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Determination of the Place of Implementation of a Biorefinery Based on Logistics Parameters

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Abstract

Airlines and the aviation industry are committed to emission reduction targets. Biokerosene was pointed out as one of the key elements to achieving this goal. The use of oilseeds in the production of biokerosene is interesting due to the great Brazilian experience in the production of biofuels from this raw material. In view of this scenario, this dissertation has as its main objective the definition of the place of implantation of a biorefinery in Brazilian territory that has aviation biokerosene as its main product. For this, data on supply and demand for fossil aviation kerosene in Brazilian regions were collected, an extensive review was carried out in scientific articles on the oleaginous raw materials used for the production of this biofuel, and logistical parameters were selected and used as criteria for that selection. The oilseeds selected for the production of biofuel were macaúba and soybean and the state was chosen for the implementation of the biorefinery was Goiás. Based on logistical parameters, the city of Formosa (GO) was selected to host the biorefinery. The soybean crushers located in Luziânia, Anápolis, Ipameri, and Itumbiara were chosen as suppliers of soybean oil and the city of Formosa (GO) as the headquarters for the commercial planting of macaúba. The destination of this fuel will be Petrobrás Distribuidora S.A., an aviation fuel distributor authorized by the ANP based in the city of Brasília (DF).

Keywords

Biokerosene, Biofuels, Oilseeds, Biorefinery, Aviation

1. Introduction

Biofuels are fuels produced from biomass renewable biological sources [1]. The world fuel market has increased its interest in biofuels, as a result of the threat of oil shortages, fluctuating prices of fossil fuels, global conflicts that can contribute to instability in the prices of these fuels, and the need to reduce greenhouse gas emissions of the greenhouse effect that contribute to global warming and increased pollution [2].

Decarbonization of the aviation sector plays an important role in mitigating the impact of climate change and biofuels will be key to achieving negative carbon growth by 2050 [3].

The aircraft has the challenge of halving carbon dioxide emissions by 2050 compared to 2005. Biokerosene will play a significant role in achieving this goal [4] [5]. This biofuel is a key element in the strategy of the aviation industry to reduce operating costs and environmental impacts [6]. Brazil has great potential in the development of sustainable biofuels for aviation, due to its long experience with biofuels [7].

According to Brazilian Law No. 12,490, of September 16, 2011, aviation biokerosene is defined as [8]:

“Substance derived from renewable biomass that can be used in aeronautical turbojets and turboprops or, according to regulation, in another type of application that can partially or totally replace fossil fuel [8]”.

Biokerosene can be produced from a wide variety of raw materials and production routes. Currently, the production route from esters and hydro processed fatty acids using vegetable oils is the most used, as it is the only commercially available technology, and paraffinic kerosene synthesized from esters and hydro processed fatty acids (HEFA-SPK) is approved as a blending fuel, drop-in by the American Society for Testing and Materials (ASTM) [9]. This production route is the most promising and studied route for the production of biokerosene from vegetable oils [10]. Different raw materials have been used for the HEFA route, such as camelina, jatropha, macaúba, palm, soy, and cooking oil [11].

The National Petroleum Agency (ANP) Resolution No. 778, of April 5, 2019, establishes the specifications of fossil-based aviation kerosene (QAV-1), alternative aviation kerosene (alternative QAV), and QAV mixture-1 with alternate QAV. According to this resolution, the maximum mixing ratio of biokerosene (alternative QAV) produced by hydroprocessing esters and fatty acids to QAV-1 is 50% [12].

The HEFA process uses proven technologies operating on a commercial scale worldwide, the objective of which is to convert vegetable oils and animal fats into biofuels that are chemically equivalent to fossil fuels [13]. It involves hydrogenation and deoxygenation reactions of triglycerides to remove unsaturated carbon chains and fatty acid oxygen. Removing the installations improves the stability of the final fuel, while the removal of oxygen ensures low reactivity with water and an increase in calorific value [14].

Due to Brazil's high experience in the use of biomass for energy purposes and the wide availability of resources throughout its territory, the country can be considered a potential producer of biokerosene. The use of oilseeds is interesting due to the great Brazilian experience in the production of biofuels from this raw material [7].

