Transport Policy 124 (2022) 61–69

Contents lists available at ScienceDirect

Transport Policy

journal homepage: http://www.elsevier.com/locate/tranpol

Evaluation of the economic and environmental impacts from the addition of new railways to the brazilian's transportation network: An application of a network equilibrium model

José Eduardo Holler Branco *, Daniela Bacchi Bartholomeu, Paulo Nocera Alves Junior, José Vicente Caixeta Filho

Luiz de Queiroz College of Agriculture, Research and Extension Group of Agro-logistics, Av. Pádua Dias, n. 11, Piracicaba, SP, 13418-900, Brazil

ARTICLE INFO

Keywords:
List: network equilibrium model
Cost-effective analysis
Freight costs
CO_2 emissions
Soybean and corn transportation
Railway

ABSTRACT

Transport policies and infrastructure investments diverge across countries, but the actions to improve transportation performance and simultaneously to reduce its CO_2 emissions have gained importance around the world. In Brazil, the infrastructure bottlenecks and the low productivity of transport have increasing freight costs and simultaneously the CO_2 emissions. Aiming to reduce the impacts of the transport sector inefficiency the Federal Government announced a public-private partnership program to increase investment in new railways. We propose a dual-step procedure to evaluate the expected economic and environmental impacts lead to the inclusion of new railways to the transportation network: i) apply a Network Equilibrium Model to simulate the interregional transportation flows of Brazilian soybean and corn production and evaluate the benefits, measured in terms of reduced transportation costs and CO_2 emissions, caused by the new railways; ii) use a cost-effective analysis to rank the investments in the railways according to their economic and environmental contributions. We found that the implementation of the Brazilian planned railways could reduce 17% the total freight cost and 20% the total CO_2 emissions of corn and soybean transportation. Three railway projects presented important economic and environmental gains and showed be attractive to private funding.

1. Introduction

The criterions used to determine transport policies and guide infrastructure investments differ across regions, but two overarching goals have gained importance: the need to improve transportation efficiencies and to reduce pollution caused by transportation (Abraham et al., 2012). Increasing the shares of rail and waterways in the transportation matrix meets both of these goals as these transport modes are more energy-efficient and less polluting than road mode, mainly due to their higher per-trip load capacities.

In Brazil, freight transport is highly dependent on highways. Roads account for roughly 61.1% of the total cargo transported, while in other countries of similar geographic size, such participation is lower than 30% (CNT, 2018). Focusing on the internal transport of Brazil's main agricultural exports, corn and soybean, almost 50% are transported by road, 40% by rail, and 10% by waterway (BRASIL, 2019). Brazil has more than 1.7 million kilometers of roads, but only 30 thousand kilometers of railroads and 20 thousand kilometers of waterway (BRASIL, 2019).

Total public investment in road, rail, port, air, and waterway infrastructure fell 37% between 2010 and 2017 (BRASIL, 2019). Over the same period, the amount of soy and corn produced in the country increased 61% (IBGE, 2019a). The land under cultivation to support this additional production came from an expansion onto territory located far from existing export hubs. As a result, the performance of freight transportation in Brazil diminished, while fossil fuel consumption and greenhouse gas (GHG) emissions reached a higher level. The Brazilian transportation sector is responsible for about 35% of the consumption of fossil fuels and for over 48% of GHG emissions in the country (BRASIL, 2019). The low productivity of transport in Brazil has increased freight costs and negatively affected the competitiveness of some economic sectors, particularly the grain exports.

The bad performance of the Brazilian grain handling system highlights the need for investment in transportation infrastructure. This

* Corresponding author.
E-mail addresses: jehbranco@usp.br (J.E. Holler Branco), daniela.bartholomeu@usp.br (D.B. Bartholomeu), pnalvesjr@usp.br (P.N. Alves Junior), jose.caixeta@usp.br (J.V. Caixeta Filho).

https://doi.org/10.1016/j.tranpol.2020.03.011
Received 10 January 2020; Accepted 17 March 2020
Available online 21 March 2020
0967-070X/

paper contains results from an evaluation of the economic and environmental impacts from the addition of new railways to the country's transportation network. We propose a dual-step procedure to make this evaluation: i) apply a Network Equilibrium Model to simulate the interregional transportation flows of Brazilian soybean and corn and evaluate the benefits, measured in terms of reduced transportation costs and CO_2 emissions, caused by the addition of new transportation infrastructure; ii) use a cost-effective analysis to rank investment priorities according to their economic and environmental contributions. Additionally, this work aims to develop an economic and environmental viability analysis of investments in new transport infrastructure, recommending the best funding strategies.

1.1. Global trends in policy investment in greening transport

Mobility and logistics are indispensable to economic development and continued societal well-being. However growing concerns about environmental protection and sustainable development combined with the diverse and diffuse external effects of transportation systems have pressured those that develop transportation and logistics plans and policies to now include comprehensive environmental and social considerations in their economic analyses. This goal to minimize the environmental effects of logistics has been dubbed "Green Logistics" (Macharis et al., 2014). Damages caused by pollution and climate change are forcing countries to adopt a common agenda: reduce the consumption of fossil fuels. The 1997 Kyoto Protocol, and the 2015 Paris Agreement are representative of international accords designed to spur ambitious efforts to combat climate change and adapt to its effects (UNFCCC, 2018). Abraham et al. (2012) discuss other initiatives taken by various national governments to combat climate change, especially by investing in more energy-efficient alternatives to current practices, including those employed in the transportation sector.

There is an urgent need for transportation sector decarbonization, especially in the road transportation segment, to meaningfully reduce the sector's negative environmental externalities (Binsted et al., 2011). The transport sector was responsible for approximately 23% of total world energy-related CO_2 emissions (6.7 $GtCO_2eq$) in 2010. Even as policies designed to reduce fuel consumption take effect and more energy-efficient vehicles replace the current fleet, transport emissions could almost double from the 2010 level (to around 12 Gt CO_2eq/yr) by 2050 (Sims et al., 2014) without the implementation of more aggressive and sustained CO_2 mitigation policies.

Emissions from passenger and freight transport can be reduced by avoiding journeys where possible; making a modal shift to lower-carbon transport systems; lowering energy intensity (MJ/passenger-km or MJ/tonne-km); and reducing the fuel's carbon intensity (CO2eq/MJ) by substituting alternative fuels (Sims et al., 2014). The governments of many countries and country groupings have recently taken action to cut transportation sector CO_2 emissions within their spheres of influence.

The European Commission's White Paper "Roadmap to a Single European Transport Area – Towards a competitive and resource-efficient transport system" (European Comission, 2011) establishes ambitious decarbonization targets and stresses load consolidation as a strategy to minimize the system's negative environmental impacts and positively impact economic growth. Also, EU Regulation No. 1315/2013 establishes EU guidelines for the development of the Trans-European Transport Network (TEN-T) embodied by many actions and policies devoted to the development of a sustainable transport system in the European Union (Öberg et al., 2017).

