Supply chain development: Criterion of decision for implementation of future seed collection centers in rural areas

The present work aims to provide an optimization model as a selection criterion for approving new Jatropha Curcas collection points in rural areas. Field work was carried out for characterizing the collection points, to establish the local Jatropha supply and to determine transportation costs. Data were complemented whit a Geographical Information System (GIS) and an objective function was defined in order to determine the Jatropha oil production-associated profit. The supply chain was optimized in order to maximize the profits and a sensitivity analysis was performed so as to find a profit-based criterion for the acceptance of future collection points. There are collection centers empirically implemented, that due to social components, can't be removed or displaced. This constitutes the starting point for this logistic model. The location of collection points and the amount of collected Jatropha are the strategic variables that determine the standard deviation, and the more disperse the values, the higher the standard deviation and the stricter the acceptance criteria for evaluating new collection points. The transport cost of Jatropha Curcas seed is affected because it´s a secondary activity for farmers. The principal production activity is maize. The economic development and the social growth of the population in rural areas are the reason why the existent seed collection centers aren't removed.

Keywords: supply chain, Linear programming, optimization, GIS, collection points, Jatropha Curcas, Ecuador,

1. Introduction

Supply chains can be defined as systems that are integrated by different stakeholders in search of a common objective, by means of planning and coordination [1] [2]. Traditional supply chain analysis is supported in analytic, deterministic, stochastic and economic models [3] [4]. However, such models need to be modified in order to provide solutions for particular cases, in which traditional analysis approaches do not apply. Supply chain design and analysis in rural scenarios challenges traditional models when raw material random distribution and deficient decision criteria for the location of collection points are taken into account [5]. Indeed, rural activities are based on complex logistics for providing and transporting raw materials from collection points to processing points [6] [7].

Logistics in rural areas usually face intermittent supply and high costs. Consequently, economic, environmental and social components need to be taken into account in order to provide rural undertakings with stability and sustainability [8].

The supply chain of energy crops represents one of the many cases involved with supply chain analysis in rural areas that promote economic growth and social development among the different stakeholders [9] [10]. Moreover, such supply chain has a multiplier effect over the development of rural communities because it groups labour from growth, harvest, storage and transportation stages [11], thus becoming the main productive activity of certain rural locations.

Energy crops-associated activities can also be developed as secondary productive activities that generate additional incomes for farmers. One of the examples of such secondary activities is the Jatropha Curcas fruit collection in Manabí-Ecuador, for oil extraction. In Ecuador, Jatropha is not formally growth, instead, it is used as a living fence to divide land where traditional crops such as maize are grown. In such circumstances, energy crops supply chain analysis needs to consider crops availability and the optimisation of the already existing collection points [12].

The supply chain analysis model presented in this work provides stakeholders with a decision tool for analysing the implementation of future collection points of energy crops in rural areas. Moreover, the mentioned model does not exclude pre-established collection points that are currently operating and generating incomes [13] [14]. The model can be applied for any supply chain system of similar characteristics.

2. Case Study: Jatropha Curcas collection in Manabí Ecuador

For the development of a tool decision for the location of Jatropha Curcas seed future storage centers in Manabí- Ecuador, the design of the supply chain starts taking into account pre-established conditions, which are:

• The transport cost of Jatropha Curcas seed is affected because it´s a secondary activity for farmers. The principal production activity is maize.

• There are collections centers empirically implemented, that due to social components, can’t be removed or displaced. It constitutes the starting point for this logistic model.

Based on these considerations, in order to acquire data and optimal routes identification, the methodology developed is supported in Geographic Information System (GIS) [15] [16] [17] [18]. Also common methods are used to solve the linear optimization problem; this is the basis for the design of this supply chain [19] [20] [21].

3. Methodology

In order to address the Jatropha supply chain issue in rural areas with poor populations, such as the one identified in Manabi-Ecuador, an operations research approach was undertaken. Moreover, an objective function subject to constraints was defined in order to adapt such mathematical model with the existing reality of Jatropha collection points in Manabi-Ecuador. The objective function was optimised using Linear programming in order to maximise the profits of the existing oil extracting plant while assuring an income for Jatropha fruit and seeds collectors. Different stages including field work and modelling were undertaken for such optimization. The notation used in this section is presented in Table 1.

