# Feasibility Analysis of a Supply Chain for Castor Oil Biodiesel Distribution in Central Mexico

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**Abstract.** The aim of this paper is to analyze the feasibility of establishing a supply chain for castor oil biodiesel distribution in Central Mexico, based on the distribution of land with the highest castor oil seed yield potential. The supply chain analysis is focused on meeting the biodiesel demand for the region, assuming a B20 mix usage, from the proposed plantation sites to refineries and gas stations, using Network Optimization, and defining the required biodiesel production increase to achieve this.

**Keywords:** Supply chain · Biofuel · Biodiesel · Castor oil · Mexico · Dynamic systems · Optimization

## 1 Introduction

Currently, Mexico imports around 262 thousand barrels of diesel daily, which represent approximately 66.8% of the 392 thousand daily barrels that conform the average national demand. This means that only 130 thousand daily barrels of diesel are produced locally [1].

The current government campaigned with an agenda highly focused on sustainability and clean energies, however, the actual policies are oriented towards the exploration and exploitation of oil fields, together with investments in PEMEX, Mexico's state-owned oil company [2]. These policies seek to reduce Mexico's reliance on oil products imports, like gasoline and diesel.

Considering this objective, the production of biodiesel is presented as a sustainable aid to meet the diesel demand, with the added benefit of supporting the development of the agricultural sector.

In previous studies, it has been presented that the mass production of biodiesel based on commercially cultivated edible plants is not considered economically feasible given the shortage of food it would trigger with a subsequent rise of food prices. Taking this into account, other plants that meet the requirements must be considered as sources, as long as they do not cannibalize or endanger current food production capabilities. One such plant is the castor oil plant (Ricinus communis), which has a relatively high yield of biodiesel and whose byproducts can be used to create compost [3].


J. A. Marmolejo-Saucedo et al. (Eds.): COMPSE 2020, LNICST 359, pp. 86–98, 2021.
https://doi.org/10.1007/978-3-030-69839-3_6

Research into biofuels as an alternative to traditional fossil fuels is not new. There are several studies, from the private as well as public sectors, that analyze the issue from an energy potential point of view [4], as well as the production processes based on used vegetable oils [5] and the production costs [6].

There are studies that analyze the supply and demand of gasoline in Mexico, like *"The demand for gasoline in Mexico: Effects and alternatives considering climate change"* ("La demanda de gasolinas en México: Efectos y alternativas ante el cambio climático") by Reyes, Escalante and Matas or *"Demand for gasoline and heterogeneity in household income in Mexico"* ("Demanda de gasolina y la heterogeneidad en los ingresos de los hogares en México") by Sanchez, Islas and Sheinbaum.

Some other studies have focused on biodiesel and biofuels, such as *"Study on the Feasibility of the Use of Biodiesel in the Public Transport System of the Metropolitan Area of Guadalajara"* ("Estudio sobre la Viabilidad de la Utilización de Biodiesel en el Servicio Público de Transporte Colectivo del Área Metropolitana de Guadalajara") from 2014 by Alcocer and Uriarte, which focused on the feasibility of using palm oil biodiesel for the public transport system of Guadalajara. There is also a study from 2017, *"Analysis of the supply chains of bioethanol and biodiesel in Mexico: Case studies"* ("Análisis de las cadenas de suministro de bioetanol y biodiésel en México: Estudios de caso"), which focuses on the current production of bioethanol and biodiesel in Mexico, including a section on the production of biodiesel based on castor oil.

However, there are few studies that analyze the risks and performance of supply chains, and their technical feasibility, specially focused on the current socio-economic environment in Mexico. These studies would help promote the use of renewable energy sources in Mexico in a practical, sustainable, and responsible way.

## 2 Castor Oil

### 2.1 Castor Oil Production in Mexico

During the second semester of 2010, the National Institute for Forestry, Agricultural and Fishing Research (INIFAP, for its initials in Spanish, Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuaria), concluded the project *"Study of Raw Materials for obtaining Biofuels in Mexico"* ("Estudio de Insumos para la Obtención de Biocombustibles en México") where they were able to obtain the following information: identification of the genetic potential for the creation of varieties with outstanding agro-industrial characteristics in pine nut (Jatropha curcas), castor (Ricinus communis) and sweet sorghum (Sorghum bicolor), and identification of the agroecological conditions for the cultivation of the Mexican pine nut, castor, sweet sorghum and beet (Beta vulgaris) [7].