In 2014, Russian Federation launched the "Transport Strategies of the Russian Federation up to 2030" aiming to reduce greenhouse gas emissions from road transport and clarify the gains from the creation of smart, low-carbon transport systems. The Russian transport strategy's goals are to provide affordable, cost-competitive, high-quality freight transport logistics services to reduce the sector's negative environmental impact by 2030 (RUSSIA , 2014). However, while the Russian transport strategy sets out the reduction of GHG emissions, it does not set a target for the amount of GHG emissions are to be reduced. In this context, Trofimenko et al. (2018) present a package of actions and measures that, if implemented, would improve the Russian transport system's energy efficiency and cut its GHG emissions level.

The government of India also has proposed a set of policies and measures to reduce the country's transportation sector's impacts on the environment. This set of policies includes the National Urban Transport Policy 2014, the Atal Mission for Rejuvenation and Urban Transformation—AMRUT, the Automotive Mission Plan - AMP2026, and the Faster Adoption and Manufacturing of Electric/Hybrid program—FAME (Mehra and Verma, 2016). For planning purposes, the country's transportation system was then divided into four key vectors for strategy definition: automobiles, infrastructure, fuels, and intelligent management.

In 2012, the United States Department of Transportation (DOT) published the "Energy Blueprint: Efficient Transportation for America." This report summarizes the policies put in effect to build the foundation for a clean energy economy by improving the efficiency of heavy and light-duty vehicles, encouraging the use of alternative fuels through the Renewable Fuel Standard, and developing technologies for advanced vehicles and fuels (USDOT, 2012). A review of the main strategies and actions proposed by individuals, entities, and by the US government to promote sustainable transportation are listed by Black (2010) and Zhou (2012).

The government of Canada has defined a set of policies related to transport aligned with the Strategic Plan for the Future of Transportation in Canada—Transportation (2030)" (CANADA, 2019a; 2019b). The Transportation 2030 plan includes a "Green and Innovative Transportation" section that sets environmental impact reduction goals and included a caveat to embrace new technologies (CANADA, 2019c).

In China, the development of green logistics has attracted the governmental attention. In 2009, Zhao et al. (2009) published the "Study on the Development of Modern Green Logistics in China" recommending the government speed-up development and implementation of policies and relevant laws and regulations to accelerate the improvement of the country's transport infrastructure, support new logistics technology, and promote the rapid development of green logistics. These suggestions appear to have been followed. Currently, many initiatives to further green transportation have been instituted in China at the provincial and the national levels.

At national level, China's government issued "Work Report 2019". The report outlines the government's plans for the current fiscal year (2019), indicates key transport sector areas to be supported, reiterates many of previous goals set to secure green transportation and highlights several additional areas that need attention (Retzer, 2019). In regards to vehicle emissions standards, China has followed the "EU pathway for vehicle emissions standards, with China 5 and China V standards analogous to Euro 5 and V for light-duty vehicles and heavy-duty vehicles, respectively" (Transport Policy Net, 2019). Beijing and other subnational regions often implement vehicle emissions standards ahead of the nationwide timeline (IBID.)

1.2. Green transport policy in Brazil

In view of the commitment made by the Brazilian Government at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP-21) to achieve a 37% GHG reduction by 2025 and a 43% reduction by 2030, (considering 2005 as the baseline), the Brazilian Government created the "National Biofuels Policy" in 2017 based on Federal law no. 13,576 (Farina and Rodrigues, 2017). This program aims to increase biofuels' share in the national energy matrix to achieve the decennial transportation sector greenhouse gas emission (GHG) reduction targets (MME, 2018). To meet these GHG reduction targets, Brazil's Government announced that 46 million cubic meters of ethanol will need to be supplied by 2028—a roughly 53%

increase from 2016 production levels—to reduce total transportation sector GHG emissions by 10% (MME, 2018; UNICA, 2017).

Additionally, the Federal Government announced a public-private partnership program to increase investment in new railways. It is expected that implantation of these new railways will improve the competitiveness of the main Brazilian agriculture exports and promote social and environmental positive effects by improving efficiencies throughout the country's main export corridors, lower freight and CO_2 emissions of transport sector, and reduce the number of heavy-duty vehicle trips over Brazilian roads.

The following is a summary of the main planned railway improvements that have received positive attention from the Brazilian government and private agents:

1) *Ferrogrão* (FG): this railway will connect Lucas do Rio Verde (MT) to Miritituba (PA) providing access to the Tapajós waterway which offers a barge transport alternative currently in operation for exports through Port of Santarém (PA). The budget for this project predicts and amount of US$[1] 3.290 billion of investments needed for the construction of 933 km of railway (BRASIL, 2020).
2) *Ferrovia Norte-Sul* (FNS): this railway will connect Palmas (TO) to Estrela D'Oeste (SP) and will provide rail access to both Port of Santos (SP) and Port of São Luís (MA). The project's budget predicts an amount of US$ 2.772 billion that will be needed for the implantation of 1534 km (VALEC, 2019).
3) *Ferrovia de Integração Oeste-Leste* (FIOL): this railway will connect Bahia West region to Port of Ilhéus (BA). The construction of 1022 km of railway will request investments totalizing US$ 1.650 billion (VALEC, 2019).
4) *Ferrovia Rumo Malha*-Norte (RMN): this project aims to extend the Railway Rumo Malha-Norte from Rondonópolis (MT) to Cuiabá (MT) and this railway provides access to Port of Santos (SP).
5) *Ferrovia Nova Transnordestina* (NTN): this project will connect Eliseu Martins (PI) to Port of Pecém (RE) and Port of Suape (CE). The latest estimative says that a total of US$ 1.740 billion will be needed for the construction of 1753 km (CSN apud EXAME, 2019).

Considering the localizations of the planned railways, crossing the main grain producing regions, it is expected that these rail assets will be predominantly used for soybeans and corn transportation.

Other important Brazilian action to improve the environmental performance of its transportation sector was the creation of the "*Rota 2030*" program. This program addressed subsidies to encourage the automobile industry to make advances in engine performance and increase the adoption of clean fuel technologies, such as those that use ethanol, biodiesel and compressed natural gas (CNG), and promote a transition to electric and fuel cell energy power.

It's important to highlight that some of the country's companies are already testing the use of biomethane from biowaste as fuel for heavy trucks in the country.

2. Materials and methods

2.1. Mathematical models for interregional freight flows

The prediction of interregional freight flows between suppliers and consumers is essential for transportation systems planning at strategic level. The Origin-Destination matrix (O-D matrix) presents the total quantity of cargo transported from each production region to each consumption region. This kind of information is needed for the evaluation of the total cost, greenhouse gas emissions and energy consumption of a transportation system, and it is useful for identify bottlenecks and determine the most efficient configuration of the transport network (APAS, 1996; Crainic et al., 1990; Friesz et al., 1983; Garrido and Mahmassani, 2000; Branco et al., 2019).

Since the first method proposed for modeling the interregional freight flows -The Harvard Model (Kresge and Roberts, 1971) - the world's researchers have developed numerous advanced models aiming to improve the simulation of freight flows, by including in the models: non-linear transport cost functions, supply and demand prices dependent functions, multimodal transport network with capacity constraints, delay functions and other logistics features that permit to construct more realistic models of a transportation system (Caixeta-Filho and Macaulay, 1989; Crainic et al., 1990; Cramer et al., 1993; De La Cruz et al., 2010; Dennis, 1999; Fernández et al., 2003; Friesz and Harker, 1983; Fuller et al., 2003; Guélat et al., 1990; Labys and Yang, 1991).