The insertion of the concept of biorefinery in plants producing biofuels is of great relevance, as it can lead to cost reduction and profit increase. It also adds value and creates new products, transforming what in the past was called waste into what is now called a by-product [15]. Factors such as raw material availability, accessibility, and cost are crucial for the economy of a biorefinery platform [16].

A complete definition of biorefinery was produced by the International Energy Agency (IEA) Bioenergy Task 42, which establishes it as sustainable processing of biomass into a spectrum of marketable products and energy [17]. The biorefinery concept is considered the best option to transform the various biomass systems into value-added products [18]. In this work, the concept of biorefinery was applied in the preferential production of aviation biokerosene from vegetable oils, in order to create a new marketable product, the pulp and almond pie, a by-product that will be processed and sold as animal feed. Also, through the use of endocarp, mesocarp, and bunches and stems of macaúba to generate energy in the boiler in order to minimize effluents, minimize costs, maximize profit and reduce environmental impacts.

Facility location modeling is an important tool to assist in locating commercial facilities, such as factories, refineries, warehouses, ports, and public stations [19]. There are several contexts in which location models can be used, but their main characteristics are always the same: an environment that includes metric, consumers in known locations, and facilities whose locations must be determined [20].

The parameters of the logistic model are important for the determination of a logistic network proposal, they are the determination of the minimum geographic unit for the location model, the annual consumption of QAV at the selected airport, the capacity of supplying raw material by the farmers of the region and the cost of transporting the raw materials to the biorefinery [21].

Thus, this work presents as the main objective the definition of the location of implantation of a biorefinery in Brazilian territory based on logistical parameters. This implementation aims to contribute to reducing the jet fuel deficit in some Brazilian states by replacing part of this fuel with jet biokerosene.

2. Methodology

Initially, data on the supply and demand for fossil aviation kerosene in Brazilian regions were collected in order to determine which region had the greatest deficit for this fuel. The data were collected in the 2019 Brazilian statistical yearbook of oil, natural gas, and biofuels, produced by the National Agency of Petroleum, Natural Gas and Biofuels (ANP) and made available on the official website of the federal government.

An extensive review of scientific articles was carried out on the oleaginous raw materials used for the production of aviation biokerosene. The choice of raw materials was based on the selection of those that presented great potential for the production of this biofuel in the region selected for the installation of the biorefinery. From this review, it was also possible to select the biorefinery model used in this work.

Subsequently, the logistical parameters and data sources used to determine the location of the biorefinery were described. The choice of parameters was based on the work of Pérez [21], they are:

1) Determination of the minimum geographic unit for the location model;

2) Annual consumption of QAV at the selected airport;

3) Ability to supply raw material by farmers in the region;

4) Cost of transporting raw materials to the biorefinery.

The minimum geographic unit is the municipality [21].

In the set i {1, 2, 3, 4, 5, ..., n}, n is the total number of candidate municipalities for the final destination of biokerosene. In the set j {1, 2, 3, 4, 5, ..., m}, and in the set K {1, 2, 3, 4, 5, ..., p}, m and p are the total number of municipalities capable of to supply raw material.

To determine the annual consumption of QAV, the demand data for this fuel available in the Brazilian statistical yearbook published by the ANP in 2019 was used. The yearbook indicated the demand for QAV in cubic meters in Brasília between the years 2009 and 2018 and the average demand value was used.

For the production of 22.4 kg of biokerosene, 45.4 kg of soybean oil are needed [13]. From the demand for QAV and the specific mass of biokerosene at 20˚C, it was possible to determine the mass of soybean oil needed to produce this biofuel. The specific mass of the QAV at 20˚C is 771.3 $kg \cdot m^{-3}$, a value used as a reference for the alternative QAV in this work [22].

For the production of 30 L of alternative QAV, 45.4 kg of macaúba oil are needed, 10,000 kg of fresh fruit produce 2141.9 kg of macaúba oil [23] [24]. A palm tree produces an average of 6 bunches per year and each bunch produces an average of 14 kg of fruit [24]. From these references, it was possible to determine the mass of macaúba needed to produce the fuel and also the amount of palm trees needed in a commercial plant in order to meet the demand for its fruit.

