

Evolution and characterization of the biodiesel supply chain

Evolución y caracterización de la cadena de suministro del biodiésel

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Abstract

This work characterizes the biodiesel supply chain at a strategic level, describing the economic, social and environmental features that are close to its profitability and sustainability and that provide the necessary basis to develop future planning and decision-making processes. The methodology describes its stages, agents, roles and interactions, related products, among other relevant aspects. The results show the economic evolution of the market and present a diagnosis of the chain that shows competitive difficulties due to the increase in the supply of increasingly cleaner energy that requires the development of strategies focused on its sustainability.

Keywords: Biodiesel; supply chain; characterization.

Resumen

Este trabajo caracteriza a nivel estratégico la cadena de suministro del biodiésel describiendo los rasgos económicos, sociales y ambientales que afectan su rentabilidad y sostenibilidad y que dan la base necesaria para desarrollar futuros procesos de planeación y toma de decisiones. La metodología describe sus etapas, agentes, roles e interacciones, productos relacionados, entre otros aspectos relevantes. Los resultados muestran la evolución económica del mercado y presenta un diagnóstico de la cadena que evidencia dificultades competitivas debido al aumento de la oferta de energías cada vez más limpias que requiere el desarrollo de estrategias enfocadas en su sostenibilidad.

Palabras clave: Biodiésel; cadena de suministro; caracterización.



I. INTRODUCTION

The growing demand for products and services that use fossil origin energies has led to an environmental crisis that must be mitigated with the use of cleaner and more sustainable energies [1]. Bioenergy has been making its way as a renewable and sustainable energy option [2]. Biodiesel is a methyl ester with characteristics similar to diesel, which is obtained from biomass from vegetable oils or animal fats, which seeks to replace it in whole or in part as fuel in combustion engines [3]. Consequently, the development of this supply chain (SC) can help some countries to reduce dependence on foreign oil and reduce the greenhouse effect [4]. Likewise, biodiesel is constituted as a viable energy alternative for countries that produce oilseed or livestock commodities, who strengthen their incomes and mitigate through this energy option their international commitments to reduce their carbon footprint.

The growing generation of residual oils and their inadequate management is becoming a matter of global importance [5], [6], [7], [8], so the search for alternatives for their environmentally friendly use is necessary, the most important is the production of biodiesel that is evident as imminent and convenient both economically and environmentally; this is due to the large quantities of residual oil, despite this, the difficulties arise in terms of logistics since a SC capable of ensuring the supply of residual oil has not been established. Since biodiesel has advantages over diesel: 1) in terms of engine performance, lower CO₂ emissions and other substances that harm the environment. 2) its renewable nature favors a priori less dependence on fossil energy sources.

However, biodiesel from agricultural commodities has been questioned due to: 1) a high water footprint that generates adverse effects on the environment. 2) the indiscriminate deforestation to carry out crops that affects biodiversity. 3) the practice of monoculture that results in: a. resistant pests that promote the massive use of pesticides and fungicides, b. the reduction of the fertility of the earth [9], [10], 4. in some cases it is about edible commodities whose use as fuel can affect food security or the availability of raw material at adequate costs for other industries [11].

Reviewing the interface between bioenergy production, logistics, and SC management, [2] found two main challenges: 1) the overall design of supply systems, and 2) raw material harvesting and storage, transportation, and of pretreatment. The authors suggest that one of the key aspects that probably determines the future competitiveness of this sector is developing an efficient SC. In this context, this article analyzes SC logistics management through its characterization, describing the economic, social and environmental features that affect its profitability and sustainability and that provide the necessary basis for developing future planning and decision-making processes.

II. DEVELOPMENT

A. Literature Review

The literature review focuses on works on the characterization, analysis and improvement of the SC of biodiesel.