Notation
Parameters

P_{EP}	Profits extraction plant [$]
p_{oil}	price of Jatropha oil [$/kg]
p_c	price of Jatropha extraction cake [$/kg]
p_i	Price of Jatropha dry seed [$/kg]
Q_T	total amount of dry Jatropha seed [kg]
Q_i	Amount of Jatropha seed per collection point [kg]
f_{oil}	Yield of the oil extraction process
d_i	Distance between collection points and oil extracting plant [km]
C_i	cost of transportation [$/kg km]
n	Number of collection points
E_{cost}	Jatropha oil extraction cost [$/kg]
Q_{MAX}	Jatropha upper collection limit per collection point [kg]
Q_{MIN}	Jatropha lower collection limit per collection point [kg]
U_I	Initial profit [$/year]
P_F	Final profit when new collection points are analysed [$/year]
Σ	Standard deviation

3.1. Identification of the existing collection points using GIS

Field trips to visit the collection points that provide the existing oil extraction plant with Jatropha curcas fruit and seeds were undertaken. Longitude and latitude coordinates of the collection points and the oil extraction plant were determined using an Garmin Oregon® 650 Global Positioning System (GPS) equipment. Only permanent collection points were considered for the analysis and they were grouped under three different zones: North, Central and South, which corresponds with the existing classification criteria for Jatropha crops in Manabí-Ecuador.

The available routes between collection points and the oil extraction plant were mapped using GIS software (ArcGIS®). Primary roads, with appropriate infrastructure for transportation, were mainly considered for the analysis. Secondary and tertiary roads were considered whenever no primary roads were available. The distances between the different collection points and the oil extracting plant were determined and the coverage radius of each collection point was identified. The roads were classified based on the criteria of the Geographic Military Institute of Ecuador.

3.2. Optimisation problem

The optimisation of the supply chain was envisioned as an alternative to provide the oil extracting plant and the Jatropha collectors with a criterion that potentially support their growth in rural areas with low incomes. Such optimisation involved maximising the oil extracting plant profit and assuring the existence of Jatropha collection in the three existing collection zones (North, Central, and South) of Manabí-Ecuador. The information regarding the existing Jatropha supply chain was gathered trough field work and surveys to different stakeholders involved in the supply chain regarding the growth of Jatropha, storage, transportation and oil extraction, in Manabí-Ecuador. The Jatropha oil extraction facility located in Manabí was considered as the only Jatropha oil extracting plant of the supply chain. The profit of the oil extracting plant considered the incomes from the trade of Jatropha oil and residual extraction cake at local market prices, as well as the costs associated with Jatropha fruit and seeds prices, collection, transportation and oil extraction costs. The selling price of the Jatropha oil involves its current use as an environmental-friendly fuel for thermal power generation in the Galapagos Islands. The amount of Jatropha fruit/seed available in each collection point and the distances between collection points and the extraction plant were considered as variables. Each zone maintained its current collection points and the implementation of new collection points was evaluated per zone throughout a sensitivity analysis

3.3. Mathematical model

The gathered information regarding the Jatropha oil extraction supply chain in Manabí-Ecuador served as an input for establishing the objective function, which describes the profits as a function of the incomes and the total costs associated to the Jatropha oil extraction supply chain.

LP was used to maximise the profit of the oil extracting plant, and the optimisation was performed in two stages. The first stage involved all the collection points at once, while the second stage optimised each zone and its collection points separately. The differentiated analysis per zone was defined on the basis of assuring an economic income to the Jatropha collectors in all the zones. In the present study the supply chain ended in the gates of the oil extracting plant. The developed model is presented below:

Inputs:

- Amount of collected Jatropha fruit and seed per collection point per year
- Cost of Jatropha fruit and seed
- Distances between collection points and the oil extracting plant

- Cost of transporting Jatropha fruit and seed from each collection points to the extracting plant
- Jatropha fruit and seed oil extraction costs
- Jatropha oil yield in the extraction process
- Jatropha oil selling price
- Jatropha residual extraction cake selling price

Decisions:

- Quantity of Jatropha fruit and seed transported from each collection point to the extracting plant per year
- Quantity of Jatropha oil that is produced in the extracting plant per year
- Quantity of Jatropha fruit and seed per year required from new collection points

Assumptions:

- The oil extracting plant is the only one that purchases the Jatropha fruit and seed produced in Manabí-Ecuador, and it works continuously
- The yield of the extraction process f_{oil} is 0.3 [kg $_{oil}$/kg $_{Jatropha\ seed}$] (Achten et al., 2007)

- The potential growth per collection point and zones is 10% per year

Maximise $P_{EP} = f_{oil}\, p_{oil} Q_T + (1 - f_{oil})\, p_c Q_T - \sum_{i=1}^{n} p_i Q_i - \sum_{i=1}^{n} C_i d_i Q_i - E_{costs}$ (1)

The objective function (1) considered all the collection points that were identified and characterized in-situ. Unitary transportation costs from collection points to the extracting plant were determined individually for each collection point on the basis of distances, transported amount, and the charges that are established by direct collector/transporter negotiation in Manabí. The total revenues are given by the total Jatropha oil and Jatropha extraction cake that can be sold to the market. The total costs considered the costs of Jatropha fruit and seed purchased from collection points, transportation costs and oil extracting costs.

The Jatropha fruit and seed costs are determined by the quantities and prices of collected Jatropha dry seed through $\sum_{i=1}^{n} p_i Q_i$, the transport costs and distances through $\sum_{i=1}^{n} C_i d_i Q_i$ and the Jatropha oil extraction costs E_{costs}.

