FUNDAÇÃO GETULIO VARGAS
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# SELECTION MODE OF FREIGHT TRANSPORT: WATERWAYS AS A COMPLEMENT OR ALTERNATIVE LOGISTICS MODAL FOR SOYA TRANSPORTATION IN MATO GROSSO

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Dissertation presented to Escola de Administração de Empresas de São Paulo at Fundação Getulio Vargas, as part of the requirements to obtain the degree of Master in International Management (MPGI).

Knowledge Field:
Management and Competitiveness in Global Companies

Advisor: Prof. Dr. Sérvio Túlio Prado Júnior

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*I graduated, I acknowledge my hard work.*

*But something else deserves way more credit.*

*To my dear Parents.*

*I had the opportunity to play competitive sports, attend top schools, gain exposure by moving to new cities, living in different countries.*
*All this created a strong foundation for life.*
*Was it my accomplishment? Or was it my privilege?*

*When I moved to study, you were always there making sure I had all the necessary and even more! Multiply this a hundred million times.*
*Who deserves the credit?*

*To my dear Sister.*

*Being the youngest sibling, I had the advantage of NOT going first. When I prepared for something, I knew what to do, what not to do.*

*To my dear Girlfriend.*

*Thank you for always supporting me and being there for me over the past years. You have fostered confidence and passion in me to work hard and pursue my dreams with no boundaries.*

*To my dear Friends.*

*My graduation wouldn't be completed without your presence. I appreciate all the encouragement and inspiration you have given me on my journey.*

*I had the freedom to follow my heart, whatever I wanted. Not many constrains. All of that gave me the tools and values to be where I am standing today. My accomplishment or privilege?*

*People have different starting points and I started kilometers ahead of most thanks to these amazing people.*

*No matter who you are, recognize your privilege.*
*Give credit to those who deserve it. It will mean the world to them.*

ABSTRACT

Brazil's transportation infrastructure did not follow the country's agricultural development. As a matter of fact, the country is characterized by a distorted freight transportation matrix, in which road mode is predominant. This imbalance in the sector suggests the need to develop a more efficient transport network that can increase the utilization and the competitiveness of alternative modes, thus, facilitating the increasing flows of goods while reducing pollution. In that context, the purpose of this study is to assess the benefits of a modal shift from the current road transportation system to inland waterways for soya shipment throughout Mato Grosso from an economical and environmental perspective. To accomplish this task, two logistics solutions (BR-163 highway and Paraguay-Paraná river) have been considered to carry out the calculations on the overall transportation costs and CO2 emissions for each mode, assessing also the potential impacts from a multimodality approach between road and waterways. The findings suggest that the waterway presents itself as a valuable complement or alternative able to remarkably decrease logistic costs and greenhouse emissions due to its energy efficiency, greater productivity in relation to the cargo volumes, lower cost per ton.

KEYWORDS: Business logistics, Mato Grosso, Soybean, Exportation, Cargo storage and transportation, Reduction of greenhouse gases.

RESUMO

A infra-estrutura de transporte do Brasil não acompanhou o desenvolvimento agrícola do país. De fato, o país é caracterizado por uma matriz distorcida de transporte de cargas, na qual o modo rodoviário é predominante. Este desequilíbrio no setor sugere a necessidade de desenvolver uma rede de transporte mais eficiente que possa aumentar a utilização e a competitividade dos modos alternativos, facilitando assim o aumento dos fluxos de mercadorias e reduzindo a poluição. Neste contexto, o objetivo deste estudo é avaliar os benefícios de uma transferência modal do atual sistema de transporte rodoviário para as vias navegáveis interiores para o embarque de soja em todo o Mato Grosso a partir de uma perspectiva econômica e ambiental. Para realizar esta tarefa, duas soluções logísticas (rodovia BR-163 e rio Paraguai-Paraná) foram consideradas para realizar os cálculos sobre os custos totais de transporte e emissões de CO2 para cada modo, avaliando também os impactos potenciais de uma abordagem multimodal entre a estrada e as vias fluviais. Os resultados sugerem que a hidrovia se apresenta como um complemento valioso ou alternativa capaz de diminuir notavelmente os custos logísticos e as emissões de efeito estufa devido a sua eficiência energética, maior produtividade em relação aos volumes de carga, menor custo por tonelada.

PALAVRAS CHAVE: Logística empresarial, Mato Grosso, Soja, Exportação, Armazenamento e transporte de cargas, Redução de gases do efeito estufa.

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# 1. Introduction

With the global population projected to rise up to 9.7 billion by 2050, demand for primary products is continuously increasing, especially for agricultural ones, which are essential in the human diet and animal fed industry. The demand for agricultural goods is expected to reach about 3 billion tons that year (United Nations, 2019).

Soybeans represent one of the predominant commodities in the world, being used either as natural grains and meals for animal industry. At present, 81% of the world's soybeans production is delivered by only three countries, Argentina, Brazil and United States (USDA, 2020). In particular, Brazil shows the fastest increment in cultivated hectares, volume produced and international market share; indeed, in 2021/2022 alone, the country harvested 125.5 million tons in 41.5 million hectares area (CONAB, 2020).

With the Brazil's agricultural economy growing and increasing productivity, it is necessary an efficient transportation system that would be able to provide an optimization in cargo transport, bringing agility, restrained costs, and reduced pollution.

However, nowadays Brazil is characterized by an imbalance in the transportation matrix, heavily dependent on road mode, despite having an enormous untapped capacity of benefiting from alternative options for moving goods, especially its natural resources. With respect to this, waterways can be considering an efficient solution since they provide cheaper freight cost per ton and, despite requiring more time, can be compensated by having greater energy efficiency, greater capacity to concentrate loads, lower fuel consumption, infrastructure costs, operating costs, and environmental emissions (Pompermayer et al., 2014). Moreover, it is efficient for transporting bulk goods of low value added such as iron ore, soybeans, and commodities in general, of which, as said, Brazil is a large producer and exporter.

Among the Brazilian states, Mato Grosso (located in the Central-west region) is the largest soybean producer, with great representation in the national agro-industrial scene. In 2021/2022 it accounted for nearly 33% of the total Brazilian soybeans production, harvesting 41.4 million tons, covering 11.1 million of hectares. (CONAB, 2023). Mato Grosso perfectly reflects the country's sick transportation matrix and an untapped utilization of waterways to move freight across and outside the country. Indeed, most of the grain is disposed through the use of road transport, incurring higher

transportation costs, as well as greater energy consumption and $CO_2$ emissions. Therefore, it is appropriate to study the economic and environmental potential use of the waterway.

In this scenario, the present paper aims to compare the existing logistics solution (roadway through BR-163 highway and Paraguay-Parana river) for the export of soybeans form Mato Grosso regarding carbon dioxide ($CO_2$) emissions in the atmosphere and transport costs.

Specifically, the article intends to answer the following research question: *What are the real possibilities of waterways as a complement or alternative logistics modal for soya transportation in Mato Grosso?*

In order to answer this central issue, this study aims at investigating what those logistic routes are, what is the impact resulting from the change of route mode and from adopting multimodality, and how they affect economically and environmentally the transportation of soya throughout Mato Grosso state.

The study has been divided into seven chapters through which the main topic of the study, the literature review on the logistics and the different modes of freight transportation, the context analyzed, method used to conduct the analysis, the data elaboration and the discussion of the results obtained are presented and, finally, the conclusion.

In the first section, the topic, the research question and the structure of the present study is introduced. The second part is aimed at providing the reader with the definition of logistics adopted in this paper, the critical importance of an efficient and sustainable transportation infrastructure for a country, the several alternatives that can be used to ship goods and different views of basic criteria for evaluation of freight movements.

The following section presents the Brazilian context, in order to guarantee a theoretical background for the reader. It introduces the evolution of the transport infrastructure in the country, and the consequences of its distorted transportation matrix that resulted from there, mainly dependent from the road modal; while suggesting also a possible value creation solution to this problem, the waterways, abundant in the country.

The fourth chapter aims to present the methodology used in this paper; the motivations behind the choice of the analysis structure and the variables involved in it are explained. Following the methodology described, the purpose of the next section is to introduce the context of the study, the Brazilian state of Mato Grosso, perfect example of the distorted transportation matrix in the country

and unexplored utilization of waterways as a logistic corridor for the soya movement. The sixth chapter, the practical part, includes calculations of performance of each transportation mode, determining the logistic costs and $CO_2$ emission involved, while investigating also the potential of multimodality between road and water option.

After the data elaboration to qualify the characteristics of each mode, the results obtained will be analyzed, and finally, based on the findings, conclusions, where a brief summary of the work done, comments and recommendations for future works will be given.

## 2. Literature review

The study will be classified from the point of view of its nature, the manner of approach to the problem, objectives, and technical procedures.

In terms of nature, this research can be defined as basic, since it is not intended to generate new knowledge, but seeks to present practical application useful for the advancement of science.

The qualitative approach is concerned with obtaining information as well as interpreting the environment in which the problem occurs. The quantitative approach, on the other hand, focuses on objectivity and translates evidences and numbers into information that will be classified and analyzed.

To carry out the study, a robust bibliographic review will be carried out in order to base the research. Data available in publications published by official agencies, such as the National Transportation Confederation (CNT); National Land Transportation Agency (ANTT); National Civil Aviation Agency (ANAC) and National Waterway Transportation Agency (ANTAQ), will be added to articles published on the topics as sources for the study.

## 2.1 Logistics and transportation

Logistics can be defined as the part of the supply chain process that plans, implements, and controls the efficient and effective flow and storage of goods, services, and related information, from the point of origin to the point of consumption, in order to meet consumer requirements (CSCMP, 2013). This definition includes incoming and outgoing movements and internal and external operations. A logistics system, according to Ballou, uses a set of terminologies to designate the areas in which it is developed that can be categorized into major activities (transportation, inventory and information flow management, and order processing), and supporting activities (storage, materials handling and packaging design) (Ballou, 2004). The concept of logistics no longer relates exclusively to distribution chains, even though it is normally its main component, but rather to a strategic process for planning and controlling inventories and material flows, from the point of origin of production to its final destination, for the purpose of transformation, shipment, or consumption" (Barat, 2011).

A company's ability to compete also depends on an effective logistics planning. To do so, operations must perform better, departments must be integrated, and quality logistics services must be offered (Ballou, 2004). As per Caixeta Filho and Martins, logistics is seen as the last frontier for reducing costs (Caixeta Filho & Martins, 2001).

Therefore, in order to have an efficient logistical structure to carry out this production flow in a viable and competitive manner, an excellent transportation matrix is necessary.

## 2.2 Importance of transport infrastructure for a country

Studies have claimed the existence of a relationship between a transport infrastructure and the country development, considering economic, social and environmental factors: the more efficiently a region is intra and interconnected with other areas, the more beneficial consequences for that region (Wolff & Caldas, 2009).

Freight transportation plays a crucial role in the economy of a country. It is the backbone of the supply chain, enabling the movement of goods and materials from one location to another. Without an efficient transportation infrastructure, the flow of goods would be hindered, leading to delays, increased costs, and reduced economic growth. In this section, it will be analyzed the importance

of an efficient freight transportation for a country's economy, focusing on the economic and logistical benefits it provides.

One of the most significant benefits of a productive transportation system is its ability to support economic growth. By allowing the correct flow of supplies and goods, it enables businesses to reach new markets, expand their customer base, and increase their revenue. This, in turn, leads to job creation and increased economic activity. Additionally, freight transportation serves as an efficient and cost-effective movement of raw materials and finished goods, which is essential for the growth and development of key industries as manufacturing, agriculture, and mining.

Another important positive consequence of an effective system is its ability to reduce costs and increase efficiency. By using the most efficient mode of transportation, businesses can reduce their transportation costs, which leads to lower prices for consumers and increased competitiveness in the global market. In addition, it can support corporations to optimize their supply chains, reducing inventory costs and improving delivery times. For instance, a study by the found that efficient freight transportation can lead to cost savings of up to 15% for businesses (Sert et al., 2017).

Furthermore, freight shipment plays a critical role in logistics and supply chain management, allowing businesses to plan and coordinate their operations more effectively, which leads again to increased efficiency, reduced costs, and improved customer satisfaction (Yeo et al., 2016).

Additionally, effective distribution helps companies to respond quickly to changing market conditions, such as increased demand for a particular product, which can be vital for their survival.

Another aspect to consider is that freight transportation also plays a vital role in international trade. By facilitating the goods movement across borders, it helps accessing new markets. Along with this, an efficient goods movement enables countries to take advantage of comparative advantages, such as access to cheaper raw materials or more efficient manufacturing processes. Quality and efficiency of a logistic system positively influence greater volume of international trade (Gani, 2017).

In conclusion, freight transportation is an essential component of a country's economy. It leads to companies reach new markets, job creation, reduced costs and increased efficiency, which, in its turn, drive to economic growth. Furthermore, it plays a vital role in logistics, supply chain management and international trade.

As a country's economy grows and evolves, it is important to continue to invest in and develop the

freight transportation infrastructure to ensure that goods and materials can be transported efficiently and sustainably.

