

STRATEGIES TO PROMOTE INTERMODALITY IN THE AMAZONIAN NORTHERN ARC REGION: A COST-EFFECTIVENESS ANALYSIS OF INFRASTRUCTURE

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ABSTRACT

In search of greater competitiveness and lower transport costs, Brazilian agribusiness explores new outflow routes to export ports, among which the departures through the Amazonian Northern Arc. In an environment of investment rationalization and sustainability, evaluating these projects' main economic, social, and environmental benefits is necessary. This study aims to evaluate whether there are socioeconomic benefits to implementing two logistics projects in the Amazon region, Ferrogrão Railway and Araguaia-Tocantins Waterway. A cost-effectiveness analysis (CEA) was applied, which consisted of analyzing the benefits of the projects, such as reduction in the cost of transport, emission of polluting gases, use of trucks, and energy efficiency, which were compared with the value of the investment in three scenarios (2018, 2025 and 2030). As a result, we found that Ferrogrão has the greatest benefits, reducing transport costs by BRL 130 million for each BRL 1 billion invested in 2030. The main conclusion was that based on the social and environmental benefits assessment, both projects contribute broadly to sustainable regional development.

Keywords: Externalities; Transportation planning; Logistics

RESUMO

O agronegócio brasileiro, em busca de maior competitividade e menores custos de transporte, explora novas rotas de escoamento com destino aos portos de exportação, dentre as quais as saídas pelo Arco Norte Amazônico. Em um ambiente de racionalização de investimentos e sustentabilidade, é necessário avaliar os principais benefícios econômicos, sociais e ambientais desses projetos. O objetivo deste estudo é avaliar se existem benefícios socioeconômicos com a implantação de dois projetos logísticos na região Amazônica, a Ferrogrão e a Hidrovia Araguaia-Tocantins. Foi aplicada uma análise de custo-efetividade (CEA), que consistiu na análise dos benefícios dos projetos, como: redução no custo de transporte, emissão de gases poluentes, utilização de caminhões e eficiência energética, que foram comparados com o valor do investimento em três cenários (2018, 2025 e 2030). Como resultado, constatamos que a Ferrogrão apresenta os maiores benefícios, redução de custos de transporte em aproximadamente R\$ 130 milhões para cada R\$ 1 bilhão investido em 2030. A principal conclusão foi que, a partir da avaliação de benefícios sociais e ambientais, ambos projetos contribuem de maneira ampla para o desenvolvimento regional sustentável.

Palavras-chave: Externalidades; Planejamento de transporte; Logística.

Código JEL: D62, R42, R58

INTRODUCTION

Agribusiness plays a prominent role in Brazil, contributing significantly to the formation of the Gross Domestic Product (GDP), which helps inflation and outstanding participation in the country's exports, contributing to the maintenance of a surplus trade balance. These factors demonstrate the participation of agribusiness in strengthening the Brazilian economy. (OLIVEIRA; LOPES, 2015).

With continental dimensions and large tracts of fertile land, Brazil plays a prominent role in the agricultural world market. In recent decades, few countries have shown growth rates as consistent as Brazil in international agribusiness trade. In the last ten years, agribusiness exports rose from 99.7 billion US\$ in 2012 to 159.1 billion US\$ million tons in 2022, a growth of 4.8% p.a. (GHOBRIIL et al., 2023).

Brazilian efficiency in some agricultural sectors is widely recognized. Brazil is the largest producer and exporter of sugar, coffee, soy, and orange juice and the second largest exporter of beef and chicken (SALIN, 2022) despite the fragility of logistics (OLIVEIRA et al., 2021). In this sense, the persistent criticism of the logistics system needs to be considered, and organizational strategies (from new investment projects and partnerships with the productive sector) must be incorporated (OLIVEIRA et al., 2022).

