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Sustainable of tomatoes supply chain management – Cases of study

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Abstract

It is important to think about ways to reduce costs and also minimize negative environmental impacts in the fruits and vegetables supply chain, seeking to improve the distribution system of these products for markets and benefits for society. An innovative approach to supply chain (SC) management requires a general multiobjective optimization framework that incorporates Life Cycle Assessment (LCA) principles. Linear Programming (LP) is a powerful mathematical technique that can be used as a tool in LCA. The objective of this work is to make an environmental and economic evaluation of the SC of tomatoes for the region of the Umuarama city, Brazil, accounting for different distribution process configurations. The production of tomatoes has an important participation in the region economy. The scope of work encompasses three levels of decision-making within the life cycle: producers, warehouses and markets. The information gathering was performed from interviews with the producers, the supermarkets and the warehouses involved. The LCA study applied in this work was carried out according to ISO 14044/2009. A model of bi-objective LP was developed for the environmental and economic evaluation of SC and the global optimization solved with CPLEX 12.1 algorithm available on GAMS®, accounting for different environmental and economic charges simultaneously. As a result, the Pareto frontier was found offering a number of feasible options for system improvements. There are possibilities for improvement in the Tomato Supply Chain Management, since changes in process configuration can be translated into minimization of costs and environmental impacts.

Keywords: Optimization. Life Cycle Assessment. Sustainability Management. Value Chain. Tomato.

1. Introduction

The tomato *Solanum lycopersicum* is a vegetable that has an important participation in the national value chain. In 2015, the Brazilian production of tomatoes was 4,145 million tons, in an area of 62,000 hectares, with an average yield of 66.8 kilograms per hectare (IBGE, 2016). This production has a participation considered important in the municipal scope. In the Umuarama region, state of Paraná in Brazil, tomatoes are produced by a group of farmers, most of them organized in a cooperative. In this context it is relevant to think about the optimization of processes, with a view to reducing production costs and minimizing negative environmental aspects. Guillén-Gosálbez *et al.* (2008) emphasize the increasing importance of the Green Supply Chain Management (GSCM) field, which addresses the influence and relationships between Supply Chain Management and the natural environment. It is clear that decisions taken by an enterprise in the context of the GSCM should not be driven solely by economic criteria, the environmental question must be observed (Camilo *et al.*,2017). As a result of the increased costs of environmental control and environmental legislation issued, companies show an increasing interest in minimizing environmental impacts in their processes. In this sense, a GSCM problem can be formulated as an optimization problem.

Accordingly, the use of Linear Programming in GSCM offers the possibility to perform a simultaneous optimization of the process operations, as well as to correlate with environmental issues. According to Azapagic and Clifit (1998), LP is an important tool to identify the best practical environmental option for a process or product system. In particular, the application of GSCM is motivated by the adopted analysis system, which covers all phases of the product life cycle. The LCA is an environmental impact assessment technique associated with a product or service during its life cycle. There is a growing interest in this technique of assessing environmental impacts in the processing system for some horticultural products (Khoshnevisan, 2013). One of the main applications of LCA is the comparison of possible modifications to an existing product or process, with the aim of improving its environmental performance (Azapagic and Clift, 1998). One of the ways to incorporate environmental perspectives into optimization projects is to treat environmental requirements as objectives, focused on multiobjective optimization. In the last decades, the field of multiobjective optimization has grown significantly and many applications are represented in the literature (Guillén-Gosálbez *et al.*, 2008).

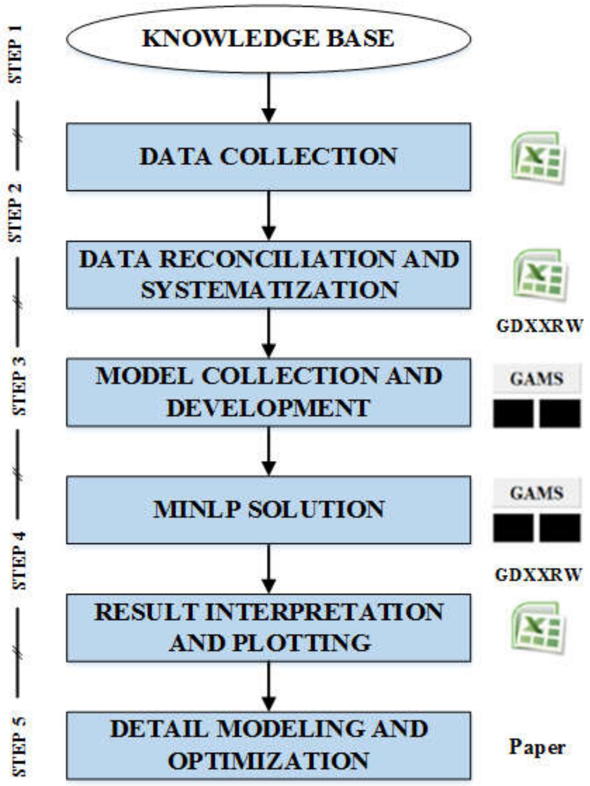
In this context, this work aims to deal with a performance evaluation of several scenarios of CS of tomatoes for the region of the municipality of Umuarama city based on a bi-objective mathematical model. Two aspects of the distribution process are considered: transportation costs between the farmers and the final market; and the environmental impact caused in the transport process.