Constraints of the amount of Jatropha in the collection points

The amount of collected Jatropha is limited by the capacities of each one of the collection points. Moreover, the constraints depend on the analysis zone. In each zone, there is one collection point with the lowest Jatropha collection (Q_{MIN}) and one with the highest Jatropha collection (Q_{MAX}).

The upper limit was defined considering an increase of 10% in the collection capacity of each collection points. Likewise, a potential increment of 10% in the collection capacity of each zone was also considered. Such increase represents opportunities for future collection capacity growth. The constraints of the mathematic model are presented in the following lines.

$$Q_1; Q_2; \dots Q_i \leq Q_{MAX} * 1{,}1 \tag{2}$$

$$Q_1; Q_2; \dots Q_i \geq Q_{MIN} \tag{3}$$

$$Q_T \geq \sum Q_i \tag{4}$$

$$Q_T \leq \sum Q_i * 1{,}1 \tag{5}$$

$$Q_T, Q_i, \geq 0 \tag{6}$$

The maximisation of the objective function was undertaken for all the collection points at once, and for each zone with its collection points.

3.4. Sensitivity analysis

The sensitivity analysis was performed only for the case when collection points were grouped under zones. The proposed mathematical model was solved for each zone with the correspondingly collection points, providing the maximum profit for the extracting plant per zone. Such optimum was defined as initial profit Ui.
The variation of the profit per zone was analysed by comparing the value of the profit in each zone, when collection points were removed from the objective function once at a time. The standard deviation σ was calculated considering the maximum profits reached per zone each time a collection point was removed.

Decision criteria for the evaluation of new collection points in Manabí-Ecuador

To analyse the feasibility of implementing new potential collection points in each zone, different steps were considered. First of all, the location of the potential new collection point and the distances to the extracting plant were determined using GIS. Secondly, all the inputs required for the objective function were determined. The potential new collection point was included in the mathematical model for determining the new profit of the zone. The new resulting profit was defined as P_F and a sensitivity analysis varying the amount of collected Jatropha for each new collection point was performed.

The criterion for accepting or rejecting new collection points in each zone, considered the initial profit Ui, the final profit P_F and the standard deviation σ, and it was defined by:

$$P_F \geq U_I + \sigma \tag{7}$$

In order for a new collection point to be accepted, the value of the optimised objective function needs to be higher than the initial profit plus the standard deviation. Consequently, any new accepted collection point will be expected to increase the profit of the geographical zone where it belongs. The implementation of one new collection points also considered the analysis of the minimum amount of collected Jatropha seed needed for a new collection point to be accepted. Within these considerations, a new collection point was evaluated in each zone, and the requirements for its acceptation were defined.

4. Results and Discusion

4.1. Identification of the existing collection points using GIS

Through GIS, 20 different Jatropha curcas collection points were identified in Manabi-Ecuador. The different permanent collection points considered 7 points in the North zone, 9 in the Central zone and 11 in the South correspondingly. The location, amount of collected Jatropha, the distances between collection points and the extracting plant, and the transport costs for each zone, are presented in Tables 2 to 4 and Figure 2.

Table 1. Identification and characteristics of the collection points located in the North zone

COLLECTION POINT OF JATROPHA CURCAS	AMOUNT [kg]	ROUTE [Km]	TRANSPORT COST [USD/kg Km]
ASOCIACIÓN AGROPECUARIA COPETON	561.90	73.69	1.45E-03
COMITÉ AGRÍCOLA LA DIFERENCIA PRODUCTIVA BOYACA	21247.11	92.58	9.15E-05
UNIÓN DE ORGANIZACIONES CAMPESINAS SAN ISIDRO	7541.44	114.43	1.74E-04
ASOCIACIÓN AGRÍCOLA ROSA BLANCA	687.36	94.84	1.53E-03
COMUNA LOS CARAS	3784.16	112.03	2.83E-04
TOSAGUA	2488.38	57.18	7.03E-04
ASOCIACÓN AGRÍCOLA RÍO CANUTO	363.60	67.37	2.04E-03

Table 2. Identification and characteristics of the collection points located in the Central zone

COLLECTION POINT OF JATROPHA CURCAS	AMOUNT [kg]	ROUTE [Km]	TRANSPORT COST [USD/kg Km]
CERRO VERDE	2167.33	60.52	6.10E-04

LA ATRAVEZADA	5669.07	64.39	8.22E-05
COMUNA DANZARIN	959.09	40.30	9.06E-04
ASOCIACIÓN LAS FLORES	222.20	37.85	3.57E-03

Table 3. Identification and characteristics of the collection points located in the South zone

