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Benchmarking freight transportation corridors and routes with data envelopment analysis (DEA)

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Abstract

Purpose – The purpose of this paper is to collectively measure and compare the efficiency of Brazilian and American soybean transport corridors, from farmers to export ports, using the data envelopment analysis (DEA).

Design/methodology/approach – This paper aims to determine routes from main producing micro-regions to main export ports, specifically using slack-based measure and variables that represent the three pillars of sustainability (economic, social, and environmental). The choice of variables was guided by literature review and analyzed through the principal component analysis. After the application of the model, the quantitative tiebreaking method of the composite index is applied.

Findings – The findings are coherent with a global report that compares soybean transportation in both countries (Brazil and USA). Efficient routes and corridors tend to present short distance truck trips and long distance train or barge trips. The efficiency of the inland waterway trips depends on how many barges are used in the same expedition. Routes with more than three modes tend to be inefficient which suggest that there is a limit for multimodality.

Originality/value – Corridor benchmarking is a rare topic in the literature and previous works normally focus on some specific and limited corridor performance characteristics, such as cost. The main contribution of this research is that it expands the discussion regarding corridor benchmarking and it focuses on efficiency as a whole. The paper also proposes a method that can be applied in different logistics contexts, like expanding the study to different countries. More specifically, this method could be used in infrastructure investments programs.

Keywords Data envelopment analysis, Freight transport, Corridor benchmarking, Route benchmarking, Slack-based measure, Soybean

Paper type Research paper

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1. Introduction

The objective of this paper is to collectively measure and compare the efficiency of Brazilian and American soybean transport corridors, from farmers to main national export ports, using the data envelopment analysis (DEA), specifically the slack-based measure (SBM) model.

The Observatory of Economic Complexity (OEC) is a tool, developed at the MIT Media Lab, which allows users to compose a visual analysis of countries and the products they exchange. The OEC classifies soybean as the 44th most important product of the world economy (in a list of 1,238 items). And shows that in 2014, the USA was responsible for 41 percent of soybean production worldwide and Brazil was responsible for 40 percent (Simoes and Hidalgo, 2011). In other words, Brazil is one of the most relevant US competitors in the soybean market, and presents relevant perspectives of soybean harvest growth up to 2030 (Matsuda and Goldsmith, 2009).

USA presents a consolidated infrastructure for transporting soybeans from farmers to main American export ports (Salin, 2016). The main American producing states, Illinois, Iowa, Minnesota, Indiana, Nebraska, Ohio, and South Dakota, were responsible for 67.47 percent of the national soybean production in 2012. Soybean is mostly exported by ports in the Mississippi Gulf coast (63 percent), but exportation by the western port in the Pacific North Western Complex is also relevant (17 percent) (USDA, 2013). Unlike the USA, Brazil faces various structural obstacles even when considering corridors from the main and most traditional producing states: Rio Grande do Sul (RS), Paraná (PR), Mato Grosso do Sul (MS), Goiás (GO), and Mato Grosso (MT) to the main export ports of Santos, Paranaguá, and Rio Grande (Salin, 2016). These main producers were responsible for 75.48 percent of Brazilian soybean exports in 2015 (MDIC – Ministry of Industry, Foreign Trade and Services, 2016).

Despite being used for years as a concept, there is no precise definition for a "transportation corridor." The World Bank publication Best Practices in Management of International Trade Corridors (Arnold, 2006) provides a descriptive definition that suits the way this term is used in this paper. According to the publication, transportation corridors have both physical and functional elements. The most relevant physical element of a corridor is that it must include one or more routes to provide a connection between economic centers, while others (most of them) are long and not defined by the main gateway, e.g. a port. In most cases, corridors involve multiple modes, but they may also be unimodal. The most relevant functional element of a corridor is that it is usually developed to support regional economic growth.

The literature describing methods for benchmarking corridors is rare. In addition to the World Bank report (Arnold, 2006) which addressed the benchmarking corridor, EU Super Green Project has been the second most relevant study. This project was aimed at advancing the green corridor concept through a benchmarking exercise involving key performance indicators (KPIs) of 16 European corridors (Panagakos, 2016). Colombian researchers developed a strategic freight transport model incorporating external costs, and applied it to the seven most important national freight transport corridors (Marquez and Cantillo, 2013). Benchmarking corridors based on the efficiency of transportation is much rarer. Researchers developed a framework for a route selection from Thailand to Vietnam, using the analytic hierarchy process (AHP) and DEA to evaluate multimodal risk (Kengpol *et al.*, 2014). Brazilian researchers have recently combined a balanced scorecard (BSC) and DEA to benchmark efficiency of uni- and multimodal routes that originate from Mato Grosso and go toward the export ports in Northern and Southern regions (Oliveira and Cicolin, 2016).

In this work, the DEA-SBM model (Tone, 2001) is proposed for benchmarking corridors. The results obtain from the DEA show a raking of the efficiency of decision-making units (DMUs). Each corridor is a DMU, defined by variables of interest (e.g. logistic costs, warehouse capacity, lead time, among others to be discussed under Sections 2 and 3). In this paper, we analyze collectively American and Brazilian national corridors which originated in from the main soybean producing states to the main export ports. The analysis of the elements of the results (e.g. rank, slacks) enables to show which characteristics must be enhanced for improving efficiency. This may be used as a tool for directing infrastructure investment programs.

Corridor benchmarking is a rare topic in the literature. The aforementioned papers about the theme are normally focused on some specific and limited performance characteristics, such as cost. The main contribution of the present research is that it expands the discussion about creating a method for benchmarking corridors and it is focused on efficiency as a whole, considering the three pillars of sustainability (economic, social and environmental). It proposes a method that can be reapplied in different logistics contexts. In particularly, it may be used to infrastructure investment programs.

The rest of the paper is organized as follows. Section 2 presents a literature review on route benchmarking, explains basic concepts of DEA and mathematically demonstrates the SBM model. Section 3 outlines the methodology. The results of the application to the aforementioned context are presented under Section 4. Section 5 analyzes/introduces relevant discussions. Finally, Section 6 summarizes the conclusions of the paper. The data and references used are shown in Table AI and References.

2. Literature review

Castro and Frazzon (2017) overviewed literature in order to track the most relevant contributions on benchmarking methods and to understand the similarities among the studies. The authors concluded that the recent increasing of production about the theme is substantial. They identified two main clusters of co-cited articles: one study using a large variation of benchmarking methods and another with the DEA. Castro and Frazzon (2017) highlighted that new DEA approaches seem to address most of the criticized issues of previous benchmarking methods.

The DEA technique is one of the most famous and widely used tools to measure productivity and efficiency in complex problems. This technique is applied to evaluate the performance of the examined units, called DMUs. There are several works related to DEA application for benchmarking different route options or transportation modes. For example, Shao and Sun (2016) analyzed performance of Chinese freight air routes; Grigoroudis *et al.* (2014) used DEA to design and analyze supply chains for biomass transportation; Sheth *et al.* (2013) analyzed the performance of bus routes; Tongzon (2001) used the DEA for analyzing the efficiency of Australian ports, as well as some specific routes. While there are many additional relevant studies, for the purpose of thematic delimitation, only investigations directly related to the scope will be detailed in the following subsections.

2.1 Benchmarking routes and corridors

Eight works, among reports (Arnold, 2006; Texas Transportation Institute (TTI), 2007, 2012; Salin, 2016), academic papers (Marquez and Cantillo, 2013; Kengpol *et al.*, 2014, Oliveira and Cicolin, 2016), and a chapter in a book (Panagakos, 2016) are known and considered as the basis for determining the most relevant variables when studying benchmarking routes and corridors.

The book chapter was written under the context of EU Super Green Project. This project aimed to advance the green corridor concept through a benchmarking exercise involving KPIs of 16 European corridors. The variables were chosen combining the three pillars of sustainability (economic, social, and environmental). After several attempts to develop this method, EU Super Green excluded social variables from its benchmark method; according to the authors, it is possible that the exclusion reflects the secondary role that stakeholders attach to social issues when it comes to freight logistics (Panagakos, 2016).

The US Department of Transportation Maritime Administration's publication "A modal comparison of domestic freight transportation effects on the general public" (TTI, 2007), elaborated by Texas Transportation Institute (TTI), provides a description of the "standardization" method used in order to compare the three modes (rail, truck, and inland waterways). A more recent publication (TTI, 2012) updated data considering fleet technology improvement but did not suggest any method alteration. The report identified the following topical study areas for its research: cargo capacity, congestion, emissions, energy efficiency, safety impacts (divided among fatalities, injuries and hazardous materials incidents) and infrastructure impact. According to the authors, the selected topics were issues associated with all modes, which enable the comparison across modes and the importance of these issues has been verified by the stakeholders. The global annual report "The soybean transportation guide" (Salin, 2016), which is published by the US Department of Agriculture, focuses on logistic direct costs and accurately describes current Brazilian transport infrastructure investment programs status. The World Bank (Arnold, 2006) report was used as a starting point but further discarded as a reference for choosing variables because it does not consider environmental impacts and external costs.

Marquez and Cantillo (2013) considered time and operation as internal costs, and congestions, accidents, air pollution, and emissions as external cost. Kengpol *et al.* (2014) proposed an integrated quantitative risk assessment, AHP, and DEA to evaluate the multimodal transportation risk. Its analysis considered origin/destination, time and cost of each route, and emissions. Oliveira and Cicolin (2016) applied the DEA, a BCC model oriented to outputs, to evaluate the efficiency of the logistics of 17 Brazilian grain freight routes. The BSC was used to define variables based on four dimensions: financial, customer, internal business, and learning and growth.

Table I details contexts, tools, and variables used by each publication.

2.2 DEA: model and associated techniques

The DEA is a non-parametric mathematical programming method used to measure relative efficiency of DMUs in a system with multiple variables, known as inputs and outputs. In 1978, the first mathematical model of the DEA was developed. The model was named CCR and it presented constant scale (Charnes *et al.*, 1978). In 1984, a model with variant scale was developed (BCC) (Banker *et al.*, 1984). For both models, it is mandatory to choose the direction of projection: to prioritize output maximization or input minimization.