According to the characterization works: [12] describes the management, from the organization and the production process and presents the actors involved in the SC of liquid biofuels in southeastern Mexico. [13] applied the SCOR Model as a methodological characterization tool, where they identified the variables and operations that make up the SC for the manufacture of biodiesel from castor castor, establishing their main management or performance indicators. [14] analyzes the biodiesel industry in Brazil, focusing on the industrial structure and the interdependence between farmers, where the effects that certification policies have on the value chain (VC) were studied, including economic and governance aspects. [15] limit their study to the SC of biodiesel from oil palm, in the study environmental, energy and economic elements are evaluated. [16] carry out a contextualization and characterization of the SC of ricin, as well as an evaluation of its prospective future.

According to biodiesel SC analysis and improvement: [17] evaluated the impact of facility integration, scale, SC configuration, and transportation on biofuel production cost. [18] provided different alternatives for the production process to improve the techno-economic viability of biodiesel production using sulfuric acid as a catalyst during the transesterification process. In [19] the legal, institutional, technological and fiscal obstacles to establishing a successful biodiesel market are analyzed, exploring the regulation of biofuels in Mexico, the national production and consumption of biodiesel, the VC and the cost of biodiesel production. The work of [20] analyzes the uncertainties of the SC using a case study in Malaysia that illustrates the impact of these uncertainties.

The review allows us to conclude that the SC of biodiesel has been studied for a couple of decades, despite this, there is no evidence of a characterization work that describes it at a strategic level.

B. Characterization Methodology

The study uses the most recent version, 2021, of the proposal developed since 2005 by García and colleagues as a methodological framework. The steps of the strategic characterization methodology are presented below:

Step 1. Identify the mission of the SC. Step 2. Synthetically identify and describe the agents involved. Step 3. Synthetically identify and describe the products and by-products. Step 4. Identify the position in the SC of the agents in the market. Step 5. Make a description of the logistiSC system of the SC. Step 6. Provide a diagnosis of SC through the application of an analysis (SWOT).

The methodology has allowed to characterize some important agricultural SSC that include: coffee [21], oil palm [22], cocoa [23], beef [24]; among others, this methodology seeks to provide a descriptive support of SC to address SC issues [25] at a strategic level, in order to facilitate decision-making at this decision level [26]. Next, the methodological development for the case study is carried out.

C. Development of the Methodology

Identify the mission of the SC.

The mission of the SC is to produce biodiesel in a profitable and sustainable way. This implies specifying precisely the region of cultivation, the area of demand, the biomass to be cultivated or the collection of waste in the case of residual oils, the development of adequate production processes and establishing a biomass mixing ratio that allows the production of biodiesel in sustainable and sustainable environmental and economic terms, that is, in accordance with the possibilities of production and sale and that minimizes environmental indicators such as: water footprint, carbon footprint, or use of pesticides and fungicides, that is friendly with biodiversity, that does not risk food security and takes into account the expectations of stakeholders. The production must be sufficient to satisfy the demand for renewable energy and the business must allow a fair benefit to the undertaking of the productive agents of the SC.

Identify and Synthetically Describe the Agents Involved

The SC of biodiesel is synthesized in (Fig. 1). It shows three sectors, or phases, related to the value they add: agricultural, industrial, and distribution and sales.

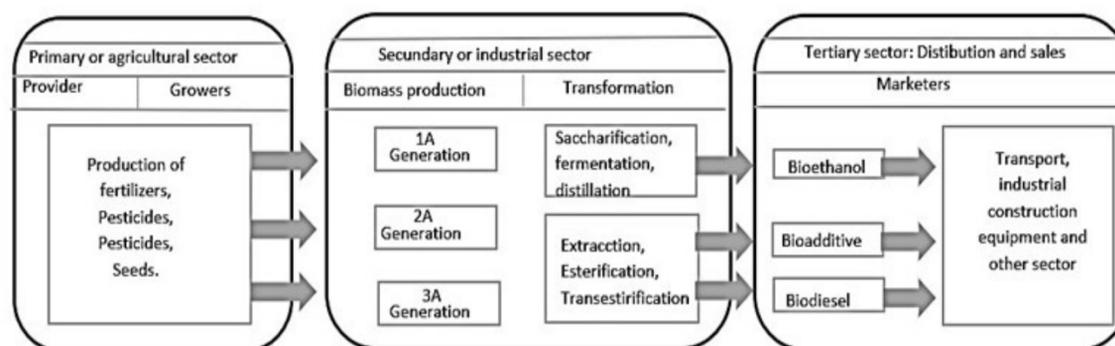


Fig. 1 Biodiesel supply chain.
Source: Authors

Biodiesel can have various sources of origin, and based on this origin, there are different types of biodiesel on the market classified by levels and types, this is detailed later where a description of the SC logistiSC system is made.

