# COST ANALYSIS OF THE LOCATION OF COLOMBIAN BIOFUELS PLANTS

# UN ANÁLISIS DE COSTO DE LA LOCALIZACIÓN DE PLANTAS DE BIOCOMBUSTIBLES COLOMBIANAS.

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**ABSTRACT:** Facility location is a strategic decision that affects supply chain competitiveness. In this study, facility location and logistics networks were analyzed in 7 biodiesel and 6 bio-ethanol production plants in Colombia. The proposed methodology provided a decision making model to compare facility location taking into account production costs and the logistics network. Preliminary technical and economic studies were conducted using Aspen Plus for process simulation. The logistics network distribution was analyzed using a linear programming method to compare and analyze the advantages and disadvantages of plants situated in different locations of the country. Factors related to location, raw materials, supply chains and capacity were also analyzed. The findings show that three biodiesel plants in Villavicencio, Bucaramanga and Santa Marta and two bioethanol plants in Valle and Cauca had the lowest production cost.

**KEYWORDS:** Facility location, biofuels, Colombia, logistics network, supply chain, simulation.

**RESUMEN:** La localización de instalaciones es una decisión estratégica que impacta directamente la competitividad de la cadena de suministro. En este estudio, la localización de instalaciones y la red logística para la producción de biocombustibles en 7 plantas de biodiesel y 6 plantas de bioetanol, fueron analizadas para el caso Colombiano. La metodología propuesta proporciona un modelo de decisión para comparar la localización de instalaciones teniendo en cuenta el costo del producto y la red logística. Estudios técnicos y económicos preliminares fueron realizados utilizando el simulador de procesos Aspen Plus. La red logística se analizó utilizando un método de programación lineal que permitió comparar las ventajas y desventajas entre cada una de las plantas localizadas en diferentes ciudades del país. Factores relacionados con la ubicación, las materias primas, la cadena de suministro y la capacidad fueron determinantes en la decisión. Los resultados muestran que, para el caso del biodiesel, los menores costos se obtienen en Villavicencio, Bucaramanga y Santa Marta y para el caso del bioetanol en el Valle y en el Cauca.

**PALABRAS CLAVE:** Localización de instalaciones, Biocombustibles, Colombia, Red logística, Cadenas de Suministro, simulación.

## 1. INTRODUCTION

Facility location is a strategic decision that affects the competitive performance of companies. Factors such as productivity, taxes and political context, among others, have motivated companies to consider new location alternatives to gain better results in terms of cost, time, flexibility and service. Therefore, companies locate their facilities in places of high value return [1].

The decisions regarding facility location are present in three levels of planning: strategic, tactical and operational [2]. These levels must be integrated in an approach that seeks to optimize global logistics costs [3]. In some countries like Colombia, however, facility location and, in particular, the location of agro-industrial plants, is not considered in planning decisions basically for two reasons: first, some companies are not aware of the existence of models for supporting the facility location decisions and hence, they don't apply them. Second, in some regions of the country, private interests or political pressures prevail in the decision. Both situations threaten the profitability of the company in the future. Profitability might be affected in the long term when decisions of facility location don't take into account factors such as transport infrastructure, public services, accessibility of raw materials and skilled labor.

Therefore, this article shows an analysis of biofuel supply chains, which helps to determine and compare costs of final goods based on the current facility locations in Colombia. A transportation model was considered in the analysis; also, fixed and variable production costs were determined by mean of *Aspen Plus Software*.

## 2. LITERATURE REVIEW

### 2.1. Facility location

Location is a common problem in operations research. Nowadays, there are different methodologies to address this problem. Most methodologies used in facility location problems are based on optimization of a cost function. In different contributions from the literature, the facility location is highlighted as one of the strategic decisions that directly affects the design and performance of the supply chain [2]. Likewise, several location models that incorporate the supply chain configuration have been studied in the last decade [4]. Some models in the literature seek to maximize customer service, responsiveness and profitability [5].