Real problems, such freight transportation, may require output maximization and input minimization simultaneously. For example, in most cases, it may be equally desired to reduce lead time and maximize cargo capacity of each trip. Furthermore, in models called "additives," developed in 1985 (Charnes *et al.*, 1985), it is not necessary to choose the direction as they will maximize output and minimize input simultaneously. Moreover, additive models may be variant or invariant regarding scale. One of the disadvantages of additive models is that they do not directly determine the efficiency of the DMU, and only identify the efficient DMUs and the targets for the DMUs inefficiencies. In 2001, the SBM was proposed due to the limitations of the additive model. The SBM is an additive variant that maximizes output and minimizes inputs, but results in efficiency being measured on a scale of 0-100 percent. For the SBM, the value of the objective function is the sum of the relative distances, also called slacks. A brief mathematical demonstration of SBM model is shown in the following paragraphs.

Table I. Summary of literature review

Publication	Type	Context	Tools	Variables
Panagakos (2016)	Chapter book	EU Super Green Project.	key performance indicators	Origin-destination, type of moved cargo, modal availability, used routes, trade imbalance, among others not specified in text
Texas Transport Institute (TTI, 2007, 2012)	Report for US Department of Transportation and Maritime Administration	Investigation of alternatives to Mississippi Waterway in case of drought	Direct comparison among different modes	Cargo capacity, congestions, emissions, energetic efficiency of each mode, safety impacts and infrastructural impacts
Arnold (2006)	Report for the World Bank	Comprehensive review of how transport corridors function	Literature review	Not applicable
Salin (2016)	Annual report for US Department of Agriculture	Visual snapshot of Brazilian soybean transportation. Data: the cost of shipping soybeans via highways and ocean Information about soybean production, exports, railways, ports, and infrastructural developments	Summary of updated data	Not applicable
Marquez and Cantillo (2013)	Article	To determine the internal and external costs of Colombian transport routes, considering three modes (road, rail and inland waterway)	Model developed by Colombian institution	Time and operations (internal costs), congestion, accidents, air pollution and accidents (external costs)
Kengpol *et al.* (2016)	Article	To develop a tool that allows the selection of the route with less risk of load loss between Thailand and China	Tool developed with the application of DEA and AHP	Time, cost of freight, emissions
Oliveira and Cicolin (2016)	Article	To compare efficiency of corn flow routes from Mato Grosso to the main Brazilian ports	Choice of variables with balanced scorecard (BSC), route benchmark with DEA-BCC	Logistics costs, time, emissions, transportation matrix, availability of warehouses, cost of corn production, line in port/ship, route extension, transport costs, transport speed, fuel consumption and fleet age

In this paper, routes were defined as DMUs. Dealing with n DMUs with inputs x and outputs y, it is assumed that the data are positive, i.e. $x > 0$ and $y > 0$. Consider an expression to describe a certain DMU ($x_0 \cdot y_0$) as:

$$x_{i0} = x_{ik}\lambda_k + s_i^-$$

$$y_{r0} = y_{rk}\lambda_k - s_r^+$$

with $\lambda_k \geqslant 0$, $s_i^- \geqslant 0$, and $s_r^+ \geqslant 0$. The λ_k indicates the contribution of the kth DMU; s_i^- and s_r^+ indicate, respectively, the excesses of ith input and rth output. Using s_i^- and s_r^+, the index ρ for efficiency can be defined as:

$$\rho = \frac{1-(1/m)\sum_{i=1}^{m} s_i^-/x_{i0}}{1+(1/s)\sum_{r=1}^{s} s_r^+/y_{r0}}.$$

In an effort to estimate the efficiency for ($x_0 \cdot y_0$), the creator of the SBM model (Tone, 2001) established the fractional programming in λ_k, s_i^-, and s_r^+, with the next step being linearization. The author multiplies the numerator and the denominator of the function by a positive number, t, in order to achieve linearization. This process sets the denominator to be equal to 1 and moves it to the constraints. The goal is to minimize the numerator. The problem remains non-linear, once the variables are multiplied by t. However, it is possible to make it linear by transforming each variable multiplied by t into a single new variable, i.e. $S_i^- = ts_i^-$, $S_r^+ = ts_r^+$, and $\Lambda_k = t\lambda_k$.

In order to insert non-discretionary variables (also known as non-controllable or environmental factors) into SBM models, such as the extension route variable used in this study, consider the following constraints of the extended additive model (Charnes *et al.*, 1987), as recommended by previous works (Saen, 2005):

$$S_i^- \leqslant \beta_i x_{i0}$$

$$S_r^+ \leqslant \gamma_r y_{r0}$$

The β_i and γ_r are the prescribed parameters between 0 and 1 that indicate the degree of discretion of each input or output. If the variable is completely non-controllable, the parameter is equal to 0. If the variable is completely discretionary, the parameter is equal to 1. If the variable is partially under control, the parameter has a value between 0 and 1. If the variables are freely discretionary, parameters $\rightarrow +\infty$, the constraint is removed and it becomes a standard SBM model.

The SBM formulation as a linear programming model with non-discretionary variables is as follows:

$$\text{Minimize } \tau = t-(1/m)\sum_{i=1}^{m} S_i^-/x_{i0} \tag{1}$$

subject to:

$$(1/s)\sum_{r=1}^{s} S_r^+/y_{r0} + t = 1 \tag{2}$$

$$\sum_{i=1}^{m} \Lambda_k x_{ik} + S_i^- - t x_{i0} = 0 \quad k = 1, 2, \ldots, z \tag{3}$$

$$\sum_{r=1}^{s} \Lambda_k y_{rk} - S_r^+ - t y_{r0} = 0 \quad k = 1, 2, \ldots, z \tag{4}$$

$$S_i^- \leqslant \beta_i x_{i0} \quad i = 1, 2, \ldots, p \tag{5}$$

$$S_r^+ \leqslant \gamma_r y_{r0} \quad r = 1, 2, \ldots, q \tag{6}$$

$$\Lambda_k \geqslant 0,\ S_i^- \geqslant 0,\ S_r^+ \geqslant 0 \text{ and } t > 0 \tag{7}$$

where τ is the efficiency; S_i^- the slack of the ith input; S_r^+ the slack of the rth output; Λ_k the contribution of the kth DMU; t the model linearization factor; x_{i0} the ith input of DMU under analysis; y_{r0} the rth output of the DMU under analysis; x_{ik} the ith input of the kth DMU; y_{rk} the rth output of the kth DMU; m the number of inputs; s the number of outputs; p the number of non-discretionary inputs; q the number of non-discretionary outputs; and z the number of DMUs.

It is possible to impose some restrictions for Λ_k, such as $\sum_{k=1}^{z} \Lambda_k = 1$ (variable returns to scale). The optimum solution (ρ^*, t^*, $\Lambda_k{}^*$, $S_i{}^{-*}$, $S_r{}^{+*}$) is given by:

$$\rho^* = \tau^*,\ \lambda_k^* = \Lambda_k^*/t^*,\ s_i^{-*} = S_i^{-*}/t^*,\ s_r^{+*} = S_r^{+*}/t^*$$

Based on this solution, it is defined that a DMU (x_0,y_0), defined as a route in this work, is efficient in an SBM model when $\rho^* = 1$.

A few of the issues among the problems related to variables are: undesirable outputs and excessive number of variables to relatively few DMUs. The maximization of some outputs, such as emissions, may not be desired, as they have negative impacts on the environment and/or on society (Camioto *et al.*, 2014). These outputs are called undesirable. It is recommended that they be inserted as input in order for them to be minimized (Cook *et al.*, 2014).

The goal of the Principal component analysis (PCA)-DEA model is to improve the discriminatory power of the DEA, which often fails when there is an excessive number of inputs and outputs in relation to DMUs (Adler and Golany, 2007). The PCA explain**s** the variance structure of a matrix data through a linear combination of variables. Consequently, it may be possible to reduce data to a few principal components, which generally describes 80-90 percent of the variance in data. If most of the population variance can be attributed to the first few components, then they can replace the original variables with minimum loss of information (Hair *et al.*, 1995). The PCA used here is based on correlation rather than covariance, as the variables used in the DEA are often quantified in different units of measure (Adler and Golany, 2007). The PCA-DEA is widely used in international research and, in comparison with variable reduction based on partial covariance (VR), presents more robust and accurate results (Adler and Yazhemsky, 2010).

A common problem found in DEA rankings is the number of ties identified as efficient DMUs. This paper applied the composite index tiebreaking method (Leta *et al.*, 2005). This method considers the average between standard and inverted efficiencies, and later standardizes them by the maximum index.

In this paper, standard efficiency E_k^{standard} is the efficiency τ^* calculated by the SBM model. The inverted efficiency E_k^{inverted} is calculated by handling inputs as outputs, and outputs as inputs (Mariano and Rebelatto, 2014; Leta *et al.*, 2005). The formulation of the composite index is as follows:

$$E_k^{\text{composite}} = \frac{\left[E_k^{\text{standard}} + \left(1 - E_k^{\text{inverted}}\right)\right]/2}{\max\left\{\left[E_k^{\text{standard}} + \left(1 - E_k^{\text{inverted}}\right)\right]/2\right\}} \quad k = 1, 2, \ldots, z \tag{9}$$

where $E_k^{\text{composite}}$ is the composite index of the *k*th DMU; E_k^{standard} the standard efficiency of the *k*th DMU; E_k^{inverted} the inverted efficiency of the *k*th DMU; and *z* the number of DMUs.

3. Methods

3.1 Definitions of routes and corridors

The corridors were defined considering the information from the harvest of 2014 (a year not affected by extraordinary climatic events). The routes were established from the top three producing micro-regions to the top export ports.