Castor oil seed sales slumped for a time, when each kilogram of ground seed went for $3.00MXN in Oaxaca, for example. However, in recent years, it's price has gone up following the discovery of different applications for castor oil, to a point where it has become more profitable for some farmers to cultivate castor plants, at $8.00MXN per kilo, rather than their traditional crops of tomato, at $2.00MXN per kilo [8]. In some other instances, farmers grow castor plants as a side crop, for additional income, given that it can be grown alongside maize and beans [9, 10] (Table 1).

**Table 1.** Unit nomenclature used in the Mexican energy sector

| Volume (liquids) | |
|---|---|
| Unit | Description |
| b | barrels |
| bd | barrels per day |
| Mb | thousands of barrels |
| Mbd | thousands of barrels per day |
| MMb | millions of barrels |
| MMbd | millions of barrels per day |
| $m^3$ | cubic meters |
| $m^3d$ | cubic meters per day |
| $Mm^3$ | thousands of cubic meters |
| $Mm^3d$ | thousands of cubic meters per day |
| $MMm^3$ | millions of cubic meters |
| l | liters |
| gal | gallons |

## 2.2 National Diesel Supply in Mexico

Between December 2018 and December 2019 (Fig. 1), the daily national average supply of diesel was 392 thousand barrels, of which, on average, 264 thousand barrels were imported daily, an equivalent of 67.35% of the total daily supply, leaving 32.65% to national diesel production [1].

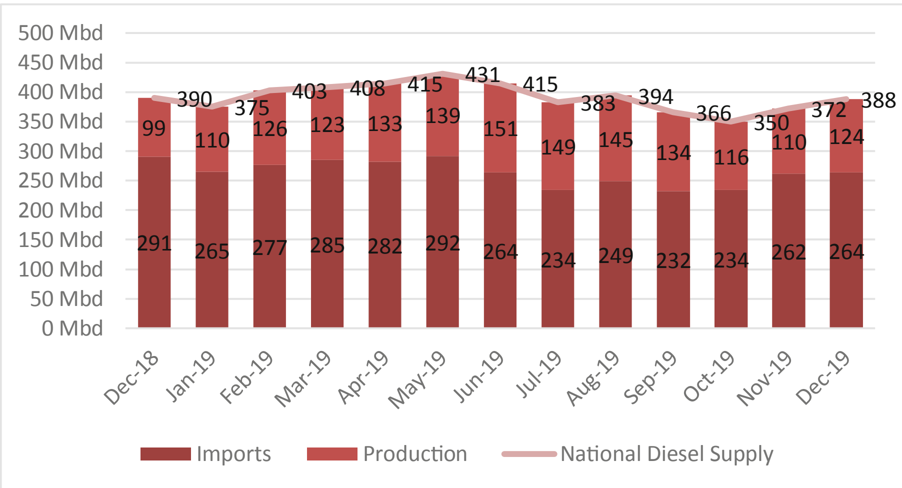


**Fig. 1.** National diesel supply, December 2018 to December 2019 (Mbd) [1]

## 3 Supply Chain Model Analysis

To evaluate different supply chain models based on meeting the demand of diesel and minimizing transportation costs, the selected analysis method is Network Optimization using AnyLogistix [11], a software tool for designing supply chains and managing them with a digital twin, which integrates supply chain design, optimization, and simulation with operations data.

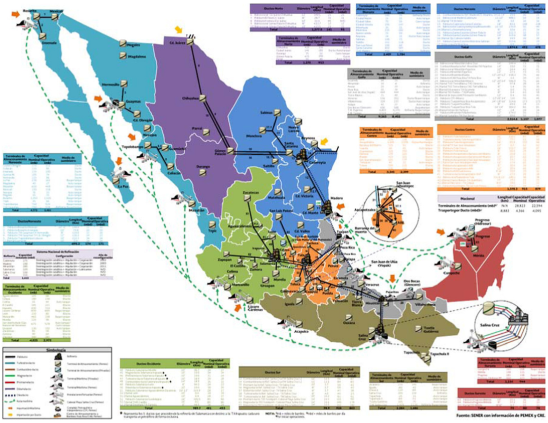

**Fig. 2.** National petroleum infrastructure [12]

Based on the production model presented in *"Biodiesel supply chain analysis in Mexico: case studies regarding biodiesel and castor oil plants as an alternative to imported diesel"* [3], in order to proceed with the analysis, the following initial assumptions were made:

- The creation of castor cultivation areas to meet the demand in biodiesel production must be considered.
- The storage and distribution centers (TARs for its initials in Spanish, Terminales de Almacenamiento y Reparto) of the national petroleum infrastructure (Fig. 2) will be used for storage, mixing at B20 and distribution of biodiesel.
- The transport of castor and biodiesel will be carried out using 31,000 kg tank trucks
- Biodiesel reserves, defined in the production model, will be distributed among the different TARs considered in the supply chain.