Despite the importance of agribusiness for the national economy, Brazilian commodities lost competitiveness against other producing countries due to deficiencies related to the transportation logistics of production (SOUZA et al., 2024; PÉRA et al., 2019). The logistics chain costs in Brazil exceed those of the United States, the second largest producer. This disparity can be attributed to various factors, one being Brazil's predominant use of road transport for exports, which accounts for 49% of the total. In contrast, the United States only relies on road transport for 9% of its exports, with waterway and rail transportation accounting for 62% and 29%, respectively (SALIN, 2022; GAIA et al., 2021).

The reliance on road transport for the logistics of Brazilian soy is primarily driven by the substantial distances separating the major production regions from waterway and rail terminals. Additionally, limited infrastructure and capacity within the road network, particularly in inland areas, further contribute to this dependency (FILASSI; OLIVEIRA, 2022; GAIA et al., 2021). Brazil's average distance to transport soybeans from farms to rail and waterway terminals is approximately 700 kilometers. In contrast, the United States has an average distance between 40 and 160 kilometers (SALIN, 2022).

Furthermore, Brazilian's soybean and corn production is concentrated in the Midwest region, responsible for 55% of the 2021/22 harvest (CONAB, 2023) above the 16th parallel, while the main ports that concentrated 59% of exports of these commodities in 2022 (COMEX STAT, 2023), are located below the 16th parallel, with emphasis at Port of Santos and Port of Paranaguá. Despite having better infrastructure regarding productivity, these ports will soon be unable to keep up with the increased demand (GONELI, 2021; LOPES et al., 2017). The current scenario consists of long waiting times for ships to dock and noncompliance with grain delivery deadlines for their international buyers (FILASSI; OLIVEIRA, 2022). Moreover, the absence of efficient transportation routes connecting the southeast and south regions to ports results in significant challenges for transporting commodities (like soybeans). These agricultural products must cover distances exceeding 2,000 kilometers, leading to substantial logistical costs (GONELI, 2021; LOPES, 2021).

To address this logistical mismatch, it is necessary to develop intermodal transport corridors that link the agricultural regions above the 16th Parallel South with the ports of Amazonian

Northern Arc. One of the ongoing projects is the Ferrogrão Railway (EF-170), which aims to consolidate a new railway export corridor through the Amazonian Northern Arc. The railway will span 933 km, connecting the grain-producing region from the Midwest to the state of Pará, leading to the Port of Miritituba (BRASIL, 2023a).

In 2018, the costs to implement the Ferrogrão Railway (EF-170) were estimated at 14.36 Billion BRL, distributed between engineering, signalization, socio-environmental compensation and rolling stock (ANTT, 2023). The private initiative became responsible for the investment, obtaining 65 years of concessions (BRASIL, 2023a).

Another important project is the expansion of the commercial navigability of the Araguaia-Tocantins Waterway. The waterway is in the second-largest basin in Brazil. It is one of the main transport routes in the Central-North Brazilian corridor, with a navigation potential of approximately 3,000 km, connecting part of the state of Mato Grosso from the municipality of Barra do Garças in the Araguaia River to the Vila do Conde's port (state of Pará) (ANTAQ, 2019). According to the Strategic Waterway Plan (Plano Hidroviário Estratégico - PHE) developed by the Brazilian Ministry of Transport (MT), as well as the National Logistics Plan (Plano Nacional de Logística) in 2018 the costs of adapting the waterway were estimated 18.65 billion BRL, divided between dredging and signaling, transposition devices, maintenance of locks and installation of terminals (CNT, 2019).

Hence, this study aims to evaluate whether there are socioeconomic benefits to implementing two logistic projects in the Amazon region, the Ferrogrão Railway, and the Araguaia-Tocantins Waterway, considering the maintenance of the Amazonian Northern Arc port capacity. This evaluation is relevant because significant agricultural poles were established in the Midwest and North regions of Brazil, which have intensified exports through transport routes to the ports of the Amazonian Northern Arc; however, due to the demand for environmental sustainability in this region, the implications and feasibility of new projects to be implemented in the Amazon biome must be evaluated.

To do so, the cost-effectiveness analysis (CEA) model is employed, considering three years (2018, 2025, and 2030) and different scenarios based on economic and socio-environmental variables. Project priorities were established in such a way as to adopt the scenario of the lowest cost and the greatest socioeconomic benefits. The study advances by integrating economic, social, and environmental variables to assess the feasibility of infrastructure projects at the Northern Arc of the Amazon.