In Brazil, official sources (ANTAQ, 2011; EMATER – State Company of Technical Assistance and Rural Extension, 2014; IMBEES – Institute Mauro Borges of Statics and Socioeconomic Studies, 2015; IMEA – Institute of State of Mato Grosso of Agricultural Economics, 2015; SEAB – Secretariat of Agriculture and Supply, 2015; SIGA – Agribusiness Geographic Information System, 2015; IBGE – Brazilian Institute of Geography and Statistics, 2016a), companies (AHRANA – Administration of Paraná Waterways, 2005, 2012, 2013; Alianca – Trevisa Investments, 2016; ALL, 2016; Ferroeste – Secretariat of Infrastructure and Logistics, 2016), and previous works (Vieira, 2002; Ojima, 2004; Rocha and Parré, 2009; Oliveira and Cicolin, 2016) were consulted. The reports of the Consulting Company Macrologística (commissioned by the National Federation of Industry) were also consulted (Macrologística, 2011, 2013). In all, 19 corridors and 72 routes were identified. In the USA, official sources (Casavant *et al.*, 2011; Salin, 2016; NASS – National Agricultural Statistics Services (NASS), 2016; NOAA, 2016; US Corps of Engineers, US Army, 2016; Waterways Council, 2016) were consulted. Ten corridors and 30 routes were identified.

All the routes assigned a code, according to the existing modes of transportation and the country. The codes of all the American routes begin with an "E". If there is road transportation, the code receives the letter "R". If there is barge transportation, the code receives the letter "H". If there is a rail transportation, the code receives the letter "F". Table II summarizes all routes and corridors.

3.2 Proposal of variables

Based on the information provided, the initial proposal of variables was: fuel consumption and planted area as inputs; transported harvest and in-farm static storage capacity as outputs. There are also undesirable outputs, such as fatalities, off-farm static storage capacity, emissions, and disposal factor. As they were undesirable, they were inserted as inputs. The reasoning as to why the variable route extension was considered non-discretionary will be discussed in the next few paragraphs. Table III summarizes how the variables were chosen, their sources, their rationality, and previous works that used the same variables.

3.2.1 Fuel consumption. The input "fuel consumption" was designed to represent the cost of transport. Different countries have different currencies, economic structures, and taxes. This context hinders the direct comparison of costs, e.g. even by converting the costs to the same currency, there may be discrepancies such as different incurred taxes, labor costs, etc. Diesel is an input consumed in transport by all modes in both countries.

Corridors Code	Origin	Destination	Mode	Routes Code
C1	RS	Rio Grande	Road	R1, R2, R3
			Rail	F1
			Road and waterway	RH1, RH2, RH3, RH4, RH5, RH6, RH7, RH8, RH9
			Road and rail	RF2
			Rail and waterway	FH1
			Road, rail and waterway	RFH1
C2	PR	Paranaguá	Road	R4, R6, R8
			Rail	F2, F3, F4
			Road and rail	RF1
C3	PR	Santos	Road	R5, R7, R9
C4	MS	Paranaguá	Road	R10, R12, R14
C5	MS	Santos	Road	R11, R13, R15
			Rail	F5
			Road and rail	RF3, RF4
C6	GO	Paranaguá	Road	R16, R18
			Road and rail	RF5, RF6
C7	GO	Santos	Road	R17, R19, R20
			Road, waterway and road	RHR1, RHR2, RHR3, RHR4, RHR5, RHR6
			Road, waterway and rail	RHF1, RHF2, RHF3
C8	MT	Paranaguá	Road	R21, R23, R25
			Road and rail	RF7, RF8, RF9
C9	MT	Santos	Road	R22, R24, R26
			Road and rail	RF10, RF11, RF12
			Road, waterway and rail	RHR7, RHR8, RHR9, RHR10, RHR11, RHR12
			Road, waterway and rail	RHF4, RHF5, RHF6
EC1	MO	Gulf of Mississippi	Barge	EH1
			Road and waterway	ERH13, ERH14
EC2	MO	NPW	Road and rail	ERF13, ERF14, ERF15
EC3	IL	Gulf of Mississippi	Road and waterway	ERH1, ERH2, ERH3
EC4	IL	NPW	Road and rail	ERF1, ERF2, ERF3
EC5	IA	Gulf of Mississippi	Road and waterway	ERH4, ERH5, ERH6
EC6	IA	NPW	Road and rail	ERF4, ERF5, ERF6
EC7	IN	Gulf of Mississippi	Road and waterway	ERH7, ERH8, ERH9
EC8	IN	NPW	Road and rail	ERF7, ERF8, ERF9
EC9	MN	Gulf of Mississippi	Road and waterway	ERH10, ERH11, ERH12
EC10	MN	NPW	Road and rail	ERF10, ERF11, ERF12

Table II. List of considered routes and respective corridors

Moreover, it is derived from oil, the price of which is governed by international quotations. Thus, diesel consumption facilitates the representation and comparison of costs between different countries.

The dimensions of the units used to transport freight vary widely within each of the three modes (rail, truck, and inland waterway). They also vary according to the availability of technology in each country. In order to build a meaningful cross-modal comparison, "standard" dimensions of the units used by each mode were defined. In this manner, all three modes were evaluated on the same scale, allowing the use of the DEA for benchmarking routes.

Table III. Summary of variable choice, source and rational

Variable	Pillar of sustainability	Type	Sources	Rational	Previous works
Fuel consumption	Economic	Input	Calculated according to TTI (2007), TTI (2012)	It represents logistics costs in both countries.	Oliveira and Cicolin (2016)
Planted area	Economic	Input	Collected from NASS (2016), CONAB – National Supply Company (2014).	It directly affects transported harvest	Oliveira and Cicolin (2016)
Transported harvest	Economic	Output	Collected from NASS (2016), CONAB – National Supply Company (2014)	It was assumed all harvest is transported	Oliveira and Cicolin (2016)
In-farm static storage capacity	Economic	Output	Collected from NASS (2016), IBGE – Brazilian Institute of Geography and Statistics (2016b)	Brazil presents warehouse deficit	Oliveira and Cicolin (2016)
Fatalities	Social	Undesirable output	Estimated based on National Highway Traffic Safety Administration (2016), Federal Railroad Administration Office of Safety Analysis (2016), Bureau of Transportation Statistics (2016), Departamento Nacional de Infraestrutura de Transportes (DNIT, 2010), IMTT – Institute of Mobility and Land Transport (2011), and Ferreira (2010)	Road transportation presents a higher level of fatalities than other modes	TTI (2007), TTI (2012), Marquez and Cantillo (2013)
Disposal factor	Environmental	Undesirable output	Calculated based on size and age of fleet based on ABIPECAS – Brazilian Association of Automotive Part Industries (2011), Alianca – Trevisa Investments (2016), Neves (2012), Bureau of Transportation Statistics (2016), Murray (2016), STATISTA (2012)	It represents the disposal of productive assets after the end of the economic cycle	Not used by previous works, but its main component is fleet age, considered by Oliveira and Cicolin (2016)
Emissions	Environmental	Undesirable output	Calculated according to Greenhouse Gas Protocol – World Resources Institute (2016)	Reducing emissions is a concern for most countries (Camioto *et al.*, 2014)	Panagakos (2016), TTI (2007), TTI (2012), Oliveira and Cicolin (2016), Marquez and Cantillo (2013), Kengpol *et al.* (2014)
Off-farm static storage capacity	Economic	Undesirable output	Collected from NASS (2016), IBGE – Brazilian Institute of Geography and Statistics (2016b)	Brazil presents warehouse deficit	Oliveira and Cicolin (2016)
Route extension	Not applicable	Non-discretionary	Collected from Google Maps (2016)	It directly affects fuel consumption, but it is not under total control of decision-makers	Oliveira and Cicolin (2016)

For the calculation of fuel consumption, Baumel (2011) and Baumel *et al.* (2015) compared several methods, including the proposed by TTI (2007), and proved that the best way to estimate fuel consumption for bulk freight transportation is specifically collecting data from each route. However, due to the purpose of this paper, it was not physically possible to locally collect data.

Fuel consumption was also calculated by using the TTI method once it was accepted by the Soy Transportation Coalition (2016). For calculation according to the TTI method, it was important to transform cargo unit capacity of the vehicles in each country, as can be seen in Table IV.

For the USA, the energy efficiency of each mode was calculated as presented in the last report (TTI, 2012). For Brazil, the energy efficiency was calculated using data from the current condition of the Brazilian freight fleet.

In Brazil, the typical bulk commodity truck's body type, axle configuration, fuel, gross, tare, and cargo weight used in this paper were confirmed by *Conselho Nacional de Trânsito*. The truck's body type used in this paper was a CVC (*Combinação de Veículo de Carga,* Combination of Cargo Vehicles in Portuguese), class 3D4, code 88, also known as *Romeo and Juliet* (a combination of a tractor and two trailers), with a Gross Vehicle Weight Rating of 57 tons, which includes 43 tons of cargo weight. The typical axle configuration is legally determined as a tractor with two/three axles, in which two are for steering, commonly named "6 × 4". The typical trailer configuration has two tandem axles. The CVC has total seven axles (CONTRAN – National Traffic Counsil, 1999).

In Brazil, the specification regarding the typical railcar for carrying bulk commodities was confirmed by the main rail company (ALL – Latin America Logistics, 2016) and national specialized publications (Neves, 2012). For information regarding the barges, two inland waterways' complexes were analyzed: the Paraná Waterway and Lake of Ducks. The Paraná Waterway is limited by the structural project to only two combinations of barges: type *Paraná* (three barges and a tow) and type *Tietê* (two barges and a tow). It was assumed that all companies operate with the combination type *Paraná*. An arithmetic average of barge cargo capacity of all operating companies was calculated (AHRANA – Administration of Paraná Waterways, 2012). This was assumed as the "standard" barge and the "standard" combination. The Lake of Ducks is a fluvial lake without known structural restrictions. The company *Aliança* is the oldest and main operator (Alianca – Trevisa Investments, 2016). Its fleet was analyzed and it was similar to the "standard" barge from the Paraná Waterway; therefore the same characteristics were assumed for barges in both inland waterways.