Other models are used to minimize functions such as total installed cost, longest distance between existing locations, fixed costs, total annual operating cost, average travel time, maximum time and distance and number of facilities located [5]. A lot of methods have been studied to solve location problems [5] [6]. A proposed classification for solution methods in facility location problems is as follows: exact methods, multicriteria technique's, heuristics and meta-heuristics techniques [7]. The main difference between these methods is the kind of solution obtained; in the exact methods is possible to get an optimal solution, while the multicriteria, heuristic and meta-heuristics techniques provide solutions that approach the optimum value. The heuristics techniques have an easy convergence with the so-called "local optimal", making it impossible to reach the global optimum without sacrificing computational times. This disadvantage is overcome by meta-heuristics techniques such as: Genetic Algorithms, (GAs) Simulated Annealing (SA), Evolutionary Algorithm, Particle Swarm Optimization (PSO), Dynamic Mesh Optimization (DMO), Ant Algorithms (AAs) and Fuzzy Logic.

An important group of studies which have carried out simulations to determine the viability and energetic costs of biomass plants have been found in the available literature [8, 9]. However, other studies have developed models focused on optimizing a group of location factors for such plants [10]. Some factors that affect facility location and supply chain management decision making, are as follows: procurement sources, markets, transportation and communication, labor, utilities, quality of life of people, weather, legal framework, taxation, community attitudes, topography, and so on. Weaknesses concerning these factors have been identified in the analysis of the lignocelluloses biomass supply chains [11]. Really, logistic focus is the key issue for the future of fuel ethanol production from biomass. The importance of the logistical variables analysis in the economic studies is evidenced in the present work.

### 2.2. Biodiesel production in Colombia

In Colombia the activities of production, distribution and use of biofuels have been focused, on the one hand, to assure energy supplies and gradually replace the use of fossil fuels, and on the other hand, to improve the agricultural sector and to increase economic and social development. However, the increase of biofuel production should be regulated and balanced [12]. In the last decade, bioethanol and biodiesel production have had a significant growth in Colombia, and also in the entire world. Biofuels can be liquid, solid or gaseous and they are actually obtained from biomass (animal or vegetable organic material). The term biofuels includes bioethanol (or fuel ethanol), methanol, biodiesel, diesel produced by Fischer-Tropsch chemical process, gaseous fuels such as methane or hydrogen and bioenergy from wood pellets (dendro energy). Table 1 describes the feedstocks used in biodiesel and bioethanol production.

**Table 1.**Yields of feedstocks used in biofuels production

| Biodiesel | | |
|---|---|---|
| **Crops** | **Yield (L/Ha-year)** | **Source** |
| Palm | 5.550 (2012) | [13] |
| Coconut | 4.200 (2012) | [14] |
| Castor | 2.600 (2011) | [15] |
| Avocado | 2.460 (2009) | [16] |
| Jatropha | 1.559 (2009) | [16, 17] |
| Rape | 1.100 (2011) | [15] |
| soybean | 840 2009) | [16, 17] |

| Biodiesel | | |
|---|---|---|
| **Crops** | **Yield (L/Ha-year)** | **Source** |
| Algae oil[a] | 136900 (2010) | Author´s Calculation |
| Algae oil[b] | 58700 (2010) | Author´s Calculation |
| **Bioethanol** | | |
| Sugar Cane | 7737 (2011) | [18] |
| Beet | 6.000 (2011) | [18, 19] |
| Yucca | 5.278 (2011) | [19] |
| Sweet sorghum | 3.010 (2007) | [20] |
| Corn | 3.200 (2011) | [19] |

[a]70% by weigh of oil in biomass, [b]30% by weigh of oil in biomass.
Source: Based on Ministerio de Agricultura y Desarrollo Rural de Colombia, 2010 [21].