## 2.3 Modes of freight transportation

Mode of transportation consist of the means through which a person or freight is moved from point A to point B, making it possible to carry out this movement in numerous ways (ITF, 2022). Different modes are available when shipping goods, four basic modes are considered including road, rail, water, and air. Each alternative has its own technical (speed, capacity) and operational (availability, safeness) characteristics, as well as unique advantages and disadvantages. The criteria for choosing the transportation mode take into account several factors, including cost, speed, reliability, and, on the other hand, the characteristics of the service as the nature of the goods being shipped (Liao & Chang, 2010). In this section, the most commonly used freight transportation modes will be explored as well as their relative strengths and weaknesses.

- Road transportation is the most common mode of freight transportation with the lowest physical constrains among the alternatives, even though they can rarely operate outside roads. Trucks are the most commonly used vehicles for road transportation, they serve numerous purposes and are able to reach a wide range of destinations and suitable for carrying a vast range of goods, mainly associated to light industries where short and fast shipments in small volumes are typical (perishable, fuels, construction materials). Along with the containerization and improvement in load capacity, this option has emerged as key component in freight transportation among ports and commercial centers. Limited entry barriers (relatively low capital costs of vehicles) and high infrastructure and vehicle maintenance costs are associated with the low life spans of less than ten years fora vehicle in road transportation networks (Engström, 2016).

  The main advantages of road transportation include its flexibility in terms of scheduling and routing, reliability, and the ability to reach remote areas. However, overcoming natural obstacles as rivers and irregular terrain road construction still represent a significant geographic limitations and considerable additional costs (Bustamante, 1999). Moreover, trucks can be subject to congestion and delays, especially in urban areas, high fuel

consumption, and environmental externalities ($CO_2$ emissions particularly). Additionally, due to legal's restrictions of size and weight, imposed for safety and infrastructural reasons, as well as technical limitations of engines, this mode has restricted potential to achieve economies of scale (Gatta & Marcucci, 2014).

- Rail transportation is another popular mode of freight transportation, it refers to the movement of vehicles on guideways, primarily used for the long-distance movement of low-value goods (minerals, chemicals, agricultural products), although it also handles some high-value goods (automobiles) (Coyle et al., 2016). Trains are suitable for the transportation of a wide range of freight, including bulk items, heavy machinery, and containers. The main advantages of rail transportation include its efficiency, cost-effectiveness, and the ability to transport large quantities of goods (Bustamante, 1999.). The rail freight transport system is safe compared to the road, with lower rates of accidents and cargo theft. It also has a lower environmental impact than trucking and is less affected by traffic congestion, even though still subject to potential delays. However, the economic structure largely accounts for the limited number of rail carriers. Indeed, rail transportation requires specialized infrastructure, such as tracks and terminals, which can be costly to build and maintain. In addition, rail transportation is the transport mode the most constrained by physiography, especially when considering gradient and turns. For instance, freight trains cannot tolerate more than 1% gradient on average, meaning that to climb only 500m it requires 50km. Thus, its availability can be limited in certain areas, making it less accessible than trucking for some businesses (Dobruszkes & Moyano, 2021).

- Water transportation is another cost-effective option for the movement of large quantities of cargo over long distances by sea or inland waterways. Ships, barges, and boats are the most commonly used vehicles for water transportation, and they are suitable for the transportation of a wide range of goods in large quantity. The capacity is much higher than that of trucks or trains and the cost of fuel is generally lower. Even though it does not require pre-initial building cost, since the road is already provided by the nature, still ships and barges necessitate capital investment, but costs are spread over massive volumes transported during their long lifespan. Ships' sizes have increased, allowing water transportation to become even more cost-effective and scalable in prices; this tendency has

been accelerated by containerization. However, shipping can be subject to weather-related delays and is often less flexible than other modes in terms of scheduling and routing. As a matter of fact, waterways are limited in their reach, with many areas not having access to water stretches for transportation, making it necessary to transport goods to and from ports by road or rail, which can add to the overall cost and time of transportation (IWT, 2015). Also, this option requires specific terminals and equipment, which can be expensive either to build and maintain.

- Air transportation is a fast and reliable mode of freight transportation, but it is also the most expensive. Even though, with the growth global supply chain combined with increased speed and number of flights have reduced inventory costs and stockout risks, resulting in lower logistics costs, this mode still is pricier among the alternatives. It is ideal for the movement of high-value, low-weight, time-sensitive cargo, such as perishable goods or component for just-in-time manufacturing. Air transport can reduce the transit time from up to 30 days by ship to just one or two by flight (Hummels & Schaur, 2001). The main advantages of air transportation include its speed, reliability, and the ability to reach remote areas. However, the high cost of fuel and the need for specialized equipment makes air transportation less practical for the movement of most types of cargo. In addition, the air modal has the lowest energy efficiency in relation to the other modes of transport, resulting in the most polluting solution.

Ultimately, it is preferable to use different modes in combination to better exploit the unique advantages of each mode. Intermodal transport is characterized by having two or more types of transportation involved in the operation and for this purpose intermodal terminals exist to create the connection between the modes (Luz, 2015). Containerization has unlocked the potential of intermodal transportation, allowing an efficient connection among water and land movements modes. The cooperation of multiple modes requires a cohesive and coordinated effort during the whole process, involving legal, technical, technological and managerial challenges. Arnold et al. (2004) state that the use of a multimodal system for the disposal of ethanol, for example, would result in better distribution, a decrease in the price of freight and consequently lower cost for the final consumer.

By qualifying the characteristics of each mode, it can be seen that they complement each other, reinforcing the need to invest in integration and multimodality and not just in a specific mode.
In conclusion, freight transportation is a vital component of the global economy, and different modes of transportation are available for shipping goods. Each mode of transportation has its own unique advantages and disadvantages, and the choice of transportation mode depends on several factors.

## 2.4 Compare different alternatives

Comparing different freight transportation modes is an important task for businesses that need to move goods and materials efficiently and cost-effectively. The choice of transportation mode will depend on a variety of factors, including the type of cargo, distance to be traveled, time constraints, and budget. In this section, it will be explored the various methods and metrics used to compare different freight transportation modes.
Comparing different modes of freight transportation requires an evaluation of several factors. Their evaluation can be categorized in four main aspects according to cost-efficiency, delivery time, sustainability, and economic impact.
The cost-efficiency of a mode of transportation is an important consideration when comparing modes. Factors such as fuel costs, labor costs, and the cost of infrastructure can greatly impact the cost-efficiency of a mode of transportation. For example, shipping by water is generally less expensive than by air or land, but the cost of building and maintaining ports and waterways can add to the overall cost. One of the most commonly used metrics for comparing transportation modes is cost. This includes not only the direct costs of transportation, such as fuel and labor, but also indirect costs, such as infrastructure, equipment, and terminals. Cost analysis can be performed using various methods, including total cost of ownership (TCO) and life cycle cost (LCC) analysis. These methods consider not only the upfront costs but also the long-term costs associated with each mode of transportation (Mangan et al., 2020).
Another important metric is service level. This includes factors such as delivery time, speed, and flexibility. Indeed, the customer is not simply interested in the shipment option chosen, but that of place and time, being in the right place and available for purchase. The product/service will only have effective value if the customer finds it where and when they need it. For instance, while trucks

average from 60 to 80 km/h, waterway transportation generally at 15 to 20 km/h. A disadvantage found in this latter transport system is the long transit time of the cargo; however, it does not face any kind of congestion, common fact when talking about road transport. In addition, it is mandatory to consider the link between speed and cost: for example, while air transportation is known for its high level of speed and reliability, making it ideal for time-sensitive cargo, it is also the most expensive mode of transportation (Choi & Park, 2020).

Environmental impact is another important factor to consider when comparing transportation modes. Sustainability is a crucial factor in the logistics industry, as emissions from transportation contribute to climate change. When comparing freight transportation options with regards to their environmental impact, there are several key factors to consider as the use of renewable energy sources, air pollution, noise pollution, land use, and most important greenhouses emissions and fuel efficiency. As regards GHG emissions, the amount produced by each mode of transportation is a critical factor to consider. Some modes produce significantly less emissions per unit of cargo than others. While air cargo has a higher carbon footprint per ton-kilometer than water cargo, still the emissions from shipping can have a significant impact on the environment (Herbert-Hansen et al., 2017).

Moreover, the fuel efficiency of each mode of transportation is also important to consider. Modes of transportation that are more fuel-efficient will produce fewer emissions and have a lower environmental impact overall (Chapman, 2007).

The economic impact of a mode of transportation can also be an important consideration when comparing modes. This can include the impact on local communities, the creation of jobs, and the overall contribution to the economy. For example, shipping by water can provide jobs in ports and along waterways, while shipping by air can provide jobs in the aviation industry.

In addition to these metrics, businesses also need to consider other factors such as accessibility, security, and compliance. For example, trucking is known for its high degree of accessibility and flexibility, making it well suited for local deliveries, while shipping is less accessible in certain areas and may require specialized equipment and infrastructure.

In conclusion, comparing different freight transportation modes is a complex task that requires businesses to consider a variety of factors, including cost, service level, environmental impact, and other operational considerations. Methods such as TCO and LCC analysis can be used to quantify the costs associated with each mode, while service level, environmental impact, and other factors can be assessed qualitatively. By considering all of these factors, businesses can make informed decisions about the most appropriate mode of transportation for their specific needs.

## 2.5 Importance of sustainable freight transportation

Despite, at first, the primary emphasis of sustainability was on how economic expansion would affect the environment, as of now, the idea of sustainability also includes concerns about social, governmental and organizational challenges. In this section, the organizational and logistic aspect will be analyzed in correlation with freight transportation in this section.

The transportation of goods plays a vital role in the global economy, but it also has a significant impact on the environment and human health. Despite enabling the access of goods and material, freight transport is a major source of atmospheric GHG emissions, especially the road transport sector (McKinnon et al., 2010). Even though there are differences in national transportation plans and infrastructure investments, improving transportation performance while lowering $CO_2$ emissions has become a global priority. Therefore, it is crucial to implement sustainable transportation practices, especially directed towards the decarbonization in the road modal, in order to effectively mitigate these negative environmental consequences (Binsted et al., 2011). This includes reducing emissions of greenhouse gases and air pollutants, as well as reducing fuel consumption. For road transport, Mckinnon (2018) presented five decarbonization strategies: (1) reduce the demand for transport; (2) optimize vehicle loading; (3) increase vehicle efficiency; (4) reducing the carbon content of the fuel; and (5) switching to low carbon intensity modes. One way to achieve these options would be the implementation of more efficient transportation methods, such as electric vehicles or the exploitation of more environmentally friendly alternatives as railroad or waterway. Along with this, technologic development can also improve the efficiency of transportation and reduce emissions. Alongside, the shipment of goods also consumes a significant amount of resources, including fuel, packaging materials, and other elements. Implementing sustainable transportation practices can help to reduce resource consumption and minimize waste.

From an energy point of view, the impact of the transportation matrix could be much lower considering that using the same quantity of energy for a truck to move goods over the distance of 100 km, a train would transport it over 300 km, whereas a barge or a ship would be able to ship it over the distance of 370 km (IWW, 2023).

Also, it is worth to mention the social impact it might derive from a more sustainable infrastructure, as the reduction of congestion and traffic on the roads. This not only improves air quality and reduces emissions, but it also improves the safety of transportation and reduces the risk of accidents (Hunt et al., 2005).
Furthermore, as regards the regulations perspective, governments are increasingly implementing regulations and policies to reduce the environmental impact of transportation, and the compliance with these regulations can be easier and cheaper if sustainable transportation practices are adopted (Santos et al., 2010).

In conclusion, the literature suggests that freight transportation is an essential component of a country's economy, ensuring a long-term economic viability and having a sustainable system is crucial to protect the environment and human health. It is important for a country to invest in and develop its freight transportation infrastructure to ensure that goods and materials can be transported efficiently and sustainably, supporting economic growth and development.

## 2.6 Freight transportation sustainable in Brazil

Brazil has been actively working towards achieving the Sustainable Development Goals (SDGs) related to freight transportation (UN, 2017). The country has implemented several policies and initiatives aimed at promoting sustainable freight transportation, which include:

- Investment in transportation infrastructure: Brazil has been investing in the development of its transportation infrastructure, including the construction of new highways, ports, and airports, with the aim of improving connectivity and reducing transportation costs. The government has also been investing in development of its waterway infrastructure, which has the potential to reduce costs, decrease traffic congestion, and decrease the environmental impact.