Identify and Synthetically Describe the Agents Involved

Raw material extraction

The primary or agricultural sector is in this stage, see Figure 1. The raw material required for the production of biodiesel represents the highest cost, 72.6% of the total cost of production [27]. [28] provide a starting point for the description of biomass feedstock and how biofuel production is carried out, and provide a discussion of biodiesel SC design and modeling approaches. Broadly speaking, it is possible to differentiate three types of biodiesel, depending on whether it comes from vegetable oil, animal fat oil, or waste cooking oils.

In reference [29] they studied the properties of biodiesel based on chicken fat. [30] compared the composition and properties of biodiesel extracted from animal fat vs vegetable oil. Authors such as [31], [32], or [33], examined the effect of biodiesel composition on the emission characteristiSC of diesel engines, the experimental results indicated that in all engine operating conditions with a higher proportion at 40% in the blend, particulate emissions from animal fat-based biodiesel are lower than other types of biodiesel with the same proportion. Despite the existence of these and other possible studies, the use of animal fat oil for the production of biodiesel has not been managed on a large industrial scale.

(Table 1) presents the main crops used for biodiesel production and their characteristiSC.

TABLE 1. MAIN CROPS.

	% of oil	Oily part	Productive areas	Average yield Kg/ha/year
Raw material	Seed: 44-57	Seed	Indonesia, Thailand, Nigeria, Colombia, Brazil, Malaysia	Seed: 800
	Pulp: 45-55	Pulp		Pulp: 5.000
Oil palm	40	Seed	India, China, Canada, Germany, France	700-1500
rapeseed and canola	18-20	Seed	USA, Brazil, China, India, Paraguay, Canada, Argentina	280-580
Soy	18-25	Seed	India, China, USA, Pakistan, Uzbekistan, Brazil	300
Cotton	45-55	Seed	Russia, USA, Ukraine, India, China, Argentina	600-950

Note: In the case of oil palm, the raw material for biofuel (CPO) is the pulp of the fruit.

Source: Authors based on [34].

The final quality of biodiesel is based on the amount of minor components considered harmful to health and the environment. The regulation seeks to comply with technical standards, especially from Europe and the EU, which include: D 6751-08, established by the American Society for Testing and Materials (ASTM) [35] or DIN EN 14214 standards for the EU [36].

Calorific Power

The calorific value is one of the most important properties of animal fats, vegetable oils and biodiesel for them to be considered viable as fuel [37]. (Table 2) shows the various caloric powers obtained through the specific correlations.

TABLE 2. CALORIFIC POWER OF THE BIODIESEL STUDIED.

Oil	[38]	[39]	[40]	[41]
Soy	38.91	39.08	39.78	39.46
Rapeseed and canola	39.07	39.39	39.85	39.55
Sunflower	38.89	39.87	39.82	39.51
Cotton	38.93	39.27	39.66	39.31
Palm oil	39.19	40.05	39.55	39.18
Animal fat	39.33	40.35	39.61	39.25
Residual cooking oils	39.12	39.61	39.78	39.47

Source: Authors.

Biofuels Classification

They are characterized according to the technology used for their elaboration, they are differentiated between first, second, third and fourth generation biofuels, see (Fig. 1).

In reference [42] they study the different uses of biodiesel, its current resurgence and future prospects, examining its strengths and weaknesses. One of the conclusions of the research is that with large plantations destined for biofuels, the results have been discouraging, causing more environmental effects negative than positive, for this reason expectations have been oriented towards second and third generation alternatives.

(Table 3) describes a synthesis of what has been established so far about the generations of biofuels.

TABLE 3. CLASSIFICATION OF BIOFUELS.