Colombia is the third American producer of biofuels after Brazil and USA. Colombia produces 1.2 million liters of ethanol from sugarcane. This ethanol volume covers about 70% of the domestic demand. Six fuel ethanol plants and seven biodiesel plants are actually operating in Colombia. Furthermore, several projects are being developed with the aim to search for new feedstocks. Figure 1 shows the location of biodiesel and bioethanol plants in Colombia as well as the regions where bioethanol and biodiesel are used as fuel [22]. Methanol is imported as Colombian production is very low and the location of biodiesel plants near to the ports decreases methanol transportation costs. Palm plantations are located throughout the country; which is divided in four areas: northern, central, eastern and western.

The use of biofuel in Colombia is a state policy, which is still in early stages. This situation generates expectations to create new plants and the need to improve the existing supply chain configurations. New logistics analyses are necessary to minimize operating costs and to increase biofuel usage nationwide. It is also important to research new production alternatives. Logistics aspects such as availability, international purchasing operations, transportation costs of raw materials, as well as operating costs, marketing infrastructure and social and economic effects, are some of the factors that strongly influence facility location decisions making [23]. This paper addresses some logistics problems of raw materials and transportation of finished goods, using a linear programming method that combines the analyses of processes and logistics networks. Based on work by Sherali and Adams (1984)[24], an algorithm was implemented, but with the difference that in this case the production costs were calculated using *Aspen Plus Simulator Software*. The aim of this study is the comparison of facility locations of biofuel plants existing in Colombia.

## 3. METHODOLOGY

The methodology used is based on three main steps. The first step addressed theoretical analysis, the collection of field data and estimated data to be used in the model. The second step developed a mathematical model using the information compiled in the first step. The last step consists of the simulation process. The simulation process allows allocating the system capacity, performing the mass and energy balance and also, a preliminary economic assessment of agro-industrial project. These data were used to analyze the appropriate configuration of the supply chain, in order to achieve the desired profitability of the process. (See Figure 2).

In this study, the methodology used has a fixed configuration of the biodiesel supply chain according to all the location alternatives existing in Colombia; therefore, the final results (in terms of finished goods costs) were used to compare them


**Figure 1.** Biofuels in Colombia.
Source: Modified from Fedepalma, 2010 [25].

## Simulation

The purpose of the simulation process was to generate the mass and energy balance; so it was necessary to establish the requirements for raw materials, consumer goods (catalyst, water and others), service fluids (in this case water and steam) and energy needs. Initial information needed for the simulation includes a comprehensive review and analysis of operating parameters in each step of the simulation process. Table 2 shows the main input data required for the simulation of one of the technological flow sheets. The selected flow sheet corresponds to the conventional technology used for biodiesel production from palm oil.

The simulation process and modelling were performed using specialized software. The simulations of different technological flow sheets, including all stages of the process for conversion of feedstock into biofuels, were performed using the Aspen Plus software version 7.2 (Aspen Technology, Inc., USA), which has been previously used for a range of design and analysis of processes [8, 9, 26].

