Sustainability Management of the VHP Sugar Supply Chain: Case Study in the Transportation Stage

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Abstract

Concerns about the environmental impacts of sugar production in Brazil opens up space for the development of research on Supply Chain Sustainability Management (SCSM). This work report uses Life Cycle Assessment (LCA) and multi-objective optimization (MOO) methods, especially in the transport phase of very high polarization (VHP) sugar, in order to perform an environmental and economic performance evaluation, for two scenarios, using a case study involving a linear programming problem. In the first scenario, the transportation is carried out only by the road modal, in the second scenario the transportation is intermodal, where a portion of the route was a railroad. With regard to the evaluation of environmental impacts, for the case study, input data regarding the equivalent CO_2 emission were used. For the economic performance indicator, primary data from a brazilian sugar mills and background data obtained through national reports, manuals and databases were used. Based on the methodology used applying MOO to minimize cost, the model provided optimal cost and CO_2 emissions solutions for scenario one, of 5.72×10^{10} kg of CO_2 and cost of USD 33,216, respectively. Scenario two shows an improvement in environmental performance, reducing CO_2 emissions to 1.51×10^9 kg of CO_2, but increasing costs to USD 98,555. The results of the scenario showed that the railroads may bring relevant environmental benefits, such as of reducing the emission of greenhouse gases, but an alternative little explored in Brazil.

Keywords: *linear programming, multi-objective optimization, life cycle assessment, sugar cane, VHP sugar.*

1. Introduction

Companies in the agro-industrial sector have been faced with a new market reality, with the increase of the achievements by lower cost and differentiation in the product (MACHADO, 2012). Supply Chain Sustainability Management (SCSM) has been growing along with the interest of decision makers in improving and optimizing the processes of a product. The SCSM concept can be extended to the study of many products or inputs, and may have, as one of its purposes, an economic-environmental analysis aimed at improving the performance of the product within the supply chain (SC) (CARTER; ROGERS, 2008).

The idea of SCSM gains significance when it comes to elementary products of consumption and economy. Based on the importance of analyzing these products, sugar cane appears on the scene because it is an extremely important product in SC in Brazil. According to the Brazilian Institute of Geography and Statistics (IBGE), sugar cane is responsible for agricultural production of 715,494,327 tons in 2017, and thus, puts the country first in the world production and export of sugar cane according to with a report made that same year by the Office of Global Analysis of the United States Department of Agriculture (USDA, 2017).

When we consider the environmental impacts involved, we can highlight the transportation phase in the supply chain of sugar cane derivatives, which is significant since a great mass movement occurs along the chain. This transport is carried out largely through the highway network (SILVA, 2006). A byproduct of cane is VHP (very high polarization) sugar, a commodity used for export. This raw sugar has physical-chemical properties aimed at reducing operational costs of refineries.

Due to the size of the transportation stage in the CS of sugar, especially VHP sugar that travels long distances from the interior of the state to the port, there is a concern about the costs of distribution and the environmental impacts generated. An improvement in the operation of SC can contribute to the reduction of greenhouse gas (GHG) emissions in the environment (ZHANG *et al.*, 2014). Also, improvements in amounts transported may reflect a large reduction of costs (JIANG; GROSSMANN, 2015).

Based on the importance of the transportation phase within the sugar industry and the new market reality, the paper proposes to develop a study aiming at sustainability management in a group of brazilian plants, in view of VHP sugar. In this way, a multi-objective optimization (MOO) is sought in the transport stage of sugar cane and VHP sugar, using a linear programming (LP) model for the performance evaluation in SC under the Life Cycle Assessment (LCA) in different scenarios.

2. Literature review

Sustainable development in the supply chain is one of the most important topics currently in the literature. The term sustainability, in relation to business, refers to concerns with the Triple Bottom Line (TBM) encompassing an evaluation that contemplates the operational dimensions: economic, social and environmental (ELKINGTON, 2002). However, a series of information can be provided by combining two dimensions, normalized to each other. In this case, indicators of economic and environmental performance of services and products, when combined, identify activities in the process that are significantly less sustainable than economic gains from human activity (CLIFT, 2004).