In resume, TTI (TTI, 2007) developed a method for comparing different transport modes applied to a study in the USA. The differences between American and Brazilian freight transport characteristics are principally the cargo capacity, fleet combination, and engine power. These characteristics directly affect fuel consumption, fuel emissions, and volume of cargo carried trip.

	Brazil		USA	
Modal freight unit	Standard cargo unit capacity (ton)	Standard fleet combination	Standard cargo unit capacity (ton)	Standard fleet combination
Highway – truck trailer	43.0	1 tractor (6 × 4):2 trailers (total: seven axes)	25.0	1 tractor (6 × 2) : trailer (total: six axes)
Barge – dry bulk	1287.0	3 barges : 1 barge-tow	1620.0	15 barges : 1 barge-tow
Rail – bulk car	80	80 cars : 4 locomotives	110	108 cars : 3 locomotives

Table IV. Standard modal freight unit capacity and standard fleet combination (per country)

3.2.2 Warehouses. Oliveira and Cicolin (2016) considered the availability of warehouses; nevertheless, the different warehouse sizes and types with various static storage capacities were not considered. This paper considers the sum of static storage capacity by state, divided between in-farm and off-farm warehouses. "In-farm static storage capacity" considers the warehouses that are located inside farms. This capacity normally presents less expensive storage costs, since it falls under the property of the farmer, and the space belong to the farmer. The producers may stock soybean for several months waiting for the best price of sale. The storage may reduce freight transportation flow from farms to export ports during the harvest season.

When considering in-farm static storage capacity as a percentage of the national crop production of each country, Brazil presents, in average, the lowest capacity (11.3 percent). The American average is 65 percent, the European 50 percent, the Argentinian 40 percent, and the Canadian exceeds 80 percent (CONAB – National Supply Company, 2005). *Banco Nacional do Desenvolvimento Social* (BNDES), or The Brazilian National Bank for Development, allegedly distributed five billions *reais* (Brazilian currency) between 2013 and 2014 in order to expand national storage capacity, through five official programs; it is expected to distribute more than 20 billions *reais* in the next few years. The effectiveness of these programs is not yet clear; in fact, one of the most important contributions of the ongoing research on the topic would be to define a way to measure their effectiveness, according to the BNDES analysts (Maia *et al.*, 2013). Due to the reasons discussed above, this paper considered the maximization of in-farm static storage capacity desirable and classified it as an output, while "off-farm static storage capacity" is considered an inputs as it is to be minimized. It is important to keep both storage capacities because they involve different players. In-farm capacity is developed by farmers, while off-farm capacity is developed by trade companies and co-ops and they may be the focus of different funding programs.

3.2.3 Disposal factor. The "disposal factor" represents the disposal of productive assets after the end of the majority of economic cycles. Fleet age, considered by Oliveira and Cicolin (2016), is a strong element of the disposal factor. However, disposal factor is more embracing because it considers the regional fleet in comparison to the national fleet so that it is possible to compare different micro-regions in different countries.

The calculation of the disposal factor is explained in the following equation. For multimodal routes, the total disposal factor is the sum of each mode factors:

$$FD = \frac{(CE)}{(IF_n)} \cdot \frac{(TF_r)}{(TF_n)} \tag{10}$$

where FD is the disposal factor; CE the duration of the economic cycle in years, adopting 100 years; IF_n the average age of the national fleet; TF_r the fleet size required for the transportation of regional crop; and TF_n the fleet size required for the transportation of the national harvest.

3.2.4 Brief considerations about other variables. The input "planted area" directly affects the output "transported harvest." The same planted area does not mean the same harvest, because micro-regions may have different productivities. Oliveira and Cicolin (2016) considered productivity, i.e. harvest divided by planted area. As harvest is already an output in the present paper, it was preferred not to use productivity as an input, because it is the quotient of harvest by planted area.

As it is presented under Section 1, soybeans represent 10 percent of Brazilian exportation. For this model, it was assumed that all collected becomes "transported harvest" sent to ports. It is an overestimation because some part of the harvest is processed near the farms, some part is transported to other harbors (not considered by this model), and some is lost during transportation. This overestimated assumption is valid for long-term decisions because Brazil and the USA present significant perspectives of soybean harvest growth up to 2030 (Matsuda and Goldsmith, 2009).

Social variables used in the comparison of the two countries were problematic since they have different laws regarding work and pollution, and different concepts of incidents and accidents at work (Salin, 2016). "Fatality" is a common term in both countries, i.e. death at work, except suicide. The average of fatalities per mode per country multiplied by the route extension of each mode is an initial attempt for the inclusion of social dimension. Dubey *et al.* (2017) executed a systematic literature review about sustainable or green supply chain management and identified its impact on the health of human beings as a possibility for further study. Panagakos (2016) used the sum of fatalities and serious injuries per year per million ton-km; however, the author did not consider fatalities per mode. The differences in fatalities per mode must be considered as road fatalities are significantly higher than in any other mode; e.g. in 2009, there were 3,236 fatalities on federal Brazilian roads, considering exclusively routes from farms to ports (DNIT, 2010), 22 fatalities on railways (IMTT – Institute of Mobility and Land Transport, 2011) and no registered fatality in inland waterways (Ferreira, 2010). The number of fatalities on roads was probably underestimated because it did not consider fatalities on state and district roads.

The variable "route extension" directly affects fuel consumption and, indirectly emissions and fatalities. It is desirable to minimize the route extension variable, but it is hardly possible. In both countries, the main farms are in centralized locations, far from the ports, due to agricultural conditions, and historical, cultural and economic processes. In most cases, government investments are assumedly not able to change their physical structure. Therefore, route extension is assumed to be non-discretionary (non-controllable).

All variables used are listed under Table AI.

4. Results

4.1 Data analysis

The PCA was performed with SPSS software, considering the initial proposal of the variables. Table V shows the results from the PCA (commonalities).

The communalities indicate the proportion of the variance explained by principal components. There are as many communalities as there are variables in the model and their values can vary between 0 and 1. If the value is 0, the communality factors do not explain any variance of the variable. If the value is 1, they explain themselves entirely. In addition, any value below 0.5 suggests the exclusion of the variable. Therefore, at this point, none of the proposed variables should be deleted.

Table VI presents the eigenvalues, the percentage of variance that the factors are able to explain and the accumulated percentage of this variance. In the last three columns, the values of the held factors in the analysis (after extraction) are repeated and the excluded

Variables	Initial	Extraction
Fuel consumption (input)	1.000	0.924
Planted area (input)	1.000	0.907
Route extension (input)	1.000	0.623
Emissions (output – undesirable)	1.000	0.899
Disposal factor (output – undesirable)	1.000	0.637
Off-farm static storage capacity (output – undesirable)	1.000	0.718
Fatalities (output – undesirable)	1.000	0.583
Transported harvest (output)	1.000	0.818
In-farm static storage capacity (output)	1.000	0.868

Table V. Communalities of proposed variables values are omitted. Table VI contains only three values with eigenvalues greater than 1, which explains 77.53 percent of the total variability. Given the aforementioned results, none of the proposed variables were excluded.

4.2 DEA-SBM model results

The model initially resulted in 58 ties of efficient DMUs. In all, 25 DMUs were efficient by SBM and were also on the inverted frontier. After the application of the standardized composite index, there were no additional efficient ties. Table VII presents the route ranking results. The most efficient route (EH1) is an American unimodal route, exclusively by barge, that links New Madrid, Missouri State, to Gulf of Mississippi. The most efficient Brazilian routes were in the Southern region.

The composite index considers standard and inverted efficiency (Equation (9)). Among the 58 tied DMUs, 25 also presented a value of 1.000 for inverted efficiency. That means they are simultaneously benchmarks for good and bad practices. Some variables' values are very good, but the other values are extremely undesired. They could be named "weakly" efficient DMUs. Table VIII presents simultaneously tied DMUs (weakly and strongly efficient).

Table IX presents the benchmark DMUs for each inefficient DMU, i.e. their $\lambda_k > 0$. In all, 27 DMUs are benchmarks for the 44 inefficient DMUs. Among the benchmarks, 19 are strongly efficient. The most influential benchmarks and the number of influenced DMUs are: ERH12 (18 DMUs may consider it as efficiency benchmark), EH1 (17), ERH9 (15), ERH4 (11), ERF14 (11), F3 (11), RF4 (10) and RF2 (9).

It is possible to determine the impact of the variables in each DMU performance by investigating their slacks. When analyzing inputs, the number of DMUs with slack that is equal to 0 (i.e. it is not necessary to improve those variables to achieve benchmarks) are 58 (regarding to fuel consumption), 79 (regarding to planted area), 58 (emissions), 58 (disposal factor), 62 (fatalities), and 86 (off-farm storage capacity). Table X shows the percentage of necessary improvement for each variable to achieve benchmarks.