Table 1. Nomenclature.

Abbreviation		*K*	Refer to the Market k
LP	Linear programming	*Parameters*	
LCA	Life cycle assessment	cp_{ij}	Cost of transport from producer i to warehouse j
SC	Supply chain	cw_{jk}	Cost of transport from warehouse j to market k
GHG	Greenhouse gases	sp_i	Total produced by producer *i*
CO_2 eq.	CO_2 equivalent	dw_j	Total defendant by warehouse *j*
GSCM	Green Supply Chain Management	ws_j	Total storable by warehouse *j*
BPS	Best Practical Solution	dm_k	Total defendant by market *k*
BC	Basic Case	ε_2	Epsilon total
Functions		tp_{ij}	Distance from producer P_i to the warehouse i
F	Bi objective function	tw_{jk}	Distance from warehouse *j* to the market k
f_1	Economic function	*Variables*	
f_2	Environmental function	x_{1ij}	Total distributed from producer i to warehouse j
Indexes		x_{2jk}	Total distributed from warehouse j to market k
I	Refer to the Producer i	z	Total cost
J	Refer to the Warehouse j	z_2	Total CO_2 emission

2. Methods

In this work, the methodology applied is based in the procedure purposed by Quaglia *et al.* (2012) who developed an integrated framework for synthesis and design processing networks. The steps are adapted to our cases of study covering the supply chain challenge being described in Figure 1 and executed hereafter.



Step 1: Problem Statement: identify the scope and scenario as well as the metrics for performance analysis.

Step 2: Cases of Study: all relevant information to the problem are collected and organized into Excel spreadsheets. The product is chosen and the different processing alternatives are presented.

Step 3: Modeling: using the software GAMS, a model with costs and sustainability metrics are developed compose the objective function and the system performance.

Step 4: Solver: the LP problem is solved in GAMS. The solution provides the optimal value of the decision variables along the objective function and the performance indicators are calculated and plotted.

Step 5: Results Analysis: based on the results, the identified solutions are discussed. Detailed modeling and optimization are described in this paper.

Fig. 1. Steps of the methodology applied to the case of study (adapted from Quaglia *et al*. (2012)).

2.1 Problem statement (STEP 1)

In the studied region (Umuarama), tomatoes are produced by a group of rural producers. Part of the production is transported to a warehouse. Then, these products are distributed to markets according specific demands. Into the traditional design, the environmental impacts of vegetable production receive low priority and these are usually incorporated as the end-of-pipe treatment. When neglect, they can often ignore the production of large quantities of substances that can pollute the environmental along the SC. This work approaches the minimization of total cost and minimization of total environmental impact involved in the transport of tomatoes, employing multiobjective optimization in the SC performance seeking balanced solutions.

2.2 Cases of study (STEP 2)

In this study, 5 cases of study are purposed. According to the field survey, base case (BC) corresponds to the usual supply chain adopted. Cases 1, 2, 3 and 4 approach two different scenarios. Case 5 takes into account a new form of distribution. The structure is taken as a reference at three decision levels: producer (P), warehouse (W) and market (M). The analyzed scenarios are described in Frame 1. In all cases a fixed number of nine producers, represented by the acronyms (P_1, P_2,…, P_9) is considered. The warehouses are represented by the acronyms (W_1 and W_2). The markets are represented by the acronyms (M_1 and M_2).

The input data to formulate the economic performance indicator are: the quantities of tomatoes produced, the storage capacities in the warehouses and markets, as shown in Table 2. The quantities produced for a horizon of one year are considered. All data was obtained from COOPERU (Umuarama producers cooperative) for quantities of tomatoes received in the year of 2015. The distances between producers, warehouses and markets are presented in Tables 3 and 4. The distances for all cases were determined with the aid of maps of the Municipal Master Plan. Due to changes in the location of the warehouses for case 3, new distances were measured.

Frame 1. Limits of the product system of different scenarios for the cases of study.