Thus, the theoretical framework of sustainability management in the supply chain helps in dynamic inter-organizational interactions, information flow and environmental management of SC in developing countries through a global approach. It also improves stakeholder understanding of the company's role and sustainable development in the supply chain describing actions needed to achieve the desired level of sustainability (GOMEZ-LUCIANO *et al.*, 2018).

For the development of performance evaluation (environmental and economic), concepts of Life Cycle Assessment techniques can be employed due to linear relationships between actions, environmental impact and costs (AZAPAGIC; CLIFT, 1998).

Linear programming is usually applied to problems involving the Management Sustainability in order to provide supply chain improvements (TASCIONE; MOSCA; RAGGI, 2015). Linear programming models in multi-objective optimization problems can control the optimality and viability within the set of decisions (GHADERI; MOINI; PISHVAEE, 2018), besides serving as a quantitative tool for decision making in the area of optimum design and SC planning (KOSTIN *et al.*, 2018).

The GAMS software in conjunction with the CPLEX solver is an instrument that allows OMO in plant management and routing (MAHMOUDSOLTANI; SHAHBANDARZADEH; MOGHDANI, 2018), as some studies show, this approach presents complex decision analyzes involving SC design strategies and tactical operation, even within a dynamic and uncertain environment (MURILLO-ALVARADO *et al.*, 2015, TSAO *et al.*, 2017).

3. Supply chain network and problem statement

For the case study (scenarios 1 and 2), a SC structure was assembled (Fig. 1). SC includes the following elements: a set of six properties (P_1 to P_6) from where the product originates; a set of two plants (U_1 and U_2) where the products are processed before being sent to the port (D_1); in one of the cases the transport is done by the modal rail from the train station (S_1).

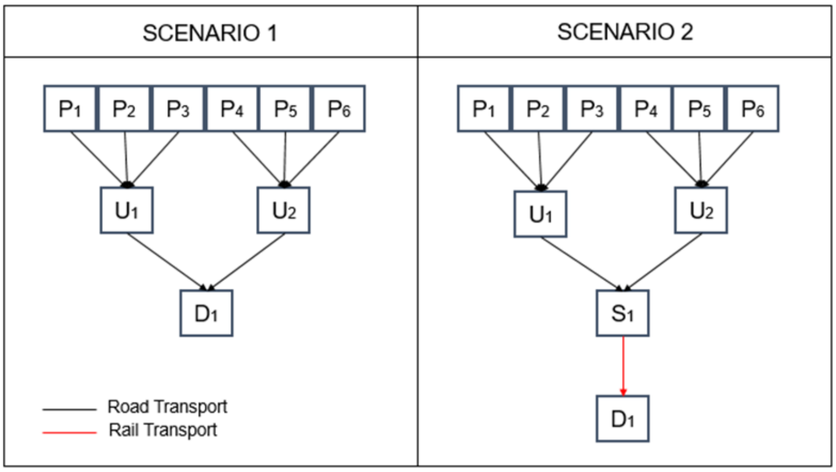


Fig. 1 SC networks that links the producing properties to the port.

SCENARIO 1: This network refers to a SC operated exclusively with road modal. In it, the properties can send the sugar cane to plants U_1 and U_2 which send the VHP sugar through the route of smaller distance.

SCENARIO 2: This network is an intermodal transport alternative, where the properties send their products to the two plants, which transport the products to a train station S_1. By modal rail the product goes to port D_1.

For performance evaluation, under multi-objective optimization, transport cost (f_1) and environmental impact are minimized. The problem described considers the following assumptions: the analyses are concentrated in the process transport stage. Costs, routes and modes of transport are known. The location of producers, warehouses and markets is previously known. The research had regional coverage, more precisely the region of the State of São Paulo, Brazil.

