industrial activity that needs logistical support both for the purchase of raw materials and for the distribution of the final product. Transport cost is cited by FIESC (2019) as the main cost of transport logistics activities. However, it is worth noting that the increase in infrastructure for the rise of other more efficient modals is routinely pointed out to solve various problems, such as those of economic and environmental nature.

The results presented in this study show that the railway modal has lower emissions of equivalent carbon dioxide (CO_2e) when compared to the road modal. The railway modal presented an emission of 118,781.67 tCO_2e and the road modal presented 337,349.06 tCO_2e, considering scenario 5, where it was estimated that both modes would have the same representativeness (50%). This fact is due to the load capacity of the locomotives, where it is possible to travel the same distance transporting more material, making the logistical transport time feasible, as well as reducing the impact of CO_2e emissions.

Silva et al. (2020) analyzed the efficiency between rail and road transport modals in the section between Uberaba/MG railway terminal and the Grain Terminal at the Port of Santos/SP. It was observed that the use of the railway modal presented an emission reduction of 37% and 40% reduction of logistical costs. Comparing the same section and the same load demand, the authors verified that 95 tons of CO_2 would be emitted using 80 wagons and 2 locomotives. On the other hand, if road transport was used, 105 road-train trucks or 142 bit-train trucks would be needed, emitting 121 tons of CO_2.

At the same time, it is extremely important that benefits exist so that the automotive industry can invest more in fleet decarbonization technologies. The use of ethanol in flex vehicles promotes a gain in relation to CO_2 emissions into the atmosphere, with no significant efficiency losses during the transport of materials (Sandaka & Kumar, 2023).

Mersky and Langer (2021) carried out a study for the ACEEE (American Council for an Energy-Efficient Economy) with the objective of investigating in a preliminary way the potential to reduce GHG emissions from cargo freight in the next decades, in the United States. The results showed that in short and medium term, the application of Information Technology (IT) tools in the logistics sector has the potential to reduce most GHG emissions (around 41%). The authors also mention that, although improvements such as electrification and vehicle automation show satisfactory results in the long term, the implementation of IT can achieve significant reductions in 10 to 15 years, which would be essential for changing scenarios.

3 CONCLUSIONS

The scenarios proposition demonstrated the investment importance in diversifying the use of transport modals in Santa Catarina State, using only rail and road modal as a basis. Results showed significant reductions up to 36% in total emissions in scenario 5, which corresponds to a decrease of 165,674.19 tons of CO_2e comparing to the current scenario.

Considering this, it is a fact that the advantages of expanding the railway network in Santa Catarina would bring great benefits to the flow of production in the state. Some projects are already in progress, such as the Coastal Railway and the East-West Railway Corridor. However, impediments to the works execution mean that deadlines are not met and the bureaucracy for defining new alternatives ends up impairing the completion of works.

Thus, it is evident that these topics should be seriously discussed by the state in order to attend the pulverized and important economy. The definition of political strategies and plans to abate/mitigate greenhouse gas emissions for the cargo transport system to ports are, therefore, extremely important. The actions taken could not only reduced GHG emissions but could also result in better energy use for the transport sector.

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