In order to obtain the cost of transporting the raw material, the types of transport routes available for the transport of soybean oil were first analyzed. Resolution No. 5867, of January 14, 2020, establishes the general rules and the general equation, represented by Equation (1), was used to determine the minimum price for the remunerated road freight transport service. The CC_{ce} and CCD_{ce} values are presented in Annex II of this resolution [25].

$$TC_{ca} = CC_{ca} + d \cdot DCC_{ca} \quad (1)$$

where:

TC_{ca}: total operational cost of road transport of cargo type "c" using a vehicle combination of axle number class "a" (R$);

CC_{ca}: cost of loading and unloading of load type "c" and number of axles class "a" (R$);

d: distance traveled in the transport operation (km);

DCC_{ca}: displacement cost coefficient of type of load "c" and of vehicle composition of class of number of axles "a" (R$·km^{-1}).

To determine the price of rail freight transport, the tariff simulator on the website of the National Land Transport Agency (ANTT) was used, which presents the type of raw material to be transported and the rail distance as input variables [26]. In this way, the crushers that had the lowest cost of transporting the load to the biorefinery were selected as soybean oil suppliers.

3. Results and Discussions

3.1. Supply and Demand for Fossil QAV in Brazilian Regions

Table 1 shows the differences between supply and demand for QAV in cubic meters in Brazilian regions [27]. As can be seen, the region with the greatest deficit for this fuel is the Midwest, a region that may have its total or partially supplied by aviation biokerosene, providing greater autonomy to the region's airports. More recent data were not used due to the Covid-19 pandemic, which changed the flow of passengers and, consequently, the number of flights carried out by airlines in the domestic and international markets.

3.2. Raw Material

In the short term, soybean presents itself as the main oilseed raw material for the production of biokerosene in Brazil, as it is the only one that meets all the basic and essential parameters for the sustainability of a biokerosene program in Brazil. There are three basic parameters, the first is related to technological development, and Brazil is a world reference in the generation of technologies for the cultivation of this oilseed in tropical and subtropical regions. The second parameter is related to the production scale, soy is the most produced oilseed in the country. The third parameter is related to the logistics of spatial distribution, it is one of the only oilseeds cultivated in all regions of the country [28].

Souza, Mendes and Aranda [14] considered soy the most promising raw material for the production of biokerosene from oilseed raw material in southeastern Brazil. According to the authors, soy was in first place mainly because of its

Table 1. Difference between QAV supply and demand in Brazilian regions in 2018.

Region	National supply (m^3)	Demand (m^3)	Supply-Demand (m^3)
North	125,360	337,441	−212.081
North East	557,751	1,115,124	−557.373
Southeast	5,220,395	4,565,398	654.997
South	472,827	486,175	−13.348
Midwest	0	660,069	−660.069

technological dominance, high production scale and lower cost of its oil. However, they emphasized the importance of evaluating and using other potential crops, since soy is already the main oleaginous raw material used for the production of biodiesel in the country. They indicated macaúba as a potential crop for the production of biokerosene due to its high productivity, yield and oil content. According to this study, macaúba oil mass composition reaches 43.45% compared to only 20% of soybean, macaúba productivity reaches 24,000 kg/ha against only 3244 kg/ha of soybean, which gives high efficiency in land use.

It is strategic to diversify the raw material for the production of bioenergy in Brazil. From a social point of view, there is a great need to diversify the biomass so that the regional potential is used. A strategy for this diversification would be the use of macaúba in the North, Northeast and Midwest of the country. Embrapa Agroenergia has focused its research on topics related to the diversification of biomass and is studying macaúba for the production of biofuels [29].

Silva *et al.* [30] demonstrate in their work that macaúba has high potential as a raw material for the industrial production of biokerosene and green diesel. Esters produced from almond oil have a composition, in relation to the size of the molecular chain, similar to the hydrocarbons present in aviation kerosene, thus being able to be used for the production of biokerosene and used in mixtures with fossil kerosene, as long as it respects to physical parameters of quality [31]. In Brazil, macaúba is considered the palm with the greatest dispersion, groups of importance are located in the North, Northeast and Center-West [32].