All kinds of routes (except Brazilian routes with exclusive rail transportation) present at least one DMU with slacks due to fuel consumption, which means it may be reduced. Table X presents the suggested percentages of alteration suggested in order to achieve benchmarks Neither American routes nor Brazilian routes with exclusively rail transportation had slacks for a planted area. The results suggest it is possible to reduce a planted area without reducing production. No route exclusively by waterway, rail, or even the combination of both modes of transportation had slacks for emissions or disposal factor. The other types of routes may reduce those variables in order to increase efficiency. No American routes with transportation by waterway and no Brazilian routes without road transportation present slacks for fatalities. Due to ethical considerations, the reduction of this variable must be a priority. No route exclusively by waterway, rail, or the combination of both modes presents slacks for off-farm storage capacity. For other routes, the results suggest the variable may be reduced; however,

Component	Eigenvalue	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.600	40.003	44.003	3.600	40.003	44.003
2	1.829	20.325	60.327	1.829	20.325	60.327
3	1.548	17.203	77.530	1.548	17.203	77.530
4	0.943	10.476	88.006			
5	0.654	7.263	95.269			
6	0.245	2.722	97.991			
7	0.108	1.200	99.191			
8	0.058	0.643	99.834			
9	0.015	0.166	100.000			

Table VI. Total variance explained of components and eigenvalues

Table VII.
Route ranking results

Code	Rank	Efficiency	Code	Rank	Efficiency	Code	Rank	Efficiency	Code	Rank	Efficiency
EH1	1	1.0000	RHR7	26	0.8922	R16	51	0.5009	R24	76	0.1901
FH1	2	0.9992	ERF14	27	0.8688	ERF9	52	0.5009	R23	77	0.1736
F5	3	0.9985	ERH4	28	0.8447	ERF5	53	0.5009	R4	78	0.1606
F1	4	0.9982	ERH6	29	0.8326	ERH2	54	0.5009	RF1	79	0.0979
F2	5	0.9978	RF2	30	0.8168	R17	55	0.5009	R5	80	0.0835
F4	6	0.9978	ERH5	31	0.7513	R11	56	0.5009	R8	81	0.0717
F3	7	0.9978	ERF7	32	0.7432	ERF6	57	0.5009	RH3	82	0.0715
ERH12	8	0.9971	ERF8	33	0.7318	ERF15	58	0.5009	R7	83	0.0690
RHR12	9	0.9939	RHF1	34	0.7171	RF3	59	0.5009	R12	84	0.0669
RHR11	10	0.9939	RF11	35	0.6513	RHR2	60	0.5009	R13	85	0.0669
ERH11	11	0.9920	RF12	36	0.6506	RFH1	61	0.5009	RH9	86	0.0662
RHF6	12	0.9918	RF5	37	0.5009	RH8	62	0.4734	RHF3	87	0.0419
ERH10	13	0.9908	R10	38	0.5009	ERH1	63	0.4662	RHR10	88	0.0408
ERH9	14	0.9891	R15	39	0.5009	RHR1	64	0.4476	RF6	89	0.0400
RHF5	15	0.9836	R14	40	0.5009	RH5	65	0.4325	R20	90	0.0399
ERH14	16	0.9829	R6	41	0.5009	RF8	66	0.4037	RHR9	91	0.0397
ERF12	17	0.9812	ERF2	42	0.5009	R2	67	0.3998	R18	92	0.0393
ERH7	18	0.9810	R3	43	0.5009	ERF3	68	0.3857	R19	93	0.0388
ERF11	19	0.9799	RH4	44	0.5009	ERF1	69	0.3832	R9	94	0.0384
ERH8	20	0.9787	ERF4	45	0.5009	RH2	70	0.3630	RHR5	95	0.0383
ERF10	21	0.9778	RH6	46	0.5009	RH7	71	0.3489	RHR6	96	0.0383
ERH13	22	0.9661	ERH3	47	0.5009	RH1	72	0.3415	RHR3	97	0.0375
RHF4	23	0.9267	RF9	48	0.5009	R25	73	0.2813	RHR4	98	0.0374
RHR8	24	0.9203	R26	49	0.5009	RHF2	74	0.2754	RF10	99	0.0350
ERF13	25	0.9067	R1	50	0.5009	RF4	75	0.2558	RF7	100	0.0290
									R22	101	0.0279
									R21	102	0.0273

Table VIII.
Originally tied DMUs divided between weak and strong efficiency. The horizontal bar separates countries

Strongly efficient DMUs Code	Route	Weakly efficient DMUs Code	Route
EH1	New Madrid-Golfo do Mississipi	ERF15	New Madrid-NPW
ERF10	Lac Qui Parle-NPW	ERF2	Champaign-NPW
ERF11	Conttonwood-NPW	ERF4	Plymouth-NPW
ERF12	Faribault-NPW	ERF5	Woodbury-NPW
ERF13	Nodaway-NPW	ERF6	Webster-NPW
ERF14	Audrain-NPW	ERF9	Montgomery-NPW
ERF7	Knox-NPW	ERH2	Champaign-Golfo do Mississipi
ERH10	Lac Qui Parle-Golfo do Mississipi	ERH3	Mclean-Golfo do Mississipi
ERH11	Cottonwood-Golfo do Mississipi	R1	Ijuí-Rio Grande
ERH12	Faribault-Golfo do Mississipi	R10	Dourados-Paranaguá
ERH13	Nodaway-Golfo do Mississipi	R11	Dourados-Santos
ERH14	Audrain-Golfo do Mississipi	R14	Chapadão do Sul-Paranaguá
ERH4	Plymouth-Golfo do Mississipi	R15	Chapadão do Sul-Santos
ERH5	Woodbury-Golfo do Mississipi	R16	Jataí-Paranaguá
ERH6	Webster-Golfo do Mississipi	R17	Jataí-Santos
ERH7	Knox-Golfo do Mississipi	R26	Sorriso-Santos
ERH8	Clinton-Golfo do Mississipi	R3	Bagé-Rio Grande
ERH9	Montgomery-Golfo do Mississipi	R6	Guarapuava-Paranaguá
F1	Santa Maria-Rio Grande	RF3	Dourados-Santos
F2	Londrina-Paranaguá	RF5	Jataí-Paranaguá
F3	Guarapuava-Paranaguá	RF9	Sorriso-Paranaguá
F4	Cascável-Paranaguá	RFH1	Ijuí-Rio Grande
F5	Chapadão do Sul-Santos	RH4	Ijuí-Rio Grande
FH1	Santa Maria-Rio Grande	RH6	Bagé-Rio Grande
RF12	Sorriso-Santos	RHR2	Jataí-Santos
RF2	Ijuí-Rio Grande		
RHF1	Jataí-Santos		
RHF4	Sorriso-Santos		
RHF5	Canarana-Santos		
RHF6	Primavera do Leste-Santos		
RHR11	Primavera do Leste-Santos		
RHR12	Primavera do Leste-Santos		
RHR8	Sorriso-Santos		

it is necessary to perform an analysis beyond the scope of this paper, once the same storage building may be used for stocking different products. Additional information regarding all input variables is shown in Table X.

When analyzing outputs, the DMUs that have a slack equal to 0 for harvest and in-farm storage capacity are 83 and 66, respectively. Neither Brazilian routes with rail transportation nor Brazilian routes with waterway transportation presented slacks for harvest at their final destination. For all the other DMUSs, it may be recommended to increase harvest. No American routes with waterway transportation present slacks for in-farm storage capacity. No Brazilian routes with exclusive transportation by barge or by train present slack for the same variable. It may be recommended to increase in-farm storage capacity for other routes; however, it is necessary to perform an analysis beyond the scope of this paper, looking into the fact that the storage building may be used for stocking different products.

In order to determine corridor efficiency, the arithmetic efficiency was calculated for all the routes of each corridor. As can be seen from the results in Table XI, American corridors are among the most efficient. Although Missouri presents the most efficient route, the most efficient corridor, considering the total of routes, connect**s** Minnesota to Gulf of Mississippi.

DMU	Benchmarks					
ERF1	ERF2	ERF6	RF12	RF2	RHR12	
ERF3	ERF6	ERH6	ERH9	RHR12		
ERF8	ERF12	ERF15	ERF6	ERF9	ERH9	RHR12
ERH1	ERH2	ERH4	ERH6	ERH9	F3	RHR12
R12	EH1	ERF14	ERH12	ERH14		
R13	EH1	ERF14	ERH12	ERH14		
R18	EH1	ERF14	ERH12			
R19	EH1	ERF14	ERH12			
R2	EH1	ERH9	F3	RH6		
R20	EH1	ERH12	ERH14	ERH9		
R21	ERF15	RHF4	RHR12			
R22	EH1	RHF4	RHR12			
R23	ERH12	ERH4	RF2	RHR8		
R24	ERH12	ERH4	ERH8	RF2	RHR8	
R25	RHF4	RHR8				
R4	ERH9	F3	RH4	RHR12		
R5	ERH6	ERH9	F3	RF2		
R7	ERH6	ERH9	F3	RF2		
R8	ERH6	ERH8	ERH9	F3		
R9	ERH4	ERH8	RF2	RHR8		
RF1	ERH4	ERH9	F3	RF2		
RF10	ERF12	ERH12	RHF4			
RF11	ERF6	ERH12	ERH4	ERH9	RF12	RF2
RF4	EH1	ERF14	ERH12			
RF6	EH1	ERF14	ERH12			
RF7	ERF15	RHF4	RHR12			
RF8	ERF6	ERH12	ERH4	RHF4		
RH1	ERH10	ERH4	RF2	RHF4		
RH2	ERH9	F3	RH6			
RH3	ERH9	F3	RH6			
RH5	EH1	ERH9	F3	RH6		
RH7	ERH10	ERH4	RF2	RHF4		
RH8	ERH4	ERH9	F3			
RH9	ERH4	ERH9	F3			
RHF2	EH1	ERF12	ERH12			
RHF3	EH1	ERF14	ERH12			
RHR1	RHF1	RHR2				
RHR10	EH1	RHF6				
RHR3	EH1	ERF14	ERH12			
RHR4	EH1	ERF14	ERH12			
RHR5	EH1	ERF14	ERH12			
RHR6	EH1	ERF14	ERH12			
RHR7	RHF4	RHR8				
RHR9	ERF7	RHF4	RHF6			

Table IX. Benchmarks for inefficient routes (DMUs)

5. Discussions

Two major obstacles were raised during this research. The first obstacle was to guarantee that the estimation of fuel consumption for Brazil was realistic. Results were compared with estimative of experts and proved to be adequate in an average scenario. The second obstacle was to guarantee that the proposed variables were suitable to the model. The choice of variables was based on literature review, data availability, and dimensions of sustainability. The PCA analysis supported the proposal of the variables. Ranking results were similar and coherent with literature.