4. Methods

4.1 LCA methodological aspects

This work was developed using the Life Cycle Assessment (LCA) technique, regulated by the standards NBR ISO14040 and NBR ISO14044. The functional unit (FU) defined for the calculations in this work was the transportation of 1 (one) kilogram (kg) of product per kilometer (km). The inventory data for the problem were obtained from different sources: interview with person responsible for the sugar mills; consultation in literature, manuals and databases.

The minced cane conveyors are diesel powered sugarcane-type trucks and have an average load capacity of 109,000 kg. The VHP sugar transport is made by medium/heavy trucks, all diesel powered and have an average load capacity of 36,250 kg. To define the scope were raised: the location of sugarcane plants; the sugarcane producing properties (Fig. 2).

The distances from all properties to the plants, as well as distances from the plants to the distributors, were calculated using QGIS software 2.18.12 (Tab 1 and Tab 2), which is a free software of geographic information system (GIS) and allows the determination of geographical distances.

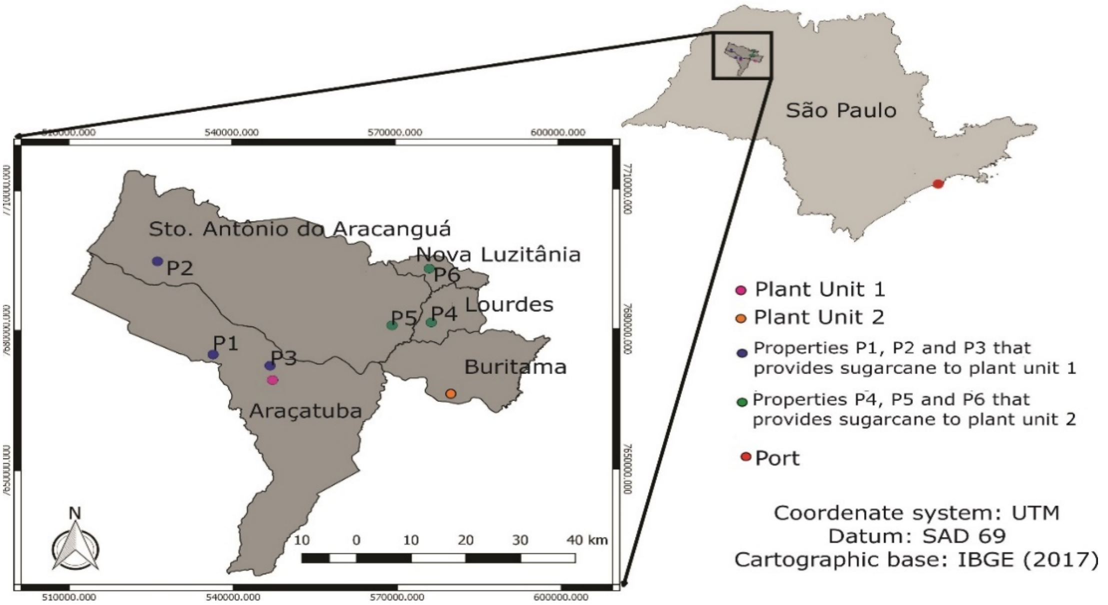


Fig. 2 Map of the location of plant units and their production units.

Table 1. Distance between property and plant.

Property P_i	Distance (km) to the plant
P_1	24,6
P_2	56,3
P_3	3,17
P_4	24,8
P_5	40,9
P_6	34,6

Table 2. Distance between plants and distributors.

Plant	Distance (km) to the port	Distance (km) to the train station
1	639	356
2	635	352

In order to quantify greenhouse gas (GHG) emissions, the distances between the sites and the corresponding transport modes were related. For that, emission factors in kg of CO_2 per liter of fuel normalized by the average efficiency of the trucks were used (Eq.1).

$$E\left(\frac{kgCO_2}{km}\right) = \frac{EF(kgCO_2/l)}{Efficiency\ (km/l)} \quad (1)$$

Where: E is the CO_2 emission in kilograms per kilometer and EF is the emission factor. The CO_2 emission factor of the diesel combustion is 2,671 $kgCO_2.l^{-1}$ and was obtained from the National Inventory of Atmospheric Emissions by Road Automotive Vehicles (MMA, 2011), as well as the efficiency of the medium/heavy sized trucks driven by diesel (Tab 3). The efficiency of the sugar cane trucks was obtained from an interview at the plant.