Generally, these interregional freight models can be classified into two main categories: the spatial price equilibrium model (SPE) and the network equilibrium model (NEM). Both models can be used to find the best distribution of transport flows between origin and destination nodes over a network to achieve the lowest cost.

According to Friesz and Harker (1983), the main difference between SPE models and NEMs is that a SPE model considers price-dependent supply and demand functions while a NEM considers supply and demand quantities as exogenous variables. As an imperfection the NEM does not consider the impact of freight cost variations in the quantity demanded at each consumption region, and for this reason this parameter is settled outside the model's solution. As an advantage a NEM allows the formulation of a linear programming (LP) model structure that guarantee a global maximum or minimum solution. Moreover, this category of models does not require the estimation of price-dependent supply and demand functions.

The use of NEMs models for estimating Greenhouse Gases emissions from transportation operations has been proposed by numerous studies (Ávila, 2016; Pinheiro, 2012). The model developed for the purpose of this paper is based on the concepts of the Multicommodity Network Flow Model (Ahuja et al., 1993).

2.2. Model formulation

The model proposed in this paper is based on the principles of network equilibrium modeling. The objectives of the model are to i) assign the optimal distribution of soybean and corn transportation flows between production and demand regions of the intermodal transport network, while minimizing total freight cost; ii) calculate the CO_2 emissions generated by the transportations flows and simulate the impact of the inclusion of new infrastructure in the transport intermodal network on freight costs and CO_2 emissions.

The main assumption of the model is that soybean and corn shippers choose the configuration of transportation flows that results in the minimum transportation cost.

This subsection will next address the transportation network connecting soybean and corn supply and demand regions and the main variables used to model this system. This transportation network is graphically illustrated in Fig. 1.

The definition of network nodes and variable indices are presented below:

- Soybean and corn supply regions (product origins);
  d : Demand regions (destination) – can be a domestic demand region or an export terminal*;*
  c : Demand market, classified as *domestic market (dm)* or *international market (im)*;
  t : Transshipment terminal where products can be loaded onto different transportation modes including rail and inland waterways, but not roadways; and
  p : Final product: *soybean (s)* or *corn (co)*.

[1] We use the average exchange rate from January to August of 2019: R$ 3.86/ US$ 1.00 (BACEN, 2019).

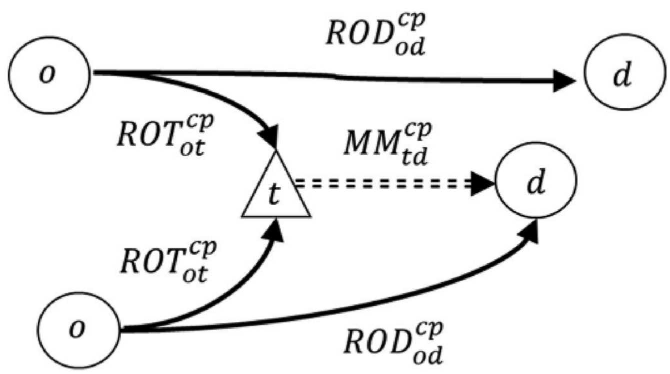

Fig. 1. Transportation network and main variables of the model.
Source: elaborated by the authors.

The nodes are connected by network arcs representing the available transportation infrastructure used to move inter-regional freight flows between supply and demand regions. The variables described below define the different types of inter-regional flows:

ROD_{od}^{cp}: Road transportation flow of product *p* between origin *o* and destination *d*, in market *c*;
ROT_{ot}^{cp}: Road transportation flow of product *p* between origin *o* and transshipment point *t*, in market *c*;
MM_{td}^{cp}: Multimodal transportation flow of product *p* between transshipment point *t* and destination *d*, in market *c*.

The objective function of the model is to minimize total transportation freight cost (*C*) while supplying soybean and corn to domestic demand regions and export terminals, as defined by Equation (1):

$$C = \sum_o\sum_d\sum_c\sum_p ROD_{od}^{cp}.TC_{od} + \sum_o\sum_t\sum_c\sum_p ROT_{ot}^{cp}.TC_{ot} + \sum_t\sum_d\sum_c\sum_p MM_{td}^{cp}.TC_{td} \quad (1)$$

TC: Transportation cost (US$/tonne of cargo) between origin and destination (TC_{od}), origin and transshipment terminal (TC_{ot}), and transshipment terminal and destination (TC_{td}).

Similarly, Equation (2) defines total CO_2 emissions:

$$CO_2 = \sum_o\sum_d\sum_c\sum_p ROD_{od}^{cp}.ECO_{2_{od}} + \sum_o\sum_t\sum_c\sum_p ROT_{ot}^{cp}.ECO_{2_{ot}} + \sum_t\sum_d\sum_c\sum_p MM_{td}^{cp}.ECO_{2_{td}} \quad (2)$$

ECO_2 : Emissions of CO_2 (tonnes of CO_2/tonne of cargo) between origin and destination (ECO_{2od}), origin and transshipment terminal (ECO_{2ot}), and transshipment terminal and destination (ECO_{2td}).

The CO_2emission for each network link "ECO_2" was determined based on the coefficient of CO_2 emission by each transportation mode by kilometer and tonne of cargo, multiplied by the distance between the nodes of the network.

We next define the set of constraints incorporated in the structure of the model to guarantee that its solution will respect production, demand, supply volumes, transportation capacities, and other conditions desirable for obtaining an optimal solution to the configuration of the Brazilian soybean and corn supply chain.

Equation (3) states that the total quantity of soybeans shipped to supply domestic demand and exports must equal the production (PRO_o^p)of each product *p* and origin region *o*:

$$\sum_d\sum_c ROD_{od}^{cp} + \sum_t\sum_c ROT_{ot}^{cp} = PRO_o^p, \ \forall\, o \ and \ p \quad (3)$$

To ensure supply for domestic demand ($c = dm$), Equation (4) states that the sum of the transportation flows allocated to supplying each demand region must equal the domestic demand (DEM_d^p) for each product in each destination region:

$$\sum_o ROD_{od}^{cp} + \sum_t MM_{td}^{cp} = DEM_d^p, \ \forall\, d, \ p \ and \ c = dm \quad (4)$$

The supply of the international demand ($c = im$) in each destination addressed as export terminal ($d \in \{sp\}$) is guaranteed by Equation (5):

$$\sum_o ROD_{od}^{cp} + \sum_t MM_{td}^{cp} = EXP_d^p, \ \forall\, d \in \{sp\}\ , \ p \ and \ c = im \quad (5)$$

Equation (6) guarantees the continuity of the flows passing through each transshipment terminal *t*:

$$\sum_o ROT_{ot}^{cp} = \sum_d MM_{td}^{cp}, \ \forall\, t, c \ and \ p \quad (6)$$

Equation (7) states that the total quantity of soybeans and corn assigned to each transshipment terminal *t* must be equal to or less than the load capacity of that terminal, represented by $TCAP_t$:

$$\sum_o\sum_c\sum_p ROT_{ot}^{cp} \leq TCAP_t, \ \forall\, t \quad (7)$$

2.3. Data

2.3.1. Freight prices

Road freight prices between each origin-destination pair in the transportation network were estimated using a linear model, as described by Equation (8).

$$F_{ij} = \alpha + \beta.x_{ij} \quad (8)$$

Where:

F_{ij}: Freight price between nodes *i* and *j* (US$/tonne for soybeans and corn);
x_{ij}: Distance between nodes *i* and *j* (km);
α: The y-intercept of the linear function;
β : The slope of the linear function.