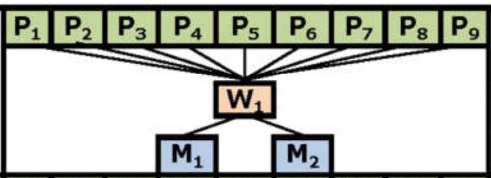
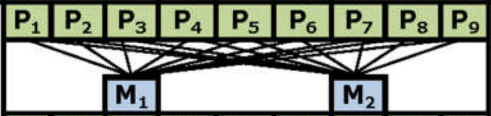
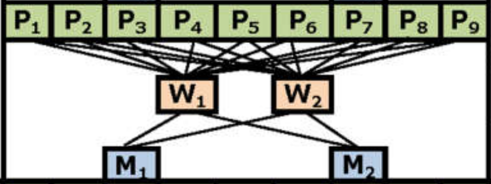
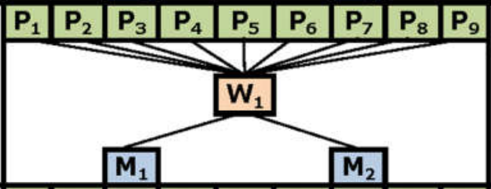
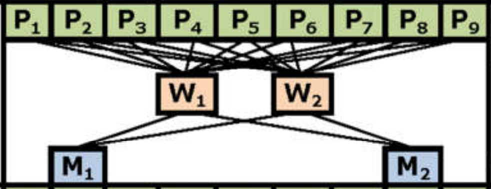
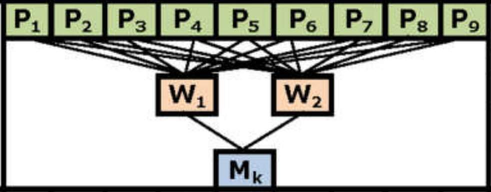
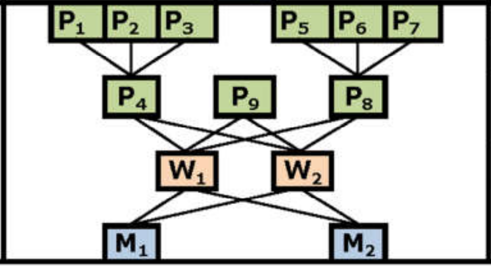
BC		**Base Case:** The original case with one warehouse is considered. Producers send theis products to a warehouse and this one supplies the markets. Topological constraints are not considered.
C1	 	**Scenario 1:** No warehouses are considered. The producers send the product directly to the markets. **Scenario 2:** Two warehouses are considered. Producers have another option of warehouse to store the product.
C2		**Scenarios 1-2:** the capacity of the warehouse increases 44% and 82% respectively, in relation to BC. These values were according the possibility of system expansion.
C3		**Scenarios 1-2:** the location of the warehouses (W_1 and W_2) are modified in order to reduce distances between producers, warehouses and markets. The new locations were determined based on strategic county's master plan.
C4		**Scenarios 1-2:** only one market is considered (M_k for k=1,2) comparing the system perfomance when warehouses send their product directly to a specific market.
C5		This case purposes a new form of distribution where the producers (P_1, P_2, P_3, P_5, P_6 e P_7) send their product to other cooperating producers (P_4 and P_8), who carries the products to the warehouses. As a matter of logistics only P_9 would have to take your product to the warehouse.

Table 2. Storage capacities of the cases.

Warehouse	Base case [kg]	Case 2 –Scenario 1[kg]	Case 2 – Scenario 2 [kg]
W_1	24720.0	35729.0	45000.0
W_2	16500.0	25500.0	35000.0

Table 3. Distances [km] between warehouses and producers.

Case	Warehouse	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9
BC,1,2,4	W_1	31.00	35.90	18.90	30.10	19.10	29.86	15.77	15.80	10.23
BC,1,2,4	W_2	24.00	28.10	17.20	23.10	17.30	22.80	14.20	14.00	8.90
3	W_1	24.20	29.00	15.20	23.70	15.30	22.90	13.20	13.10	10.40
3	W_2	12.70	17.50	27.60	12.10	27.70	11.40	25.80	25.70	22.20

For Case 5, the distances traveled were appropriate to the case, as shown in Figure 1, where P_4 and P_8 represent transshipment points.

Table 4. Distances [km] between warehouses and markets.

Case	Warehouse	M_1	M_2	M_1	M_2
BC,1,2,4,5	W_1	4,80	7,50	2.50	3.70
3	W_2	5.10	0.90	17.0	13.7

The quantities of product demanded by warehouses and markets are described in Table 5 and the cost of distributing from producers to warehouses and then to markets in Table 6. The cost of acquiring raw materials for tomato production are not considered in optimization. Costs were converted from Brazilian real to American dollar (1R$=3,330US$) based on that annual average value (BCB, 2015).

Table 5. Total demand of the warehouses and markets.

Warehouse	Demand (kg)	Market	Demand (kg)
W_1	16480	M_1	13440
W_2	8240	M_2	10752

Table 6. Cost of distributing from producers to warehouses and then to markets (US$/kg).