DMU	Fuel consumption (%)	Planted area (%)	Emissions (%)	Disposal factor (%)	Fatalities (%)	Off-farm static storage capacity (%)
ERF1	19.45		41.42	14.63		3.46
ERF3	9.11		34.33	8.04	1.96	2.28
ERF8	24.89		42.28	25.14		
ERH1	7.23		20.98	14.28		5.88
R12	13.81		21.83	9.82	21.72	
R13	13.81		21.83	9.84	21.72	
R18	8.32	0.45	12.82	4.36	12.86	
R19	8.35	0.25	12.92	4.85	13.08	
R2	28.36	10.00	62.57	35.07	56.12	
R20	8.19		12.93	4.18	13.11	
R21	10.53		10.63	10.32	5.04	0.31
R22	10.87		10.95	10.65	4.98	0.91
R23	58.55	0.05	61.91	48.59	36.06	
R24	60.57		65.07	45.25	37.74	
R25	92.77		94.91	82.75	36.36	
R4	18.59		34.49	22.69	43.42	2.02
R5	12.12		22.44	1.38	24.09	2.50
R7	10.73		18.67	1.10	19.71	1.02
R8	14.58	1.58	23.96	16.77	24.50	
R9	7.97	0.74	11.11	1.75	9.99	
RF1	4.15		11.76	6.14	16.91	2.55
RF10	12.40		12.96	12.16	4.22	2.94
RF11	32.20		27.30	29.10		
RF4	9.08	0.55	18.78	11.12	16.79	
RF6	7.01	0.61	12.29	5.89	12.15	
RF7	10.69		10.88	10.61	3.58	0.86
RF8	58.04	0.58	61.07	55.03	29.49	
RH1	40.45	0.62	71.49	3.85	65.63	
RH2	19.75	12.11	31.31	24.26	29.42	2.21
RH3	14.87	19.78	22.46	10.08	20.28	3.56
RH5	26.58	9.54	63.85	48.52	54.63	
RH7	43.00	1.33	57.13	8.30	14.90	
RH8	16.73	10.80	21.07	21.01	16.19	1.00
RH9	12.40	18.64	17.93	8.88	14.46	2.66
RHF2	5.41	0.16	10.05	6.88	10.89	
RHF3	6.59	0.13	11.16	6.33	10.80	
RHR1	6.33		26.08	12.80	29.20	
RHR10	3.72	0.38	5.80	5.06	4.04	0.38
RHR3	7.56	0.45	11.97	9.33	12.04	
RHR4	7.55	0.40	11.99	9.39	12.14	
RHR5	7.37	0.06	11.99	8.68	11.90	
RHR6	7.36	0.01	12.01	8.74	11.95	
RHR7	3.35		9.15	11.61	10.12	
RHR9	3.79		5.52	5.20	3.84	
Average	18.30	3.88	27.14	16.15	19.95	2.16

Table X.
Slack analysis of input variables

Regarding results, Table XII summarizes the resemblance among the more and less efficient routes. Among the efficient routes, the combination of two modes in the same route is predominant. This is in accordance with the green premise, which prioritizes multimodal corridors (Panagakos, 2016). According to a previous work (Oliveira and Cicolin, 2016), the three most efficient routes in Brazil are combinations of two modes. Among the least efficient, unimodal routes are more frequent, followed by tri-modal routes, suggesting that a

Table XI. Corridor efficiencies

Code	Rank	Efficiency	Origin	Destination	Code	Rank	Efficiency	Origin	Destination
EC9	1	0.9933	MN	Gulf of Mississippi	EC6	11	0.5009	IA	NPW
EC1	2	0.9872	MO	Gulf of Mississippi	EC3	12	0.4893	IL	Gulf of Mississippi
EC7	3	0.9829	IN	Gulf of Mississippi	C2	13	0.4467	PR	Paranaguá
EC10	4	0.9796	MN	NPW	EC4	14	0.4232	IL	NPW
EC5	5	0.8095	IA	Gulf of Mississippi	C4	15	0.3562	MS	Paranaguá
EC2	6	0.7588	MO	NPW	C6	16	0.2703	GO	Paranaguá
C1	7	0.6878	RS	Rio Grande	C7	17	0.2404	GO	Santos
EC8	8	0.6586	IN	NPW	C8	18	0.2360	MT	Paranaguá
C5	9	0.5777	MS	Santos	C3	19	0.0636	PR	Santos
C9	10	0.5748	MT	Santos					

limit of modes to multimodal routes be considered efficient. Three or more modes in the same route may induce inefficiency.

Road mode is highly placed among the more and the less efficient routes. In the USA, trucks are used for transporting cargo through short distances (less than 200 km on average), while, in Brazil, trucks may be used for transportation through more than 3,000 km. American routes are dominant among the most efficient, while there is no American route among the least efficient, suggesting that short road routes are more adequate to strengthen efficiency.

Among the efficient routes, trains (F1, F2, F3, F4, and F5) and barges (EH1, FH1) are frequently present. In the USA, the combination of truck and barge is the most frequent occurrence among efficient DMUs. Among the least efficient, long routes performed exclusively by truck are the most common (15 occurrences), followed by the combination of barges and trucks (ten occurrences). The barges are exclusively from the Paraná Waterway, which is limited, by the infrastructural project, to a maximum combination of three barges and tow. In the USA, combinations of 15 barges and a tow can navigate through the Mississippi River. Also, the Paraná Waterway is not directly connected to Port of Santos, so it is mandatory to perform the last kilometers of the route by truck; however, this situation is does not occur in the USA. The results suggest that it is recommended to focus investments on waterways projects without structural limitations and directly connected to ports. Oliveira and Cicolin (2016) analyzed routes in Amazon River (with a barge configuration similar to Mississippi, but still under-utilized) and concluded that they were among the most efficient routes.

In accordance with the fact that the existence of barges or trains supports an efficient route, Marquez and Cantillo (2013) analyzed the cost of Colombian and multimodal routes. The authors concluded that the barges, followed by trains and trucks, present less external costs. Nevertheless, a caveat is in order: the study did not consider the risks of drought and did not specify the type of barge combination.

In 2007, the Brazilian Government began a comprehensive infrastructural improvement strategy with major institutional and regulatory changes to facilitate agricultural exports. The objective is that within 15-20 years, the railways' participation will increase from 25 to 35 percent; waterways from 13 to 29 percent; and truck shipments will be reduced by 28 percent, from 58 to 30 percent. In January 2007, the Brazilian Government created the Growth Acceleration Plan 1 (PAC 1) in order to modify the transportation matrix. This plan promoted sustainable social and economic development by generating employment, income and reducing regional inequalities. By March 2010, the Government announced a second Growth Acceleration Plan (PAC 2) 2011-2014 (Salin, 2016).

The 2015 Transportation assessment report and the ninth evaluation results of Growth Acceleration Program 2 (PAC 2), 2011-2015, showed that Brazil did not finish the projects as planned. An example is highway BR-163 which began in PAC 1. The 619 miles highway, connecting Brazil's Midwest to the Amazon River, has not been completed. The completion of this highway will significantly reduce transportation costs to the Amazon River ports (Salin, 2016). The present study suggests investments in waterways without structural limitations, such as Amazon-Tapajós, should be prioritized.

Table XII. Summary of the 30 top and less efficient routes

	Number of modes			Type of modes			Country	
	One	Two	Three	Road	Rail	Waterway	USA	Brazil
30 most efficient	6	17	7	23	15	19	16	14
30 least efficient	15	7	8	30	7	10	0	30

6. Conclusions

The DEA was presented as a solution tool for benchmarking the efficiency of freight transport routes and corridors. The choice of variables was guided by the availability of the data, the dimensions of sustainability, and literature review. Data analysis for maintaining variables in the model was performed guided by the PCA.

The DEA is an adequate tool because it attributes the best weight possible to each analyzed unit, overcoming the weight obstacles faced by a previous work (Panagakos, 2016). A few of the restrictions cited by Panagakos were: weights required for calculation rely heavily on user interpretation, attributed weights can lead to misinterpretation, weights change over time, and weights may not reflect specific characteristics of a country in transport operations.

The weight choice with DEA is not dependent on human attributions and subject to political or particular interpretations. As a matter of fact, weights change with time and consequently, the data will also change. DEA applied with the updated data will automatically apply updated weights after a certain period of time, resulting in the use of the best possible attributes. Country-specific characteristics can be resolved with an accurate choice of variables, validated by literature review, statistical tools, and stakeholder consulting.

The best DEA weight attribution may cause many ties. In the present application, the problem of ties was overcome by the tiebreaking method of a composite index (Leta *et al.*, 2005). Hence, an initial method for benchmarking freight transport routes and corridors was formulated. This method may be used to direct private and public investments on logistics infrastructure. Corridor benchmarking is a rare topic in the literature. Previous works normally focused on some specific and limited corridor performance characteristics, such as cost. The main contribution of this research is that it expands the discussion about corridor benchmarking and it focuses on efficiency as a whole. The fact that the method used can be reapplied in different contexts in logistics is also a significant contribution.

Among DEA models, the SBM was chosen, because it minimizes inputs and simultaneously maximizes outputs. Since SBM is not affected by units of measure, it is possible to compare variables originated from different dimensions (economic, social, and environmental). The results were similar to those of Oliveira and Cicolin (2016), which applied the DEA-BCC model to measure Brazilian route efficiencies, and to a respected annual international report (Salin, 2016) that compares soybean transportation in both countries. The report also shows that routes in the Southern Brazilian regions (C1) are less onerous.

The practical implications show that American routes are more efficient than Brazilian ones. Routes with terminals for exchanging transportation mode tend to be more efficient, but there may be a limit for multimodality. The most efficient routes tend to present only two modes: short truck trips and long barge trips or short truck trips and long train trips. Inland waterway transportation tends to be efficient only with big combinations of barges (i.e. 15 barges pushed by a tow) and when they are directly connected to the final destination port. In accordance with a previous work that analyzes current Brazilian transport matrix (Barros *et al.*, 2015), the finding presented here not only contribute to the literature through their empirical application, but may also assist Brazilian authorities in setting up more adequate policies and investments to minimize the country's excessive dependence on road transportation. The results suggest that an increased focus should be given to railways and inland waterways projects.