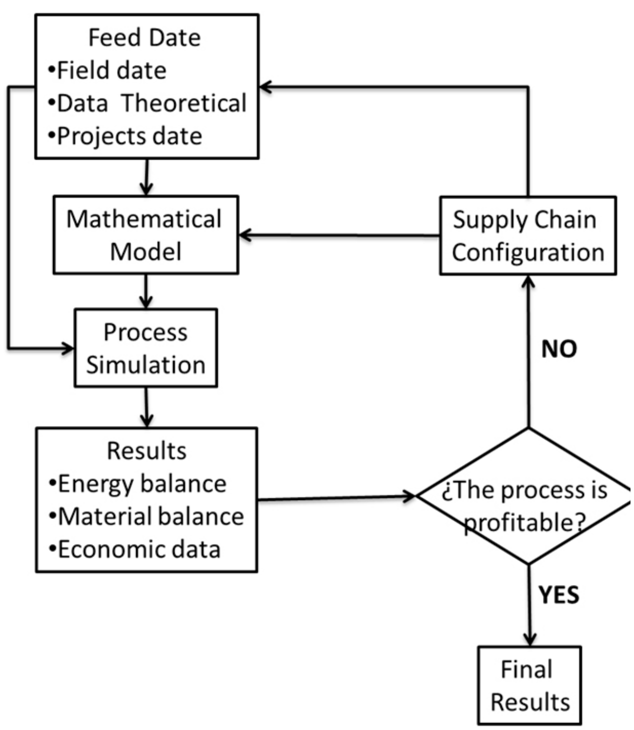


**Figure 2.** General methodology for comparing location alternatives. Source: Author's elaboration.

Special software packages for performing mathematical calculations such as Matlab 2009 were also employed. Some specific optimization tasks were accomplished using the package GAMS version 23.4 (GAMS Development Corporation, USA). In addition, software especially designed and developed by our research group like Modell-R was used for performing specific thermodynamic calculations because the determination of thermo-physical properties for certain components involved in the process is not found in available literature. Data of the physical properties of some of the components required during the simulation process were obtained using the Nannoolal methods [27], which estimates the critical property data, boiling point and vapour pressure by group contributions and group interactions.

The Economic aspects (storage costs, supply costs, inventory costs, and so on) for fuel ethanol and biodiesel production were evaluated using the Aspen Economic Evaluator V7.2 (ICARUS). The Aspen Economic Analyzer was designed to automate the preparation of detailed design and to perform the analysis of investments and programs, from the results of the simulation or the size of the equipment.

**Table 2.** Example of Input data needed for biodiesel production simulation from palm oil in Colombia

| **Item** | **Value** | **Item** | **Value** |
|---|---|---|---|
| **Raw material** | **Palm Oil** | **Product** | **Biodiesel** |
| Composition [a] | | Composition | |
| Palmitic acid | 44.3% | Methyl esters | 99.43% |
| Stearic acid | 4.6% | Water | 0,02% |
| Oleic acid | 38.7% | Methanol | 0.06% |
| Linoleic acid | 1.90% | Triglycerides | 0,17% |
| Protein | 0.04% | | |
| Water | 0.33% | | |
| Feed flow | 25,214 kg/h | Product Flow | 24,898 kg/h |
| Co-product 1 | Kernel cake | Co-product 2 | Glycerin |
| Oil Extraction | | Distillation for methanol recovery | |
| Press filter | | Number of columns | 1 |

| Item | Value | Item | Value |
|---|---|---|---|
| **Raw material** | **Palm Oil** | **Product** | **Biodiesel** |
| Number of units | 3 | Pressure | 1 atm |
| Extraction efficiency | 72% | Content of methanol at top product | 99% |
| Catalyst | *Sodium hydroxide* | | |
| Temperature | 60°C | Involved components | 10 |
| Residence time | 1 h | Process units | 35 |
| Number of units | 2 | Streams | 43 |

[a] % in mass fraction. Source: Author's elaboration.

**Analysis of Supply Chain Configuration:**

Supply chain management includes the efficient integration of suppliers, manufacturers and retailers so that customers receive the right product, the right quantity, in the right place and at the right time [28]. In this study, for each location alternative of biofuel plants in Colombia, an analysis of the supply chain configuration was made taking into account the logistics of transportation for raw material and finished goods. Figure 3 shows the scheme used to address the analysis.

**Mathematical model:**

A function of capital and operation costs includes inventory management, labor and equipment cost; which was obtained with the aid of the Aspen Plus Simulator. Therefore, in the mathematical model a modification of the typical transportation problem is proposed. This modification seeks to minimize the function of total transportation costs of raw material and finished goods, adding the production cost function obtained by mean of the simulation process. Equation 1 describes the mathematical problem [29] as follows:

Minimize:

$$CT = \sum_{i=1}^{m}\sum_{j=1}^{n} C'_{ij} * X'_{ij} + C''_{ij} * X''_{ij} + C^{P}_{ij} * X^{P}_{ij} + C_{pj}(Q_j) \quad (1)$$

Subject to:

$$\sum_{i=1}^{m} X_{ij}^{(',",p)} \leq b_j \quad (2)$$

$$\sum_{j=1}^{n} X_{ij}^{(',",p)} \leq a_i \quad (3)$$

$$X_{ij}^{(',",p)} \geq 0$$

Where:

$C'_{ij}$: Transportation costs of raw material (Palm oil for biodiesel and sugar cane for bioethanol) from source *i* to destination *j*.