Warehouse	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	M_1	M_2
W_1	0.011	0.030	0.012	1.041	0.041	0.130	0.046	0.071	0.057	0.0042	0.0099
W_2	0.009	0.023	0.011	0.799	0.038	0.099	0.042	0.063	0.050	0.0066	0.0081

To formulate the environmental performance indicator, the input data are the emissions of kg of CO_2 eq./km driven from the producer to the warehouse and from the warehouse to the market. The transport emission factors are specified by manufacturers of small pickups by gasoline with 700 kg of load capacity (10 km/l of efficiency) used by producers, and mid-sized trucks powered by diesel with a load capacity of 9,000 kg (3 km/l of efficiency), used by the warehouses (ANFAVEA, 2015).

3. Calculation

A Linear Programming (LP) model is purposed based on the transport model developed by Zhang *et al.* (2014), which can be solved using the software GAMS. The LCA study applied in this work is performed according to the ISO 14044/2009. The objective functions of the model describe economic and environmental aspects. The concept of *Pareto Dominance* was used to compare feasible solutions.

3.1 *Modelling (Step 3)*

The model is composed of two main blocks of equations: objective function (Eq. 1), and the constraints (Eq. 2), obtained after the mass balance of the SC:

$$\min F(f_1,f_2)=\left(f_1\left(x_{1ij},x_{2jk}\right),f_2\left(x_{1ij},x_{2jk}\right)\right)=\left(\sum_{i,j}x_{1ij}cp_{ij}+\sum_{j,k}x_{2jk}ca_{jk},\sum_{i,j}x_{1ij}tp_{ij}v_{1ij}+\sum_{j,k}x_{2jk}tw_{jk}v_{2jk}\right), \tag{1}$$

$$\text{s.t.:}\left\{\sum_{j}x_{1ij}\le sp_i,\quad \sum_{k}x_{2jk}\le sa_j,\quad b_i\le x_{1ij},\sum_{i}x_{1ij}\ge da_j,\quad \sum_{j}x_{2jk}\ge dm_k,\right. \tag{2}$$

where, x_{1ij} and x_{2jk} are variables that represents the quantity of tomatoes (kg) transported from producer *i* to the warehouse *j* and from the warehouse *j* to the Market *k* respectively. The variables cp_{ij} and ca_{jk} are the transport associated costs (US$/kg) from producer *i* to the warehouse *j* and from the warehouse *j* to the Market *k* respectively. The variables tp_{ij} is the distance from the producer *i* to the storehouse *j* (km) and tw_{jk} is the distance from the storehouse *k* to the market *j* (km); The quantities sp_i and da_j refer to the tomato production (kg) offered by producer *i* (kg) and defendant by warehouse *j* respectively. The variables sa_j and dm_k are the quantities (kg) offered by the warehouse *j* and the quantities (kg) defendant by the market *k* respectively. Finally, b_i is the minimum amount (kg) that the producer must delivery to the warehouse, stipulated as 10% of its total production. Then, the model is implemented in GAMS. The set of Eqs. 1-2 is solved as global optimization using the solver CPLEX 12.1, which employs a filtering algorithm that solves a sequence of linear programming (LP) sub problems. The results of a sub problem are used to select the columns of the original model for inclusion in the next sub problem.

3.2 Pareto frontier

Pareto curves show trade-off relationships between both objectives. Increasing one objective function, the other one experiences a steep decrease in the first part of the curve and small decreases in the next part in which almost no further improvement can be achieved. In a bi-objective optimization problem, the Pareto dominance concept is used to compare two feasible solutions to the problem (Mavrotas, 2009). Consider a set $x=(x_1, x_2,...,x_n)$ of variables and the problem of bi-objective optimization presented in Eq. 3.

$$\min F(x) = \left(f_1(x), f_2(x)\right), \qquad \text{s. t. } \{h(x)=0; \quad g(x) \le 0. \tag{3}$$

In comparison with an optimal Pareto solution, any other solution cannot further decrease the value of an objective function without any increase in other objective functions. The Pareto frontier is formed by the points in the space of the objective functions that correspond to the Pareto optimal set.

3.3 *The ε-constraint method*

In the ε-constraint method we optimize one of the objective functions using the other objective functions as constraints using the epsilon value as the bound. Hence, consider the following single-objective (Eq. 4) new optimization problem (Mavrotas, 2009):

$$\min f_1(x), \qquad \text{s. t. :}\{f_2 \le \varepsilon_2;\ h(x)=0;\ g(x) \le 0. \tag{4}$$

Varying the value of ε_2, we obtain efficient solutions of the problem. We should be able to convert the range of f_2 (objective values) into finite number of discrete values (in this work was used *10 points)*, starting from the min value and ending at the maximum value.