Table 1
Freight equations and statistical significance tests of the linear regression of freight prices.

Statistical Tests	Linear Regression
Estimated equation	$F_{ij} = 8.15 + 0.03368x_{ij}$
R-squared (R^2)	0.79
P-value	<0.01%
Sample size	11,073 freight prices

Source: elaborated by the authors.

The values of parameters α and β were estimated using linear regression (least squares method) of soybean and corn freight price data collected by SIFRECA (2019) [2] for the year 2018, as presented in Table 1.

Statistical testing of the regression returned a high value for the coefficient of determination, R^2, and the P-value test suggested a rejection of the null hypothesis $\beta = 0$, at a confidence level of 99%, implying that the predictor variable (distance) exhibits a strong relationship with the response variable (freight prices).

We considered the cost of rail transport to be 70% the price of road freight, and the prices of pipeline and waterway transport to be 40% the price of road freight (EPL, 2015; ANTT, 2019).

[2] SIFRECA is a specialized system that collects Brazilian real freight prices for numerous commodities and routes <http://sifreca.esalq.usp.br/>.

Table 2
Soybean and corn supply and demand balance (2017).

Description	2017
Total Soybean Supply - Demand (10^6 tonnes)	127.161
+ Soybean production	127.161
- Soybean domestic consumption	43.556
- Soybean exports	83.605
Total Corn Supply - Demand (10^6 tonnes)	87.931
+ Corn production	87.931
- Corn domestic consumption	64.365
- Corn exports	23.566
Total Soybean and Corn Supply - Demand (10^6 tonnes)	215.092

Source: ABIMILHO (2019); ABIOVE (2019b); BRASIL, 2018, IBGE (2019d).

2.3.2. Geographic divisions

The supply and demand areas were defined by microregion, a political geographic division established by the Instituto Brasileiro de Geografia e Estatística (IBGE).[3] For each supply microregion, we defined a centroid marking the area with the highest soybean and corn production. For each demand microregion, we defined a centroid marking the location with the highest demand for soybeans and corn. The centroids are considered as the origin or destination nodes of the multimodal transportation network.

2.3.3. Supply and demand data

We calculated the domestic demand for soybeans for each microregion by extrapolating from the 2017 domestic soybean consumption declared by ABIOVE (2019b), in proportion with the soybean crushing capacity of each microregion (ABIOVE, 2019a).

To estimate domestic corn demand, we divided the national consumption of this product in 2017, as declared by ABIMILHO (2019), by microregion according to the following indicators, per microregion: the gross industrial product (consumption of corn by industry), the number of hogs (consumption of corn by the pork industry), the number of broilers and layers (consumption of corn by the poultry industry), the number of dairy cows (consumption of corn by the dairy industry), and the population (human consumption) based on data from IBGE (IBGE, 2019b, 2019c; 2019d). The soybean and corn export data by port were reported by Comex Stat - Ministry of Industry, Foreign Trade and Services (BRASIL, 2018).

We used corn and soybean production data from IBGE to represent the supply of each product per microregion (IBGE, 2019a).

Table 2 presents the 2017 supply and demand balances used in our modeling.

2.3.4. CO_2 emission coefficients

The CO_2 emission coefficients were calculated based on the diesel consumption of typical truck, barge and train used for grain transportation in Brazil. Table 3 presents the respective diesel consumption and CO_2 emission coefficients adopted for each transport mode.

2.3.5. Transportation network and scenarios

We mapped the 2017 multimodal transportation network and defined the capacities of transshipment terminals within this network based on soybean and corn quantities shipped through railways and waterways in 2017 (ANTAQ, 2017; ANTT, 2017). For the new terminals in planned railways we assumed unconstrained capacity.

Aiming to evaluate the impact of new multimodal infrastructure on transportation costs and CO_2 emissions, we found the optimal configuration of inter-regional transport flows for soybeans and corn considering the following scenarios:

1) Current Multimodal Network Scenario ("Current"): multimodal transportation network used for grain transportation in 2017 and its respective constrained transshipment and port terminals capacities;
2) *Ferrogrão* Scenario ("FG"): multimodal transportation network used for grain transportation in 2017 and its respective constrained transshipment terminals capacities plus *Ferrogrão* railway with unconstrained capacity for transshipment and port terminals with no capacity restrictions;
3) *Ferrovia Norte-Sul* Scenario ("FNS"): multimodal transportation network used for grain transportation in 2017 and its respective constrained transshipment terminals capacities plus *Ferrovia Norte-Sul* railway between Palmas (TO) and Estrela D'Oeste (SP) with unconstrained capacity for transshipment and port terminals with no capacity restrictions;
4) *Ferrovia de Integração Oeste-Leste* Scenario ("FIOL"): multimodal transportation network used for grain transportation in 2017 and its respective constrained transshipment terminals capacities plus *Ferrovia de Integração Oeste-Leste* railway with unconstrained capacity for transshipment and port terminals with no capacity restrictions;
5) *Ferrovia Rumo Malha-Norte* ("RMN"): multimodal transportation network used for grain transportation in 2017 and its respective constrained transshipment terminals capacities plus *Rumo Malha-Norte* railway between Rondonópolis (MT) and Cuiabá (MT) with unconstrained capacity for transshipment and port terminals with no capacity restrictions;
6) *Complete Multimodal Network Scenario ("Complete"): multimodal transportation network used for grain transportation* in 2017 plus all planned railways, with no capacity constrains for all transshipment and port terminals (see Fig. 2).

Table 3
Diesel consumption by each transport mode and CO_2 emission coefficients.

Transport mode	Diesel consumption	CO_2 emission coefficients	
	l/tonne.10^3 km	$kgCO_2$/liter of Diesel	$kgCO_2$/km
Road	14.2[a]	2.591	0.037
Water	5.0[b]	2.591	0.013
Rail			0.021[c]

Source: Elaborated by the authors.
[a] Diesel consumption rate of the most common truck used for grain transportation in Brazil (Bi-train - 57 tonne) provided by the Research and Extension Group of Agrologists (ESALQ-LOG), based on extensive research applied to trucking companies (ESALQ-LOG, 2019).
[b] Diesel consumption declared by Waterway Department (DEPARTAMENTO HIDROVIÁRIO, 2009).
[c] Diesel consumption published by the 1st National Inventory of Rail Freight Transportation Gas Emissions (ANTT, 2017).

Table 4 summarizes the railway transshipment terminals and port terminals capacities considered in each scenario.

2.4. Computer packages

We used Transcad® software to calculate the origin-destination distance matrix. We ran our model using General Algebraic Modeling System (GAMS®) software with the CPLEX solver.

In the Complete Network Scenario, a total of 558 origins, 67 transshipment terminals, 14 export terminals and 149 consumption regions were considered, resulting in transport network that includes a total of 83,142 road links and 158 rail and barge links.

2.4.1. Results and discussion

The results from our modeling suggest that the complete future transport network has the potential to move a total of 83.21,10^6 tonnes

[3] Brazilian Institute of Geography and Statistics <https://www.ibge.gov.br/>.