### 3.1 Castor Production Distribution

Because there is no access to the original data from which the map of suitable regions for the cultivation of castor (Fig. 3) was drawn, and their calculated yields, to carry out the distribution of the production capacity, a histogram analysis of the map was made in order to estimate this items. The regions considered for this analysis were Cerritos, in San Luis Potosí, and Tierra Blanca, in Veracruz. The yields used for the analysis were 850 kg/ha, for the light green/yellow areas, and 1.35 t/ha, for the dark green areas.

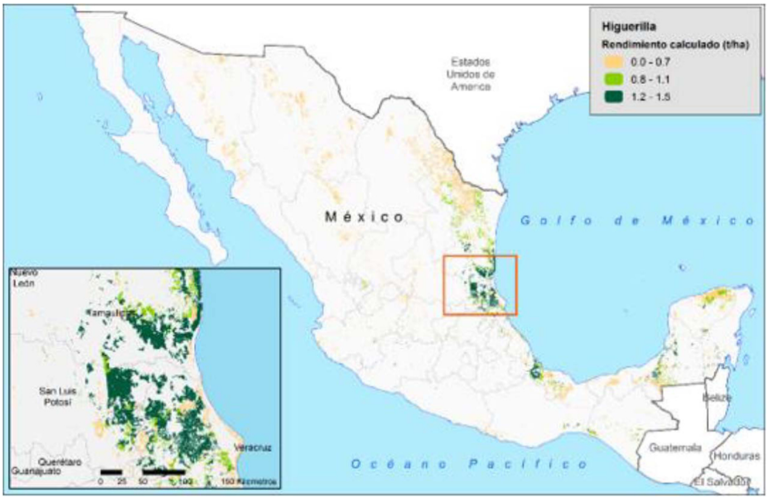


**Fig. 3.** Suitable regions for the cultivation of castor [13] (Color figure online)

**Cerritos, San Luis Potosí**

Based on the image for the region of Cerritos in San Luis Potosí (Fig. 4), which presents the largest concentration of soil with high yield of castor production, the histogram analysis is done by applying color filters in order to isolate the pixels corresponding to each yield level.

$$\frac{100\text{ km}}{30\text{ px}} * 197\text{ px} = 656.67\text{ km} \tag{1}$$

$$\frac{100\text{ km}}{30\text{ px}} * 157\text{ px} = 523.33\text{ km} \tag{2}$$

$$656.67\text{ km} * 523.33\text{ km} = 343,655.56\text{ km}^2 = 34,365,555.56\text{ ha} \tag{3}$$

Considering that the map scale shown in the image indicates there are 100 km per each 30 px, and that the image measure 197 px by 157 px, the surface presented in the map is approximately 34.365 million hectares.

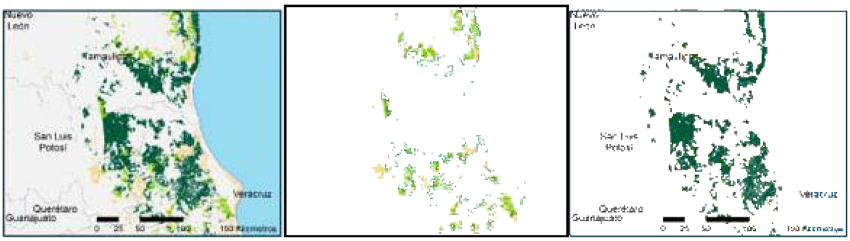


**Fig. 4.** Histogram analysis for Cerritos, San Luis Potosí – (own elaboration)

After applying the color filters, 13.72% of the image corresponds to high yield areas and 5.48% to medium/low yield areas.

$$13.72\% * 34,365,555.56 \text{ ha} = 4,714,954.22 \text{ ha} \tag{4}$$

$$5.48\% * 34,365,555.56 \text{ ha} = 1,883,232.44 \text{ ha} \tag{5}$$

This equals to around 4.714 million hectares of high yield soil and 1.883 million hectares of medium/low yield soil, which in total represents around 66% of the total national castor production capacity [14].