- Promotion of alternative modes of transportation: The Brazilian government has been promoting the use of alternative modes of transportation, such as rail, water, and intermodal transportation, as a way to reduce the environmental impact of transportation and promote economic and social benefits. This is aligned with the n.9 SDG – Industry, Innovation and Infrastructure, which aims to build resilient logistics, promote inclusive and sustainable industrialization, and foster innovation.
- Implementation of sustainable logistics practices: Brazil has been implementing sustainable logistics practices, such as green supply chain management, to reduce the environmental impact of logistics operations, and sustainable transportation planning to optimize the use of transportation resources and reduce emissions and costs. This aligns with n.12 SDG – Responsible Consumption and Production, which aims to ensure sustainable consumption and production patterns.
- Implementation of policies and regulations: Brazil has been implementing policies and regulations to promote sustainable freight transportation, such as fuel taxes, emissions standards, and incentives for the use of alternative modes of transportation. Aligning with n.13 SDG – climate Action, a commitment to take urgent action to combat climate change and impacts.
- Investment in research and development: Brazil has been investing in research and development to improve the efficiency and sustainability of its transportation system, including the development of new technologies and innovations. This is in line with n.17 SDG – Partnerships for the Goals, which calls for the strengthening of the means of implementation and revitalization of the national and global partnership for sustainable development.

It's worth noting that even though Brazil, like other developing countries, has made progress in implementing policies and initiatives to achieve sustainable freight transportation, still faces some challenges to achieve all the SDGs related to freight transportation, such as lack of funding, inadequate infrastructure.

## 2.7 Similar studies

The most direct way to examine the results of a selected transportation mode is from models that consider the direct impacts, mostly denoted by minimization in total transportation costs and reduction in travel time (Engebrethsen & Dauzère-Pérès, 2019). Few other more sophisticated models consider also indirect consequences, as social impacts in generating new jobs and boost of regional economy. Moreover, these evaluation models are frequently recognized through quantitative methods to compare different shipping alternatives even to support investment decisions from a long-term perspective. However, when is not possible to elaborate or gather real data, qualitative models can also be adopted to assess the alternative (McGinnis, 1989).

However, the cargo transit analysis only recently has given enough attention to the environmental impact. Sustainability in transportation is a relatively new idea, according to Zhou (2012), and it is based on a number of indirect measurements using various transport indicators.

In general, in order to evaluate the impact of adopting different transportation modes considering infrastructure effectiveness in Brazil and sustainable development, more qualitative methods are implemented.

For instance, Monteiro discuss correlation between regional growth and transport infrastructure, stating that the benefit for the context studied improve as better the region is served in terms of route connection (Monteiro, 2015).

Branco et al. proposed a two-step process to assess the economic and environmental impact of including a new railway to the transportation network, by simulating soybean and corn flows measured in terms of decrease overall shipping costs and $CO_2$ emissions (Branco et al., 2022).

Moreover, the study case by Santos and Silva, compare railways and roadways as transportation alternatives for cement in Minas Gerais, using a qualitative approach to present advantages and disadvantages of each mode. (Santos & Silva, 2015).

In the state of Mato Grosso, de Oliveira and Santos, examined the alternatives for agricultural production flow through a multimodal mechanism, presenting a qualitative comparative study of logistics modes and their costs (Oliveira & Santos, 2004).

As regards waterways potential, several studies have found that waterway transportation can provide significant cost savings for businesses and reduce the environmental impact of transportation when compared to road transportation. The increase in cargo handling in the country

shows that the current transportation matrix does not meet the demand, in addition to hampering the mobility of port cities, as per Chaves et al. They presented an increase in waterway cargo transportation as an element of mitigating these problems, focusing on the Port of Santos and proposing possible actions that can be taken to practically implement their solution (Chaves et al., 2014). In the same direction but with a more quantitative method, Garcia et al., investigated the potential impact of the Tapajós-Teles Pires Canal in Mato Grosso on the sustainability of the soybean export routes, adopting a data envelopment analysis (DEA). They claimed that a combination of the two transport modes (highway and waterway) showed the best efficiency indexes, arguing that the development of the water mode is a crucial component to enhance the outflow of soybeans for export (Garcia et al., 2019). This aspect is further supported by de Barros et al., which argues that waterway transportation can provide significant cost savings for businesses and reduce the environmental impact of transportation (Barros et al., 2022).

As regards the environmental impact, Dai and Yang (2020) stated that waterway transportation emits significantly less pollutants per ton of cargo than road transportation, which aligns with the SDG 13 - Climate Action, which aims to take urgent action to combat climate.

Other studies have addressed logistics and governmental deficiencies highlighting the lack of infrastructure and maintenance of existing waterways as a main challenge to the implementation of waterway transportation in Brazil. Among them, in FAL Bulletin (2018) it is claimed that, even though tentative have been made to minimize such weaknesses since 1970s with numerous national development plan, still these deficiencies are in place. Weschenfelder (2015) published a study in which he examines the potential for the development of waterway transportation in Brazil, mainly focusing on the existing infrastructure and the regulatory framework, claiming that there's a lack of investment in the development, maintenance, and modernization of ports and related infrastructures. This study examines the potential of waterway transportation to increase the competitiveness of Brazilian exports.

These studies provide an insight into the potential benefits and challenges of using waterways for freight transportation in Brazil and can help to inform decisions about the future development of the country's transportation infrastructure. They suggest that there are opportunities for cost savings and environmental benefits from using waterways, but also challenges such as lack of infrastructure, lack of regulation, and the need for more efficient regulation.

# 3. Brazilian context background

## 3.1 Transports evolution in brazil

In order to investigate a potential use of alternative cargo transport modes, the existing dialog between logistics, economicy and history cannot be ignored.

In the historical dimension, it was seen that the understanding of the logic of transport in the country followed the direction of the colonization, which represented a direction of the colonial organization towards the external market, especially in the supply of tropical products and precious metals to Europe, based mainly on farming, monoculture and slave labor. Transportation and the communications system at that time exerted considerable influence on the formation of the country and accompanied the progression of the settlement, installing first on the coast and progressively penetrating the interior, through centers fairly close to the sea. At the beginning, reaching the interior was very slow, cargo transport was mainly by sea. On the land, one could only count on the use of animals or means of transportation pulled by them. Gradually penetrating the interior was mainly due to gold exploration, when roads were outlined toward the continent. Their roads started in this same direction and later on went in the opposite direction, starting from the same centers already established in the interior and irradiating to the most convenient way out to the sea. This circumstance was caused by geographical factors such as great distances, obstacles to transit in the territory, the rugged terrain, forest cover, poorly oriented coastline, rugged rivers with problematic routes. In this scenario, the highly fragmented exceptions were the roads that were effective in the search for articulation between the coast and the interior. There was no systematic vision at a broad level, only small autonomous systems formed by the extremes of the interior and the coast, whose centers were partially connected to each other and the irradiations pervaded the entire Brazilian coast, from North to South (Vasconcelos, 2018).

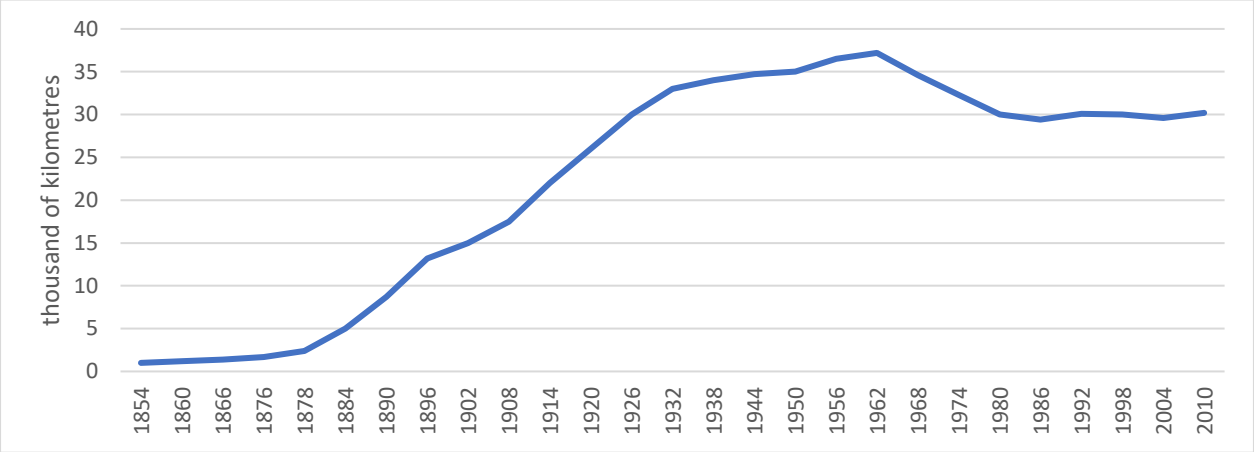
This lack of interconnection only started to be questioned after the 19th century, with the advent of some plans that streamlined the railway and waterway modes, which, although they were not effective in practice, represented an advance in the understanding of transportation in a systemic way. The first of these, the Rebelo Plan (1838), foresaw the construction of royal roads; the Moraes Plan (1869) represented an outline for integration with inland ports; the Queiroz Plan (1874) began to think about the organization of the railway network; The Rebouças Plan (1874) envisioned Brazil

as an interconnected triangle, with the Amazon River, the coast and the frontier as its vertices; the Bicalho Plan (1881) and the Bulhões Plan (1882) were based on developing railroads and river navigation; and the General Plan of Transportation (1886) was based on building new railroads and river navigation.

Afterwards, during the Old Republic, the Plan of the General Transportation Commission (1890) sought an integration between the railroad and fluvial modalities; the Railroad Plan (1912) aimed to integrate the Amazon region with railroads; and the Catrambi Plan (1926) started thinking about the expansion of the road network. This change of dynamic to this mode is based on the premise that the previous transport system proved inadequate at the time Brazil was oriented to the development of productive forces, focused on the domestic market as the main frontier of expansion. There was already a network of roads suitable for animal traction, which provided the capillarity required for an export-oriented economy (Barat, 1978).

However, a new development model demanded the integration of the country's regions through trunk lines that could provide reasonable freight rates and make the domestic market as a whole available to the nascent national industries. Moreover, in the 1920s, when Brazil began to assemble first cars, roads prevailed. This was the scenario that permeated the discussion between proponents of highways and railroads. This process of choosing which mode would prevail in the transportation system was a pendulum between the 1920s and the 1940s. With the Plano Geral de Viação Nacional (PGVN) (General Plan of National Transportation) there was the installation of a logic of railroads and rivers. The Brazilian railroad network grew rapidly at the beginning of the 20th century, but with the arrival of the multinational manufacturers of motor vehicles and the encouragement of investments in highways in the 60s, the growth of the Brazilian railway network stagnated. Figure 1 shows the evolution of the Brazilian railway network over the years.

Figure 1. Historical evolution of railways in Brazil




(IBGE, 2013)

From the 1940s and 1950s, highways construction received a powerful impulse, due to three main factor: due to the wear and tear of the railway fleet and the high cost of reinstalling it, the road option was chosen; the creation of the National Highway Fund (1946), which imposed a tax on liquid fuel used to finance road construction; and the founding of Petrobras (1954), which began producing large quantities of raw materials for the asphalt and fuels (Sánchez, 2008).

In this direction, it is notable to mention the role of the president Juscelino Kubitschek's economic vision of the country, who claimed that Brazil's attractiveness to foreign companies would have increased the wider the road network would have been. Moreover, in the 1950s, the automobile industry registered a considerable expansion, making the trucks the most adopted of freight transport over the country (Goularti Filho & Queiroz, 2011).

Also, with the next governments, a clear human contribution was given to the configuration of transports matrix: there was an increase in terms of investments, construction and usage of roadways, while an evident reduction in absolute numbers for rail, water and air transportation. It is notable to mention that, even though there was a contraction in the railway's extension, there has been an increment in freight's volume transported; as a signal that, despite the continuous effort only to the road mode, still other alternatives were screened. Furthermore, by moving the capital from Rio de Janeiro to Brasilia in the center of the country, the main purpose was interconnecting the regions. Thus, the road network reached the most distant places, facilitating cargo transportation especially on roadways.

During the military governments (1964-1985), concomitantly the creation of the Ministry of Transportation, there was a substantial increase in the kilometers' number of roads (which more than doubled its productivity), water navigable channels and railways, even the air modal tripled its productivity during that period.

With the establishment of the Sixth Republic (Nova Republica), as the Constitution art.174 states: with regard to strategic planning, the State (seen as a normative and regulating agent of the economic activity) would have exercised, in the form of law, the functions of control, incentive and planning, being determinant for the public sector and indicative for the private sector. However, until the first 2000s, the direction was parallel to the previous governments' ones: a slight increase in road modalities, showed no increase in railways and brought a significant decline in water modalities (Bertussi & Ellery Junior, 2012).

Starting from 2003 on, four main policies can be highlighted regarding transport matrix: The National Policy for Territorial Planning (2006); the Growth Acceleration Program (2007); the National Plan for Logistics and Transportation (2009); and the National Road System (2011). However, in terms of number, despite the huge increase in legislative contribution and national plan, the transport matrix still shows a clear distortion, with the roadways that centralize more than 90% of the country's transport (considering either passengers and cargos), a slight increase in the railways, and a significant increment only in waterways and air movements (not enough to overbalance the roadways utilization).