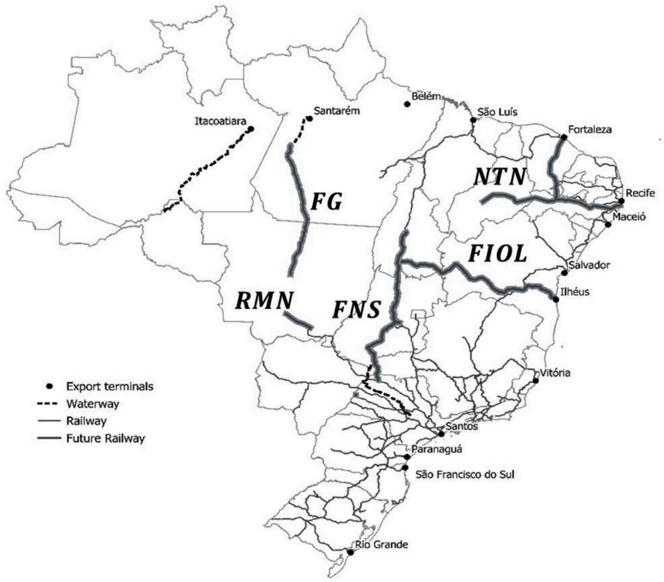

Fig. 2. Current Brazilian multimodal transport network and main planned railways.
Source: elaborated by the authors.

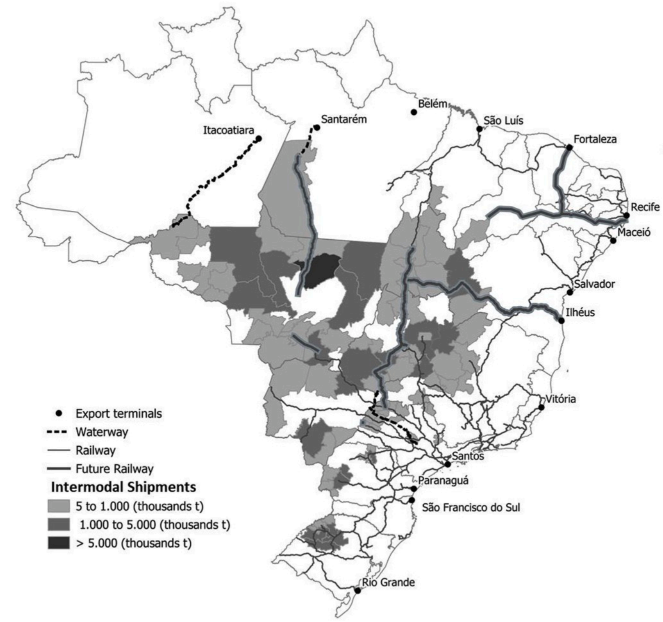

Fig. 3. Microregions with intermodal shipments through the complete future transport network (Complete Scenario).
Source: model results.

Table 4
Assumptions related to railway transshipment terminals and port terminals capacities.

Scenario	Transshipment terminals		Port terminals
	Existing railway	Planned railway	
"Current"	Restricted	–	Restricted
"FG"	Restricted	Unrestricted	Unrestricted
"FIOL"	Restricted	Unrestricted	Unrestricted
"RMN"	Restricted	Unrestricted	Unrestricted
"FNS"	Restricted	Unrestricted	Unrestricted
"NTN"	Restricted	Unrestricted	Unrestricted
"Complete"	Unrestricted	Unrestricted	Unrestricted

of soybeans and corn annually. Fig. 3 highlights the microregions with the potential to ship grain through the future intermodal network.

The introduction of new railways to the transport network decreases the share of roads in soybean and corn transport, promoting a more balanced transport matrix (Table 5). The *Rumo-Malha Norte* (RMN) railway substitutes trucking, and increases the share of railways to 45%. The *Ferrogrão* (FG) scenario meanwhile increases the share of railway and barge transport to 40% and 12%, respectively, and reduces the share of transport by road to roughly 48% of total soybean and corn transportation. These results suggest a current lack of multimodal infrastructure near the main production regions, and reflect a high dependence on roads, a mode that is both more expensive and more polluting.

A comparison of "Current" and "Complete" multimodal network scenarios shows that the implementation of all planned railways could mitigate roughly 20% of CO_2 emissions and simultaneously reduce the freight cost of soybeans and corn in Brazil by 17%, as presented in Table 6.

The inclusion of the FG in the multimodal network proved to be the main factor for decreasing CO_2 emissions (−15%) and reducing freight costs (−15%). The significant impact of this infrastructure may be explained by two factors. First, this railway will connect to the Tapajós waterway, consolidating a very competitive rail-barge transport alternative for soybean and corn production from the center-northern region of Mato Grosso state and the southeastern region of Pará state. Second, this transport alternative demonstrated a high potential for attracting

Table 5
Total quantity shipped through multimode transportation network and mode shares.

N	Intermodal Transportation		Roads	Railway	Barge
	(10^6 tonnes)	(10^6 TKU[a])	TKU (%)		
"Current"	49.83	42,996.14	71%	25%	4%
"FG"	67.81	74,354.66	48%	40%	12%
"FIOL"	54.80	47,400.90	68%	28%	4%
"RMN"	65.50	71,678.11	54%	45%	2%
"FNS"	54.59	51,597.91	65%	31%	4%
"NTN"	50.42	43,524.95	70%	26%	4%
"Complete"	83.21	86,003.28	40%	48%	12%

Source: model results.
[a] Tonnes per useful kilometer (TKU): quantity of cargo assigned for each route, multiplied by distance of route.

Table 6
CO_2 emissions and freight cost of each scenario.

Scenarios	CO_2 Emissions			Freight Cost		
	Total	Average[c]	Δ[a]	Total	Average[c]	Δ
	10^6 tonnes/year	kg CO_2/tonne	%	10^6 US $[b]/year	US $/tonne	%
"Current"	4.7	21.9	–	5950.7	27.7	–
"FG"	4.0	18.5	−15%	5071.1	23.6	−15%
"FIOL"	4.5	21.1	−4%	5853.5	27.2	−2%
"RMN"	4.6	21.4	−2%	5761.3	26.8	−3%
"FNS"	4.7	21.6	−1%	5904.8	27.5	−1%
"NTN"	4.7	21.9	0%	5948.3	27.7	0%
"Complete"	3.8	17.6	−20%	4915.4	22.9	−17%

Source: model results.
[a] The variation, Δ, is measured in comparison to the "Current" multimodal scenario.
[b] We use the average exchange rate from January to August of 2019: R$ 3.86/US$ 1.00 (BACEN, 2019).
[c] Total CO_2 emissions and total freight cost divided by total soybean and corn production.