First generation biofuels: These are conventional biofuels created from food crops, such as fuels made from crops such as soy or palm.
Second generation biofuels: These biofuels are produced with biomass that is derived from plant materials, such as: permanent crops, agricultural residues and animal fats.
Third generation biofuels: These biofuels would be extracted from algae that have a natural oil content of at least 50%.
Fourth generation biofuels: These include the use of genetically modified bacteria that use carbon dioxide.

Source: Authors based on [43].

Regarding third generation biofuels, they are a promising option for the production of biodiesel. This oil produced with microalgae can be up to 25 times more productive than that produced with traditional crops. These microalgae have a priori conditions that are friendly to the environment as they are: they can exist and reproduce in a diversity of environmental scenarios and do not require large tracts of land [44], [45]. Despite this, currently its production is in the research and identification phase of suitable species and for its part technological scaling in terms of production; this because the production of biodiesel and bioethanol from microalgae has only been carried out in pilot plants [46], a condition similar to that of the cultivation of bacteria related to the fourth generation of biofuels

Biodiesel production process

In [27] the operating costs of biodiesel production were evaluated, the analysis included: raw material, supplies, labor, electricity, quality and maintenance.

(Fig. 2) presents a diagram of the biodiesel production process.

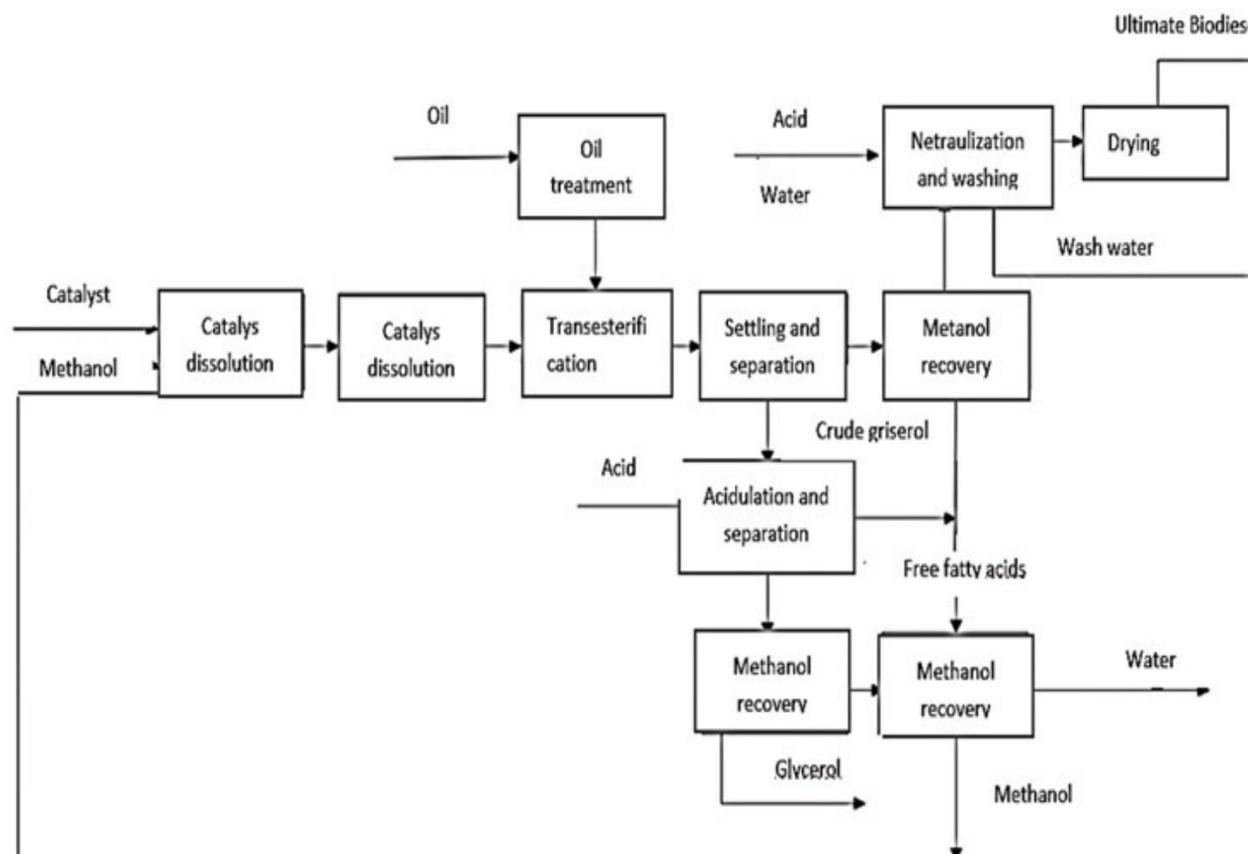


Fig. 2 Biodiesel production process.
Source: Authors.

As can be seen, some of the processes related to SC are commonly used in the industry. Next, the process that characterizes the production of biodiesel, the transesterification process, is presented.

Transesterification process