The article is structured in four sections, beginning with a concise introduction highlighting the significance of the research topic. The second section overviews the methodology employed and outlines the issue questions. The third section presents the results, which are subsequently discussed in relation to relevant literature. The last section concludes the article.

METHODOLOGY

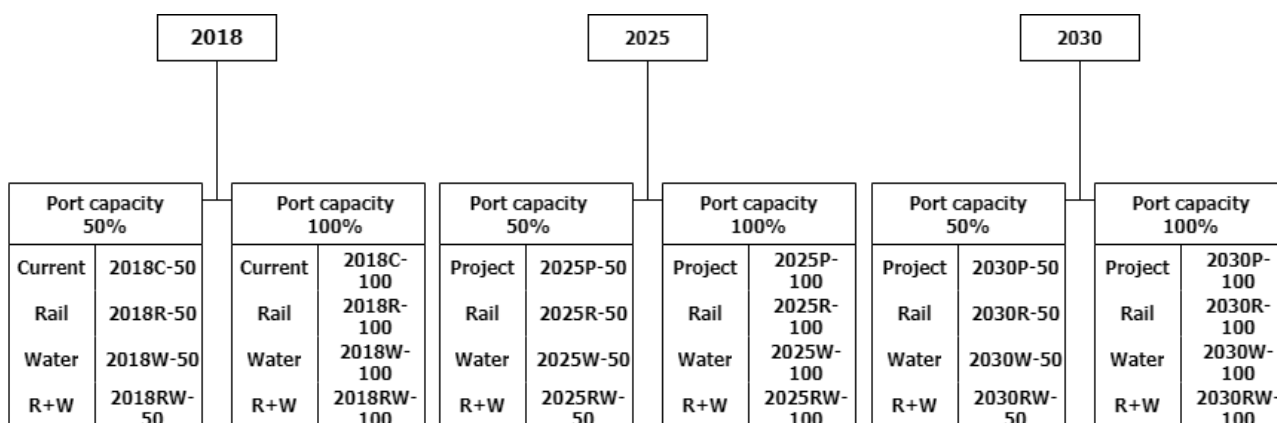
The assessment of impacts arising from infrastructure projects can be measured using various methodologies, including Cost-effectiveness Analysis (COPPOLA et al., 2022) as one of the methods. Cost-effectiveness analysis (CEA) is an evaluative method to compare projects by assessing the cost-to-outcome ratio. This analytical approach is utilized in various sectors, including health, education, and other domains, where effectiveness is measured using quantifiable indicators not expressed in monetary terms (GLANDON et al., 2023). CEA serves as both a screening and classification tool for projects, aiding in identifying viable solutions (HOLLER BRANCO et al., 2022; JAROSINSKI, 2021).

Krelling and Badami (2022) utilized this methodology in New Delhi, India, to evaluate emissions impacts and cost-effectiveness of buses powered by vehicular natural gas (CNG) compared to diesel. Their analysis incorporated critical health, greenhouse gas emissions, and capital, operating, and maintenance costs. Similarly, Coppola et al. (2022) employed a cost-effectiveness analysis in Italy to assess the effects of rehabilitating railway stations in urban areas. Their evaluation criteria included safety, equity, accessibility, sustainability, and architectural quality.

Moon et al. (2022) conducted a study in South Korea that examined the costs associated with reducing greenhouse gas emissions using vehicles powered by alternative fuels. The authors utilized fuel switching and life cycle cost analysis in their research. So, cost-effectiveness analysis (CEA) is vital in evaluating policies, technologies, and infrastructure interventions within transportation. Therefore, this method provides decision-makers with valuable information, allowing them to determine the most suitable options to implement while considering resource constraints such as budget limitations (COPPOLA et al., 2022; QUADE, 1966).