COLLECTION POINT OF JATROPHA CURCAS	AMOUNT [kg]	ROUTE [Km]	TRANSPORT COST [USD/kg Km]
RECINTO SANDIAL	4445.92	56.58	8.75E-04
COMUNIDAD CERRITO DE LA ASUNCIÓN	247.90	48.50	1.66E-02
SANCAN- SANCAN	8420.84	48.99	5.33E-04
MERO SECO	1014.02	84.38	3.04E-03
COMERCIAL CASTILLO BUSTAMANTE	1501.70	66.21	2.51E-03
COLIME SAN ANTONIO	318.00	96.72	9.75E-03
GUALE	524.19	127.38	4.49E-03
COMERCIAL ISIDRO ARGUELLO	6335.89	140.44	3.93E-04
EL PESCADOR OLMEDO	799.47	38.96	5.78E-03

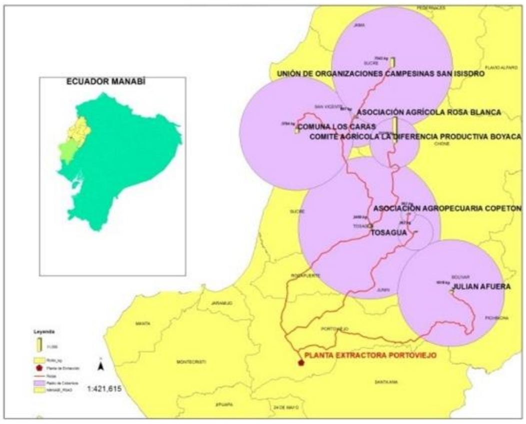

Fig. 1(a). North Zone

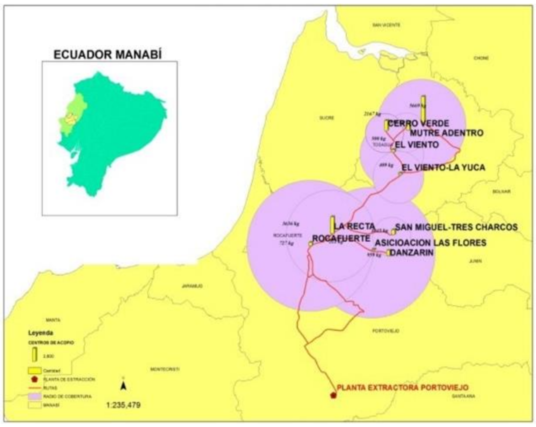

Fig. 1(b). Central Zone

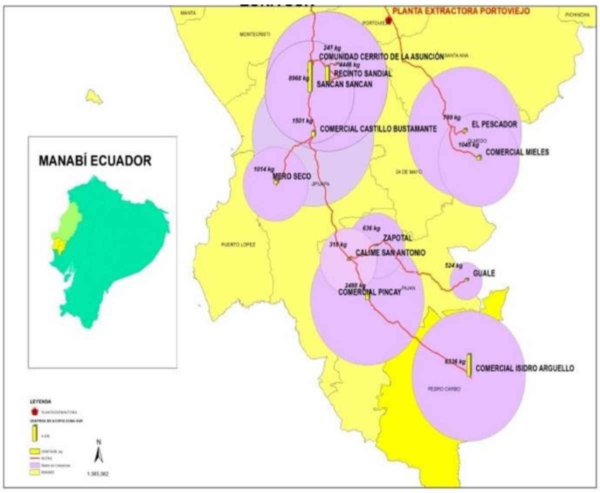

Fig. 1(c). South Zone

Fig 1. Maps of the different location of collection points

The information presented in Tables 2, 3 and 4 evidences an important variation of the transportation costs of the supply chain, within and between zones. For instance, for COMUNIDAD CERRITO DE LA ASUNCION and SANCAN-SANCAN, both collection points located in the south zone; the difference between their distances to the oil extracting plant, 48.5 km and 48.9 km respectively, is nearly 1%. However, the difference between the cost of transportation, 4.21 [$/km] and 4.49 [$/km], is approximately 8%. Likewise, there are important differences in the Jatropha transportation cost between collection points from different zones, even if they are located at similar distances from the extraction plant. When comparing the ASOCIACION AGRICOLA ROSA BLANCA collection point located in the north zone, with COLIME SAN ANTONIO in the south; for a 2% difference in the distance to the extraction plant, an 84% difference in the transport costs are evidenced. This behaviour is explained by the existing direct negotiation between collectors and transporters, and by the fact that Jatropha is not the main crop of the area and it is often transported along with other crops such as maize, which ultimately defines the Jatropha transport costs.

4.2. Optimization problem (excluding some collection centers)

The results of the optimised objective function when all the collection points are considered at once are presented in Figure 3.