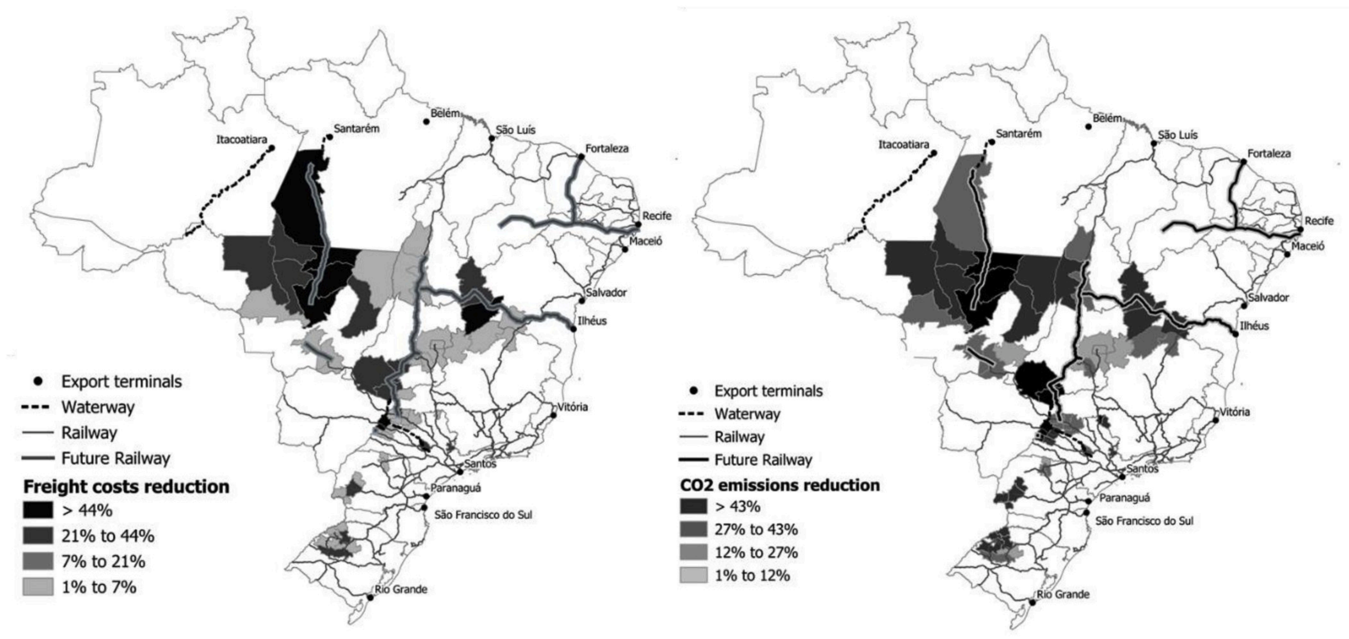

Fig. 4. Impact of the infrastructure projects on freight costs and CO_2 emissions per microregion.
Source: model results.

cargo since the area of influence of this infrastructure presents very high freight costs attributed to large distances to export terminals combined with poor transport infrastructure in this region. We also emphasize that barge transportation presents a lower rate of CO_2 emissions compared to the modes of railways and roadways.

The second most impactful infrastructure was the *Ferrovia Integração Oeste-Leste* (FIOL) railway, followed by the RMN, the planned stretch of railway between Rondonópolis (MT) and Cuiabá (MT). The FIOL and RMN scenarios showed a potential for reducing CO_2 emissions by 4% and 2%, respectively.

Impacts in terms of reductions in CO_2 emissions and freight costs per origin (microregion) are shown in Fig. 4. The spatial distribution of these positive impacts resulting from the implementation of the planned railways is similar among regions, with significant benefits from the new railways particularly in the center-north of Mato Grosso state, southeast of Goiás state, and west of Bahia state.

The reductions in transportation costs and CO_2 emissions are due to the expansion of soybean and corn shipments through railways and waterways, which are more cost- and energy-efficient transport modes compared to roadways.

2.4.1.1. Cost-effectiveness and prioritization of investments. Considering the scarcity of government resources, an analysis of the marginal benefits from investments in the respective railways is critical. Therefore, in addition to modeling the total impact on transport costs and CO_2 emissions from each alternative, we investigated the cost-effectiveness of each investment, as a complementary method for identifying priority investments.

For each investment, we calculated the marginal benefit related to the following:

i) the reduction in CO_2 emissions per monetary unit invested in each respective project (10^6 tonnes of CO_2 per year/US$ 1 million invested in the project);
ii) the reduction in freight costs per monetary unit invested in each respective project (10^6 US$ per year/US$ 1 million invested in the project); and
iii) the total monetary gain due to simultaneously reducing freight costs and CO_2 emissions per monetary unit invested in each respective project (10^6 US$ per year/US$ 1 million invested in the project). In this case, to monetize CO_2 emissions, we considered the social cost of CO_2 emissions suggested by the *Empresa de Planejamento e Logística S.A* – EPL (2019), which was quantified for a cost-benefit analysis of transport infrastructure in Brazil. The social cost of CO_2 emissions estimated by EPL was based on the Dynamic Integrated Climate-Economy model proposed by Nordhaus (2017).

The FG railway exhibited the best marginal benefit in terms of CO_2 reduction, with a decrease around 0.95,10^6 tonnes of CO_2 for each US$ 1 million invested in this infrastructure. The RMN and *Ferrovia Norte-Sul* (FNS) projects followed, presenting potential marginal benefits of 0.54,10^6 tonnes of CO_2 for each US$ 1 million invested and 0.39,10^6 tonnes of CO_2/US$ 1 million invested, respectively. Analyzing the total marginal benefit of reductions in freight costs and the social cost of CO_2 emissions, we found similar results for the three projects, and a total marginal benefit of 0.21,10^6 US$ per year for each US$ 1 million invested, for the three railways combined. See Table 7.

The total marginal benefit resulting from the FIOL proved to be the

Table 7
Marginal benefits of the investments in intermodal infrastructure.

Planned Railway	CO_2 Reduction	Freight Cost Reduction	Total Marginal Benefit (CO_2 Cost + Freight Cost Reduction)
	(10^6 tonnes of CO_2/10^6 US$)	(10^6 US$/$10^6$ US$)	(10^6 US$/$10^6$ US$)
FG	0.95	$ 0.34	$ 0.35
RMN	0.54	$ 0.34	$ 0.34
FNS	0.39	$ 0.07	$ 0.07
FIOL	0.10	$ 0.03	$ 0.03
NTN	–	$ -	$ -
Complete	0.39	$ 0.15	$ 0.15

Note: We used the average exchange rate from January to August of 2019: R$ 3.86/US$ 1.00 (BACEN, 2019).
Source: model results.

Table 8
Economic viability indicators of the investments in intermodal infrastructure projects.

Infrastructure		Freight cost reduction as benefit		Freight cost + monetized CO_2 emission reduction as benefits	
	Investment	IRR[a]	Payback[b]	IRR	Payback
	(10^6 US$)	(%)	(years)	(%)	(years)
FG	$ 2565	34.3%	3.5	34.8%	3.4
RMN	$ 560	33.8%	3.5	34.1%	3.5
FNS	$ 1451	5.3%	>50	5.6%	43.0
FIOL	$ 1658	<0%	>50	<0%	>50
NTN	$ 1736	<0%	>50	<0%	>50
Complete	$ 7970	12.6%	10.9	12.9%	10.9

Note: We used the average exchange rate from January to August of 2019: R$ 3.86/US$ 1.00 (BACEN, 2019).
Source: model results.
[a] IRR: Internal rate of return.
[b] Payback: average basic interest rate of the Brazilian economy from January to August of 2019 (6.5% per year) – (Brazilian Central Bank).

lowest, at roughly 0.03 10^6 US$ per year for every US$ 1 million invested. The *Nova Transnordestina* (NTN) railway demonstrated no significant total marginal benefit.