3.4 *Knee point*

The *Pareto frontier* plays an important role in engineering design; The more indicated solution for bi-objective problems is the nearest point to the **utopia point**, which represents the optimum cost and optimum environmental impact. The set of individual optimum (best value for each objective function) represents the utopic point $f^U = (f_1^*, f_2^*)$, while the set of maximum values (worst value for each objective function) $f^N = (f_1^N, f_2^N)$ indicates the **nadir point**, Fig.2. Analysed the Pareto frontier, it seems that the most interesting operation point for supply chain is around the so-called ***"knee point"***, which is located at the intersection of the line segment determined by the nadir point and the utopia point with the Pareto frontier. In this work, knee points were used as a criterion to obtain a Best Practical Solution (BPS) to the proposed bi-objective optimization problem, according Deb and Gupta (2010).

4. Results and discussion *(steps 4 and 5)*

The optimization results were analyzed for the following cases: base case, as shown in Figure 1; cases 1, 2, 3, 4 and 5, as shown in figures 3, 4, 5, 6, 7 and 8, respectively. For all cases, depending on the position in the Pareto curve, different optimal solutions can be obtained and they can represent the BPS for that particular state the CS. The Pareto frontier of f_1 and f_2 obtained was plotted on the axes *x* and *y* for each case respectively. Thus, for example, for each case, the Pareto frontier was obtained by optimizing one objective (cost) function and subdividing the domain of the other objective (environmental impact) function into 10 subintervals and leaving it as a restriction. All curves have similar shapes. Figure 2 illustrates the discussed points previously. The "**x**" point in the figures represents the "knee point", an equilibrium point between the objective cost function and the environmental impact function.

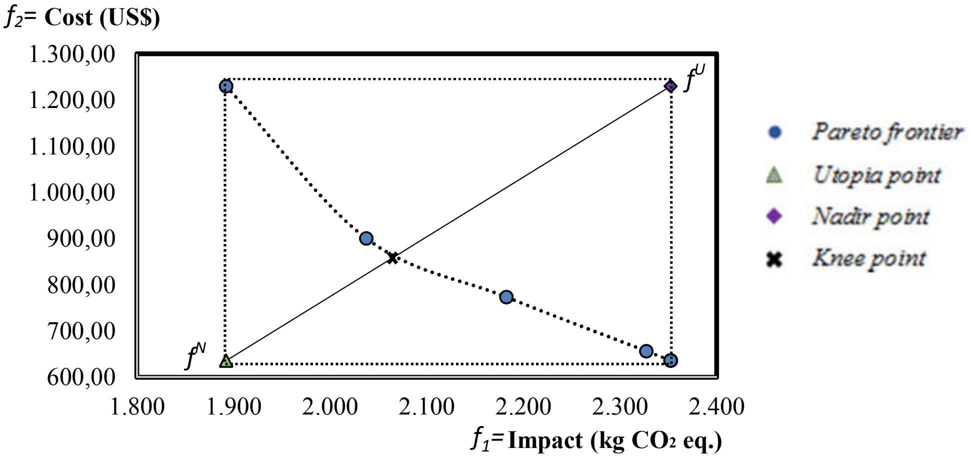


Fig. 2. BC – Original configuration with one warehouse.

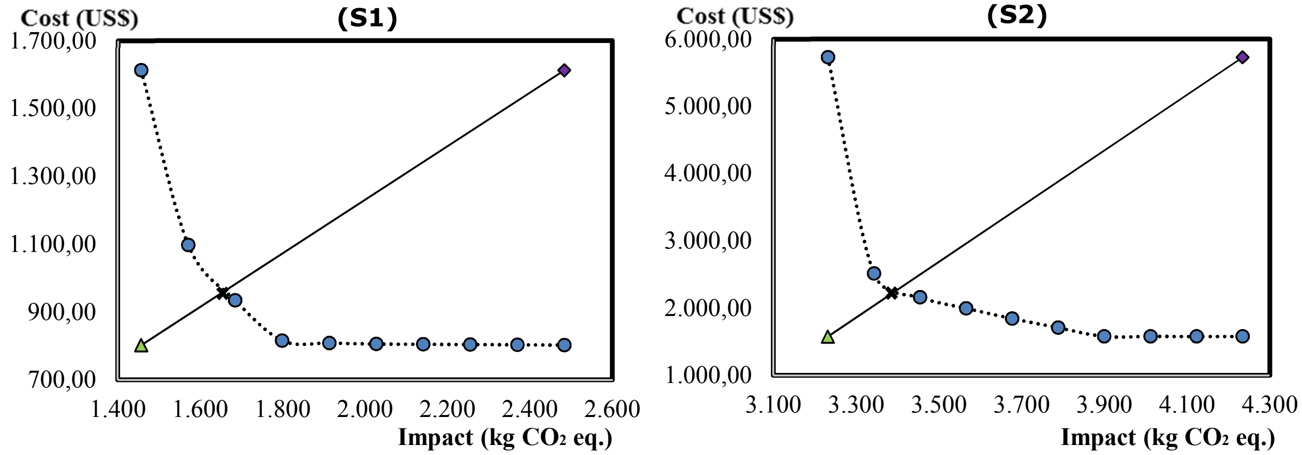


Fig. 3. Case 1 – Scenarios 1 (S1) and 2 (S2).