The by-products formed from the extraction of macaúba oil can be used as animal feed [33]. The endocarp of its fruit is a lignocellulosic residue that can be used for the production of activated carbon [34]. Its by-products can also be used for energy production through production of pellets and coal. The possibility of using the by-products of raw material processing is attractive, as it promotes the generation of environmental and economic benefits [35].

It is expected that seeds with higher oil yield than soybeans will increase their share as raw material for the production of biofuels in Brazil. Ideally, each region of the country should plant its own raw material and produce biofuel from it in local industrial plants [36].

The Midwest region is the largest producer of soybeans in Brazil [37]. Macaúba is found mainly in Goiás (Central-West), Mato Grosso (Central-West), Mato Grosso do Sul (Central-West) and Minas Gerais (Southeast) [38]. Soybean and macaúba were the two oilseeds selected for the next stage of this study, which aims to promote the logistical analysis of the implementation of a biorefinery in Brazil for the production of aviation biokerosene and other products such as HVO (Hydrogenated vegetable oil or Green Diesel, as it is also known), naphtha, among others.

3.3. Biorefinery

The biorefinery model used in this work for the production of biokerosene and other products from any type of vegetable oil was taken from the work of Pearlson, Wollersheim and Hileman [13]. From this model there was a change in the hydrogen production process. This biorefinery has a commercial HEFA plant project and consists of several unit processes, such as: raw material storage (vegetable oil), hydrodeoxygenation, catalytic cracking and selective isomerization, heat integration to generate steam and cooling water, cleaning and fuel gas recycling, hydrogen gas production, product separation, and product storage and mixing. **Figure 1**, based on the work of Pearlson, Wollershim and Hileman [13], provides a general overview of the structure of the process.

In this process, vegetable oil is fed into a hydrotreater with hydrogen gas. The deoxygenated effluent is cooled and sent to a catalytic cracking and isomerization unit. The isomerized hydrocarbon product is then cooled with cooling water before being sent to a separation tower where mixed paraffin gases, carbon dioxide and excess hydrogen are separated from the liquid products. The paraffin gases and hydrogen are separated from the carbon dioxide and recycled to the hydrotreater. Liquid products are separated into liquefied petroleum gas (LPG), naphtha, biokerosene and green diesel streams and then sent to product storage tanks. Wastewater is separated from the product stream and sent to treatment units.

Table 2 shows the profile of the products, with the process having 45.4 kg of soybean oil and 1.8 kg of hydrogen as raw materials [13].