Centuries of historical evolution in utilization and investments in freight transport modes have left, as of today, a distorted transport matrix, dependent on road mode as primary alternative and, consequently, on its problems, which increases logistics cost. In view of this scenario, it is important to emphasize the need to invest in more efficient and sustainable options and intramodality. The collaboration between the modes is important and is directly related to competitiveness.

## 3.2 Actual Transportation Matrix

Brazil's economic activities are among the essential reasons for the evolution of cargo transportation. After all, new demands require new methods of transportation. One of the factors of economic growth in a nation is directly related to the ease of flow of their commodity production in such a way that they reach the points of consumption, whether in the national or international context. In this sense, operating costs can be decisive in the competitiveness of these products. Despite this theoretical keystone concept, the reality is slightly different.

The trajectory of cargo transportation has culminated in the reality we have today: a distortion of transport matrix where roadways play the major role in freight overland transportation. Indeed, the country presents more than 1.8 million km of roads, but only less than 30 thousand km of railroads and 20 thousand km of commercial navigable stretches. According to data from the CNT (2022), road transport has its largest share, as shown in figure 2 with 64.9% of cargo, followed by rail transport with 15.0% and waterway transport with 13.6% (of which only 5.3% though inland water stretches), representing 95.4% of all cargo transported in the Brazilian context.

Figure 2. Brazil freight transportation matrix in 2022.

| Mode | TKU (billions) | Percentage |
|---|---|---|
| Roadway | 1.548,0 | 64,9% |
| Railway | 356,8 | 15,0% |
| Cabotage* | 249,9 | 10,5% |
| Internal Waterway | 125,3 | 5,3% |
| Pipeline | 106,1 | 4,5% |
| Air transport | 0,6 | 0,0% |
| **Total** | **2.386,7** | **100%** |

(*cabotage: coastline movement, seaport to seaport)

Thus, it appears that better sizing with the use of modes with lower costs may generate better competitiveness for Brazilian products. Indeed, according to the PNLT (2014, actualized 2022), if Brazil's transportation matrix were more balanced, it is estimated that the avoidable logistics costs

would be around US$ 2.6 billion a year, considering the reduction in transportation costs for certain goods, freights could be decreased by 62% for the waterway mode and by 37% in the railroad mode compared to roadways.

Knowing the characteristics of this network is fundamental for logistics and for a complete dimension of the activity.

In Brazil, the transportation matrix is composed of:

- Road transport: the mode responsible for most of the cargo moved, approximately 65%, which is unusual if compared to similar geographic size and characteristics countries (for instance US, Canada and China) where it settles down around 30%, in favor of railways and waterways (CNT, 2022). It is not the most economical means of transport, either in terms of the cost of fuel, tolls and safety. Even so, it is primarily responsible for integrating the Brazilian transportation system and the mode with the highest investment. Today Brazil shows one of the major roadways network of the world. Although road transport is the majority in Brazil, this does not mean that it has the best quality. According to the CNT, Brazil has 1,720,700 km of highways, however, only 213.453 km are paved, which represents approximately 12.4% of the total (CNT, 2022). Not to mention that according to a study conducted by DNIT (2017), it has been identified that 74.9% of the road network state of conservation is evaluated as terrible, poor, or deficient, which contributes to the increase in transportation costs and to a greater number of accidents. This representation of approximately over 60% in cargo transportation, combined with the low number of paved highways, has a direct impact on the operating costs of the sector, as well as on the price of the products, whether for local or international trade, compromising the competitiveness of sectors dependent exclusively on this mode.

- Rail transport: This option carries about 15% of the cargo in the country. It is used especially for the circulation of low added value industry materials, such as mineral ores. It has a lower cost compared to roadways, but the infrastructure is still deficient. Historically, the railway mode has been associated with the development of the country, due to its territorial extension. On the other hand, there is a need for high-value investments in the implementation of this type of infrastructure. The Brazilian Railway System currently

totals 30,129 km in length, distributed throughout the country (CNT, 2022). The location of the Brazilian railways follows the most economically dynamic and developed centers in the country, distributing production mainly to the ports. This justify why a greater concentration of this mode in the center-south of Brazil (Pego & Campos Neto, 2010). According to data from the CNT (2022), iron ore, which accounts for 67% of the total volume transported by railways, is among the main products transported by the railways. Based on the comparison above, it is possible to analyze that all large countries use railroads a lot, in Russia, for example, 81% of transport is carried out by railways. However, we can see that these countries seek to balance their modes in order to bring benefits to you with the use of an intermodal system, a situation that unfortunately has not yet happened successfully in Brazil.

- Waterway transport: It can be basically classified into two transportation systems: the maritime one, which covers the circulation on the ocean coast, and the river one, which uses navigable rivers. In this study it will inspect the latter one. Internal waterways carries only 5% of Brazilian freights. It is mainly used to transport mineral and agricultural products from the interior of the country through the major water channels. The costs involved are very low, but the delivery time is longer. Besides this, the waterways have not received and still does not enough investment either. According to the National Transport Confederation (CNT, 2022), Brazil has more than 40 thousand kilometers of potentially navigable roads. Even so, waterway cargo accounts for one of the lowest utilized alternatives in Brazil. Waterway transport is characterized by using lakes, rivers and artificial canals to move goods within the same country or between different nations. As in other sectors, this modality also underwent restructuring, starting with the enactment of the Port Modernization Law in 1993, which granted greater private participation in port operations. In the period prior to the enactment of the law, the port system was directly or indirectly controlled by the Federal Government. This resulted in a highly bureaucratic environment, with low efficiency and high costs. The main products handled at ports include general cargo (76.3%), solid bulk (13.7%), liquid bulk (5.3%) and containers (1.5%) (CNT, 2022). Of all the modes, waterway transport has the lowest cost but also the lowest delivery time. In addition, it is less polluting, has greater load capacity, insurance, cheaper maintenance and, finally, longer useful life.

- Air transport: moves less than 1% of the cargos. It is a very modest amount, mainly because high costs involved including fixed (aircrafts) and variable costs (fuel, maintenance. On the other hand, it is the most agile of all types considered the geographical extension and composition of the country. It is controlled by the National (Wanke & Fleury, 2006).

As regards the multimodality, despite there are many benefits in relating modes to reduce final costs, both for customers and for transportation companies, this technique is still not applied very frequently in the country, due to the differences in tax charges between Brazilian states, which entail significant burdens, making intramodality often higher than the use of a single mode.

## 3.3 Consequences of distorted matrix

Having a distorted freight transportation matrix can have several negative consequences. One potential effect is that it can lead to inefficiencies in the transportation of goods, resulting in higher costs and longer delivery times. This can have a negative impact on the competitiveness of businesses that rely on the extended logistic, as well as on the overall economy. Indeed, as the Brazil's matrix mainly depend on roadways, large logistical costs are expected due to the lack of effective infrastructure (physical and management) and issues in intelligently combining the movements among road-based transport and other alternatives (BNDES, 2017). The low productivity of transport in Brazil has increased freight costs and negatively affected the competitiveness of some economic sectors, particularly the grain exports. According to data from the ILOS Institute, the price of road freight is the second most expensive after the airline mode, which reinforces the need to seek diversification in Brazilian cargo transportation (ILOS, 2010) Additionally, a distorted freight transportation matrix can also lead to an imbalance in the distribution of goods, with some regions experiencing shortages or surpluses of certain products. This can result in increased prices for consumers and can also affect the stability of the market.

Furthermore, a distorted freight transportation matrix can also result in a significant impact on the environment, as goods may be transported in a less efficient manner, leading to higher emissions increasing fuel consumption and air pollutants, which can contribute to climate change and have

negative effects on human health. Not to mention that road mode is, by far, the most polluting option, whereas transportation by railroad or cabotage has low pollution levels (CNT, 2013).

As a result of its unbalance transport systems, Brazil's performance of freight movement is declining, while fossil fuel consumption and greenhouse gas (GHG) emissions are amplifying out of control. The transportation sector alone accounts for more than 46% of GHG emissions and 38% of fossil fuel consumption. In fact, the road mode registered the highest emission among cargo transportation modes in Brazil with 82% of the total (EPE, 2020). The annual estimates of greenhouse gas emissions in Brazil, prepared by the Ministry of Science, Technology and Innovation (MCTI), demonstrated the existence of a strong correlation between total $CO_2$ emissions from the transportation sector and those from the road transport sector (Brazil, 2016).

## 3.4 Waterways as source of value creation

Using inland waterways instead of roadways for freight transportation can have both economic and environmental impacts.

From an economic perspective, using waterways for freight transportation can lead to cost savings for businesses. Water transportation is generally cheaper than road transportation, particularly for large and heavy shipments, as well as for international trade. The lower costs can be attributed to several factors, such as the lower fuel consumption of ships, the lower maintenance costs for vessels, and the smaller costs associated with the construction and maintenance of waterways compared to roads. Additionally, waterways can help to reduce traffic congestion on the roads, which can lead to faster and more efficient transportation of goods.

On the environmental side, using waterways for freight transportation can lead to a reduction in greenhouse gas emissions and air pollution, since ships emit significantly less pollutants per ton of cargo than trucks. Furthermore, water transport is known for being a more energy-efficient mode of transportation than road transport, as ships can carry large amounts of cargo and use less energy per ton of cargo. Additionally, waterways can help to reduce the risk of accidents and spills, which can have serious ecological and environmental impacts.

However, as previously introduced, in Brazil the use of waterways is still underdeveloped and there are some challenges that need to be addressed. One of the main challenges is the lack of infrastructure and maintenance of existing water stretches. The country has a vast network of rivers

and coastlines that have not been fully explored for freight transportation due to lack of investment in development, maintenance, and modernization of ports, locks, and other frameworks. In addition, the lack of regulations and standards for freight transportation on waterways may also be a hindrance to its implementation.

As the CNT states (2022), the country's inland waterway transportation has a tremendous potential due to the underutilization and inefficiency of the navigable routes (rivers, lakes, lagoon, artificial canals). As a matter of fact, only 13 thousand km (approximately 30%) of the actual water navigable network are commercially used for freight movement, leaving more than two-third of the total 60 thousand km unutilized. River navigation is predominantly concentrated in the Amazon river, where the its natural characteristics allow navigability without requiring significant investment.

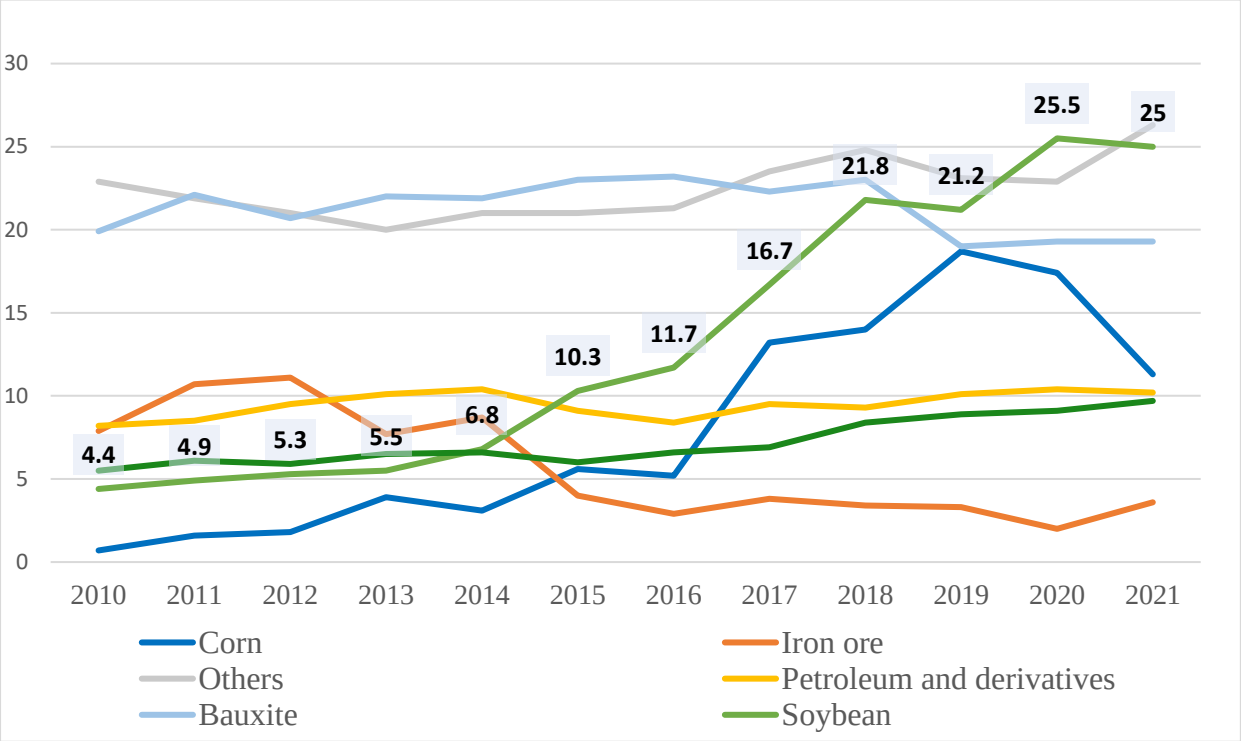
Figure 3. Brazilian waterways extension

| **Brazil's Waterways** | |
|---|---|
| **Waterway** | **Extension (Km)** |
| Tiete-Parana | 1.660 |
| Madeira | 4.164 |
| Tapajos | 1.046 |
| Capim | 372 |
| Tocantins Araguaya | 3.040 |
| San Francisco | 1.371 |
| Jacui, Tapajos, and Lagoa Dos Patos | 670 |
| Paraguay | 1.323 |
| **Total** | **13.646** |

(CNT, 2022)

Through the water channels, a large variety of goods are transported: in 2021 the most transported products were soybeans, bauxite, flour and pellets, petroleum and derivatives, containers and iron ores, which amounted to 79.9% of all freights in this period. To better understand the evolution of next sections, it is notable to mention the large increase in the recent years of soybeans movements, +420% in the period 2010-2021.