$X'_{ij}$ : Quantity of raw material (Palm oil for biodiesel and sugar cane for bioethanol) for transportation from source *i* to destination *j*.

$C''_{ij}$ : Transportation costs of other raw material (only used for Methanol in biodiesel case) from source *i* to destination *j*.

$X''_{ij}$ : Quantity of other raw material (only used for Methanol in biodiesel case) for transportation from source *i* to destination *j*.

$C^{P}_{ij}$: Transportation cost of finished goods, from source *i* to final destination *j*.

$X^{P}_{ij}$ : Quantity of finished goods for transportation from source *i* to destination *j*.

$Cp_j(Q_j)$ : Cost function according to the installed capacity ($Q_j$) in each destination *j*. This function was obtained of the simulation process (US$/Ton.).

m: Number of storage centers.

n: Number of factories.

CT: Total production and transportation cost.

$b_j$: Maximum demand in location *j*.

$a_i$: Maximum supply capacity in source *i*.

## 4. RESULTS AND DISCUSSION

**Simulation and initial date:**

The following calculation basis was adopted in the simulation process (See table 3).

**Table 3.** Calculation basis in the simulation of bioethanol and biodiesel plants.

| Biodiesel Case | | |
|---|---|---|
| **Raw material** | Methanol (kg/h) | 656 |
| | Palm oil (kg/h) | 2916 |
| **Product** | Biodiesel (kg/h) | 2809 |
| **Bioethanol Case** | | |
| **Raw material** | Sugarcane juice (kg/h) | 143,484 |
| **Product** | Bioethanol (kg/h) | 8639 |

Source: Author´s elaboration.

The Table 4 shows the production costs in each case using ICARUS tools in Aspen Plus Software. Using the *Aspen Plus Software,* the functions of cost per unit were calculated changing the installed capacity in the bioethanol and biodiesel plants. The results are shown as follows:

Bioethanol

$$\mathbf{Cp_j(Q_j)}: = 1286.7*(Q_{ij})^{-0.047} \quad R^2 = 0.9635 \qquad (4)$$

Biodiesel

$$\mathbf{Cp_j(Q_j)} = -161.4 \ln(Q_j) + 2453.2 \quad R^2 = 0.9063 \qquad (5)$$

**Analysis of Supply Chain Configuration:**

According to Figures 1 and 2, five scenarios were considered in the biodiesel production case. The plants in Santa Marta and Cesar were grouped in one place and other plants were individually analyzed. The central, northwest, east, southeast and southwest of the country were taken into account in the analysis of biodiesel distribution network (see figure 3).

In the same way, according to Figures 1 and 2, three scenarios were analyzed in bioethanol production. Three plants in El Valle were grouped. Cauca and Valle were considered individually as they both have large acreage planted with sugar cane. In the analysis of the distribution network, the central, northwest, northeast, southeast and southwest of the country were taken into account because these states are the most important bioethanol consumers. Proexport Colombia [30], the organization in charge of promoting Colombian non-traditional exports, international tourism and foreign investment, provided the road freight transportation rates. The final logistic network is shown in Figure 4 for biodiesel and bioethanol.