2.4.1.2. Financial attractiveness of investments. We also quantified the financial attractiveness of the investments in the analyzed railways, aiming to evaluate the policy strategies for their implementation. Macharis et al. (2014) outline three basic methods for evaluating the return on investment from logistics projects:

i) *Projects that demonstrate positive economic return*: Such projects attract private investment most easily because they are designed to take advantage of new logistics framework and provide an economic return that is above breakeven. As a result, they are very attractive to private investors and are quickly implemented;
ii) Projects implemented by private actors alone that cannot reach a positive economic return when implemented using new logistics framework: Society may benefit from such projects, and societal gains and economic gains from this project are collectively higher than breakeven. However, this type of project is less attractive to private investors because a fraction of the return is a societal gain. Nonetheless, the societal gain may induce the support of public investments or subsidies to assure that the project attracts private funds. This type of gain-sharing mechanism must be well designed;
iii) Projects from which the economic and social returns combined are not sufficient to reach breakeven: This type of project is rarely implemented. To complete this type of project, extensive analysis is necessary to properly monetize external effects and social gains.

Table 8 exhibits the economic viability indicators of the transport infrastructure projects from two benefit perspectives:

i) considering only the reduction in freight costs as a benefit; and
ii) considering both the reduction in freight costs and the monetarized reduction in CO_2 emissions as benefits.

In both cases, we considered 50 years as a time horizon for cash flow and an average basic interest rate of the Brazilian economy of 6.5% per year (January to August of 2019).

We found significant differences in the economic viability indicators among the projects. The high IRR and low payback time presented by FG and RMN indicated that these projects are very attractive to private capital. The FNS presented both a lower return rate and a long payback time, and the results were slightly improved when including the monetized social gain from CO_2 emissions reduction. This project alone suggests a public-private partnership for its implementation.

The FIOL and NTN proved to be less attractive projects, given their low IRR and a payback for each that was more than 50 years. This result indicates the need for higher public funding in relation to private funding to make the project viable.

2.4.2. Concluding remarks

The total CO_2 emissions from soybean and corn transportation following the implementation of the planned railway projects (17.6 kg CO_2 per tonne of soybean and corn transported) was found to be 20% lower than the current CO_2 emissions (21.9 kg CO_2 per tonne) from transporting soybeans and corn. We found the total freight cost of transporting corn and soybeans (US$ 22.9 per tonne) after implementing the planned railway projects to be 17% lower than the current total freight cost (US$ 27.7 per tonne of soybean and corn transported). Specifically, our results showed that these railways projects have the potential to cut 0.9 10^6 tonnes of CO_2 emissions per year from Brazilian soybean and corn transportation and save US$ 1035,10^6 per year in freight expenses.

The cost-benefit analysis showed that the FG railway is the project that presents the highest return on investment in terms of reducing CO_2 emissions and freight costs, followed by the RMN railway between Rondonópolis (MT) and Cuiabá (MT) and the FNS railway between Palmas (TO) and Estrela D'Oeste (SP). The implementation of these projects will promote economic and environmental gains that justify their investment, and were shown to be attractive to private funding.

The investments in the FIOL and NTN railways presented lower returns and were found to be less attractive financially, and therefore suggest a higher dependence on public investments. We emphasize that this paper considered only the transportation of soybeans and corn in its cost-benefit analysis. However, we expect that an analysis considering all the cargo expected to be transported by this infrastructure would yield an even higher return on investment. Additionally, the inclusion of monetized gains related to other positive externalities such as reductions in accidents and traffic congestion would further result in better cost-benefit indicators. Moreover, a railway could be an important factor in increasing economic production in its area of influence, and this gain was not considered in our analysis.

The future configuration of transport network infrastructure is expected to affect the spatial distribution of future agricultural production. As a result, we suggest further studies that consider an integrated analysis of the impact of the planned railways and the changes in the spatial distribution of future agricultural production. Furthermore, we recommend the internalization in a cost-benefit analysis of other gains resulting from a reduction in accidents and traffic congestions.

Acknowledgments

The authors thank the São Paulo Research Foundation (FAPESP) for the financial support to the Project #2017/50420-7.

References

ABIMILHO, 2019. Oferta e Demanda do Milho - Brasil, 2017.
ABIOVE, 2019. Pesquisa de Capacidade Instalada, 2017.
ABIOVE, 2019. Balanço Anual de Oferta e Demanda do Complexo Soja, 2017.
Abraham, S., Ganesh, K., Kumar, A.S., Ducq, Y., 2012. Impact on climate change due to transportation sector-research prospective. Procedia Eng 38, 3869–3879. https://doi.org/10.1016/j.proeng.2012.06.445.
Ahuja, R.K., Magnanti, T.L., Orlin, J.B., 1993. Network Flows: Theory, Algorithms, and Applications, First. ed. Prentice-Hall, New Jersey.
ANTAQ, 2017. Estatístico Aquaviário.
ANTT, 2017. Declaração de Rede - Ferrovias.
ANTT, 2019. Tarifas de Referência do Transporte Rodoviário de Cargas: Concessionárias.
APAS, 1996. Transport Estrategic Modelling. Luxemburgo.

Ávila, E.S. de, 2016. Impactos de regulações ambientais sobre o transporte de cargas no Brasil: uma análise para o transporte de soja. Universidade de São Paulo, Piracicaba. https://doi.org/10.11606/T.11.2016.tde-07062016-163230.

BACEN, 2019. Cotação - Dólar EUA. [WWW Document] https://www.bcb.gov.br/ acessed 12.15.19.

Binsted, A., Clark, A., Waygood, O., Avineri, E., 2011. Communicating the impacts of transport choices to encourage low carbon travel behaviours. In: Proceedings of the 8th SoNorA University Think Tank Conference.

Black, W.R., 2010. Sustainable Transportation: Problems and Solutions. The Guilford Press, New York.

Branco, J.E.H., Branco, D.H., Aguiar, E.M. de, Caixeta Filho, J.V., Rodrigues, L., 2019. Study of optimal locations for new sugarcane mills in Brazil: application of a MINLP network equilibrium model. Biomass Bioenergy 127, 105249. https://doi.org/10.1016/j.biombioe.2019.05.018.

BRASIL - Ministério da Economia, Indústria, Comércio Exterior e Serviços. Estatísticas de Comércio Exterior, 2018. [WWW Document] http://www.mdic.gov.br/index.php/comercio-exterior acessed 10.15.2019.

Brasil, Política de Concessões - EF170 Ferrogrão (PA), BRASIL - Ministério da Infraestrutura, EPL - Empresa de Planejamento e Logística, 2019. Anuário Estatístico de Transportes, 2010-2018, 2019.

BRASIL - Ministério da Infraestrutura. Concessões: Mapa de projetos das ferrovias, 2020. [WWW Document] https://infraestrutura.gov.br/concessoes/ acessed 01.15.2020.

Caixeta-Filho, J.V., Macaulay, T.G., 1989. A utilização de modelos de equilíbrio espacial para a avaliação econômica de políticas agrícolas: estudo de caso australiano. In: Sober (Ed.), XXVII Congresso Brasileiro de Economia e Sociologia Rural. São Paulo, pp. 232–245.