For further studies, the expansion and inclusion of variables such as maintenance route costs, trade imbalance, lead time, type of cargo, and a variable that represents social values, such as the quality of life of the operator, is recommended. It is also recommended that a risk analysis considering environmental catastrophic events, such as droughts, be included. Slack interpretation of SBM to variables in- and off-farm storage capacity may point the number of storages that should be built as to increase route efficiency. Further studies should focus on guiding storage investments. It is also recommended to include link and carryover variables, and to explore the possibilities of other DEA models, such as network and dynamic models; structural window analysis; and other tiebreaking methods.

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Appendix

Table AI. Routes and data

Code	Fuel consumption (L)	Planted area (thousand ha)	Emissions (kg of CO 2eq)	Disposal factor	Fatalities	Harvest (t)	In-farm static storage capacity (t)	Off-farm static storage capacity (t)	Route extension (km)	Route
EH1	33,987.63	438.00	124.67	0.13	9.00	1,369,420.86	14,151,971.00	6,667,756.00	650.3	New Madrid-Mississippi
ERF1	570,521.24	616.00	11,560.99	0.64	2,908.50	2,393,696.94	39,489,441.00	39,734,379.00	4,267.2	Edgard-NPW
ERF10	281,827.76	627.00	3,920.75	0.48	1,455.67	1,784,318.53	40,822,992.00	19,595,036.00	3,004.9	Lac Qui Parle-NPW
ERF11	266,092.99	552.00	3,453.89	0.46	1,352.97	1,706,645.99	40,822,992.00	19,595,036.00	2,991.9	Conttonwood-NPW
ERF12	238,382.38	493.00	2,993.22	0.41	1,307.15	1,537,856.53	40,822,992.00	19,595,036.00	2,986.1	Faribault-NPW
ERF13	286,951.62	442.00	4,462.56	0.39	2,879.16	1,452,890.27	14,151,971.00	6,667,756.00	3,700.3	Nodaway-NPW
ERF14	230,205.75	341.00	4,959.08	0.29	4,502.61	1,065,670.59	14,151,971.00	6,667,756.00	3,818.8	Audrain-NPW
ERF15	334,596.85	438.00	5,381.09	0.37	3,697.48	1,369,420.86	14,151,971.00	6,667,756.00	4,554.8	New Madrid-NPW
ERF2	522,894.27	566.00	9,171.40	0.61	2,461.74	2,285,570.44	39,489,441.00	39,734,379.00	4,206.0	Champaign-NPW
ERF3	479,331.92	524.00	8,586.39	0.56	2,520.87	2,083,632.71	39,489,441.00	39,734,379.00	4,214.1	Mclean-NPW
ERF4	544,326.78	642.00	9,395.73	0.58	3,899.02	2,171,837.58	54,430,656.00	38,917,919.00	4,620.0	Plymouth-NPW
ERF5	617,219.30	565.00	14,906.10	0.59	6,206.86	2,213,830.83	54,430,656.00	38,917,919.00	4,800.3	Woodbury-NPW
ERF6	461,537.86	503.00	5,387.83	0.53	2,343.82	1,992,434.14	54,430,656.00	38,917,919.00	4,498.5	Webster-NPW
ERF7	208,698.23	279.00	2,950.14	0.27	2,468.05	1,003,565.21	32,114,087.00	24,410,789.00	3,948.1	Knox-NPW
ERF8	445,556.94	469.00	9,178.79	0.52	4,033.91	1,948,290.88	32,114,087.00	24,410,789.00	4,080.8	Clinton-NPW
ERF9	273,995.17	47.00	7,259.94	0.29	5,761.43	1,089,157.42	32,114,087.00	24,410,789.00	4,227.2	Montgomery-NPW
ERH1	119,700.58	642.00	3,726.77	0.42	796.05	2,393,696.94	39,489,441.00	39,734,379.00	977.6	Edgard-Mississippi
ERH10	119,322.24	627.00	3,214.23	0.32	978.43	1,784,318.53	40,822,992.00	19,595,036.00	1,375.3	Lac Qui Parle-Mississippi
ERH11	109,157.14	552.00	2,649.59	0.30	831.17	1,706,645.99	40,822,992.00	19,595,036.00	1,356.6	Cottonwood-Mississippi
ERH12	81,459.51	493.00	943.45	0.27	275.49	1,537,856.53	40,822,992.00	19,595,036.00	1,286.3	Faribault-Mississippi
ERH13	96,634.33	442.00	4310.89	0.26	2,931.21	1,452,890.27	14,151,971.00	6,667,756.00	1,083.2	Nodaway-Mississippi
ERH14	48,944.99	341.00	1,287.87	0.19	1,126.49	1,065,670.59	14,151,971.00	6,667,756.00	951.5	Audrain-Mississippi
ERH2	116,068.79	565.00	3,710.10	0.40	832.34	2,285,570.44	39,489,441.00	39,734,379.00	982.6	Champaign-Mississippi
ERH3	98,935.56	503.00	2,794.63	0.37	678.11	2,083,632.71	39,489,441.00	39,734,379.00	961.4	Mclean-Mississippi
ERH4	119812.45	616.00	2422.38	0.38	929.65	2171837.58	54430656.00	38917919.00	1224.3	Plymouth-Mississippi
ERH5	156,640.84	566.00	5,654.04	0.39	2,313.13	2,213,830.83	54,430,656.00	3,891,7919.00	1,298.2	Woodbury-Mississippi
ERH6	111,765.68	524.00	2,592.89	0.35	1,112.14	1,992,434.14	54,430,656.00	38,917,919.00	1,204.4	Webster-Mississippi
ERH7	54,516.37	279.00	2,112.17	0.18	1,770.30	1,003,565.21	32,114,087.00	24,410,789.00	961.9	Knox-Mississippi
ERH8	82,348.96	469.00	2,807.86	0.35	1,196.86	1,948,290.88	32,114,087.00	24,410,789.00	796.0	Clinton-Mississippi
ERH9	37,480.90	47.00	838.76	0.20	603.69	1,089,157.42	32,114,087.00	24,410,789.00	745.7	Montgomery-Mississippi

(continued)

Table AI.

Code	Fuel consumption (L)	Planted area (thousand ha)	Emissions (kg of CO 2eq)	Disposal factor	Fatalities	Harvest (t)	In-farm static storage capacity (t)	Off-farm static storage capacity (t)	Route extension (km)	Route
F1	96,249.41	902.00	1,767.14	0.14	6.90	2,348,669.66	4,549,953.00	28,732,246.00	627.0	Santa Maria-Rio Grande
F2	158,919.08	1,535.00	2,917.76	0.27	5.91	4,527,862.00	2,321,959.00	30,962,392.00	537.0	Londrina-Paranaguá
F3	119,688.69	1,497.00	2,197.49	0.27	4.57	4,415,811.00	2,321,959.00	30,962,392.00	414.7	Guarapuava-Paranaguá
F4	151,921.76	1,188.00	2,789.29	0.21	7.30	3,504,301.00	2,321,959.00	30,962,392.00	663.3	Cascável-Paranaguá
F5	40,735.23	182.00	747.90	0.04	13.03	526,437.12	1,947,286.00	7,016,459.00	1,183.9	Chapadão do Sul-Santos
FH1	117,147.41	902.00	1,019.56	0.28	5.00	2,348,669.66	4,549,953.00	28,882,287.00	640.0	Santa Maria-Rio Grande
R1	621,988.69	3,463.00	71,410.53	2.02	3,948.79	9,020,409.31	4,549,953.00	28,732,246.00	593.0	Ijuí-Rio Grande
R10	418,526.12	1,289.00	4,8050.99	0.84	1,1401.92	3,737,616.41	1,947,286.00	7,016,459.00	963.0	Dourados-Paranaguá
R11	463,725.20	1,289.00	53,240.30	0.84	12,633.28	3,737,616.41	1,947,286.00	7,016,459.00	1,067.0	Dourados-Santos
R12	163,806.18	421.00	18,806.59	0.28	13,663.36	1,220,739.25	1,947,286.00	7,016,459.00	1,154.0	Sidrolândia-Paranaguá
R13	162,812.55	421.00	18,692.51	0.28	13,580.48	1,220,739.25	1,947,286.00	7,016,459.00	1,147.0	Sidrolândia-Santos
R14	72,966.64	182.00	8,377.30	0.12	14,113.28	526,437.12	1,947,286.00	7,016,459.00	1,192.0	Chapadão do Sul-Paranaguá
R15	59,560.86	182.00	6,838.19	0.12	1,1520.32	526,437.12	1,947,286.00	7,016,459.00	973.0	Chapadão do Sul-Santos
R16	851,893.26	1,977.00	97,805.87	1.29	14,964.11	5,732,615.00	1,875,807.00	12,434,499.00	1,278.0	Jataí-Paranaguá
R17	715,243.71	1,977.00	82,117.14	1.29	12,563.76	5,732,615.00	1,875,807.00	12,434,499.00	1,073.0	Jataí-Santos
R18	199,421.28	468.00	22,895.56	0.31	14,800.18	1,356,822.00	1,875,807.00	12,434,499.00	1,264.0	Rio Verde-Paranaguá
R19	163,449.72	468.00	18,765.67	0.31	12,130.53	1,356,822.00	1,875,807.00	12,434,499.00	1,036.0	Rio Verde-Santos
R2	100,228.12	902.00	11,507.19	0.53	2,443.86	2,348,669.66	4,549,953.00	28,732,246.00	367.0	Santa Maria-Rio Grande
R20	144,894.43	443.00	16,635.33	0.29	11,357.73	1,284,631.00	1,875,807.00	1,2434,499.00	970.0	Cristalina-Santos
R21	2,138,823.38	1,350.00	245,558.32	2.20	20,044.53	327,876.67	14,201,140.00	28,882,287.00	1,870.0	Canarana-Paranaguá
R22	1,906,640.95	1,350.00	218,901.45	2.20	17,868.58	327,876.67	14,201,140.00	28,882,287.00	1,667.0	Canarana-Santos
R23	1,167,677.66	1,912.00	134,061.08	1.32	18,286.62	5,886,300.00	14,201,140.00	28,882,287.00	1,706.0	Primavera do Leste-Paranaguá
R24	1,060,902.91	1,912.00	121,802.27	1.32	16,614.45	5,886,300.00	14,201,140.00	28,882,287.00	1,550.0	Primavera do Leste-Santos
R25	1,090,712.86	3,206.00	125,224.75	0.93	24,278.54	9,836,300.00	14,201,140.00	28,882,287.00	2,265.0	Sorriso-Paranaguá
R26	921,688.49	3,206.00	105,819.06	0.93	20,516.17	9,836,300.00	14,201,140.00	28,882,287.00	1,914.0	Sorriso-Santos
R3	35,791.44	460.00	4,109.22	0.27	1,711.37	1,197,689.90	4,549,953.00	28,732,246.00	257.0	Bagé-Rio Grande
R4	255,876.86	1,535.00	29,377.23	1.02	4,671.92	4,527,862.00	2,321,959.00	30,962,392.00	486.0	Londrina-Paranaguá
R5	333,271.71	1,535.00	38,262.93	1.02	6,085.03	4,527,862.00	2,321,959.00	30,962,392.00	633.0	Londrina-Santos
R6	181,253.64	1,497.00	20,809.74	0.99	3,393.39	4,415,811.00	2,321,959.00	30,962,392.00	353.0	Guarapuava-Paranaguá
R7	358,399.55	1,497.00	41,147.86	0.99	6,709.88	4,415,811.00	2,321,959.00	30,962,392.00	698.0	Guarapuava-Santos