Table 3. Average mileage values per liter.

Vehicle	Average efficiency ($km.l^{-1}$)
Sugar cane trucks	1,160
medium/heavy sized trucks	4,365

The energy efficiency of the locomotive was calculated using data provided by the logistics operator MRS, which is 2,480 l/KTKB. The KTKB unit indicates the amount of liters of diesel used to transport 1,000 gross tons per 1 (one) km. The value was normalized by the amount of VHP sugar that is transported by the locomotive.

4.2 Methodological aspects of the mathematical model

To solve the multi-objective optimization problem, the Pareto dominance concept was employed in order to compare two feasible solutions (KONAK; COIT; SMITH, 2006). The transport problem of this work was based on the model for sustainable fuel supply chains developed by Mele *et al*. (2011), and applied in a case study of the sugarcane industry in Argentina.

Three sugar cane supplier properties were selected for each of the VHP sugar producing plants. Producing properties that provided the largest quantity of cane to the mills per year were used as the selection criterion (Tab 4). In addition, the demands and costs of distributors of a given commodity were also provided (Tab 5).

Table 4. Annual individual sugar cane production of each property.

Property P_i	Production in kg.year^{-1}
P_1	59224100
P_2	54007200
P_3	56717700
P_4	83944900
P_5	91559650
P_6	76146200

Table 5. Annual demand in kg of VHP sugar per year.

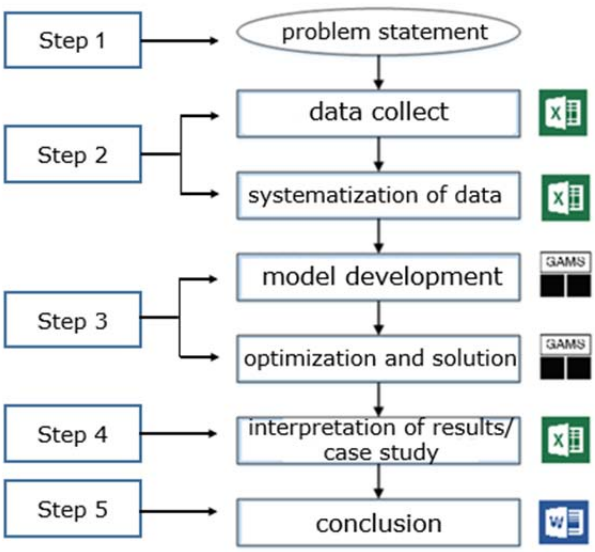
Plant	VHP sugar demand
1	49381000
2	97345000

In order to calculate transport costs (Eq. 2), the fuel price was calculated based on reports from the National Agency for Petroleum, Natural Gas and Biofuels (ANP, 2017) for October 2017. The average price of diesel was USD 0.98 per liter.

$$Cost\ (USD/kg) = \frac{Distance\ (km).2.\frac{Price(USD/l)}{Efficiency(km/l)}.frequency}{Production(kg)} \quad (2)$$

4.3 Solution approach

The methodology applied in this work was based on the procedure proposed by Quaglia *et al*. (2012). The steps are adapted to the case study, as shown in the flowchart in Fig. 3.



Step 1: Problem statement - identify the scope as well as the elements for performance analysis.

Step 2: Data collection - All information relevant to the problem was collected and organized into spreadsheets in Excel.

Step 3: Modeling and solver - the GAMS environment was used to develop a model.

Step 4: Results - Based on the results of LP, the solutions that have been identified are discussed.

Step 5: Conclusions - the main optimization results are described according to the proposed analysis.

Fig. 3 Steps of the methodology applied to the case study.