Figure 2 presents a set of Pareto solutions for BC. Among all points shown in the curve, the solution closest to the "knee point" (f_1=2,037.27 CO_2 eq. and f_2 = US$ 900.73) represents a possible optimal solution for the case, which minimizes the objective functions. Analyzing case 1 (S1) it is verified that the production of CO_2 eq. decreases approximately 17% in relation to BC, because producers forward their product directly to shorter paths, saving fuel and releasing less GHG from vehicles. In other hand, when the quantity of warehouses is increased, there is a significant increase in the total cost and also in the eq. CO_2 emissions. If we compare case 1 (S2) with the BC, the cost is 42% above the possible optimal value, in addition, we verified that the production of CO_2 eq. is approximately 62% higher.

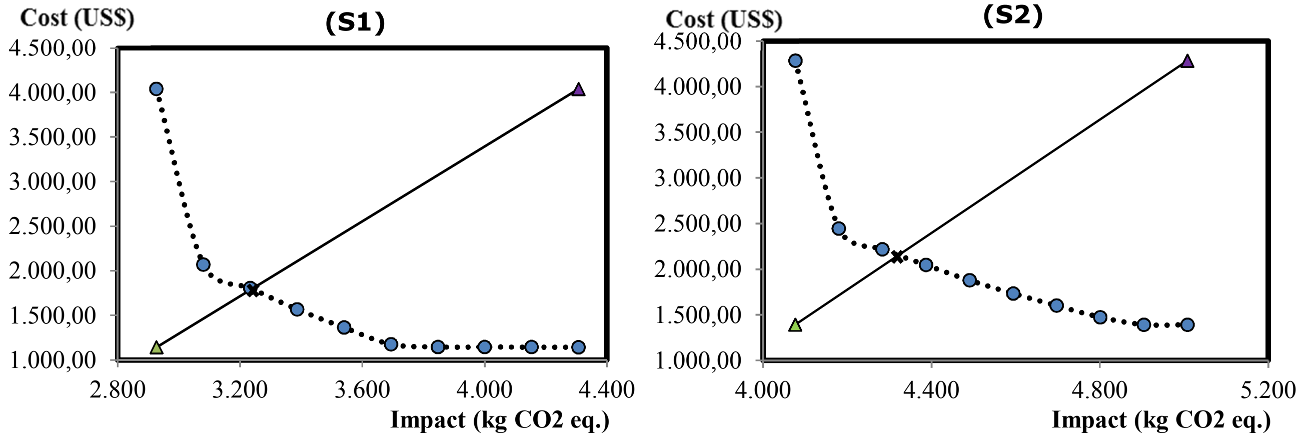


Fig. 4. Case 2 – Scenarios with different capacities (44% in (S1) and 82% in (S2)).

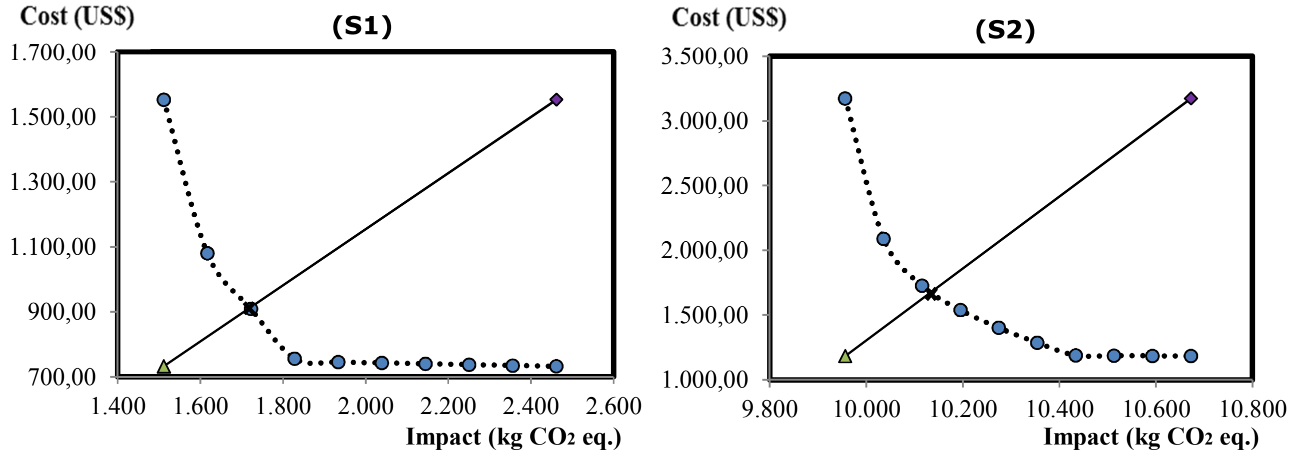


Fig. 5. Case 3 – Scenarios 1 and 2 with different distances of the warehouses.