In this study, the scenario analysis proposal is based on the research conducted by Souza et al. (2020), according to which three years were considered: 2018, 2025, and 2030, considering the respective productions (2018) and projections (2025 and 2030). This timeframe was established considering the inherent characteristics of infrastructure projects, which involve extensive planning, implementation, and operation periods (ANTT, 2023). Moreover, it considers port demand projections (BRASIL, 2023c). Figure 1 illustrates the analyzed scenarios.

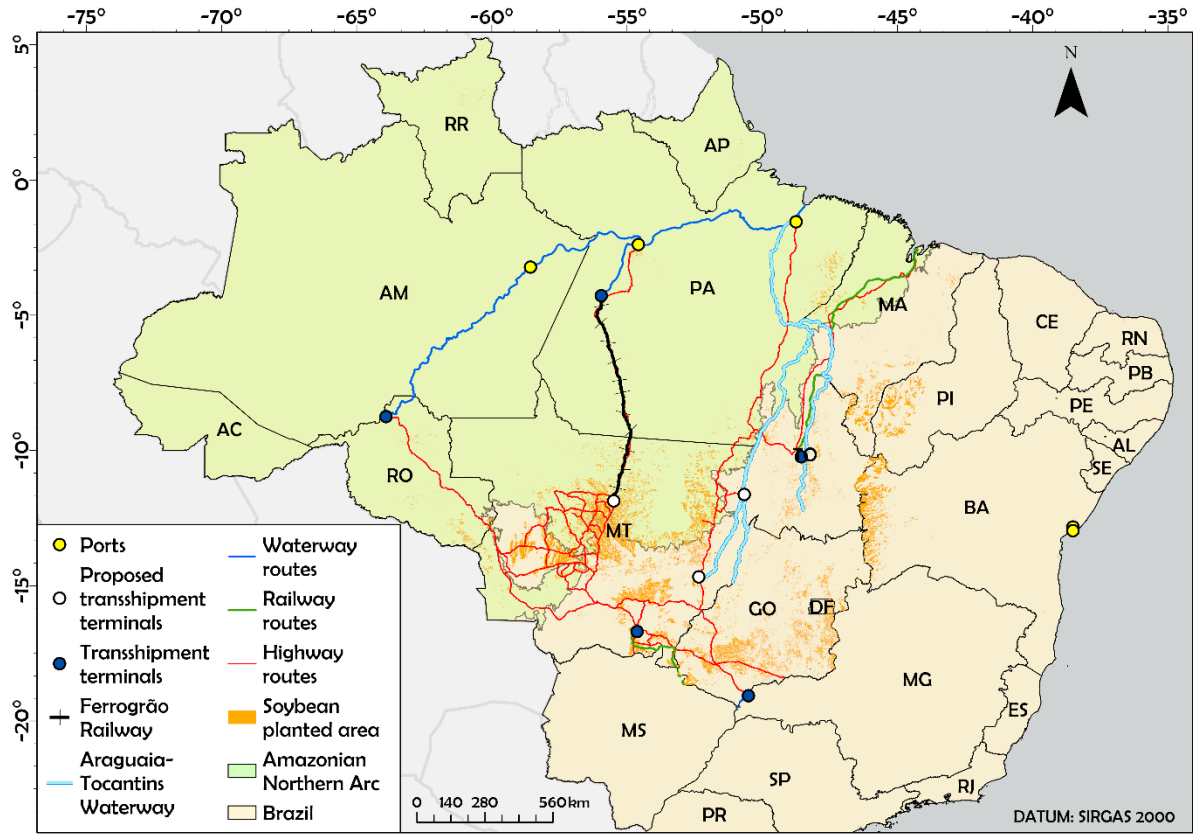
Figure 1: Evaluated scenarios and port capacities considered, 2018/2025/2030



Source: Prepared by the authors based on Souza et al. (2020).

The scenarios nominated by R and W evaluate the Ferrogrão Railway and the Araguaia-Tocantins Waterway individually for productive transportation, aiming to analyze the impact of each one concerning port capacities of 50% and 100% in Amazonian Northern Arc on the operational cost of soybean transportation destined for export. Conversely, those named RW evaluate both routes simultaneously, with 50% and 100% of the capacity in Amazonian Northern Arc. The considered regions and the analyzed projects are illustrated in Figure 2.