Considering a yield of 1.35 t/ha, for the high yield areas, and 0.85 t/ha, for medium/low yield areas, the amount of castor produced in the area can be calculated.

$$1.35\frac{t}{ha} * 4,714,954.22 \text{ ha} = 6,365,188.20 \text{ t} \tag{6}$$

$$0.85\frac{t}{ha} * 1,883,232.44 \text{ ha} = 4,600,747.58 \text{ t} \tag{7}$$

These calculations show that the region of Cerritos can produced around 10.966 million tons of castor per harvest.

**Tierra Blanca, Veracruz**

The second largest concentration of high yield castor production potential is in Tierra Blanca in Veracruz (Fig. 5), which is selected as the second region for the analysis.

$$\frac{195 \text{ km}}{31 \text{ px}} * 78 \text{ px} = 490.65 \text{ km} \tag{8}$$

$$\frac{195 \text{ km}}{31 \text{ px}} * 62 \text{ px} = 390 \text{ km} \tag{9}$$

$$490.65 \text{ km} * 390 \text{ km} = 191,351.6129 \ \text{ km}^2 = 19,135,161.29 \text{ ha} \tag{10}$$

Taking the border with Guatemala as a reference, the scale used on the map is 195 km for each 31 px, and the image measure 78 px by 62 px, which amounts to an approximate area of 19.135 million hectares.

After applying the color filters, the area of high yield equates to around 1.2% of the image and 5.96% correspond to medium/low yield soil.

$$1.2\% * 19,135,161.29 \text{ ha} = 229,621.94 \text{ ha} \tag{11}$$

**Fig. 5.** Histogram analysis for Tierra Blanca, Veracruz – (own elaboration)

$$5.96\% * 19,135,161.29 \text{ ha} = 1,140,455,61 \text{ ha} \tag{12}$$

Considering the area covered by the image, the percentages represent around 229,621 ha of high yield soil and 1.140 million hectares of medium/low yield soil, around 13.69% of the total national castor production capacity [14].

Considering a yield of 1.35 t/ha, for the high yield areas, and 0.85 t/ha, for medium/low yield areas, the amount of castor produced in the area can be calculated.

$$1.35\frac{t}{ha} * 229,621.94 \text{ ha} = 309,989.61 \text{ t} \tag{13}$$

$$0.85\frac{t}{ha} * 1,140,455,61 \text{ ha} = 969,387.27 \text{ t} \tag{14}$$

Tierra Blanca can produce around 1.279 million tons of castor per harvest.

**Ejido Yogana, Oaxaca**

Given that there already exists a biodiesel refinery in Oaxaca, with a production capacity of 3 million litres of biodiesel per month, and that it acquires its castor from the Ejido Yogana, it was included in the model and its production surface estimated, considering a yield of 0.85 t/ha.

$$3{,}000{,}000\, {}^{l\,(cbd)}\!/_{mes} * \frac{1\,mes}{30\,dias} * 180\,\frac{días}{cosecha} = 18{,}000{,}000\, {}^{l(cbd)}\!/_{cosecha} \tag{15}$$

$$\frac{18,000,000^{l(cbd)}/_{cosecha}}{232.05^{l(cbd)}/_{ha}} = 77,569.49\ ha/cosecha \approx 77,570\ ha/cosecha \tag{16}$$

Considering this, the Ejido Yogana has around 77,570 ha of castor per harvest.

## 3.2 Demand Distribution Within Central Mexico

There are 2,964 service stations in Central Mexico, according to the Listing of Service Stations of 2017 [15], distributed among the 7 states that conform the region. The states considered for the region are the following:

- Hidalgo
- Mexico City
- Morelos
- Puebla
- Queretaro
- State of Mexico
- Tlaxcala

Given the limitations of the educational license of AnyLogistix, which restricts the maximum number of customers to 100, an adjustment was made by calculating the percentage of service stations each state has, in relation to the total number of stations in the region, and a random selection was made based on this distribution (Table 2).

**Table 2.** Service stations in Central Mexico

| States | Number of stations | Percentage | Sample size |
|---|---|---|---|
| Hidalgo | 302 | 10% | 10 |
| Mexico City | 376 | 13% | 13 |
| Morelos | 172 | 6% | 6 |
| Puebla | 576 | 19% | 19 |
| Queretaro | 314 | 11% | 11 |
| State of Mexico | 1,103 | 37% | 37 |
| Tlaxcala | 121 | 4% | 4 |
| Total | 2,964 | 100% | 100 |

As the scope of this study is the analysis of the supply chain for the entire demand of castor biodiesel in a B20 mixture for Central Mexico, the total demand of each state was distributed among the number service stations that were taken as sample of each one in relation to the percentage they represent within the region (Table 3). For example, each one of the 10 stations selected to represent the state of Hidalgo, which has a daily demand of 1,799.67 barrels, is modeled as having a daily demand of 179.97 barrels.