Table 3 shows the volume of naphtha, biokerosene and green diesel produced

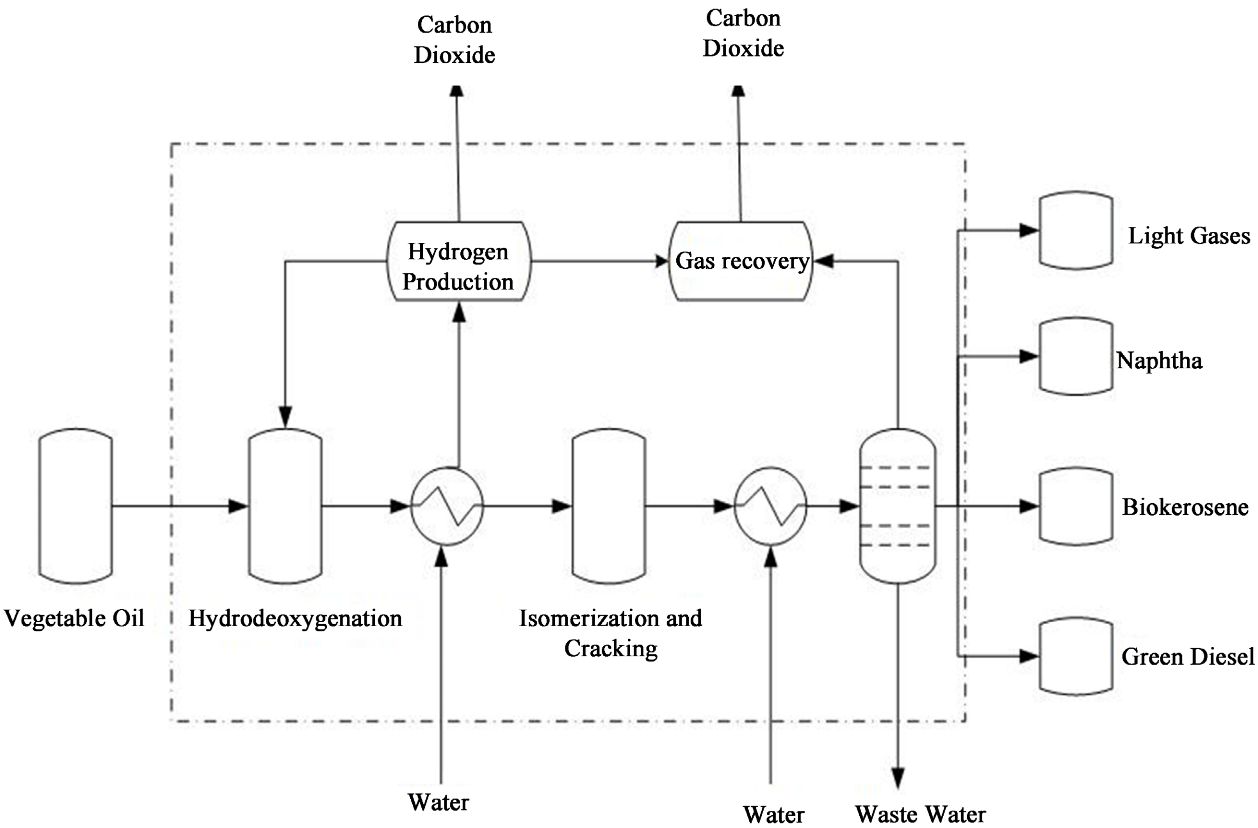

Figure 1. Simplified design of the HEFA process, adapted from Pearlson, Wollershim and Hileman [15].

Table 2. Yields of products based on 45.4 kg of soybean oil.

Products	Mass (kg)
Water	4.0
Carbon dioxide	2.4
Propane	1.9
LPG	2.7
Naphtha	3.2
Biokerosene	22.4
Green diesel	10.6

Table 3. Yields based on 45.4 kg of macaúba oil.

Products	Volume (L)
Naphtha	4.0
Biokerosene	30.0
Green diesel	13.7

from 45.4 kg of macaúba oil and 1.5 kg of H_2 as raw materials [23]. Hydrogen is produced industrially by steam reforming of hydrocarbons such as methane, naphtha, LPG, refinery gas (C1 - C2), among others [39].

The steam reforming of LPG and propane, raw materials produced only by processing soybean oil, already makes the process self-sufficient in H_2, as it produces the amount of hydrogen gas needed by the biorefinery. As for the other raw materials, soybean oil will be purchased from agro-industrial plants, which process soybeans. As for macaúba, the fruit will be acquired and processed in the biorefinery itself.

The green diesel produced will be used as fuel in agricultural machinery and trucks used in the biorefinery. The by-products of macaúba fruit processing are the endocarp, the epicarp and the pie. The epicarp and endocarp will be used as fuel in the boiler [35]. The pulp and almond pies will be sold as animal feed to producers in the region, as they have a rich nutritional composition [40]. The processing of macaúba fruit is self-sufficient in terms of energy, through the burning of stems and bunches of fresh fruits [23].

3.4. Biokerosene Logistics

The supply chain involving a biofuel production unit consists of supplying biomass, transporting the biomass by truck to the production unit, converting the biomass into fuel and transporting the biofuel by tanker truck to the airport facilities [41]. Therefore, the biokerosene production logistics comprises the transport of raw materials to the biorefinery, the production of oil, the production of hydrogen gas, the production of biokerosene and its transport to authorized distributors.

The determination of an implantation site was based on location alternatives considering an existing infrastructure, suppliers of raw materials available in the region and Petrobras Distribuidora S.A., an aviation fuel distributor authorized by the ANP, as the final destination.