**Table 4.** Biofuels production costs.

| Item (US$/year) | Costs Biodiesel | Costs Bioethanol |
|---|---|---|
| **Raw materials** | 15.578,70 | 23.871,90 |
| **Utilities** | 177,16 | 6.481,47 |
| **Operating labor** | 73,20 | 19,76 |
| **Maintenance** | 94,90 | 1.600,00 |
| **Operating charges** | 18,30 | 4,94 |
| **Factory overhead** | 84,05 | 809.88 |
| **G and A cost** | 5.096,42 | 2.687,36 |
| **Operating cost** | 17.308,40 | 35.475,31 |
| **Capital depreciation** | 929,71 | 4.153,85 |
| **Total (US$/year)** | **18.238,11** | **39.402,43** |
| **Product rate (L/year)** | 25.428,34 | 78.830,16 |
| **Production cost (US$/ Gal)** | **2.71** | **1.89** |

Source: Author's elaboration.

Tables 5 and 6 show the results obtained from the analysis of raw material transportation for biofuel production plants and also, the results of the transportation cost in the logistics network. Table 7 shows that the Villavicencio, Santa Martha and Bucaramanga plants offer lowest supply costs in biodiesel case; likewise, Valle was the best for bioethanol case The total production costs are lowest in the Santa Marta, Bucaramanga and Villavicencio plants, due to their capacity and their geographical location closer to raw material suppliers. This is consistent with the results shown in Table 5, where lowest costs of logistics supply network were obtained in plants located near to the ports. In the same way, this result is consistent with the geographical location of the plants in the distribution network, and emphasizes the importance of transportation costs in decision making regarding facility locations [28].

Table 7 shows the results of the optimal production cost in different plant location.