CNT, 2018. Boletim Estatístico CNT.

European Comission, 2011. Write Paper: Roadmap to a Single European Transport Area – towards a Competitive and Resource Efficient Transport System. Brussels.

Crainic, T.G., Florian, M., Léal, J.-E., 1990. A model for the strategic planning of national freight transportation by rail. Transport. Sci. 24, 1–24. https://doi.org/10.1287/trsc.24.1.1.

Cramer, G.L., Wailes, E.J., Shui, S., 1993. Impacts of liberalizing trade in the world rice market. Am. J. Agric. Econ. 75, 219. https://doi.org/10.2307/1242970.

De La Cruz, B.C.B., Pizzolato, N.D., De La Cruz, A.B., 2010. An application of the spatial equilibrium model to soybean production in tocantins and neighboring states in Brazil. Pesquisa Operacional 30 (2). https://doi.org/10.1590/S0101-74382010000200011. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0101-74382010000200011.

Dennis, S.M., 1999. Using spatial equilibrium models to analyze transportation rates: an application to steam coal in the United States. Transport. Res. Part E Logist. Transp. Rev. 35, 145–154. https://doi.org/10.1016/S1366-5545(99)00010-1.

DEPARTAMENTO, HIDROVIÁRIO, 2009. Hidroanel Metropolitano & Dinamização da Hidrovia Tietê-Paraná.

EPL (Empresa de Planejamento e Logística), 2015. Estudo Dos Custos Hidroviários No Brasil - Fase III.

EPL, 2019. Parâmetros de Custo-Benefício para Projetos de Infraestrutura. [WWW Document] https://www.epl.gov.br/metodologia-da-analise-de-custo-beneficio acessed 11.22.19.

ESALQ-LOG, 2019. Consumo de combustível no transporte rodoviário de cargas.

EXAME, 2019. Ferrovia Transnordestina pode voltar para o governo. Exame.

Farina, E.M.M.Q., Rodrigues, L., 2017. A importância de diretriz para os biocombustíveis. Rev. Opiniões. Ed. 54.

Fernández L, J.E., de Cea Ch, J., O, A.S., 2003. A multi-modal supply–demand equilibrium model for predicting intercity freight flows. Transp. Res. Part B Methodol. 37, 615–640. https://doi.org/10.1016/S0191-2615(02)00042-5.

Friesz, T.L., Harker, P.T., 1983. Multicriteria spatial price equilibrium network design: theory and computational results. Transp. Res. Part B Methodol. 17, 411–426. https://doi.org/10.1016/0191-2615(83)90007-3.

Friesz, T.L., Tobin, R.L., Harker, P.T., 1983. Predictive intercity freight network models: the state of the art. Transport. Res. Part A Gen. 17, 409–417. https://doi.org/10.1016/0191-2607(83)90161-9.

Fuller, S., Fellin, L., Salin, V., 2003. Effect of liberalized U.S.–Mexico rice trade: a spatial, multiproduct equilibrium analysis. Agribusiness 19, 1–17. https://doi.org/10.1002/agr.10042.

Garrido, R.A., Mahmassani, H.S., 2000. Forecasting freight transportation demand with the space-time multinomial probit model. Transp. Res. Part B Methodol. 34, 403–418.

Guélat, J., Florian, M., Crainic, T.G., 1990. A multimode multiproduct network assignment model for strategic planning of freight flows. Transport. Sci. 24, 25–39. https://doi.org/10.1287/trsc.24.1.25.

IBGE, 2019. Produção Agrícola Municipal, 2017.

IBGE, 2019. Projeções da População, 2017.

IBGE, 2019. Pesquisa da Pecuária Municipal, 2017.

IBGE, 2019. Produto Interno Bruto, 2017.

Kresge, D.T., Roberts, P.O., 1971. Techniques of Transportation Planning: Systems Analysis and Simulation Models. Washington, D.C.

Labys, W.C., Yang, C., 1991. Advances in the spatial equilibrium modeling of mineral and energy issues. Int. Reg. Sci. Rev. 14, 61–94. https://doi.org/10.1177/016001769101400104.

Macharis, C., Melo, S., Woxenius, J., van, Lier T., 2014. Sustainable Logistics. Emerald Group Publishing Limited.

Mehra, S., Verma, S., 2016. Smart Transportation - Transforming Indian Cities: Transportation Sector Reforms and Developments in India. New Delhi.

MME, 2018. RenovaBio [WWW Document]. www.mme.gov.br. accessed 2.14.18.

Nordhaus, W.D., 2017. Revisiting the social cost of carbon. Proc. Natl. Acad. Sci. Unit. States Am. 114, 1518–1523. https://doi.org/10.1073/pnas.1609244114.

Öberg, M., Nilsson, K.L., Johansson, C., 2017. Major transport corridors: the concept of sustainability in EU documents. Transp. Res. Procedia 25, 3694–3702. 10.1016/j.trpro.2017.05.339.

Pinheiro, M.A., 2012. Estimativa da redução das emissões gases de efeito estufa através da intermodalidade no setor sucroenergético: uma aplicação de programação linear. Universidade de São Paulo, Piracicaba. https://doi.org/10.11606/T.11.2012.tde-31052012-085545.

Retzer, S., 2019. China transport policy briefing: the monthly update of GIZ in China [WWW Document]. Dtsch. Gesellschaft für Int. Zusammenarbeit. http://www.sustainabletransport.org/archives/6927.

RUSSIA (Ministry of Transport), 2014. Transport strategy of the Russian federation up to 2030 [WWW Document]. http://government.ru/en/dep_news/13191/. accessed 6.20.19.

SIFRECA, 2019. Soybean and Corn Real Prices in Brazilian Freight Market, 2018.

Sims, R., Schaeffer, F., Creutzig, X., Cruz-Núñez, M., D'Agosto, D., Dimitriu, M.J., Figueroa Meza, L., Fulton, S., Kobayashi, O., Lah, A., McKinnon, P., Newman, M., Ouyang, J.J., Schauer, D., Sperling, G.T., 2014. Transport. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovern-Mental Panel on Climate Change. Cambridge University Press, Cambridge.

Transport Policy Net, 2019. Regions China [WWW Document]. 2019. http://www.transportpolicy.net/region/asia/china/.

Trofimenko, Y., Komkov, V., Donchenko, V., 2018. Problems and prospects of sustainable low carbon development of transport in Russia. IOP Conf. Ser. Earth Environ. Sci. 177, 012014 https://doi.org/10.1088/1755-1315/177/1/012014.

UNFCCC, 2018. United Nations framework convention on climate change [WWW Document]. https://unfccc.int/.

UNICA, 2017. RenovaBio: Cenários e Simulação de Impacto.

USDOT, 2012. USDOT's Energy Blue Print. Efficient Transportation for America, Washington, D.C.

VALEC, 2019. Ferrovia Norte-Sul.

Zhao, P., Liu, J., He, L.. Study on the Development of Modern Green Logistics in China. https://doi.org/10.1109/ICIM.2009.17.

Zhou, J., 2012. Sustainable transportation in the US: a review of proposals, policies, and programs since 2000. Front. Archit. Res. 1, 150–165. https://doi.org/10.1016/J.FOAR.2012.02.012.