5. Model formulation and problem solution

The LP model that takes into account the evaluation of the environmental objective f_2, analyzed here together with the economic objective f_1, was motivated based on the work of Camilo (2017), with application in the sustainable transportation of products. The difference is that for both scenario 1 (C1) and scenario 2 (C2), the proposed set of constraints and objective function was applied to the sustainable transport of VHP sugar. In particular for C2, modifications were made to the objective function, since there is an increase of the rail route (x_3). Thus, the model developed for scenario 2 becomes an intermodal transport problem. The objective functions and their restrictions were included (Eqs.3 to 8).

$$f_1(x_{1\,ij}, x_{2\,js}, x_{3\,sk}) = \sum_{i,j} x_{1\,ij} cp_{ij} + \sum_{j,s} x_{2\,js} cu_{js} + \sum_{s,k} x_{3\,sk} cs_{sk} \quad (3)$$

$$f_2(x_{1\,ij}, x_{2\,js}, x_{3\,sk}) = \sum_{i,j} x_{1\,ij} tp_{ij} v_{1\,ij} + \sum_{j,s} x_{2\,js} tu_{js} v_{2\,js} + \sum_{s,k} x_{3\,sk} ts_{sk} v_{3\,sk} \quad (4)$$

$$\sum_{j} x_{1\,ij} \leq sp_i \quad (5)$$

$$\sum_{i} x_{1\,ij} \geq du_j \quad (6)$$

$$\sum_{k} x_{2\,jk} \leq su_j \quad (7)$$

$$\sum_{j} x_{2\,jk} \geq dd_k \quad (8)$$

$$\sum_{k} x_{3\,ks} \geq ds_s \quad (9)$$

Where: F is the multi-objective function; f_1 is the minimum cost function [USD]; f_2 is the total CO_2 emission function [kg]; $x_{1\,ij}, x_{2\,jk}$, $x_{3\,sk}$ are the variable quantities of sugarcane and VHP sugar (kg) transported from property p_i to the plant u_j, from the plant u_j to the port d_k and from station s_s to port d_k respectively; ds_s is the quantity required by station s_s; cp_{ij} and cu_{jk} are the costs (USD/kg) associated with transport of VHP sugar from s_s to d_k; sp_i and du_j are the quantities (kg) produced by property i and the amounts (kg) required by the plant j, respectively; su_j and dd_k are the quantities (kg) offered by the plant j and the amounts (kg) required by the distributor k, respectively; tp_{ij} is the distance from property p_i to the plant u_j (km); tu_{jk} is the distance from the plant u_j to the distributor d_k (km); $v_{1\,ij}$ is the emission of kilograms of CO_2 per kilometer traveled from property i to plant j; $v_{2\,jk}$ is the emission of kilograms of CO_2 per kilometer traveled from plant j to distributor k; ; $v_{3\,sk}$ is the emission of kilograms of CO_2 per kilometer traveled from train station s to port k and t_s is the distance from station s_s to port d_k.

The models developed in this work were implemented in the GAMS environment. The set of equations were solved using the CPLEX 12.0 solver. The CPLEX solved the problem of LP using several alternative algorithms, starting from the minimization of f_1.

6. Results and discussions

A simplified structure was developed for the case study, where two scenarios were analyzed. Sugar cane and VHP sugar were the products that represent the mass displacement in SC. Considering the properties that supply most sugar cane to the mills, a fixed number of six sugar cane producing properties (P_i), the quantity of sugar cane plants (U_J) being two, and the port (D_k) as destination Last. Road transport of VHP sugar to the port can occur in two ways. This occurs, therefore, every amount of VHP sugar has only one destination that is export through the port (Fig. 4). Optimum values were found for the total annual cost (f_1) and annual CO_2 emissions (f_2) (Tab 6). A graph containing two points was generated (Fig. 5), obtained according to the proposed procedure.