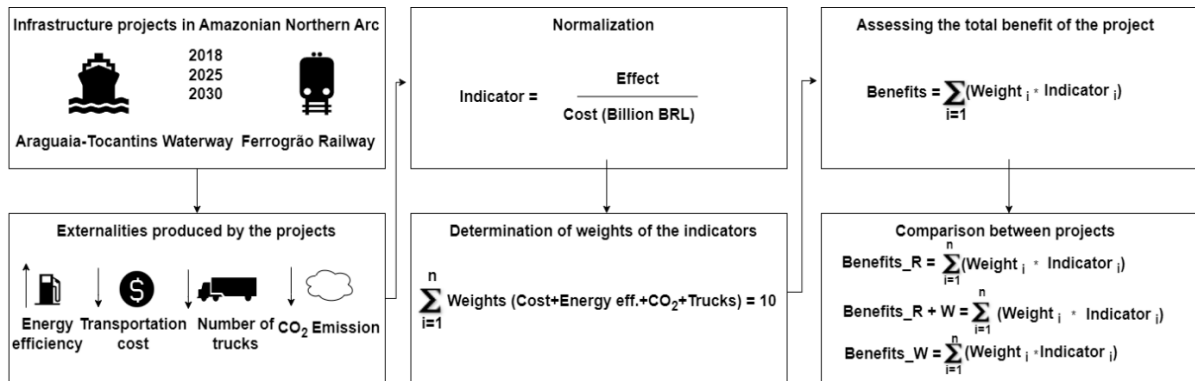
Figure 2: Analysis of regions and logistics projects considered



Source: Prepared by the authors based on Brasil (2023b) and IBGE (2022).

The methodological steps related to the application of cost-effectiveness analysis followed the methodology proposed by Coppola et al. (2022) and adapted by the authors to establish which undertaking provides greater economic and socio-environmental benefits (Figure 3).

Figure 3: Chart of the CEA methodological steps



Source: Prepared by the authors based on Coppola et al. (2022).

The main expenses are related to the adaptation of waterway stretches, approximately 60% of the total cost with beacon and signalization works, mainly because these are long stretches. The costs of implementing the Nova Xavantina and S. Félix do Araguaia terminals were based on the cost proposed by the PHE for the implementation of a similar terminal in the same waterway. Moreover, all costs were adjusted for inflation in the current scenario for 2018 and projected in the proposed scenarios (BRASIL, 2021; ANTT, 2023; SOUZA et al., 2020).

The variable reduction in transportation cost, as well as the reduction in CO₂ emissions, increased energy efficiency, and reduction in the number of trucks, result from the transportation cost optimization model developed by Souza et al. (2020). Furthermore, the variable number of trucks reduction considered only one trip per truck. Based on these values, the benefits were divided by the investment value, which resulted in the model scenarios (Table 1).

Table 1: Database used in CEA

Scenarios	Estimated value (Billion BRL)	Reduction in transportation cost (Billion BRL)	Reduction in CO ₂ emission (Million t/t.km)	Increase in Energy Efficiency (Billion t-km/l)	Reduction in the number of trucks (Million)
2018R-50	14.36	0.586	0.864	2.266	0.559
2018W-50	18.65	0.585	-0.040	0.212	0.518
2018RW-50	33.01	0.702	0.158	0.688	0.617
2018R-100	14.36	0.756	-0.139	1.239	0.581
2018W-100	18.65	0.797	-0.076	0.870	0.485
2018RW-100	33.01	0.949	0.136	0.814	0.454
2025R-50	18.66	1.607	0.241	2.168	1.154
2025W-50	24.24	1.579	0.572	0.413	1.081
2025RW-50	42.90	1.883	0.966	1.366	1.279
2025R-100	18.66	2.114	0.332	2.546	1.198
2025W-100	24.24	2.181	0.499	0.345	1.016
2025RW-100	42.90	2.578	1.082	1.305	1.173
2030R-50	23.34	2.317	-0.041	2.036	1.432
2030W-50	30.30	2.305	0.034	-0.099	1.432
2030RW-50	53.64	2.758	-0.337	0.475	1.432
2030R-100	23.34	3.018	-1.058	1.817	1.339
2030W-100	30.30	3.151	0.028	-0.014	1.432
2030RW-100	53.64	3.744	0.273	0.750	1.432

Source: Prepared by the authors based on Souza et al. (2020).