Figures 4 and 5, present a set of Pareto solutions for cases 2 and 3. These cases were designed to evaluate the behavior of distribution cost and environmental impacts in SC changing storage capacities and the location of warehouses. In case 2, The potential optimal solution is close to the knee point, both for scenarios, S1 (f_1=1722.46 CO_2 eq. and f_2 = US$ 908.73) and S2 (f_1=10115.41 CO_2 eq. and f_2 = US$ 1722,46). Thus, an accented increase of 82% in warehouse capacity implies an increase of around 30% in environmental impact and around 17% in the cost. It is also observed that considering the configuration S2, Fig. 4, there is presents an increase in the two variables (f_1 and f_2). The results shown in Fig. 5 (case 3) reflect the importance of design decisions for a product system: one warehouse with a good location tends to minimize distribution costs and environmental impacts, saving inputs and shortening the distances traveled, implying reduction of GHG emissions; A warehouse with poor location tends to increase distribution costs by approximately 54% (S2), while environmental impacts have also increased significantly. The same analysis can be performed at the other points under the curve plotted, which are all optimal, in the Pareto sense. Decision makers can select any solution on the chart, depending on how much one goal is achieved over another.

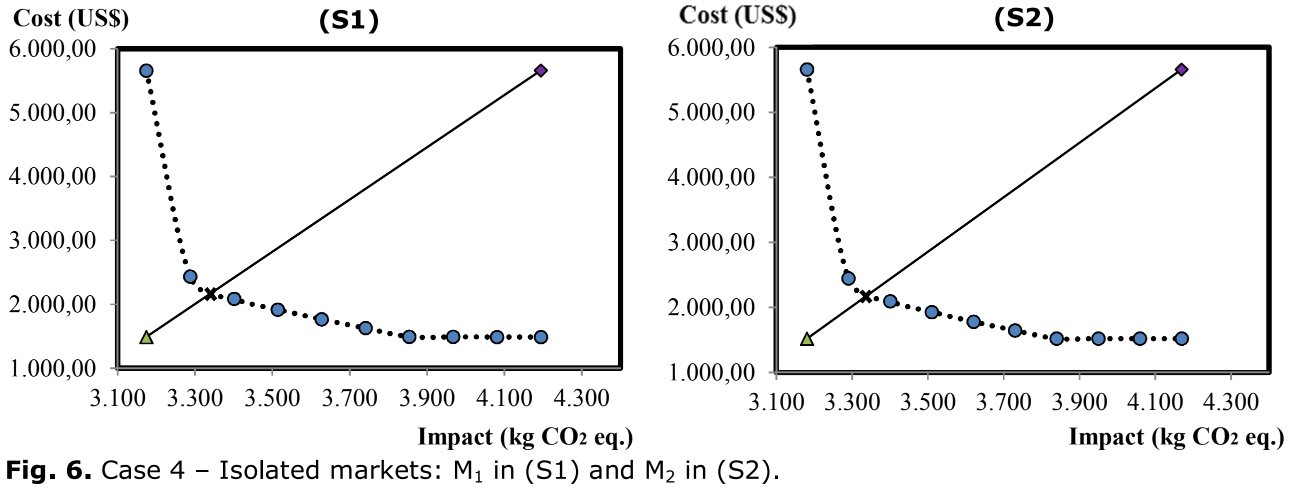


Fig. 6. Case 4 – Isolated markets: M_1 in (S1) and M_2 in (S2).

Figure 6 presents a set of Pareto solutions for case 4, where the warehouses have the option of sending their product to only one of the two markets. Figure 6 shows a decrease of approximately 3.2% in the CO_2 emission and of 0.5% in the cost, when comparing M2 (S2) with M1 (S1). This reduction in cost and impact is due to the positioning of M_1, which is relatively closer to the warehouses, implying lower GHG emissions and lower costs.

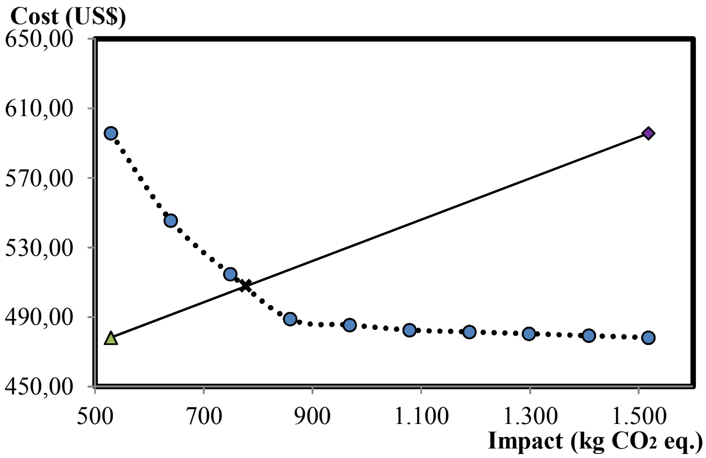


Fig. 7. Case 5 – New distribution form.