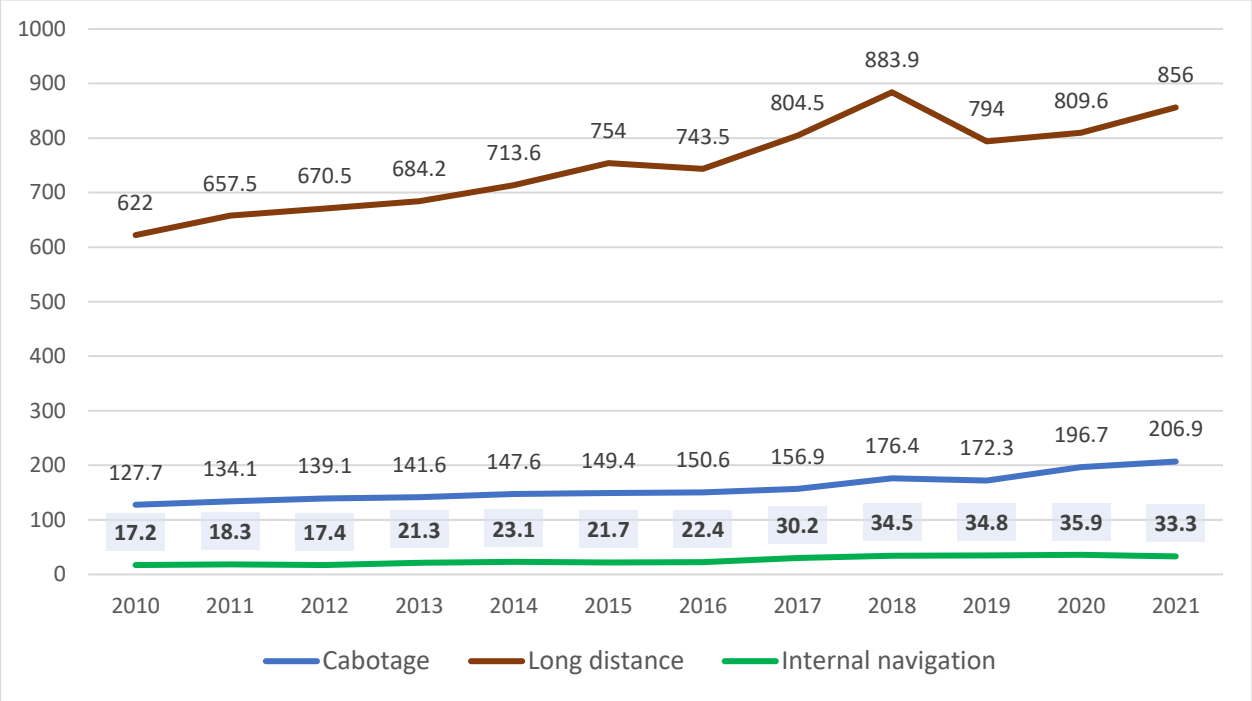
Figure 4. Inland waterways transport flow (2010-2021) in million tons.




(ONTL, 2023)

Despite this untapped capacity, Brazilian navigable channels have experimented a notable increase in volume carried, in 2021 more than 856 million tons were transported, showing their potential support to the nation's economic growth.

Figure 4. Brazil inland waterway transport evolution (2010-2021) in million tons




(ONTL, Observatorio Nacional de Transporte e Logistica, 2023)

It's worth noting that waterways may not be the most appropriate option for all types of goods and all regions, depending on the availability of infrastructure, the cost of transport, and the time required to transport goods. Therefore, it is important to consider the specific context and location when evaluating the potential impacts of using waterways for freight transportation.

# 4. Research question and methodology

Inserted in this topic, the present study aims to compare the existing logistics solutions for the export of soybeans from Mato Grosso regarding the logistic costs and the carbon dioxide ($CO_2$) emissions into the atmosphere. Specifically, it proposes the impact resulting from the change from the road mode to the waterway option for soybean transportation from Mato Grosso state through Paraguay-Paraná river.

The scenarios are evaluated uses quantitative variables, not only technical and economic but also environmental, to perform a cost-benefit comparison of the two modal alternatives. The data for carrying out this study were provided by publications from official agencies, such as the National Transportation Confederation (CNT); National Land Transportation Agency (ANTT) and National Waterway Transportation Agency (ANTAQ). In particular, the study aims to answer the following research question: *What are the real possibilities of waterways as a complement or alternative logistics modal for soya transportation in Mato Grosso?*

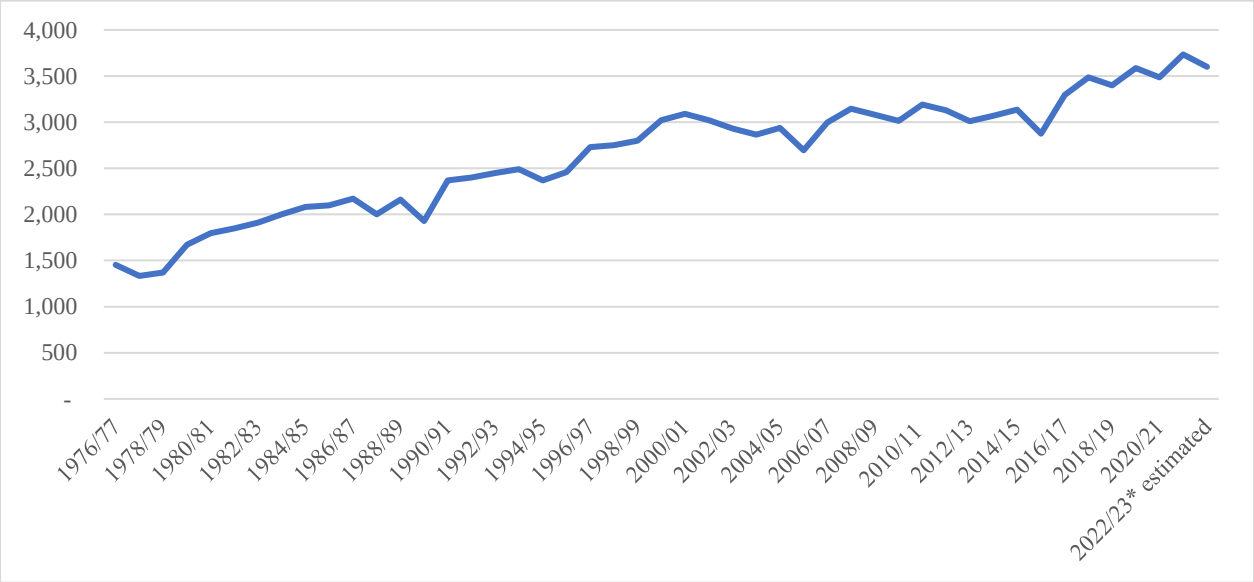
# 5. Case Study: Mato Grosso

Mato Grosso, one of the Brazilian states, perfectly represents the Brazilian context. It is a perfect example of a sickness transportation matrix and an untapped utilization of waterways to move freight across and outside the country.

In addition of being the largest state producer in brazil, Mato Grosso is also the national leader in the production of cotton, beans, corn and sunflower and from animal perspective, breeding of pigs, poultry and cattle plays an important role in the state's economy, given that the supply of raw materials (soybeans and corn) to invest in the creation of animal protein (pigs, poultry and cattle) is abundant.

Since the first introduction of the soybean crop in the state, it overspread over registering a constant growth in cultivated area and volume produced, by taking advantage of the state’s natural geographic conformation, wide availability of land at low costs and the public policies adopted financing agricultural projects.

Figure 5. Production per hectare in Mato Grosso in kg/ha



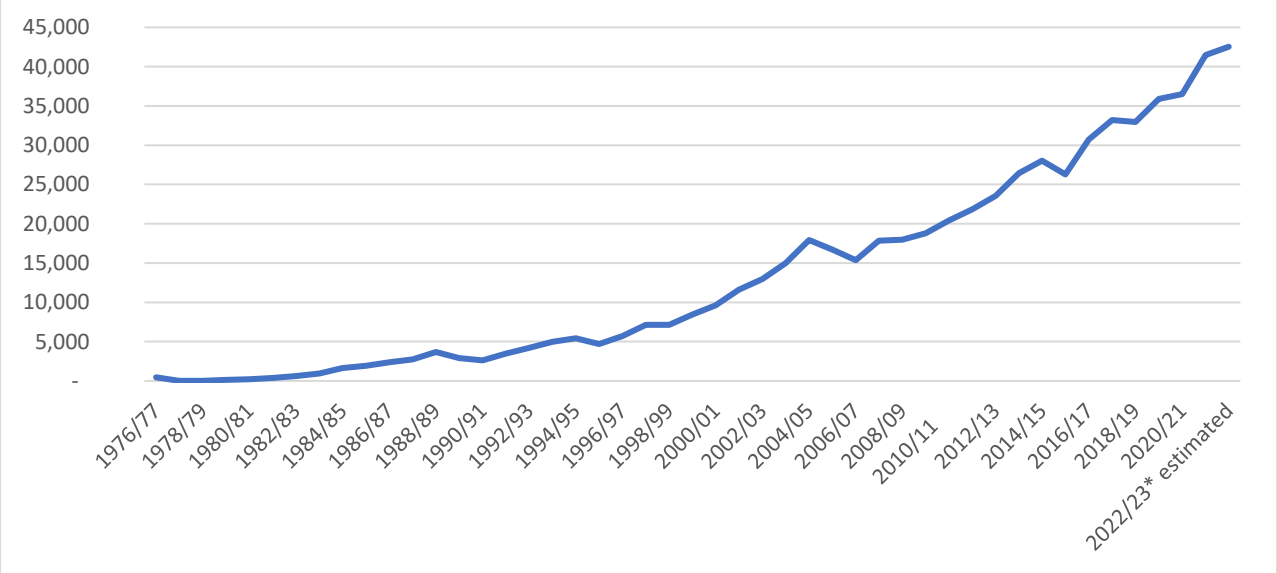

(CONAB, 2023)

As shown in Figure 5, soybean productivity in Mato Grosso State and the Midwestern Brazil region has evolved significantly over the 40 years analyzed here. In terms of yields, the 1976/77 harvest was around 1,400 kg/ha. There have been small fluctuations over time, generally due to bad weather and less investment in the harvest, which could be due to lower grain sales prices for example, still there has been a remarkable evolution as yields in 2021/22 exceeded 4,000 kg/ha. This represents an almost 200% improvement in productivity during the reporting period. Therefore, expansion of cultivated area and significant improvement in productivity, especially for soybeans and corn, are the main reasons for the rapid growth in grain production in the Mato Grosso.

By extending this topic to the transformations that took place in Mato Grosso, it is comprisable especially on a technical and productive evolution. As Dentz (2008) points out, the state's grain production potential has increased significantly, especially in the last two decades. In addition to technological progress, other factors were important to the development of such a highly mechanized agriculture in this province, including: lands dedicated to cultivation were flat and favorable to the scale mechanization, suitable climatic conditions (with two well-distinct seasons),

strong state support with specific public policies and subsidized loans, attraction of farmers from other parts of Brazil to the state due to favorable conditions just presented. Indeed, if, on the one hand, there was abundant and cheaper land in Mato Grosso in the 70s, the soil was not very suitable for an intensive production. With the Mate Grosso Foundation as the main agent, a strong research and development effort was required to create a complete know-how for the introduction of culture within the state (Frederico, 2008). In other words, there have been strategic reasons and ways to settle in Mato Grosso, and exploit its agricultural potential.