After defining the indicators, a sensitivity analysis was performed using six criteria: the variation of proposed weights. This analysis can be used to verify if a change in the indicators' importance alters the undertaking's final evaluation (COPPOLA et al., 2022; JAROSINSKY, 2021). The attribution of weights was based on interviews with a grain logistics specialist at a private company and an infrastructure specialist at a public agency. This methodological approach is called rapid assessment or quick appraisal (BEHERA; FRANCE, 2023; GOW, 2019).

According to this technique, indicators, or attribution of weights to criteria are validated with key actors and (or) specialists in the evaluated sector. The technique is widely used in several areas of agribusiness, such as in the evaluation and proposition of grain warehouse location (SOUZA et al., 2024), strategies to reduce postharvest losses (LIMA; OLIVEIRA, 2021), and drivers to increase the competitiveness of the soybean supply chain (FILASSI; OLIVEIRA, 2022).

RESULTS AND DISCUSSION

According to the cost-effectiveness analysis, all scenarios show the best results for Ferrogrão Railways, considering the economic and socio-environmental benefits. The Ferrogrão Railway presented the highest transportation cost reduction rate, approximately BRL 130 million for every BRL 1 billion invested in 2030. At the end of the 65-year concession period of Ferrogrão Railway, the estimated total reduction in transportation costs was BRL 8.45 billion. This amount corresponds to the total invested by Brazilian road concessionaires in 2017. If it were divided by the current paved road extension, it would represent BRL 158,000 per km, a value higher than invested by the Federal Government from 2018 to 2021 (CNT, 2021a).

Regarding energy efficiency, the Ferrogrão Railway could potentially increase by 160 million tons-km/l for every BRL 1 billion invested in 2018, that is, a 68% increase in soybean transport capacity. Moreover, 50 million tons/t.km of CO₂ per BRL 1 billion invested in 2030 can be saved, a value corresponding to a reduction of 10% (SOUZA et al., 2020). Moreover, the railroad can remove 60,000 trucks from the logistics of soybean transportation in the Amazonian Northern Arc region in 2030.