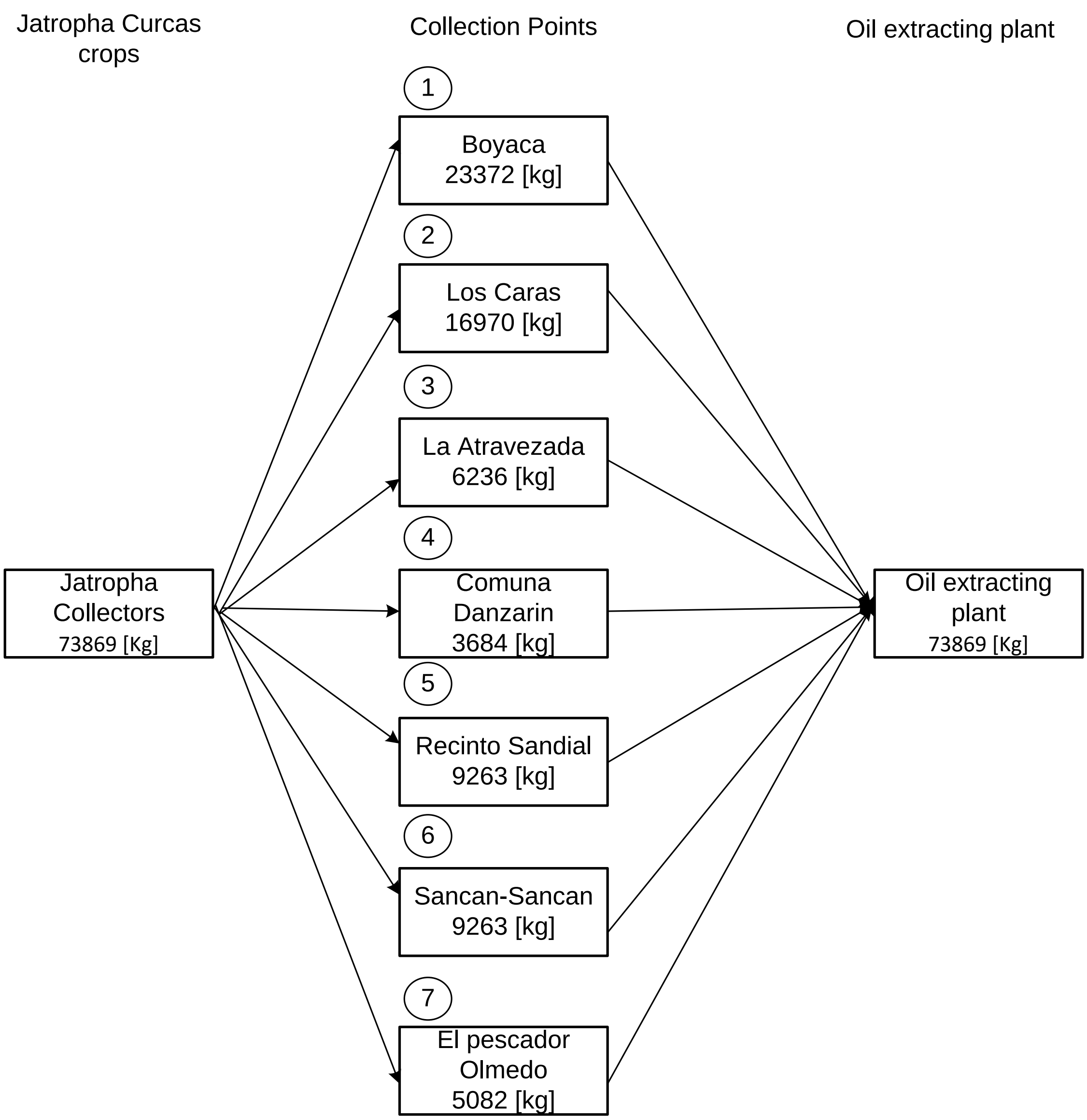

Fig. 3. Optimised supply chain for oil extraction considering all the collection points

The profit of the oil extracting plant, when all the collection points were considered, was of **5437.5 [$/year]** and involved only 35% of the total number of collection points in Manabi-Ecuador. The maximum profit requires the elimination of most of the collection points that already exist in Manabi-Ecuador. Even though such alterative is the optimal in terms of profit, it generates a complicated social issue. Indeed, most of the collectors in the rural areas of Manabi are farmers that live in poverty and depend upon the additional incomes generated by Jatropha collection. Considering that

Jatropha farming in Manabi-Ecuador started as a social-targeted program, the optimal solution would deeply affect the interests of the community and those of the Jatropha farming project. A potential alternative for overcoming such limitations regards the optimisation of the supply chain in each zone, assuring the existence of more collection points.

4.3. Optimization problem without excluding any collection centers

The results of the optimisation of the objective function for each zone are presented in Table 5.

Table 4. Profit when all the collection points are analysed per zone

Zone	Profit [$/year]	Amount [kg/year]
North	3185.30	36673.95
Central	802.37	9017.69
South	629.26	23607.93
Total	4616.93	69299.57

When a zone-by-zone optimisation is performed and all the available collection points are included in the Jatropha oil extraction supply chain, the overall profit decreases 15%; which evidences that economic and social benefits follow different directions in rural areas. Nonetheless, even when all the collection points are considered, it is still possible to generate profits for the oil extracting plant. Consequently, a compromise needs to be made between the profits of the extracting plant and the social benefits derived from including as much Jatropha farmers as possible, as suppliers. Governmental support seems to be decisive for bridging the economic gap originated by the inclusion of all the collection points, and alternatives to compensate the productive sector in such scenarios need to be developed.