(continued)

Code	Fuel consumption (L)	Planted area (thousand ha)	Emissions (kg of CO 2eq)	Disposal factor	Fatalities	Harvest (t)	In-farm static storage capacity (t)	Off-farm static storage capacity (t)	Route extension (km)	Route
R8	243,263.69	1,188.00	27,929.11	0.79	5,738.97	3,504,301.00	2,321,959.00	30,962,392.00	597.0	Cascável-Paranaguá
R9	414,811.45	1,188.00	47,624.51	0.79	9,786.04	3,504,301.00	2,321,959.00	30,962,392.00	1,018.0	Cascável-Santos
RF1	210,252.40	1,535.00	8,811.34	1.28	1,061.32	4,527,862.00	2,321,959.00	30,962,392.00	634.5	Londrina-Paranaguá
RF10	1,564,074.88	1,350.00	92,699.26	2.78	6,540.66	327,876.67	14,201,140.00	28,882,287.00	1,981.0	Canarana-Santos
RF11	772,399.06	1,912.00	36,692.55	1.67	3,978.81	5,886,300.00	14,201,140.00	28,882,287.00	1,742.0	Primavera do Leste-Santos
RF12	774,569.96	3,206.00	52,352.94	1.17	9,123.93	9,836,300.00	14,201,140.00	28,882,287.00	2,222.0	Sorriso-Santos
RF2	397,403.95	3,463.00	11,848.76	2.55	306.19	9,020,409.31	4,549,953.00	28,732,246.00	639.0	Ijuí-Rio Grande
RF3	531,723.81	1,289.00	33,152.59	1.06	6,619.75	3,737,616.41	1,947,286.00	7,016,459.00	1,741.9	Dourados-Santos
RF4	153,793.30	421.00	8,546.38	0.35	4,962.15	1,220,739.25	1,947,286.00	7,016,459.00	1,601.9	Sidrolândia-Santos
RF5	779,261.84	1,977.00	65,290.76	1.62	9,292.60	5,732,615.00	1,875,807.00	12,434,499.00	1,462.0	Jataí-Paranaguá
RF6	182,861.62	468.00	15,272.19	0.39	9,175.51	1,356,822.00	1,875,807.00	12,434,499.00	1,452.0	Rio Verde-Paranaguá
RF7	2,031,355.18	1,350.00	191,737.03	2.78	15,161.14	327,876.67	14,201,140.00	28,882,287.00	2,069.0	Canarana-Paranaguá
RF8	1,062,983.12	1,912.00	97,216.66	1.67	12,770.81	5,886,300.00	14,201,140.00	28,882,287.00	1,846.0	Primavera do Leste-Paranaguá
RF9	1,028,611.68	3,206.00	100,629.55	1.17	1,9019.98	9,836,300.00	14,201,140.00	28,882,287.00	2,429.0	Sorriso-Paranaguá
RFH1	473,538.79	3,463.00	8,901.80	3.08	305.00	9,020,409.31	4,549,953.00	28,882,287.00	645.0	Ijuí-Rio Grande
RH1	672,621.23	3,463.00	47,964.68	2.55	2,631.57	9,020,409.31	4,549,953.00	28,732,246.00	710.0	Ijuí-Rio Grande
RH2	146,729.79	902.00	9,227.81	0.67	1,939.03	2,348,669.66	4,549,953.00	28,732,246.00	606.0	Santa Maria-Rio Grande
RH3	86,800.88	460.00	6,080.74	0.34	2,511.71	1,197,689.90	4,549,953.00	28,732,246.00	692.0	Bagé-Rio Grande
RH4	529,047.97	3,463.00	55,584.85	2.55	3,070.03	9,020,409.31	4,549,953.00	28,732,246.00	516.5	Ijuí-Rio Grande
RH5	91,868.74	902.00	9,205.19	0.67	1,951.31	2,348,669.66	4,549,953.00	28,732,246.00	348.5	Santa Maria-Rio Grande
RH6	32,503.49	460.00	3,047.25	0.34	1,265.44	11,97,689.90	45,49,953.00	28,732,246.00	245.5	Bagé-Rio Grande
RH7	719,267.99	3,463.00	32,235.16	2.55	1,746.83	9,020,409.31	4,549,953.00	28,732,246.00	804.0	Ijuí-Rio Grande
RH8	149,589.90	902.00	4,066.21	0.67	827.89	2,348,669.66	4,549,953.00	2,873,2246.00	666.0	Santa Maria-Rio Grande
RH9	91,880.29	460.00	3,864.33	0.34	1,573.70	1,197,689.90	4,549,953.00	28,732,246.00	778.0	Bagé-Rio Grande
RHF1	689,834.35	1,977.00	18,797.54	1.96	2,348.41	5,732,615.00	1,875,807.00	12,434,499.00	1,389.0	Jataí-Santos
RHF2	159,960.04	468.00	4,068.71	0.47	2,102.29	1,356,822.00	1,875,807.00	1,2434,499.00	1,368.0	Rio Verde-Santos
RHF3	203,999.59	443.00	10,176.56	0.44	6,426.64	1,284,631.00	1,875,807.00	12,434,499.00	1,715.0	Cristalina-Santos
RHF4	77,694.63	3,206.00	5,465.41	0.12	12,913.59	9,836,300.00	14,201,140.00	28,882,287.00	2,392.0	Sorriso-Santos
RHF5	37,254.38	1,350.00	2,209.79	0.07	8,567.94	327,876.67	14,201,140.00	28,882,287.00	1,987.0	Canarana-Santos
RHF6	24,666.35	1,912.00	1,408.70	0.05	7,719.94	5,886,300.00	14,201,140.00	28,882,287.00	1,886.0	Primavera do Leste-Santos

(continued)

Table AI.

Table AI.

Code	Fuel consumption (L)	Planted area (thousand ha)	Emissions (kg of CO 2eq)	Disposal factor	Fatalities	Harvest (t)	In-farm static storage capacity (t)	Off-farm static storage capacity (t)	Route extension (km)	Route
RHR1	752,027.00	1,977.00	41,477.19	2.90	6,255.65	5,732,615.00	1,875,807.00	12,434,499.00	1,294.0	Jataí-Santos
RHR10	38,078.02	1,912.00	2,880.67	0.10	1,1708.10	327,876.67	14,201,140.00	28,882,287.00	1,830.0	Canaran-Santos
RHR11	26,440.07	1,350.00	1,955.26	0.07	1,1290.15	5,886,300.00	14,201,140.00	28,882,287.00	1,813.0	Primavera do Leste-Santos
RHR12	25,521.92	1,350.00	1,881.12	0.07	10,861.30	5,886,300.00	14,201,140.00	28,882,287.00	1,751.0	Primavera do Leste-Santos
RHR2	713,898.44	1,977.00	38,398.32	2.90	5,787.20	5,732,615.00	1,875,807.00	12,434,499.00	1,232.0	Jataí-Santos
RHR3	174,680.08	468.00	9,436.63	0.69	6,009.76	1,356,822.00	1,875,807.00	12,434,499.00	1,273.0	Rio Verde-Santos
RHR4	165,655.64	468.00	8,707.91	0.69	5,541.31	1,356,822.00	1,875,807.00	12,434,499.00	1,211.0	Rio Verde-Santos
RHR5	220,505.70	443.00	15,262.83	0.65	10,330.38	1,284,631.00	1,875,807.00	12,434,499.00	1,642.0	Cristalina-Santos
RHR6	211,961.42	443.00	14,572.88	0.65	9,861.93	1,284,631.00	1,875,807.00	12,434,499.00	1,580.0	Cristalina-Santos
RHR7	81,251.73	3,206.00	6,762.58	0.17	16,478.15	9,836,300.00	14,201,140.00	28,882,287.00	2,297.0	Sorriso-Santos
RHR8	79,070.98	3,206.00	6,586.48	0.17	16,049.30	9,836,300.00	14,201,140.00	28,882,287.00	2,235.0	Sorriso-Santos
RHR9	39,383.05	1,912.00	2,986.05	0.10	12,136.95	327,876.67	14,201,140.00	28,882,287.00	1,892.0	Canarana-Santos

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