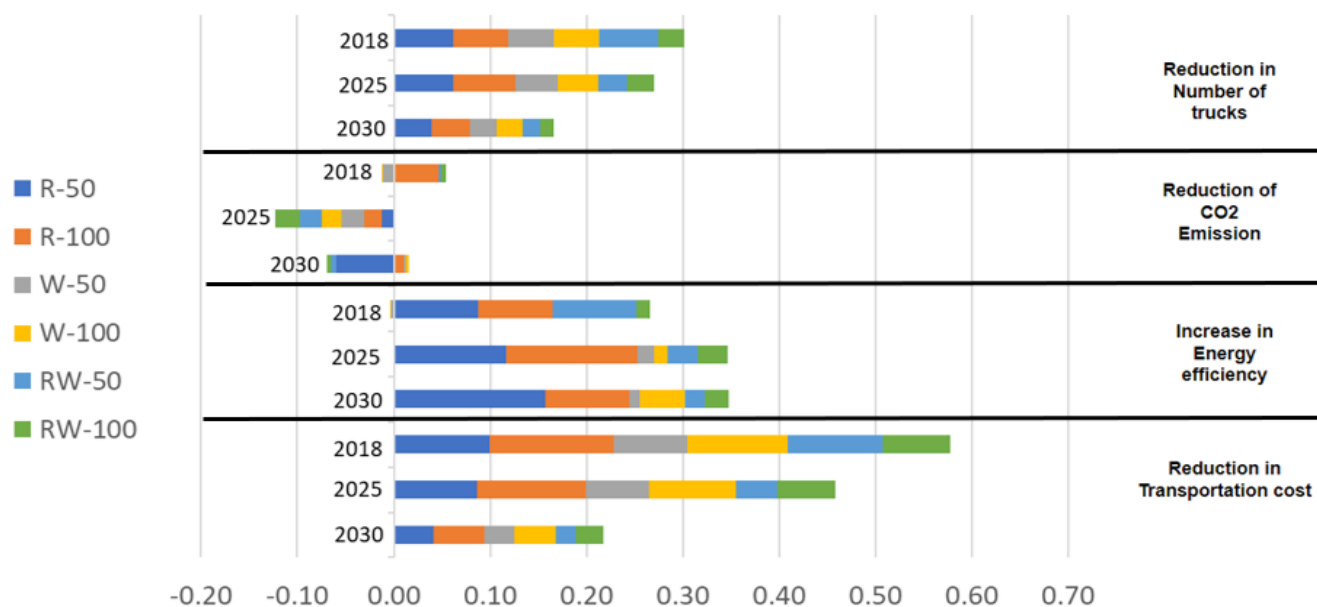
Thus, considering that between 2007 and 2017, accidents involving trucks were responsible for 8,635 deaths, approximately 10% of all fatalities on Brazilian roads (CNT, 2021a), and that the cost of accidents was estimated at BRL 29.46 billion only in 2016 and 2017, the removal of 60,000 trucks can represent more excellent safety in the highways as well as savings for the health system (CNT, 2021a). Finally, with the expansion of intermodality, especially at the Amazonian Northern Arc, there will be a decrease in the operational cost of transportation. Considering roads with "poor" pavement conditions, the cost increase can be up to 91.5%, and the geographic regions that have the highest proportion of roads in these conditions are the North region (75.5%) and the Midwest region (71.2%) (CNT, 2021b).

The Araguaia-Tocantins Waterway showed a potential reduction of up to BRL 100 million per every BRL 1 billion invested, approximately 30% lower than that provided by the Ferrogrão Railway. Furthermore, the waterway also has the potential to increase energy efficiency by 50 million tons/t.km per BRL 1 billion invested in 2018, an increase of 21.25% in transport capacity. Last, the waterway can remove approximately 50 thousand trucks from the roads in 2030, a value 16.6% lower than that provided by the Ferrogrão Railway.

When evaluating the implementation of the Ferrogrão Railway and the Araguaia-Tocantins Waterway, we concluded that the reduction in transportation costs reaches levels of up to BRL 100 million per BRL 1 billion invested in 2030, a value like that obtained by the implementation of the Araguaia-Tocantins Waterway alone and lower than that provided by the Ferrogrão Railway. The energy efficiency increase is 90 million tons-km/l for every BRL 1 billion invested in 2030, an increase of 38.2% in transport capacity, whereas the projected CO₂ savings corresponds to 10 million tons/t.km per BRL 1 billion invested, a decrease of 2% (SOUZA et al., 2020). Conversely, the expected reduction in the number of trucks is 60,000.

Overall, the scenarios that considered only the implementation of Ferrogrão were more cost-effective, both from an economic and socio-environmental perspective (Figure 4). Similar results were verified in the study conducted by Holler Branco et al. (2020), who evaluated the economic and environmental impacts of new railways in Brazil and analyzed the cost-effectiveness of investments. In the scenario that includes the Ferrogrão Railway, there was an increase in the railroad share and barge transportation of 40% and 12%, respectively, in addition to a reduction in the cost of freight and CO₂ emissions due to the use of intermodality.

Figure 4: Cost-effectiveness in all scenarios



Source: Research data.

In another study, Rocha and Caixeta-Filho (2018) conclude that despite port capacity restrictions, the Ferrogrão Railway contributes to increasing intermodality of grain transportation in the state, consequently reducing the average distance of road transportation in some producing regions and reducing the average cost of transportation by approximately BRL 37.3 million.