3.5. Determinação dos Parâmetros Logísticos

3.5.1. Minimum Geographic Unit for the Location Model

According to Pérez [21], the minimum geographic unit is the municipality. The region selected for the construction of the logistics system is the Midwest, which has 3 states (Goiás, Mato Grosso and Mato Grosso do Sul), plus the Federal District, which together have 466 municipalities, which could be possible destinations for biokerosene. As aviation biokerosene will be produced to supply Brasília International Airport, only distributors located in Brasília will be used, in order to obtain the lowest cost of transporting aviation fuel to the airport, therefore n = 1.

The only distributor located in Brasília is Petrobras, which will be the final destination for biokerosene [42].

In order to avoid charging interstate fees, all the logistics that make up the biorefinery will be built in the state of Goiás. Thus, the possible origins for the raw materials will be the 246 municipalities belonging to the state. In the set j, m is the total number of municipalities in the state that have soybean crushers to supply oil to the biorefinery. **Table 4** shows the 7 municipalities with soybean crushing units located in the state of Goiás, so m = 7 [43] [44].

In the set K, p is the total number of municipalities in Goiás that have natural massifs or commercial macaúba plantations to supply their fruit. Vilela *et al.* [45] mapped the natural massifs of macaúba in some municipalities in Goiás, whose number of individuals is shown in **Table 5**.

Table 4. Location of soybean crushing units in the state of Goiás and their processing capacities.

Company	City	Soybean processing capacity (ton $year^{-1}$)	Amount of soybean oil (ton $year^{-1}$)
Bunge	Luziânia	584,000	115,515
Coinbra (Louis Dreyfus)	Jataí	730,000	144,394
Caramuru	São Simão	657,000	129,955
Caramuru	Itumbiara	620,500	122,735
Comigo	Rio Verde	365,000	72,197
Cargill	Rio Verde	500,000	98,900
Brejeiro	Rio Verde	133,333	26,373
Brejeiro	Anápolis	133,333	26,373
Granol	Anápolis	255,500	50,538
Carol	Ipameri	100,000	19,780

Table 5. Number of individuals mapped by municipality.

Municipality	Number of individuals
Formosa - GO	15,752
Brasília - DF	1779
Rio Paranaíba - GO	281
Cabeceiras - GO	147

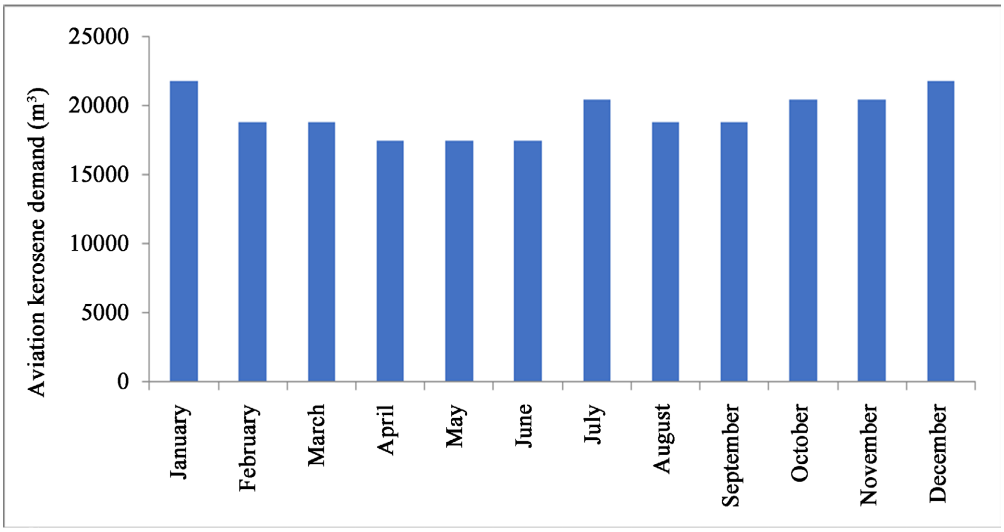

Figure 2. Distribution of QAV demand.

As seen, the natural massifs of macaúba are distributed over 4 municipalities, so p = 4.