Figure 7 shows the Pareto frontier for case 5. In this case, two transshipment points were created in the routes between producers and warehouses, with an effective decrease in the distances traveled from the producers to the warehouses. In this case, the load capacity of the trucks is sufficient to ensure the transportation of the production stored at the transshipment points. In this configuration the costs and CO_2 emissions eq. decreases markedly in relation to the SC configurations verified in all previous cases. For example, if we compare case 5 with case 1 (S2) it is possible to note a reduction of approximately 23% for impacts and 24% for costs. According to this, with creation of transshipment points, it is possible to say that there are great possibilities for improvements in the SC management.

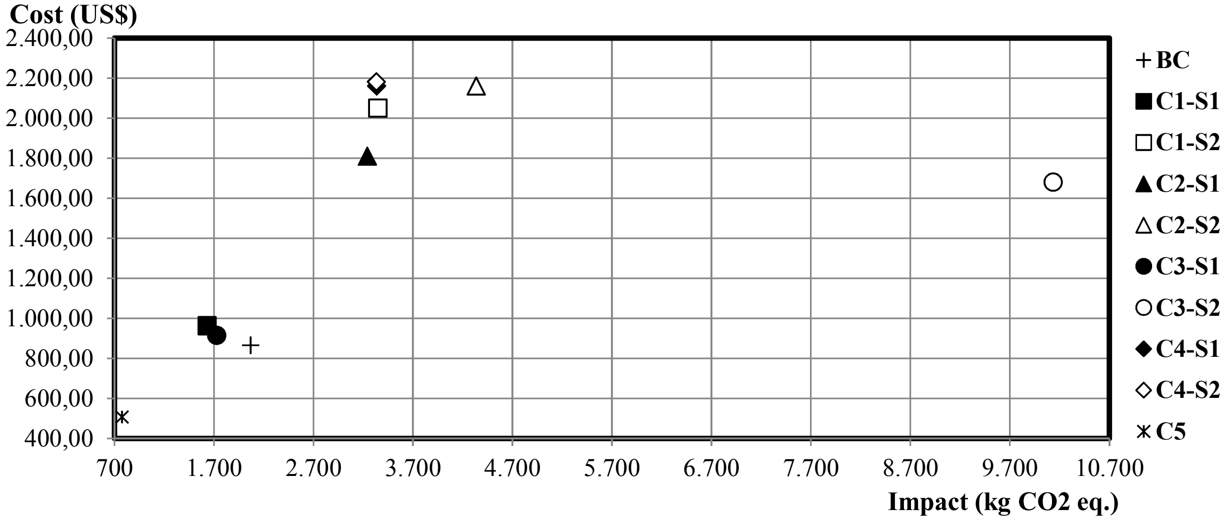


Fig. 8. Knee points of all cases and scenarios.

Aiming a better comparison between cases, the "knee points" were presented in a single graph, as shown in Figure 8. In this sense, can be observed that case 5 actually presents an SC that minimizes f_1 and f_2 and it is possible to indicate to the decision maker new strategies, such as the creation of other transshipment points to obtain improvements in the SC considered. On the other hand, comparing the Pareto frontier obtained for the BC with the ones obtained in the other cases, BC can be considered as a satisfactory alternative. However, the rural producers should give special attention to transshipment points, reducing the distances traveled and the cost of transporting their product. In general, if all Pareto solutions are considered of equal importance, being possible choose the best solution applicable to each case through knee point analysis. Therefore, the value of multiobjective optimization in the context of LCA is based on offering a range of choices for environmental and economic improvements in a system, allowing preferences to be identified after analyzing all interchanges between the objectives studied.

5. Conclusion

For all the analyzed cases, different optimal solutions can be obtained and they can represent the BPS for that particular state of operation of the CS. Likewise, as we look at a different point in the curve the BPS can also change. Comparing the Pareto knee point obtained in the BC with the knee points obtained for the other cases, it can be concluded that the configuration with one warehouse is a minimally satisfactory alternative, since the SC in operation meets the demand for warehouses and market products. However, special attention should be given to rural producers in order to reduce distances and transport costs. On the other hand, case 5 of this paper presents an SC that minimizes f_1 and f_2 and can indicate to the decision maker new strategies, such as the creation of transshipment points to obtain improvements in the SC considered. According to this, it is possible to conclude that there are great possibilities for improvements in the tomatoes SC management, since changes in the process configuration can be translated into minimization of costs and also of environmental impacts. The best practicable options for SC management will depend on the decision maker's knowledge and appropriate analysis. The performance model presented here can be translated into improvements in the distribution process of fruit and vegetable products, bringing economic and environmental benefits to farmers, warehouses and supermarkets administrators.

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