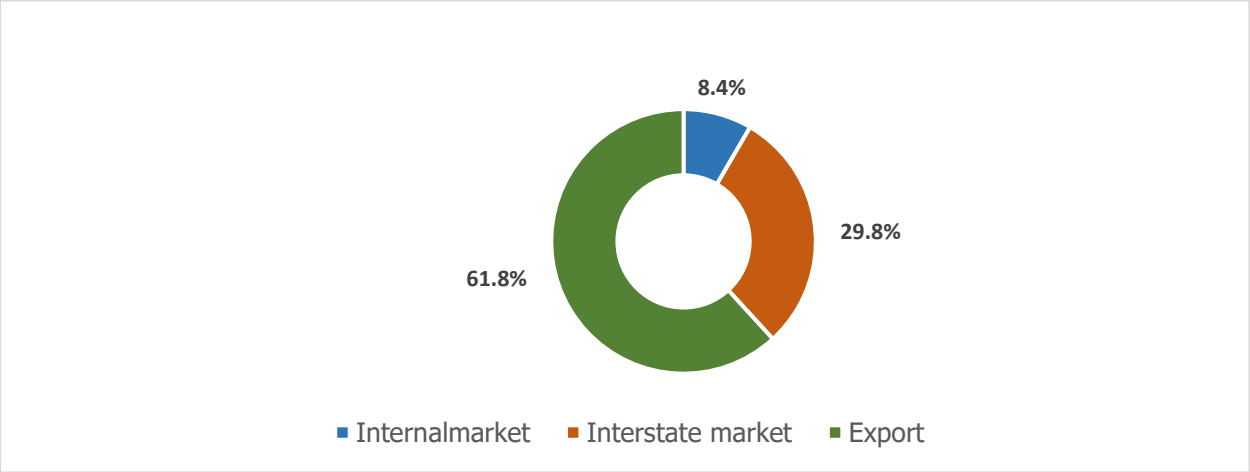
Figure 6. Production of soybean in Mato Grosso (1976-2022/2023)




(CONAB, 2022).

Once harvested, soybean is moved across the country: 8.4% remained in Mato Grosso, transformed into two main derivates (soybean meal and oil) and commercialized internally; 29.8% is transported and sold across other states; over half 61.8% directly bounded for the exportation (IMEA, 2023).

Figure 7. Destination of soybean produced in Mato Grosso




(IMEA, 2023)

As the graph suggests, export is the primary market for producers, reflecting the need of an extremely efficient global transportation network. Indeed, focusing on the transport infrastructure in Mato Grosso, more than 55% of goods are moved by road, 35% by rail and only 10% are moved by waterways (IMEA, 2023).

In practice, even though the Mato Grosso is agricultural producers, it faces significant challenges in relation to environmental impact and inefficient transportation system unable to properly connect main logistic centers to cultivated areas separated by huge distances. Transports system has not kept up with the agricultural expansion, and trucks still represent the major component in the country's macro-logistics activities.

The lack of different alternative shipment modes led to considerable movement costs either to collect the crops inputs either for the flow of soybean harvested. This inconvenient scenario enhances the importance of having a reliable differentiated transfer system, not dependent only on roadways, to achieve competitive prices and boost economic growth (Vilhena & Ribeiro, 2015). As also stated by Garrett et al. (2013), since costs to get agricultural inputs are inversely correlated to road quality and distances, the poorest the roads conditions and significant distances (as it happens in Mato Grosso and the majority of Brazil interior states) the higher transport costs, which ultimately would result in increased soybeans prices. (Garret et al, 2013). Moreover, trading

agricultural agencies set the price per ton according to soybean supply and demand and the transportations infrastructure accessible, heavily dependent on trucks (Kussano & Batalha, 2012). In some regions, producers and public administrators paved highways, built new roads, and invested in basic service networks to meet the needs of new cultures. However, considering today's volumes is not possible to rely only on this mode.

However, some problems still hampered the development of the culture, such as logistics and producer debt. At the same time, the state government established the State Soybean Culture Promotion Fund (Facs), which allowed the implementation of many projects aimed at creating conditions for the development of soybean cultivation.

On the other hand, while the amount of soybean soared, over the same period, public investment in transport infrastructure significantly dropped, particularly between 2010-2017 registered a 37% contraction (BCECE, 2019). This resulted in a deteriorating freight performance and an increasing fossil fuel consumption and $CO_2$ emissions. Transport logistic accounts more than 48% of national $CO_2$ emissions and around 35% of fossil fuel consumption (BCECE,2019). Moreover, underdeveloped shipment infrastructure has driven up freight costs and harmed not only grains industry competitiveness but also other various economic sectors related to that cited infrastructure. These consequences emphasize the need to invest in freight infrastructure, focusing on exploring underemployed alternative modes. An analysis of the economic and environmental impact from the utilization of waterways instead of roadways as shipment mode is presented in this paper.

To support the increased demand, the new territories to land for the cultivation were far from the actual export centers, thus, waterways can result strategic mode of transport. These figures give a clear idea of the potential of waterways if efficiently utilized in this state but also in the country.

# 6. Analysis

For comparison purposes, two section were considered for each mode. From to the port of Cáceres (BR) to seaport Nueva Palmira (UY) for the waterway, while from Cáceres (BR) to seaport Paranaguá (BR) as regards the roadway. Even though the two selected paths are slightly different in terms of destinations and length, they represent the closest seaport for each option. Since, as explained in the previous section, the majority of soybeans produced is exported, what is important for the producers is to reach the seaport and from them shipping to other Brazilian ports or worldwide. For this reason, to perform the comparison the most realistic path has been taken in consideration for both alternatives.

The Paraguay-Paraná water stretch has a total length of 3,342 km, from Cáceres in Mato Grosso (Brazil) to the seaport Nueva Palmira (Uruguay). It connects four of the five members of the Southern Common Market (MERCOSUR) - Brazil, Paraguay, Argentina and Uruguay - and Bolivia, cutting in half the South America. It has been chosen to carry out the study because of its diversity in cargo transportation (from ores to agricultural products and grains), its potential for integration at the international level and being the only navigable large water stretch that connect the center-western of the country to the port regions, where the goods are exported.

The Paraguay-Paraná River has two distinct segments from the point of view of navigation: Southern Section - from the mouth of the Apa River to Corumbá (MS), the river is navigable by large commercial trains, without major obstacles; and, in the Northern Section - between Corumbá (MS) and Cáceres (MT), it is navigable by small and medium-sized vessels, presenting major difficulties and obstacles, which are mainly due to river islands, silting and excessive sinuosity.

The characteristics of the Southern Section allow the navigation of trains with a length of 290 meters, 48 meters wide, a draft of 2.7 meters and a capacity of 24 thousand tons. Convoys up to 140 meters long and 24 meters wide can travel on the Northern Section, with a depth of 1.5 m and a capacity of up to 750 tons of cargo. The vessels transport soybeans, rice, corn and wood, in addition to cement and iron and manganese ore derivatives (DNIT, 2021).

The highway BR-163 from Cáceres to Paranaguá is 2073 km long; it is an important set of roads, facilities and infrastructure which have been used by shippers and transporters to dispose and sell

most of the agricultural bulk cargo from Mato Grosso. In Paranaguá is located the largest bulk shipping complex in the country (ANTT, 2020).

Both of the routes presented can be choose by the contractor to carry out the transportation, even though they lead to differences in costs and environmental impact.
In this comparative analysis it has been assumed moving 4,6 million tons, which is the amount of freight moved in 2022 from Mato Grosso through Paraguay-Paraná river (ANTAQ, 2023). It is an overestimation because not all the freight moved through the studied river is soya and some part of the transport is lost during the transportation.

The logistics solutions for transporting soybeans from Mato Grosso considered to carry out the calculations, according to each destination port, were:

- Cáceres - Port Paranaguá: transportation by road only;
- Cáceres - Port Nueva Palmira: waterway mode.

Based on these export possibilities and respective configurations of transport flows, three different scenarios (1, 2, 3) were created to compare both the logistic costs and the carbon dioxide emissions, where:

- Scenario 1: the transportation carried out solely and exclusively by road mode to Paranaguá destination port;
- Scenario 2: transportation is carried out considering multimodality;
- Scenario 3: transportation is uniquely through the waterway mode to port Nueva Palmira.

For scenarios 2, the percentage of use of alternative mode of road (waterway) was defined according to analysis conducted on the logistic network regarding the export of soybeans from Mato Grosso. In particular, it has been considered the possibility from Cáceres to reach Corumbá, 750 km south, by road and from there on to Nueva Palmira by barges adopting the water option. Corumbá has been selected as mid-point since other important port on the Paraguay river with similar characteristic (capacity, equipment, infrastructure) of the Cáceres one, and in this way, to avoid the tightest Paraguay river stretch from Cáceres-Corumbá which can be a limitation to transport efficiency during dry season. As the stretch considered is 750 km of total 3342 km, the multimodality will be considered as 22% road option and 78% waterway.

Table 1. Percentage of use of road and waterway modes in the scenarios considered

| | Route | Road (%) | Water (%) |
|---|---|---|---|
| Scenario 1 | Cáceres – Paranaguá | 100% | 0% |
| Scenario 2 | i) Cáceres – Corumbá (road)<br>ii) Corumbá – Nueva Palmira (water) | 22% | 78% |
| Scenario 3 | Cáceres – Nueva Palmira | 0% | 100% |

(elaborated by author)

## 6.1 Logistic differences

The differences between the two freight transport modes are principally the cargo capacity, delivery time and engine power, which directly affect fuel consumption, fuel emissions, volume of cargo carried per trip and most importantly, freight cost.

As regards the first element, in this study it has been considered a traditional convoy made of one tug boat and four barges with a total capacity of 3 thousand tons, due to the characteristic of the Paraguay–Paraná river. Indeed, a bulk barge (used to transport grain) holds up to 750 tons per trip and it can carry up to 9 wagons containing this product. However, in the specific case considered, due to river constrains, especially in the stretch Cáceres-Corumbá with the lowest width and draft, a tug-boat can take only up to 4 barges per trip. This was assumed as the *standard* barge and the *standard* combination. On average, it can transport over 500,000 tons of soybeans per year from Cáceres to Nueva Palmira.

On highways, it has been considered a CVC (Combinação de Veículo de Carga, Combination of Cargo Vehicles of a tractor and two trailers) (refers to a category in which one part has the driving force (engine), traction wheels and the cab of the driver and the other two party receives the cargo) intended for transporting grain, which takes an average of 42 tons per trip, according to the ANTT

(2014). To transport the 4,6 million tons of moved in 2022 from Mato Grosso, around 110 thousand trucks or 300 trucks/day would be needed.

Based on the data provided, it is possible to claim that each convoy departing from Cáceres, consisting of 4 barges, all loaded with maximum capacity, would replace about 71 trucks, or it would take about 18 trucks to carry approximately 750 tons of cargo that only one traditional barge carries.

Table 2. Modal Freight unit capacity

| | Standard cargo unit capacity (t) | Standard fleet combination |
|---|---|---|
| Road – truck trailer | 42 | 1 tractor (6x4): 2 trailers |
| Water – barges | 3000 | 1 barge-tow: 4 barges |

(ANTT 2014; ANTAQ 2014)

Concerning the energy-efficiency, it is known that one of the main advantages of waterway cargo transportation includes the reduction of energy consumption and pollution, given the use of vehicles with high capacities able to move freight for longer distance with less energy. A road truck with a capacity of more than 35 tons would consume 0,0297 k/t.km, while the water mode considered with higher capacity than 2000 tons would consume 0,0050 l/t.km (CETESB, 2018).

Table 3. Fuel consumption factor per each mode

| | Fuel consumption factor (l/t.km) |
|---|---|
| Road Truck | 0,0297 |
| Water tug-boat | 0,0050 |

(CETESB, 2019)

Finally, in order to calculate the delivery time, the average speed values provided by the ANTT were considered to find the final value in hours for each origin-destination journey studied: the

average operating speed of the water convoy considered is on average 15 km/h for the transportation of soybeans, while 60 km/h for the truck (ANTT 2014). By analyzing the data, it was found that the speed of a barge, as well as that of a truck with the same purpose, varies according to the traffic perimeter. In general, close to the urban areas the speed of the truck is at its lowest averaging around 20 km/h, while, close to turns or ports, the barge's speed drops to 5 km/h. However, this average speed may vary according also to the nature of goods transported.

Based on the data collected, it was possible to establish a travel time for the section studied, as shown in the table below:

Table 4. Elements of delivery time calculation

| | Road mode | Water mode |
|---|---|---|
| Distance (km) | 2073 | 3342 |
| Average speed (km/h) | 60 | 15 |
| Travel work shift (hs) | 8 | 24 |
| Time per single trip (h) | 35 | 223 |
| Time per single trip (days) | 4,3 | 9,3 |

(Elaborated by author consulting data from ANTT 2015, ANTAQ 2014)

In the road mode, a truck with a maximum grain load (approximately 42 tons) that travels from Cáceres to Paranaguá via the BR-163 highway at an average speed of 60 km/h, while considering the stopping and rest time of 8 hours work shift established by law (CLT, 1943), would take about 4 days to reach its destination. At the same time, a water convoy has not such working limitation, since able to operate the whole day; anyway, considering the lower average speed it will take approximately 9 days.

It is known that agricultural products are generally perishable, requiring adequate distribution logistics, avoiding excessive and immobilized inventories during their movement, making it necessary to reduce transportation time. However, in longer delivery times, in addition to the obvious reduction of distribution costs, there is the advantage of reducing the price of the final product, increasing competitiveness and country's exportations.