3.5.2. Annual QAV Consumption at the Selected Airport

In this work, the average value (464,386.4 m^3) of consumption per QAV between 2009 and 2018 will be used as a consumption reference for Brasília. To formulate aviation kerosene C (QAV-C), alternative aviation kerosene (QAV alternative) must be added to aviation kerosene (QAV-1) in the proportion of a maximum of 50%, thus considering the maximum replacement percentage, the requested quantity of alternative QAV needed to supply the demand for QAV-C is 232,193.2 m^3. The distribution of demand for QAV, indicated in Figure 2, throughout the year in Brasília was not found, so it was projected based on the domestic demand of passengers transported at Brasília International Airport throughout 2019.

3.5.3. Ability to Supply Raw Material By Farmers in the Region

With the intention of promoting the diversification of oleaginous raw materials used in the production of biofuels in Brazil, macaúba will be the main raw material of the biorefinery, since soy is already one of the main raw materials in the production of biodiesel. In the short term, in a period of up to 5 years, soybean will provisionally be the main raw material for the production of biokerosene, since the palm trees that will be planted in the municipality of Formosa (GO) need this period to start their fruiting. After this period, the soybean will be used in the macaúba off-season.

Macaúba fruiting in the Midwest region occurs throughout the year and the fruits ripen mainly from September to January [46] [47]. Thus, macaúba will be used as a raw material for the production of biokerosene in the months of September to January and the oil of soybeans from February to August, the macaúba off-season period.

Knowing the annual demand for fossil aviation kerosene in Brasília, the specific mass of biokerosene at 20˚C and the required amount of soybean oil needed to produce 22.4 kg of biokerosene, it was possible to determine the mass of soybean oil needed to meet the annual demand for this fuel in a period of up to 5 years, which is 365,502.5 t of soybean oil per year. After this period, soybean oil will be used in the biorefinery from February to August, thus requiring a total mass of 201,738.3 t of soybean oil.

As indicated in **Table 3**, for the production of 30 L of alternative QAV, 45.4 kg of macaúba oil are needed, consequently, to meet the demand for biokerosene from September to January, 156,015.3 t of macaúba oil are needed.

According to Rettore *et al.* [24], 10,000 kg of fresh fruit produce 2141.9 kg of macaúba oil, that is, for the production of 156,015.3 t of macaúba oil, 728,396.8 t of fresh fruit are needed. The fruiting of macaúba generally takes place between 4 and 5 years, with an average annual yield of 4 to 10 bunches per palm, depending on the fertility of the soil in the region. Each bunch can produce 12 to 15 kg of coconut. Thus, considering that each palm will produce 6 bunches per year and that each bunch will produce 14 kg of fruit, 8,671,391 palm trees will be needed to supply the total annual demand for fresh fruit.

The amount of palm trees mapped and identified in the study is small compared to the biorefinery demand and they are dispersed in several municipalities in the Center-West region. Formosa (GO) was the municipality with the largest number of mapped and grouped palm trees and, therefore, was chosen for the collection of fresh fruits needed by the biorefinery. The region mapped in the municipality of Formoso has 15,752 palm trees and, therefore, is capable of providing 1323.2 t of fruit per year. To increase the fruit supply capacity in this municipality in order to supply the need for macaúba fruits by the biorefinery, it is recommended the commercial planting of 8,655,639 palm trees close to the region where native palm trees are concentrated. As already shown, it is necessary to transport 728,396.8 t of macaúba fruit and 201,738.3 t of soybean oil to the biorefinery during the year. As a result of the greater demand for macaúba fruits, the biorefinery will be built in the municipality of Formosa (GO), thus promoting savings in the transport of raw materials.

It is important to emphasize that the soybean grain has approximately 20% oil in its mass composition. In this work, it was considered that soybean processing companies use mixed processing, which uses pressing with a solvent extraction system, which produces crude oil with an oil residue in the cake of 1.1% [48]. Thus, 365,502 are produced 5 t of soy oil/year by the crushers, 1,847,838.7 t of soy must be processed in the first years of operation of the biorefinery. For the production of 201,738.3 t of soy oil, it is necessary to process 1,019,910.5 t of soy by the crushers. **Table 6** specifies the type of oleaginous raw material to be acquired by the biorefinery and its annual demand in the initial five years of operation and after that period.

3.5.4. Cost of Transporting the Raw Material to the Biorefinery

In order to determine the costs of transporting the raw material, it is first necessary to consider the type of transport route, that is, whether the transport will be by road, rail or waterway. Oliveira [49] indicates that the rivers close to the cities analyzed as possible suppliers of raw material have little navigability, so the waterway modal was disregarded.