The increase in competitiveness of soybean exports through the reduction in logistics costs with the use of the Araguaia-Tocantins Waterway was also verified in the study conducted by Lopes et al. (2017), who evaluated the feasibility of the waterway for transporting soybeans from Mato Grosso and indicated a reduction of up to 35% in transportation costs via the Araguaia-Tocantins Waterway to the Port of Vila do Conde/Barcarena (state of Pará). In another study, Lopes et al. (2016) concluded that the full operationalization of the Araguaia-Tocantins Waterway, without restrictions, can provide a reduction of up to USD 926 million and focus on exports through ports in northern and northeastern Brazil.

The distance between producing municipalities and the transshipment terminals of the routes is also important in choosing the undertaking, considering that the Ferrogrão Railway will have a terminal in the municipality of Sinop (state of Mato Grosso). It is present in the largest soybean-producing region of Mato Grosso, thus facilitating the transportation process, with

shorter distances traveled by trucks and reduced time, cost, emission of polluting gases, and highway accidents. Due to its geographic location, the transshipment terminals of the waterway are in the state's Northeast region, further from the main producing regions.

Among the advantages of the Ferrogrão Railway in relation to the Araguaia-Tocantins Waterway, there is the issue of the route, as the railway route has a 30% shorter distance than the waterway between the transshipment terminals in the Midwest and the ports of export. This factor is also important in terms of transit time and meeting delivery deadlines. The cost of implementing the Ferrogrão Railway is approximately 30% lower than the cost of adapting the Araguaia-Tocantins Waterway, and considering that the private sector will finance the former and the latter by the Federal Government, bureaucratic and financial obstacles may affect the waterway project.

CONCLUSIONS

Based on the Cost-Effectiveness Analysis (CEA), the Ferrogrão Railway is presented as the option that offers the greatest economic and socio-environmental advantages in the analyzed years. This logistical project plays a fundamental role in fostering the development of the Amazonian Northern Arc region, as it has the potential to attract various investments. For example, promoting the installation of an agro-industrial soy processing park promotes adding value to soy and generating jobs for this industrial segment.

That said, the main contribution of this study lies in employing methodologies that consider not only economic factors but also social and environmental aspects. This approach makes it possible to establish guidelines to assess the feasibility of infrastructure projects systematically and helps formulate public policies for regional development. From the point of view of scarcity of public resources, profitability of private entities, and alignment with sustainable development objectives, it can be said that both projects bring substantial contributions to the development of the Amazonian Northern Arc. They balance the cargo transport matrix, boost multimodality, promote sustainability, and expand their impact beyond agribusiness.

Ferrogrão Railway and the Araguaia-Tocantins Waterway hold strategic importance for the region as they serve as catalysts for enhanced competitiveness in international trade. However, to make these projects viable, it is crucial to establish supporting infrastructure, including the development of road access points, proper signaling installation and paving roads, construction of grain storage facilities, the establishment of transshipment terminals, and port capacity maintenance. These infrastructure elements are essential for ensuring the successful implementation and operation of the projects.

As the agricultural frontier continues to expand towards Brazil's North and Northeast regions, the expectation of optimizing agribusiness logistics through effective public policies increases. Inspired by the decentralization of soy transport in the South and Southeast regions, implementing new transport routes has the potential for numerous benefits. These benefits include a decrease in accidents and congestion. In a region where road infrastructure tends to be inadequate, projects such as Ferrogrão Railway and Araguaia Tocantins Waterway contribute to reducing investments in road maintenance, reducing the rates of loss in transport, and reducing the costs of health units resulting from accidents in the streets.

The study's authors highlight some limitations, among which a certain level of empiricism stems from the subjectivity in assigning weights by experts. In addition, it is important to point out that there is a gap in the consideration of project costs in relation to factors such as inflation, project duration, execution, and operation. As future recommendations, the authors propose

carrying out studies incorporating other socio-environmental and economic variables, such as the potential for job creation, impacts on biodiversity, and payback period. Finally, they suggest considering the spatial variability of crops, as it is an important driver of expansion and directly influences the transport network.

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