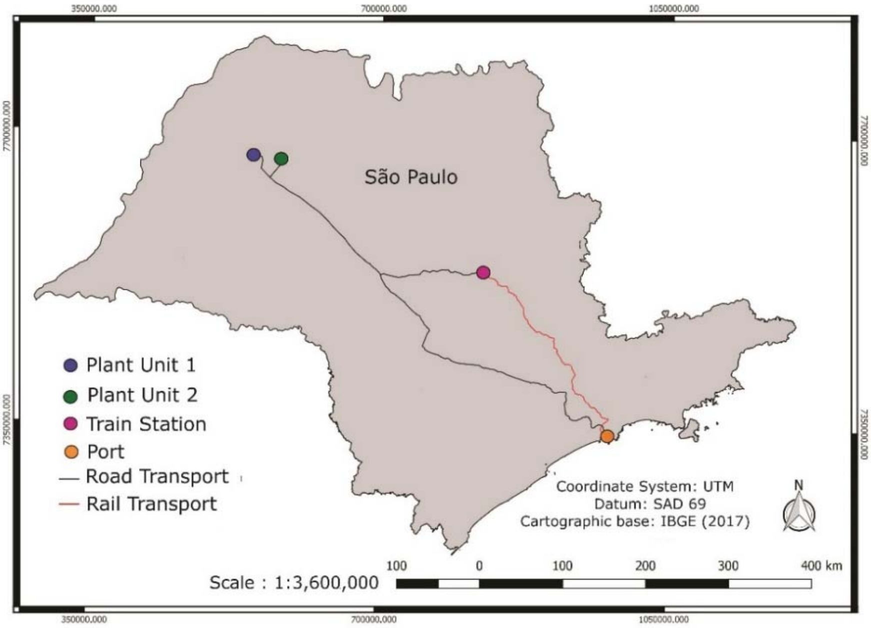


Fig. 4 Configuration of transport routes of VHP sugar in the State of São Paulo.

Table 6. Optimum cost and environmental impact solutions.

Scenario	Total annual cost (USD) (f_1)	Annual CO_2 emission (kg) (f_2)
1	33,216	$5.72x10^{10}$
2	98,555	$1.51x10^{9}$

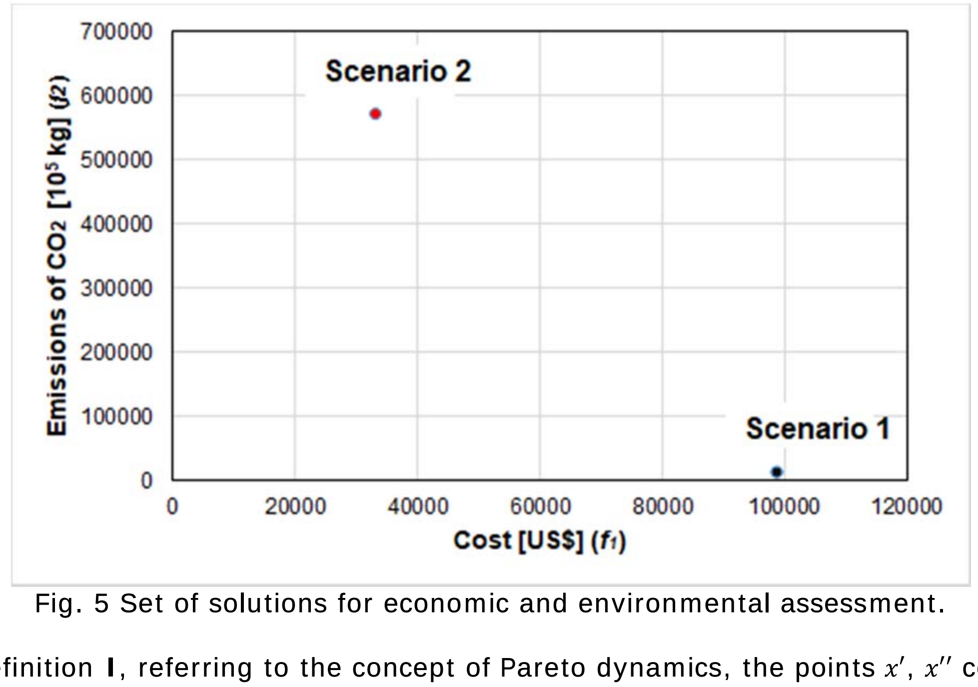


Fig. 5 Set of solutions for economic and environmental assessment.