**Table 3.** Daily demand per sampled station

| States | Sampled service stations | Daily biodiesel consumption by state (barrels) | Daily biodiesel consumption by station (barrels) |
|---|---|---|---|
| Hidalgo | 10 | 1,799.67 | 179.97 |
| Mexico City | 13 | 2,240.65 | 172.36 |
| Morelos | 6 | 1,024.98 | 170.83 |
| Puebla | 19 | 3,432.49 | 180.66 |
| Queretaro | 11 | 1,871.18 | 170.11 |
| State of Mexico | 37 | 6,572.98 | 177.65 |
| Tlaxcala | 4 | 721.06 | 180.27 |

### 3.3 Simulation and Analysis of the Supply Chain for Central Mexico

As was mentioned previously, this study will be using the existing TARs from the national petroleum infrastructure for the storage and distribution of biodiesel between the refineries and the service stations.

Given the analysis was done using an academic license of AnyLogistix, only 7 TARs in Central Mexico were selected and the other 3 available slots were used for the 3 refineries considered in this model (Fig. 6).

Two of these refineries are already in operation: Dertek, in the State of Mexico, with a monthly production capacity of 2,000,000 L of biodiesel, and Ricinomex, in Oaxaca, with a monthly production capacity of 3,000,000 L of biodiesel.

The third refinery is configured as a virtual source of biodiesel, in Poza Rica, which will help cover any deficit of biodiesel and will help to determine the amount of additional production of biodiesel required to fulfill the entire demand of Central Mexico.


**Fig. 6.** Distribution of each member of the supply chain

To align the supply chain model to the production model, the supply chain simulation was broken up into blocks of 15 days with a maximum duration of 600 days (Table 4).

During the first 225 days, according to the production model, there is no consumption of biodiesel as production starts and stocks are created. Given this, the demand coefficient for these periods is set to zero.

Following these 225 days, the consumption start ramping up during the next 180 days until reaching the full biodiesel requirement for the region. This maximum consumption is represented in the demand coefficient as 1, which will be maintained until the end of the simulation, on day 600.

As the transportation medium for the raw materials and biodiesel, 31,000 kg tank trucks are being used at a cost of $1.08MXN per ton per kilometer [16], to establish the distribution routes and costs.

Using these parameters and restrictions, the network optimization was done to generate the supply chain represented in the following figures.

As seen on Fig. 7 and Fig. 8, out of the three proposed castor cultivation areas only two are used, Cerritos, in San Luis Potosi and Yogana, in Oaxaca.

The model considers the use of the three refineries, considering that the third refinery, the virtual one in Poza Rica, must produce around 33.4 million of liters each month,

**Table 4.** Simulation periods and demand coefficient

| Period | Start date | End date | Demand coefficient |
|---|---|---|---|
| S1-S15 | 2020–01-01 | 2020–08-12 | 0 |
| C1 | 2020–08-13 | 2020–08-27 | 0.077 |
| C2 | 2020–08-28 | 2020–09-11 | 0.154 |
| C3 | 2020–09-12 | 2020–09-26 | 0.231 |
| C4 | 2020–09-27 | 2020–10-11 | 0.308 |
| C5 | 2020–10-12 | 2020–10-26 | 0.385 |
| C6 | 2020–10-27 | 2020–11-10 | 0.462 |
| C7 | 2020–11-11 | 2020–11-25 | 0.538 |
| C8 | 2020–11-26 | 2020–12-10 | 0.615 |
| C9 | 2020–12-11 | 2020–12-25 | 0.692 |
| C10 | 2020–12-26 | 2021–01-09 | 0.769 |
| C11 | 2021–01-10 | 2021–01-24 | 0.846 |
| C12 | 2021–01-25 | 2021–02-08 | 0.923 |
| C13–C25 | 2021–02-09 | 2021–08-22 | 1 |