4.4. Sensitivity analysis

The undertaken sensitivity analysis involved the determination of the profit in each zone separately and it required the elimination of collection points one at a time, in order to determine resulting profits and standard deviations. The results of the mentioned analysis for the North zone are presented as it follows.

The resulting objective function for the North zone is presented in equation (8).

$$P_{EP} = f_{oil}\, p_{oil} Q_T + (1 - f_{oil})\, p_c Q_T - \sum_{i=1}^{7} p_i Q_i - \sum_{i=1}^{7} C_i d_i Q_i - E_{costs} Q_i \qquad (8)$$

The same mathematic model (8) can be applied to the remaining zones with their corresponding collection points, constraints, costs and amounts. The results for central and south zones are presented in Figure 5 and 6.

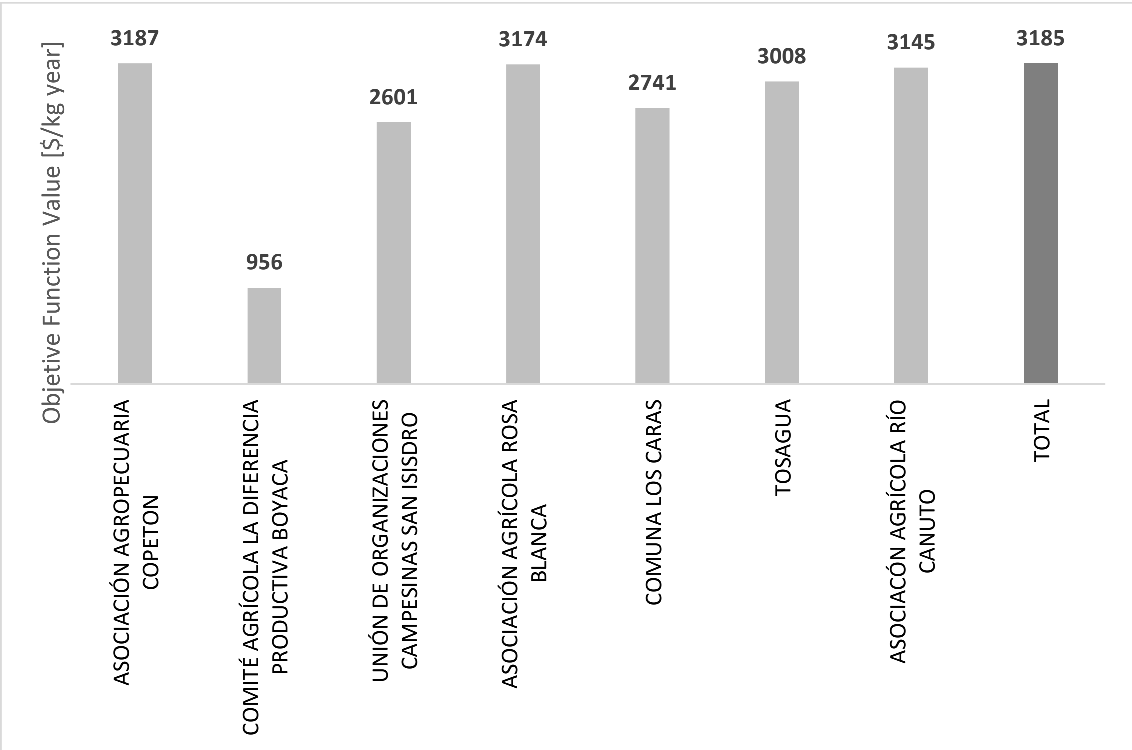

Fig. 4. Sensitivity analysis for the North zone

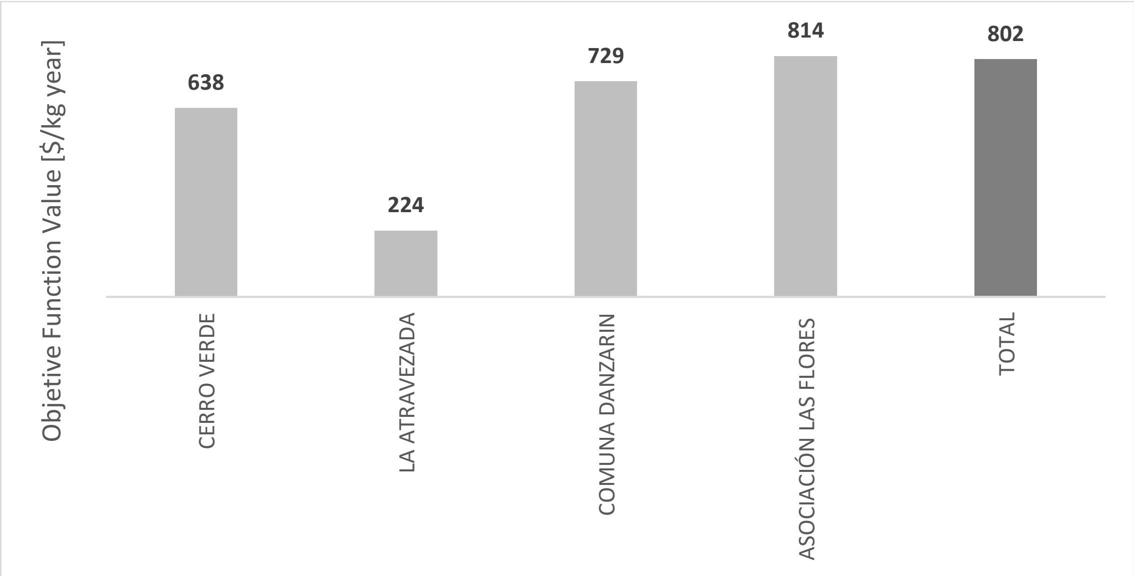

Fig. 5. Sensitivity analysis for the Central zone

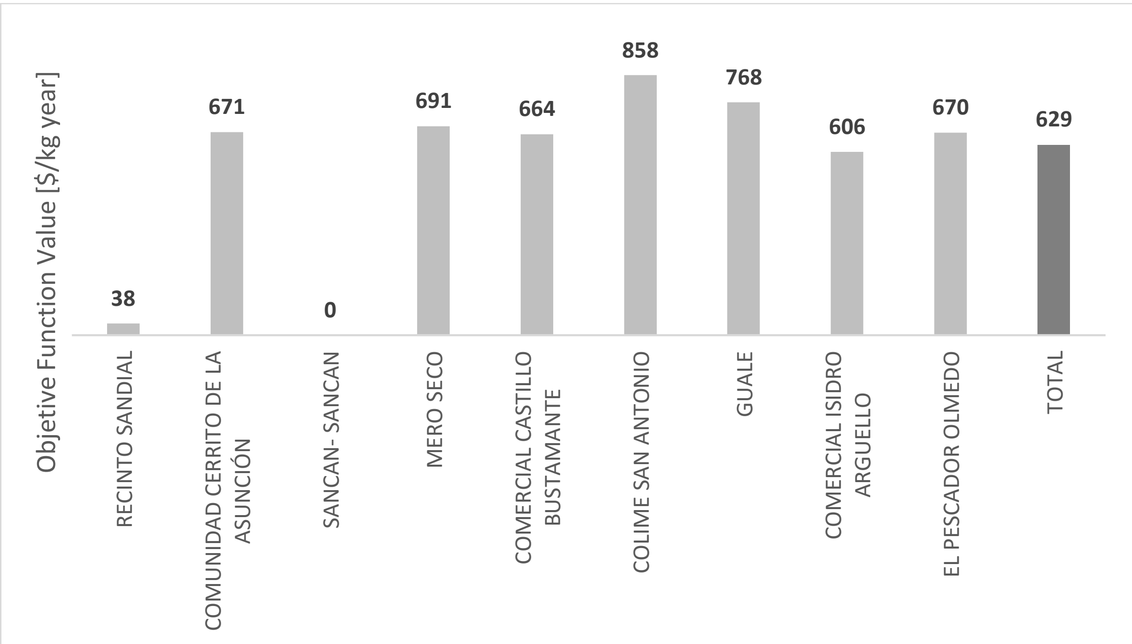

Fig. 6. Sensitivity analysis for the South zone

The results from the sensibility analysis show that when the objective function is evaluated without the biggest collection point in each zone, the profit lowers to a minimum value. In the north zone, as it is presented in Figure 4, when BOYACA is excluded the profit lowers 70%. Similarly, the biggest collection points in the Central and South zones generate a 72% and 100% reduction in the corresponding profits. These results show that for the existing Jatropha supply chain in Manabi–Ecuador, the profit of the oil extracting plant depends mainly on one collection point per zone. Such behaviour evidences that the profit of the extracting plant strongly depends on the amount of feedstock and its associated prices.

Criteria for new collection points

The considered criteria for analysing the feasibility of new collection points considered a minimum profit that every new collection point must comply, in order to be accepted. Figure 7 evidences that such criteria involve the overall profit of each zone and the standard deviation in the profit when current collection points are removed one at a time. The $U_i+\sigma$ criterion guarantees that the implementation of new collection points increases the overall profit in each zone. Figure 7 also evidences that the transport costs in the North zone are the lowest, compared with the other zones.