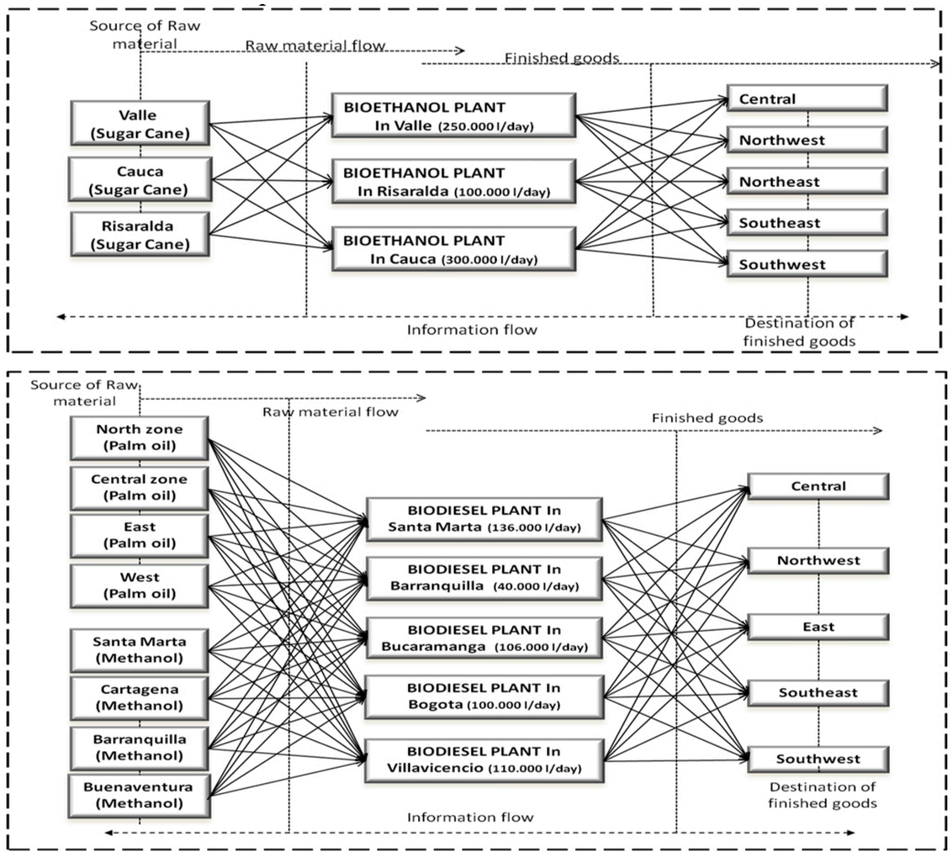


**Figure 3.** Initial logistics network in biofuels production.Source: Author's elaboration.

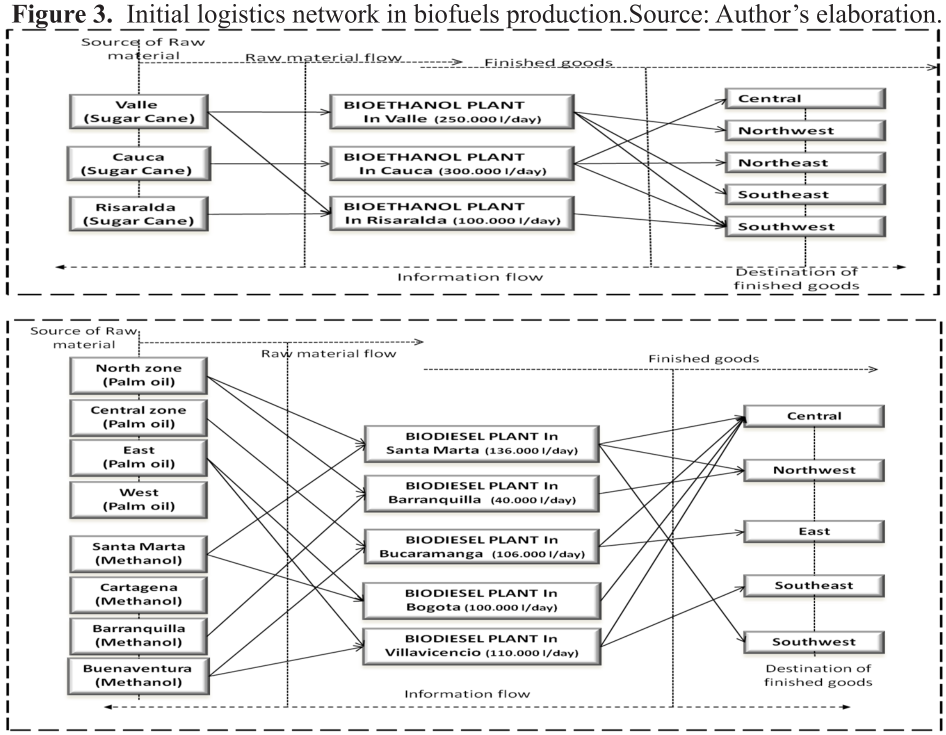


**Figure 4.** Final logistics network in biofuels production. Source: Author's elaboration
Source: Author's elaboration.

**Table 5.** Final logistic network in biodiesel case

| Transport Cost / Ton/year | | Santa Marta | Barranquilla | Bucaramanga | Bogota | Villavicencio | ai |
|---|---|---|---|---|---|---|---|
| PALM OIL | North | 4 / 129.524 | 11 / 38.095 | 74 / - | 53 / 0 | 85 / - | 319.905 |
| | Central | 43 / - | 44 / - | 4 / 95.238 | 44 / - | 56 / - | 262.575 |
| | East | 63 / - | 64 / - | 43 / - | 24 / 95.238 | 4 / 104.762 | 363.405 |
| | West | 100 / - | 94 / - | 80 / - | 68 / - | 76 / - | 110.757 |
| bj | | 129.524 | 38.095 | 95.238 | 95.238 | 104.762 | 462.857 |
| METHANOL | Santa Marta | 4 / 14.803 | 18 / - | 74 / 0 | 53 / 10.884 | 85 / - | NA |
| | Cartagena | 22 / - | 19 / - | 79 / - | 59 / - | 92 / - | NA |
| | Barranquilla | 16 / - | 6 / 4.354 | 77 / - | 57 / - | 88 / - | NA |
| | Buenaventura | 87 / - | 86 / - | 57 / 10.884 | 68 / - | 64 / 11.973 | NA |
| bj | | 14.803 | 4.354 | 10.884 | 10.884 | 11.973 | 52.898 |
| DISTRIBUTION NETWORW | Central | 74 / 20480 | 77 | 44 / 22240 | 4 / 100000 | 24 / 80840 | 223560 |
| | Northwest | 65 / 28040 | 62 / 40000 | 54 / - | 39 / - | 50 / - | 68040 |
| | East | 93 / - | 94 / - | 61 / 77760 | 33 / - | 42 / - | 77760 |
| | Southwest | 93 / 87480 | 96 / - | 88 / - | 69 / - | 76 / - | 87480 |
| | Southeast | 85 / - | 88 / - | 56 / - | 24 / - | 4 / 29160 | 29160 |
| bj | | 136.000 | 40.000 | 100.000 | 100.000 | 110.000 | 136.000 |