According to definition **I**, referring to the concept of Pareto dynamics, the points x', x'' corresponding to scenarios 1 and 2 (the points are indicated in the graph with red and black color) belong to the Pareto optimal set for this model. By employing the above mentioned indexes, the Pareto optimal points for this set of scenarios appear as follows in Eqs. 9 and 10:

$$x' = (x_{1\,ij}, x_{2\,jk}), \qquad with\ i = 1, \dots, 6\ , j = 2\ e\ k = 1 \tag{9}$$

$$x'' = (x_{1\,ij}, x_{2\,js}, x_{3\,sk}), \qquad with\ i = 1, \dots, 6\ , j = 2\ , s = 1\ e\ k = 1 \tag{10}$$

Each defined point (Fig. 5) implies a specific SC structure and a set of planning decisions. The proposal of environmental and economic evaluation through mathematical models led to the study of two existing configurations of SC, where the possible mass displacement routes are applied to the distributors that receive VHP sugar (kg) from the plants. In this context, the study of the Pareto front resulted in a set containing "Pareto optimal points".

In scenario 1, when minimizing cost and impacts, the results were the same, that is, the minimum cost was obtained, both minimizing the own (main) cost and minimizing the impact function. Therefore, for this model, the cost function is not conflicting with the impact function. The logic of this, of course, is involved with fuel. Since the cost is related to the optimization of the route, therefore, when optimizing the route will be spending less fuel and, consequently, releasing less CO_2. This directly results in reduced environmental impact. Therefore, in this model it was possible to find the Pareto dominance making it possible to compare the quality of the two solutions of the MOO problem.

It was also possible to evaluate the amount of product that each plant should carry (kg) when VHP sugar moves in scenario 1 (Tab 7), respectively, and the associated environmental and economic impacts.

Table 7. Optimum quantities in kg of VHP sugar to be delivered to the port by the plants in scenario 1.

Plants	Port D_K
U_1	$8.98x10^7$
U_2	$5.69x10^7$

For the two scenarios proposed, the optimal quantities of products to be delivered were calculated using the model, and the decision maker should evaluate the best feasible solution for the case study.

For scenario 2 (rail transport inclusion), by minimizing the cost function, the impact function presented a worsening of its value. The same occurs when the impact function is taken as the main objective function. That is, they are conflicting. Thus, in this case it is possible to obtain the two or more solutions to form the Pareto frontier. Therefore, in a future work, it will be necessary to find the other solutions of the Pareto frontier in order to confront possible scenarios.

Analyzing each solution separately, we have that the two solutions found are qualitatively distinct, showing an indirectly proportional relationship between them, being consistent with a higher cost along which the associated environmental impacts are reduced. Deciding to carry VHP sugar transport over the scenario that takes a rail route into account can provide a way for plant managers to generate less environmental impacts.

Although the study portrays real scenarios, the model can also be applied to proposed scenarios that aim at an analysis involving different demands and routes, as well as to improve positions and configurations, in order to establish optimal conditions that allow the distribution of the product emitting smaller amounts of CO_2, also generating lower costs.

7. Conclusion

Using the linear programming in a transport model, it was possible to find Pareto solutions, based on supply chain optimization, cost minimization and environmental impact, providing valuable insight into the problem design and suggesting process alternatives that lead to improvements of performance. In the study, it pointed to a potential savings in environmental charges, obtained by adjusting the conditions of operation of the supply chain for intermodal transport. The formulated model opens up spaces for further research in order to find the best feasible solutions.

The results showed that the railroads can be an alternative means of transport, having less of an impact from an environmental standpoint. The values obtained can be used as an Environmental Management tool to promote performance improvements in sugar SC. Sustainable Supply Chain Management promotes environmental, social and economic gains to organizations, as well as a better view of consumers in relation to the company's commitments. In addition, this tool, leads to new proposals for improvements in the supply chain, fostering new work on the subject.

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