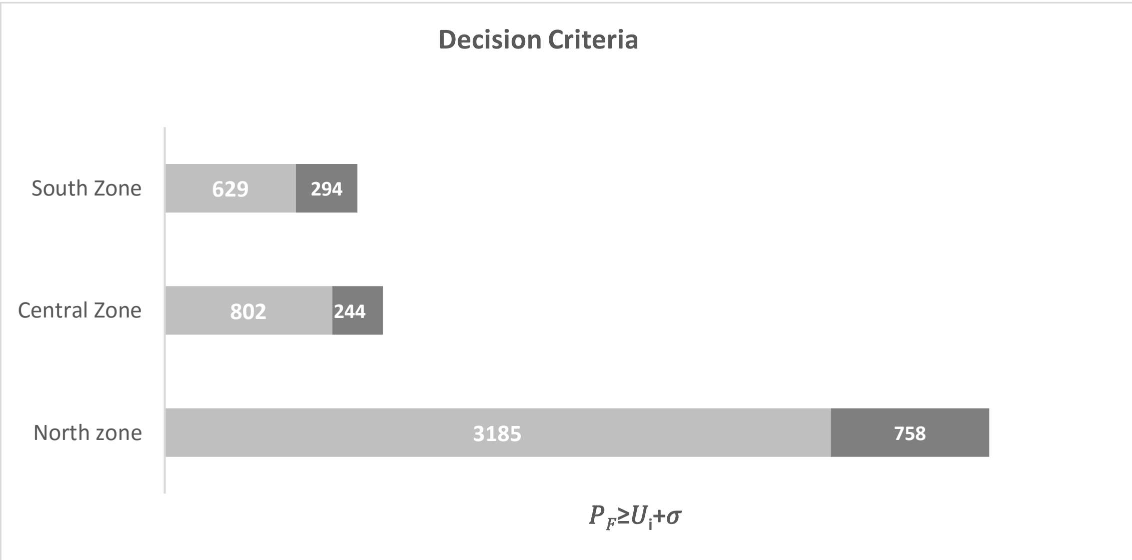

Fig. 7. Decision criteria for evaluating new collection points

Evaluation of new collection points in Manabi

The results of the sensitivity analysis considering variations in the amount of collected Jatropha in each new collection point, are presented in Table 6.

Table 5. Sensitivity analysis for new collection points in the different zones

North Zone				
Julian Afuera Collection Point				
	Collection [kg]	**Profit [$/year]**	$P_F \geq U_i + \sigma$ **[$/year]**	**Status**
Scenario 1	10000	3942	3944	Rejected
Scenario 2	10025	3944		Accepted
Scenario 3	10200	3956		Accepted
Central Zone				
San Miguel de los tres Charcos Collection Point				
	Collection [kg]	**Profit [$/year]**	$P_F \geq U_i + \sigma$ **[$/year]**	**Status**
Scenario 1	2000	964	1046	Rejected
Scenario 2	3050	1046		Accepted
Scenario 3	4000	1120		Accepted
South Zone				
Zapotal Collection Point				
	Collection [kg]	**Profit [$/year]**	$P_F \geq U_i + \sigma$ **[$/year]**	**Status**
Scenario 1	8500	921	923	Rejected
Scenario 2	8581	923		Accepted
Scenario 3	9000	934		Accepted

Table 6. Minimum amounts of Jatropha for being accepted in the different zones

Zone	**Collection Point**	**Minimum amount to be accepted [kg/year]**
North	JULIAN AFUERA	10025
Central	SAN MIGUEL TRES CHARCOS	3050
South	ZAPOTAL	8581

Tables 6 and 7 evidences that the new collection points can be established in the different zones as long as a minimum amount of Jatropha is collected. For the new collection point in the north zone, near 4000 [kg/year] are required for complying with the decision criterion. Similarly, near 1050 [kg/year] and 900 [kg/year] are required in the Central mmand South zones for complying with the proposed criteria. The differences in the criteria for the collection zones respond to the location of the analysed collection points, and the availability of roads for Jatropha transport towards the extracting plant.

5. Conclusions

The developed objective function can be used to evaluate the feasibility of implementing new Jatropha collection points in rural areas. In such decision, the amount of collected Jatropha and the resulting profit generated from the sale extracted oil and extraction residual cake needs to be considered.

From the 20 existing collection points in Manabi, only 7 are required to obtain the maximum profit in the extraction plant of nearly 5438 [$/year], involving only 35% of the total number of collection points in Manabi-Ecuador. However, the potential social benefits associated for Jatropha collectors make it necessary to involve as many collection points and communities as possible even if such decision represents a lower profit.

Optimisation per zones represent showed to be a suitable alternative to analyse and to improve the supply chain of existing oil extracting plants. The maximum profit obtained with this optimisation was nearly 4617 [$/year]. Consequently, specific constraints need to be determined in each zone of interest.

The north zone has the highest Jatropha collection amount (69%), followed by the central (14%) and south zones (17%), respectively.

Jatropha curcas collection is not the main productive activity in Manabi. Jatropha transport costs are based on the transport of other products associated to the Jatropha project such as maize, and this shared transport ultimately affects the transport costs.

The location of collection points and the amount of collected Jatropha are the strategic variables that determine the standard deviation, and the more disperse the values, the higher the standard deviation and the stricter the acceptance criteria for evaluating new collection points.

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