Another factor combined with time is the availability of the use of transportation, where the road mode can be used at any time in view of the largest number of trucks and companies specializing in freight, while the waterway sector has a more limited number of companies and equipment. Moreover, the latter option is available only 10 months per year because of two months of dry season.

In the same way, in terms of maintenance costs, the water mode is much lower compared to the road mode (34US$/t/km for road and 12US$/t/km for water, making this characteristic a very strong point when choosing the first option when the infrastructure is available for the desired transport (PNLT, 2011).

## 6.2 Transportation Costs Findings

After the data was consolidated, in the Excel software, the calculations of the total logistic costs of each soybean export flow from Mato Grosso per single trip (Cjk) were carried out in accordance with Equation (1), based on distance (D), the amount of cargo exported per flow (Qjk), Freight cost per ton (Pi), Fuel expenses (F) and the number of trips necessary to ship 4,6 million tons of soya assumed in the study.

$$Cjk = n* [(Pi * Qjk) + (Fi * Djk * E * Qjk)] \quad \text{(Equation 1)}$$

In which:

Cjk = Total logistic costs from origin j to destination port k in US$ per single trip;

n = total number of trip necessary to move the considered amount of soybean;

P*i* = Freight cost per ton for each transport mode *i*, in US$/t;

Q*jk* = Quantity of soybeans exported by from origin *j* to destination port *k*, in t;

F*i* = Factor of fuel consumption for each mode, in l/t.km;

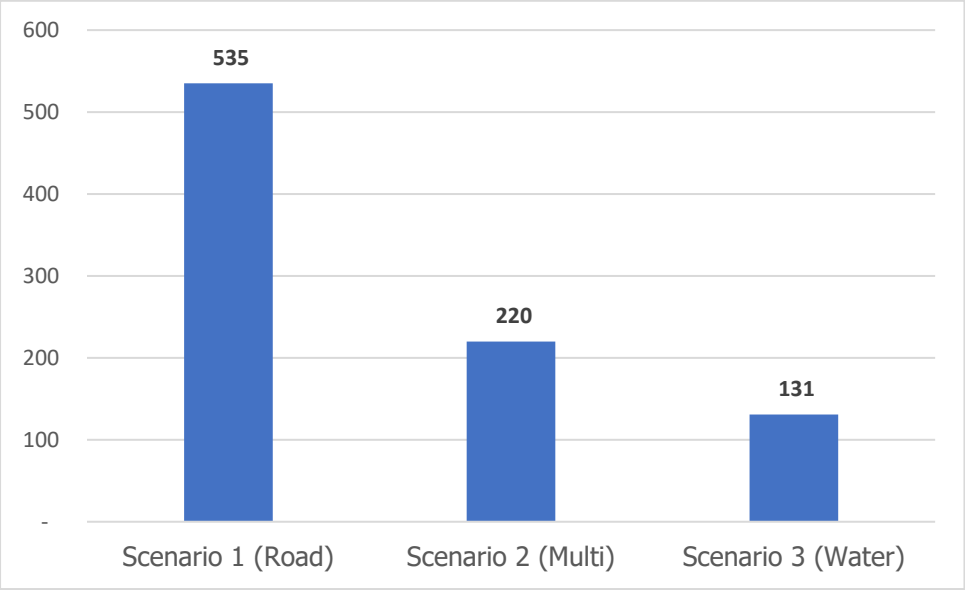
E = Cost of fuel (Diesel), in US$/l;

D = Distance traveled, in km.

The calculation of freight cost may vary from company to company or even from self-employed people who ships with their own vehicles. In this study, it has been adopted a simulator of freight transport which consider distances, mode and type of goods transported, provided by ONTL

(Observatorio Nacional Transporte Logistico). To convert R$ in US$ it has been used the average exchange rate of the year 2022: 5,17R$/US$ (Trading Economics. 2023). Based on this software, it was possible to verify the average cost of road freight at 60,58US$/t (313,40R$/t) for each ton transported for a distance of up to 2150km. While, the average freight cost for transporting agricultural cargo on inland waterway with low restrictions is 12,95US$ (67,69R$/t). It is understood that restrictions are lowered where the dismemberment of barges is not necessary and the river rarely has operational restrictions on navigation, as in the Paraguay-Paraná river. As a result, there are low limitation to access ports and on average commercial speed of navigation (ONTL, 2023). As concern the number of trips needed to move 4,6 million tons from Mato Grosso, taking into consideration the capacity of each mode (42tons for truck and 3000tons for barges), it is determined that it would be required 95.238 trips (or similarly number of trucks) for the road option and 1.333 for the waterway transportation (or similarly number of fleet combination). For the cost of fuel, it has been adopted the average cost in 2022 in Brazil, which is 1,19US$/l (Trading Economics, 2023). After the data was consolidated, in the Excel software, the calculations of the total logistic costs for each export flow from Mato Grosso were carried out in accordance with Equation (2):

Figure 8. Total Logistic costs calculated in millions of U$




(elaborated by author)

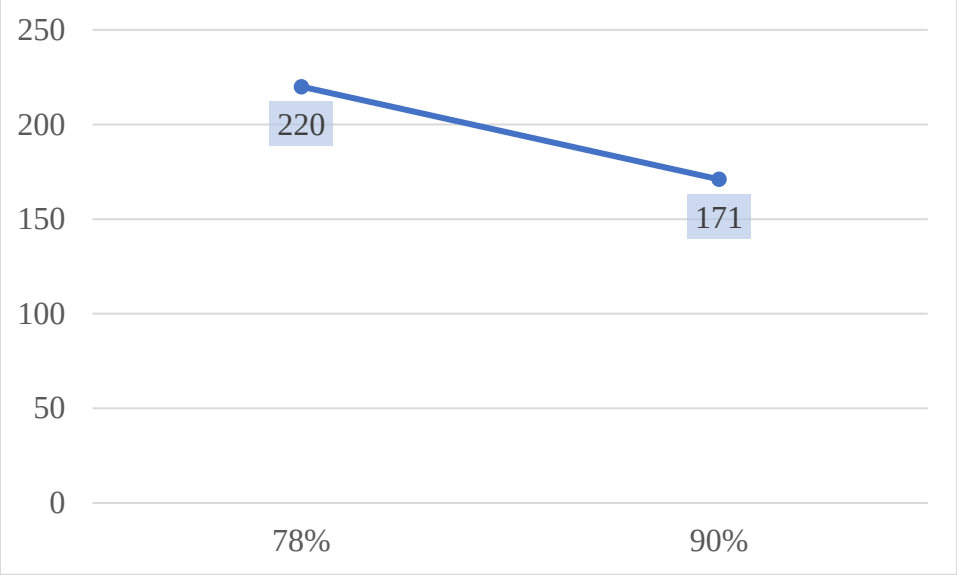
Comparative analyses and sensitivity studies were conducted based on the total logistic costs' calculations in the different logistical solution scenarios to evaluate the outcomes.

Firstly, by comparing the scenario 1 (transportation carried out solely by road mode) and 2 (in which multimodality has been adopted), the use of alternative, more energy-efficient modes of transportation resulted in a 59% reduction logistic cost for soybean movements throughout the state of Mato Grosso. In the scenario 1, it is estimated a total cost of 535 million US$. The use of multimodality positively impacted the costs reducing them by over 315 million US$, mainly driven by the lower freight cost when water option is chosen (4,7 times cheaper than road mode) since used for a larger volume of cargo transported and fewer fuel costs as it takes advantage of the water flow.

As expected, scenario 3 represent the cheapest option among the others, with 131 million US$ to move a total of 4,6 million tons, which results in a decrease of 40% compared to scenario with multimodality and 76% compared to the full road scenario.

To deepen the potential of water transportation, a sensitivity analysis has been adopted. Assuming a possible increase in the waterway utilization from 78% up to 90% in the shipment of soya, it would reduce the overall logistic cost by 22% to 171 million US$. In this case, the additional volume of cargo collected by the waterway refers to movements previously linked to the road mode.

Figure 9. Total Logistic costs, sensitivity analysis (millions of US$)




(elaborated by author)

This economic analysis emphasizes the advantages of giving waterways more precedence over roads for soybeans exports from Mato Grosso, since it proves to be more economical in relation to road mode.

## 6.3 Environmetal impact Findings

Furthermore, as a result of the greater search for sustainability in logistics operations, it is essential that environmental issues also be considered when defining the best options for the freight movement. The analysis of CO2 emissions in logistics activities becomes an important indicator, given that there is greater use energy derived from the greater use of multimodality in the transportation of cargo, resulting in reduced environmental impacts. Indeed, as previously claimed, the transportation sector in Brazil has the largest share of total CO2 emissions, with 46% on CO2 emissions from the burning of fuels (BRASIL, 2019).

The CO2 emission coefficients in the transport sector were calculated based on the energy consumption, that is, of fuel of typical truck and barge. The more efficient use of these fuels, or even the use of alternative fuels, are options already adopted by some countries to reduce their total GHG emissions.

Therefore, to quantify the total emissions from the soybean supply chain in Mato Grosso, the values of the CO2 emission factors (kg/t.km) from João et al. (2016) were considered, which are given in kg of CO2 per ton of soybeans exported per kilometer traveled (kg/t.km) for each mode of transportation, namely: 0.11917 kg/t.km for road mode and 0.018 kg/t.km for waterways (Joao et al., 2016). Table 5 shows the respective fuel consumption and CO2 emission coefficients adopted for each transport mode.

Table 5. Fuel consumption and CO2 emission coefficient per mode

| Transport mode | Fuel consumption (km/l) | CO2 emission coefficients (kg/t.km) |
|---|---|---|
| Road | 2,5 | 0,11917 |
| Water | 22 | 0,018 |

(ESALQ-LOG, 2019)

After the data was consolidated, in the Excel software, the calculations of the CO2 emissions of each soybean export flow from Mato Grosso per single trip (Ejk) were carried out in accordance with Equation (2), based on distance (D), the amount of cargo exported per flow (Qjk), the factors for CO2 emissions of each mode of transportation (Fei) and the number of trips necessary to move 4,6 million tons of soya assumed.

$$E_{jk} = n * (F_i * D * Q_{jk}) \qquad \text{(Equation 2)}$$

In which:

Ejk = Total CO2 emission from origin j to destination port k in kg per single trip;

n = total number of trip necessary to move the considered amount of soybean;

Fi = CO2 emission factor of transport mode i, in kg/t.km;

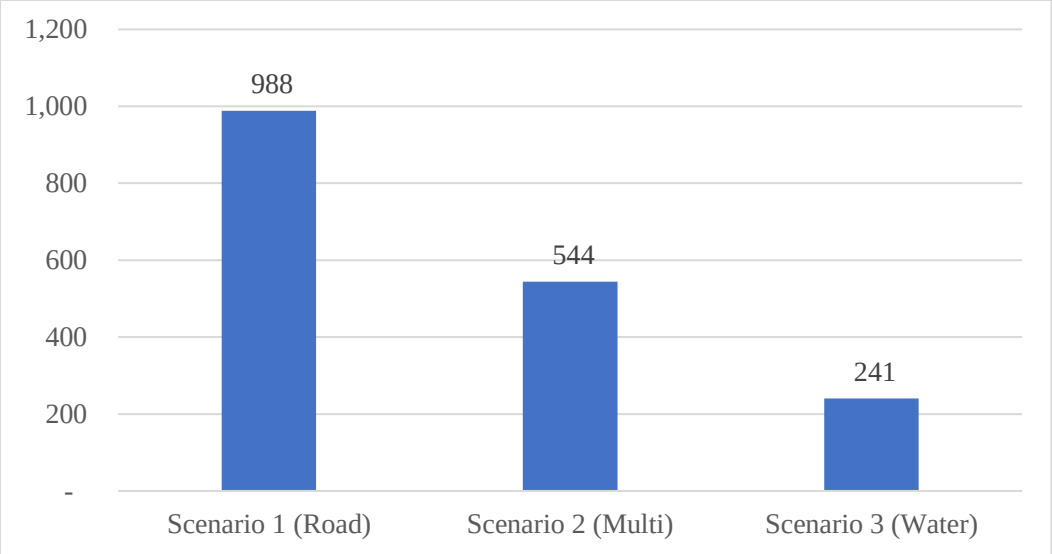
D = Distance traveled, in km;

Qjk = Quantity of soybeans exported by from origin j to destination port k, in t.

As previously introduced, three different scenarios have been analyzed to compare the alternative transportation modes.