**Table 6.** Final logistic network for bioethanol case

| Transport Cost / Ton/year | | VALLE | RISARALDA | CAUCA | ai |
|---|---|---|---|---|---|
| SUPPLY NETWORK | Valle | 4 / 49.967 | 25 / 1.975 | 22 / 0 | 52.292 |
| | Cauca | 22 / - | 37 / - | 4 / 69.954 | 71.605 |
| | Risaralda | 17 / - | 4 / 18.012 | 24 / - | 18.012 |
| bj | | 49.967 | 19.987 | 69.954 | |
| DISTRIBUTION NETWORK | Southwest | 39 / 61.735 | 51 / 19.987 | 39 / 5.721 | 87.443 |
| | Central | 46 / - | 43 / - | 49 / 49.967 | 49.967 |
| | Southeast | 57 / 24.984 | 51 / - | 54 / - | 24.984 |
| | Northeast | 63 / - | 51 / - | 73 / 14.266 | 14.266 |
| | Northwest | 31 / 72.453 | 26 / - | 25 / - | 72.453 |
| bj | | 159.896 | 19.987 | 69.954 | |

Source: Author's elaboration

the plants located in Risaralda showed the highest total bioethanol production costs; this situation could be caused due to their low installed capacity. The results showed that the lowest supply cost is obtained for bioethanol plants, because these have their own raw material. Valle, Risaralda and Cauca are closer and their plants showed similar costs in the distribution network. However, similar to biodiesel production case,the relationship between production, transportation and inventory cost, directly influence facility location decisions. Therefore, the integration and strategic location among suppliers and distribution networks ensure lowest transportation and production costs.

**Table 7.** Final production cost for biofuels plant

| LOCATION | CAPACITY PLANT (ton/year) | US$/GAL |
|---|---|---|
| **BIODIESEL LOCATION** | | |
| Santa Martha | 136000 | 2,51 |
| Barranquilla | 40000 | 2,63 |
| Bucaramanga | 100000 | 2,51 |
| Bogota | 100000 | 2,57 |
| Villavicencio | 110000 | 2,50 |
| **BIOETHANOL LOCATION** | | |
| Valle | 159.896 | 1,58 |
| Risaralda | 19.987 | 2,61 |
| Cauca | 69.954 | 1,99 |

Source: Author's elaboration+

## 5. CONCLUSIONS

Facility location is one of the strategic decisions in the design of supply chains, which under a functional and vertical integration approach, might become a competitive advantage for organizations. This approach allowed the selection of facility locations minimizing transportation and production costs and allowing a better interaction between customers and production systems.

The *Aspen Plus software* was used to calculate an estimate production costs and then, these were integrated into the transportation network which allowed the comparison of different location alternatives in the Colombian case study.

Specifically, Plants located in Villavicencio, Bucaramanga and Santa Martha had the lowest production costs in the biodiesel production case. Their capacity was an influential factor in this result; therefore, in the case of plants with high capacity, the cost per unit were optimized. Similarly, as plants located in Cauca and Valle had greater installed capacity in the ethanol production case, they obtained the lowest price per gallon. Lowest costs in the logistics supply network were obtained in plants strategically located near raw material sources, and in biodiesel production plants located close to the ports, which ensured the lowest cost of methanol supply.

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