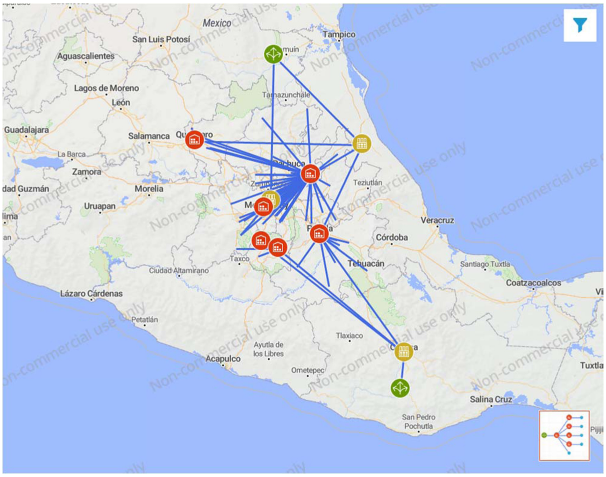


**Fig. 7.** Proposed supply chain map

approximately 87% of the total production, in order to fulfill the entire castor biodiesel demand (Table 5). This means that, to fulfill the production requirement, it is necessary to consider the construction of at least 12 refineries with the same capacity as Ricinomex.

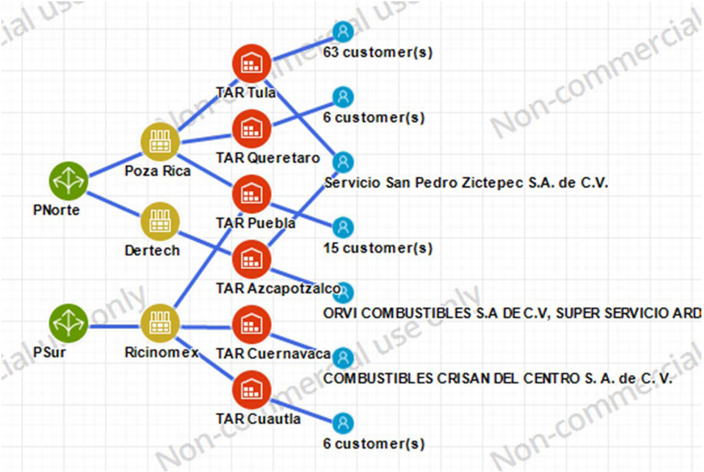


**Fig. 8.** Proposed supply chain structure

**Table 5.** Biodiesel production distribution

| Refinery | Monthly Production (liters) | Percentage |
|---|---|---|
| Dertek | 2,000,000 | 5.2% |
| Ricinomex | 3,000,000 | 7.8% |
| Poza Rica *(virtual)* | 33,400,000 | 87.0% |
| Total | 38,400,000 | 100% |

Out of the seven TARs that were programmed into the model, the simulation considers that the TAR in Toluca can go unused, and that the main storage and distribution will be done via the TAR located in Tula, Hidalgo.

The total cost of transportation, of castor and biodiesel, using 31,000 kg tank trunks was $4,367,022,707.026 MXN, as can be seen in Table 6.

**Table 6.** Breakdown of transportation cost

| Product | Transportation cost (MXN) | Percentage |
|---|---|---|
| Castor | $3,575,808,800.254 | 82% |
| Biodiesel | $791,213,906.772 | 18% |
| TOTAL | $4,367,022,707.026 | 100% |

## 4 Conclusions

Using a Network Optimization analysis, the results of the simulation of the supply chain model show that it is technically feasible to establish a supply chain that can completely meet the demand of castor biodiesel for Central Mexico, using a B20 mix. This is done using 6 TARs, 3 refineries and 2 cultivation areas.

As the simulation showed, there are enough lands with the potential to produce castor to meet the demand of castor biodiesel based on a B20 mix for Central Mexico, without exhausting them. This could potentially allow other regions of the country to take advantage of castor biodiesel to transition towards more sustainable and cleaner sources of energy.

Even though technically feasible, and considering that the virtual refinery produced the same amount of biodiesel as 12 refineries the size of Ricinomex, it would require an important investment to build the required refineries and establish the castor cultivation regions required to meet the demand of biodiesel.

A future study, using a commercial license of AnyLogistix, could use the supply chain model presented here and expand upon it, considering the entire universe of service stations and TARs that exist for Central Mexico, as well as the production capacity of each castor cultivation region, the storage capacities of each TAR, as well as the evaluation of possible risks.

Refining biodiesel from other types of raw materials, like used oils, also show great promise, however they face similar obstacles as castor biodiesel; mainly the logistics of collecting and transporting the raw materials to the refineries [17], as well as the policies toward renewable energy sources established by the current government in Mexico.

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