Considering the capacity presented in the above section for each mode and so, the number of trips necessary to move the considered quantities, the results of the total CO2 emissions have been calculated:

Figure 10. Total CO2 emissions per mode calculated (million kg)




(Elaborated by author)

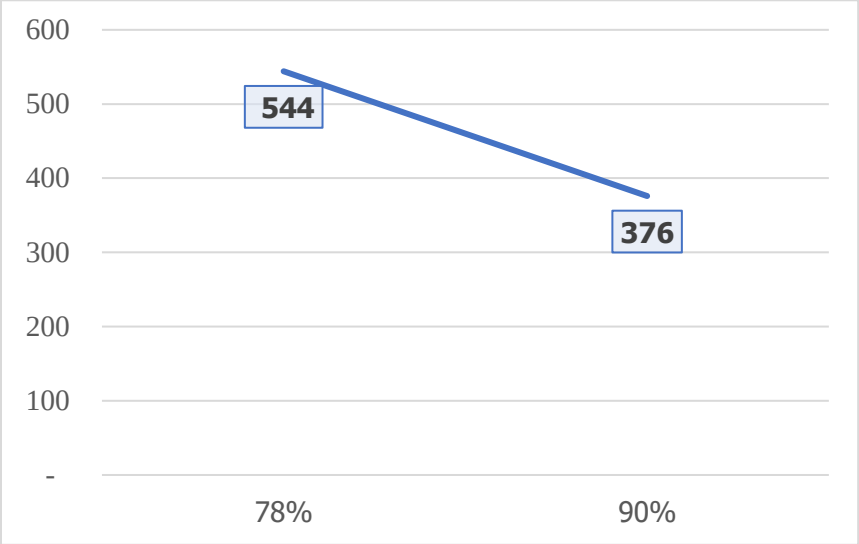
Based on the CO2 emission calculations and the different scenarios considered for logistics solutions, comparative analyses were carried out and also sensitivity analyses in order to assess the results.

Initially, the comparative analysis between scenarios 1, with transportation carried out solely by road mode, and 2, in which multimodality has been adopted, shows a 45% reduction in carbon dioxide emissions in soybean movements throughout the state of Mato Grosso, as a consequence of the use of alternative more energy efficiency modes of transportation to roadway. In the scenario 1, that refers to the exclusive use of road transport, it is estimated a total emission of CO2 into the atmosphere of almost one billion kilograms, as 988 million kg. The use of multimodality reduced emissions by over 444 million kilograms of CO2. There is a very significant impact on the reduction of CO2 emissions through the use of multimodality in transporting soybeans from Mato Grosso.

Moreover, the water mode represents the more environmentally friendly option among the others, contributing to the GHG emission with only 241 million kg, which results into a notable reduction of 56% compared to scenario with multimodality and 76% compared to the exclusively road scenario.

In order to better explore the analyses, a sensitivity analysis was used, which shows that a possible increase in the share of the water mode from 78% to 90% in the transportation of soybeans from Cáceres to the port of Nueva Palmira, would result in an 31% decrease in the total CO2 emissions of this export corridor. In this case, the additional volume of cargo collected by the waterway refers to movements previously linked to the road mode. In this situation, emissions would be reduced to 376 million kilograms of CO2. This analysis highlights the environmental benefit derived from a greater prioritization of waterway over road transport in exports from Mato Grosso through the port of Nueva Palmira.

Figure 11. Total CO2 emissions (million kg). Sensitivity analysis.




(elaborated by author)

In view of the analysis of the results, it is concluded that there is a significant reduction in carbon dioxide emissions in the state of Mato Grosso when multimodal logistics solutions are used, which proves the relevance of the combined use between different modes for the composition of the Brazilian transportation matrix. The environmental benefit brought by the use of alternatives to road modes for transporting soybeans from Mato Grosso is observed in the movements of traditional export corridors, mainly the port Paranaguá (PR) and Nueva Palmira (UY).

## 6.4 CapEx and OpEx

To give a complete understanding of the potential economic impact on using the waterways as complement of road option, it is presented in this section the costs of a project for implementing it, generally referred to as the capital expenditure (CAPEX) and operational expenditure (OPEX). The first one is the total investment required to put a project into operation, including engineering and construction of the facility, while, the term OPEX refers to the expenses incurred during its operation to run the day-to-day business, including cost of materials, and utilities.

The CAPEX is calculated based on the price per ton transported by the chosen mode considering its lifespan, while, the OPEX on the freight price per ton considering 15% margin (estimation

considering cost and price asked to producers). As for the port costs, the ANTAQ Brazilian agency provided the amount (ANTAQ, 2015).

As regard the road option, the initial investment for a truck is assumed to be around 180.000 US$, with an actual capacity of 42tons. As calculated before, from Cáceres to reach Paranaguá seaport (2073km), at an average speed of 60 km/h it will take 4,3 days. It is assumed the same time needed for the way back to Cáceres. On average, the truck has a lifespan of 5 years, which means that in its lifetime can move up to 26.272 tons of soya. Thus, the Capex of a single truck calculated is 6,83 US$/t.

Table 6. CapEx calculation for road transport

| | |
|---|---|
| Initial investment for a truck (US$) | 180.000 |
| Volume of soybeans transported per truck (ton) | 42 |
| One-way Cáceres - Paranaguá (days) | 4,3 |
| Way-back Cáceres - Paranaguá (days) | 4,3 |
| Number of trips per truck/year | 41,8 |
| Volume transported /year (ton) | 1.758 |
| Lifespan (years) | 15 |
| Volume transported/useful life (ton) | 26.272 |
| CAPEX/ton transported by truck (US$/t) | 6,83 |

(Elaborated by the author)

By having estimated the freight cost per ton in the section above, the port cost in Paranaguá provided by ANTAQ, and assumed an average margin of 15% asked to producers; the total Opex for road transport is 61,5 US$/t.

Table 7. OpEx calculation for road transport

| | |
|---|---|
| Freight cost US$/t | 60,58 |
| (-) Estimated margin | 15% |
| Port costs in Paranaguá US$/t | 10 |
| OPEX road transport system Cáceres - Paranaguá (US$/t) | 61,5 |

(Elaborated by the author)

As for the waterway option, the initial investment for a fleet combination considered in this study (one tug-boat and four barges) is 1 million US$, with an overall capacity of 3000tons. As calculated before, from Cáceres to reach Nueva Palmira seaport (3342km), at an average speed of 15km/h it will take 9,3 days. It is assumed the same time needed for the way back to Cáceres. On average, it has a lifespan higher than the trucks of 25 years, which means that in its lifetime can move up to 48.387 tons of soya. Thus, the Capex of the water combination considered is 0,83 US$/t.

Table 8. CapEx calculation for water transport (US$/t)

| | |
|---|---|
| Initial investment for the fleet combination (US$) | 1.000.000,00 |
| Volume of soybeans transported (ton) | 3000 |
| One-way Cáceres – Nueva Palmira (days) | 9,3 |
| Way back Nueva Palmira - Cáceres | 9,3 |
| Number of month activity per year | 10 |
| Number of trips per barge/year | 16 |
| Volume transported /year (ton) | 48.387 |
| Lifespan (years) | 25 |
| Volume transported/useful life (ton) | 1.209.677 |
| CAPEX/ton transported by water (US$/t) | 0,83 |

(Elaborated by the author)

By having estimated the freight cost per ton in the section above, the port cost in Nueva Palmira provided by ANTAQ, and assumed an average margin of 15% asked to producers; the total Opex for water transportation is 61,5 US$/t.

Table 9. OpEx calculation for water transport (US$/t)

| | |
|---|---|
| Freight cost by river (US$/t) | 12,95 |
| (-) Estimated margin | 15% |
| Port costs in Nueva Palmira (US$/t) | 5,4 |
| OPEX total river modal Cáceres - Nueva Palmira (US$/t) | 16,41 |

(Elaborated by the author)

As presented in the calculations, again the water option is preferable both in terms of CapEx and Opex, meaning that it is cheaper on both sides. By considering the CapEx, the waterway transportation resulted 8 times cheaper than road mode, mainly driven by the longer lifespan and higher load capacity, capable of reducing the economic impact of the initial investment. Even from the Opex perspective, the water barges are cheaper to run on the day-to-day business (almost 4 times more cost-effective), especially because of the lower fright costs per ton for the agricultural product analyzed.
These calculations further support the need to prioritize that option instead of road mode, to reduce transportation costs and further improve exports competitiveness.

# 7. Conclusion

The paper begins by providing a broad overview of the logistics and transportation solution, describing the main characteristics of each mode presented. Subsequently, a detailed review of the Brazilian context and transportation matrix is proposed, underlying the unbalance and deficiencies, which guided the analysis that this paper provided on the study of the waterways as a complement or alternative logistics modal for soya transportation. The context analyzed is the exportation of soya from Mato Grosso through two logistic solutions: roadway through BR-163 and waterway using the Paraguay-Paraná river. Consistent with the literature, a deep analysis of the economic and environmental impact of the water option compared to road modal is presented. It has been assessed transportation cost and $CO_2$ emissions values consistent with the current freight prices and fuel consumption, considering a potential load of 4,6 million tons of soya moved from Mato Grosso, and discussing the potential of adopting the Paraguay-Paraná River as a large-scale logistics corridor, with a long-distance canal, with a view to reducing $CO_2$ emissions. Answering the research question proposed at the beginning of this paper, the estimates point to: a positive decline in transportation cost up to 76% if only water barges are adopted and 59% when multimodality is chosen, and, at the same time, a 76% reduction in total emissions from the Mato Grosso logistics chain, based on the use of only water transportation and 56% decrease in case of multimodality.

Despite the road pattern is still predominant in Brazil, an overall evaluation of the results suggests that waterways have a huge economic and environmental potential, since, in addition to other

factors, it is a transporter of large volumes of goods at a single moment, it offers lower costs over long distances, and lower GHG emissions. Although, the waterway system remains underutilized and logistics remain inefficient due to the increases in costs.

Through the research conducted, it is possible to identify that Brazil needs greater investments in infrastructure in the diversification and improvement of the various modes, especially in waterways. This situation directly compromises the country's competitiveness, since direct and indirect freight costs are part of the composition of the final price of a particular product, even for soya. Investing in multimodal systems is certainly a starting point for expanding the movement of cargo through waterways, especially for the transportation of agricultural production, to efficiently and productively transport products throughout Mato Grosso, taking advantage of the natural navigation conditions of Brazilian rivers and lakes (mostly already navigable).

To encourage and smooth this modal shift and better use the already available water stretches, improvements are needed in port - roadways coordination to combine the arrival of barges with the landing of grain from trucks. Moreover, by developing load generation centers in the region of Cáceres and other potentially identified areas in Mato Grosso as well incrementing storage capacity by building new warehouses or the renovation of the old ones close to the port of Cáceres or Corumbá would further enhance the potential of waterways and their logistics. From the Mato Grosso producers' perspective, the creation of a fluvial education and training center would be strategic to continue to promote and facilitate access to this alternative modality and how to efficiently implement it in their transport system. Link to that, the establishment of an agency that would support infrastructure projects and initiatives, facilitating actions to ensure their efficiency utilization and maximize the return on investment. Finally, by develop new technologies and modes of navigation, it will ensure an even more efficient river logistics even with current restrictions and under severe low-water conditions.

By being a water stretch shared among several countries, a shared vision and a common management are necessary to make the most of its potential. For this reason, in 1992 the Paraguay-Paraná Waterway Treaty was signed among Brazil, Argentina, Bolivia, Paraguay and Uruguay. The purpose of this agreement is to facilitate navigation and commercial, fluvial and longitudinal transportation on the Paraguay - Paraná Waterway (Port of Cáceres - Port of Nueva Palmira), through the establishment of a common regulatory framework that favors the development,

modernization and efficiency of such operations, and that facilitates and allows access under competitive conditions for overseas markets. The provisions of this agreement apply to navigation, commerce, and transportation of goods and persons involving the use of the waterway, ensuring the conditions of equal opportunities for greater competitiveness, dispute resolution, and the provisional cessation of the flag. Improvement projects along the Paraguay-Parana waterway included in the agreement were directed to multiple sub-projects, such as deepening river beds, dredging, constructing ports, improving navigability and safety, and increasing capacity in terms of vessels, maintenance and services. Despite the good intentions, after more than thirty years, still the treaty has not been efficiently implemented, jeopardizing the implementation of a single legal framework. The waterway system remains underutilized and logistics remain inefficient due to the increases in costs and navigation times generated by restrictions on the waterway. The public authorities are inactive, with very low investments in infrastructure, maintenance and effort in creating a joint legal and management framework.

## 7.1 Limitations

It is worth mentioning that road and waterway modes each has its own benefits and downsides, which must be known to correctly choose the one that best meets transportation needs and reduces costs; depending on several variables and the context in which they are analyzed the comparison results can differentiate. However, based on the analyses conducted, it is possible to outline some considerations between road and water modes in Brazil, in which the latter presents many justifications regarding the prioritization of its use. Moreover, this study does not consider warehouses and distribution centers, assuming soybean are immediately transferred after harvested.

## 7.2 Future research

In this case, the cost of transportation was highlighted as a driver of sectoral logistics costs; however, as new modal alternatives become available, new studies must be prepared, and freight nature should also be understood as differentiated between transportation corridors; in other words,

specific situations determine the optimal situations themselves, implying the need for constant updating and regionalization of this analysis.

Next studies can focus on the possible incentive programs by the Federal Government and other actions it might take to support this transition, since they are essential and necessary to improve and guarantee the country's competitiveness. Despite the present study do not take into consideration already implemented plan, since the scope of the topic is broad and complex, it is a fact that initiatives in this sector require government support because they are issues related to public infrastructure.

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