In calculating the cost of road transport, using Equation (1), it was considered that soybean oil will be transported by 9-axle Romeo and Juliet trucks (truck trucks plus trailer) that can transport a maximum of 84 tons [50]. The distance via the road modal between the soy crushers and the biorefinery was determined using Google Maps.

The rail distance between the origin and destination stations, the input variable of the tariff simulator, was not found on the websites of ANTT, the Ministry of Infrastructure, the National Department of Transport Infrastructure (DNIT), VLI Logística, among other means of information, so the value of the distance between the stations was considered to be the value of the distance in a straight line, given by the Rota Mapas website, between the cities that accommodate the origin stations and the destination stations in rail transport.

The FCA (Central-Atlantic Railroad) crosses the state of Goiás and has loading and unloading rail terminals in the municipalities of Anápolis, Pires do Rio, Luziânia, Brasília, Ipameri and Catalão [51].

Table 7 shows the distances from the cities of origin to Formosa (GO), the minimum price of road freight per ton transported, calculated from Equation (1), and the annual supply capacity of soybean oil.

The cities of Anápolis, Luziânia, and Ipameri have loading and unloading stations belonging to the FCA, so the maximum rates for rail transport per ton transported from the cities of origin to Brasília were calculated, since the city of Formosa does not have a railway station. **Table 8** shows the distances from the

Table 6. Demand for oilseed raw material.

Period	Oilseed raw material to be acquired by the biorefinery	Annual demand
In the initial 5 years	Soy oil	365,502.5 t of soybean oil
After the initial 5 years from February to August (macaúba off-season period)	Soy oil	201,738.3 t of soybean oil
After the initial 5 years from September to January	macauba fruits	728,396.8 t of fruit

Table 7. Distances from crushers to Formosa (GO), minimum price for road freight and annual soybean oil supply capacity.

Cities of Origin	Distance (km) to Formosa	Minimum Price ($R\$\cdot t^{-1}$)	Soybean oil ($t\cdot year^{-1}$)
Luziânia	134.8	12.73	115,515
Anápolis	227.3	18.07	76,911
Ipameri	346.2	24.94	100,000
Itumbiara	482.6	32.82	122,735
Rio Verde	511.3	34.47	197,470
Jataí	601.4	39.68	144,394
São Simão	646.0	42.25	129,394

Table 8. Distance from crushers to Brasília (DF) and maximum rail rate.

Cities of Origin	Distance (km) to Brasília (DF)	Maximum tariff ($R\$\cdot t^{-1}$)
Luziânia	53	33.94
Anápolis	125	43.42
Ipameri	217	55.52

cities of origin to Brasília (DF), as well as the maximum rail fare, calculated from the fare simulator. As can be seen, the tariffs charged for rail transport are higher than those charged for road transport, for this reason, the possibility of using the rail modal was discarded.

Equation (1) shows that the minimum price of road freight is directly proportional to the distance between the cities of origin and destination, so the soybean oil suppliers located at a shorter distance from Formosa were selected. For the supply of soybean oil in the first five years of operation of the biorefinery, the crushers located in Luziânia, Anápolis, Ipameri and Itumbiara were selected as suppliers. After this period, only the crushers present in Luziânia, Anápolis, and Ipameri will be selected.

4. Final Considerations

The location selected for the implementation of the biorefinery was the city of Formosa (GO). For the production of biofuel, soybean oil, macaúba oil and hydrogen gas will be used as raw materials. For the supply of soybean oil in the first five years of operation of the biorefinery, a period in which the palm trees did not begin to bear fruit, soybean crushers located in the cities of Luziânia, Anápolis, Ipameri, and Itumbiara were selected as suppliers in the state of Goiás. After this period, only the crushers present in Luziânia, Anápolis, and Ipameri will be selected and macaúba will be acquired from the commercial plantation that will be implemented in the city of Formosa. For future research, it is recommended to calculate the logistical cost related to the implementation of the biorefinery, as well as the calculation of the final price of this biofuel to distributors in order to provide subsidies to future investors.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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