This process concerns the secondary and industrial sector, see (Fig. 1), in which oils and fats are converted into biodiesel through a chemical reaction that consists of mixing a triglyceride with an alcohol, forming alkyl esters and glycerol [29]. The alcohols used should be of low molecular weight, the most used is methanol due to its low cost, followed by ethanol [19]. (Fig. 3) illustrates the chemical detail of the process.

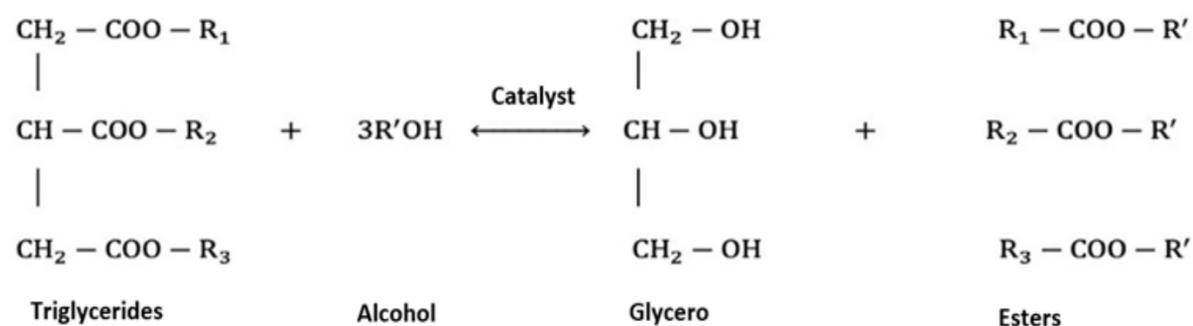


Fig. 3 Transesterification process.
Source: Authors.

Transesterification is the reaction of a triglyceride with an alcohol to form esters and glycerol. Since this reaction is reversible, plenty of alcohol is used to shift the reaction

completely to the right of chemistry. When the reaction occurs due to the intervention of the catalyst, the oil molecule is destroyed and thus an alcohol molecule is combined with an already separated ester molecule, thus obtaining biodiesel or methyl esters and glycerin as a by-product [47].

According to the report [48], it is intended to increase biodiesel production driven by mandates with higher blending rates. (Table 4) shows the biodiesel mandates in the countries that consume it the most.

TABLE 4. MAIN MANDATES FOR CONSUMER COUNTRIES (2020-2021).

Country	% mix		Country	% mix	
	2020	2021		2020	2021
USA	4%	6%	Canada	2%	2%
Norway	4%	20%	Indonesia	20%	20%
Sweden	33%	33%	Argentina	10%	10%
Finland	18%	20%	Thailand	7%	10%
Brazil	11%	12%	Colombia	10%	12%
China	0%	0.2%	Paraguayan	2%	2%
India	0.14%	0.16%			

Source: Authors based on [49], [50].

The expectation that we have is an increase in world production, managing to meet the established environmental commitments. [51] proposes a scenario called “Planned Energy Scenario”, where the production of biofuels would increase by 110% by 2030 and 189% by 2050.

(Table 5) shows the classification of biodiesel production and the main raw materials used for its production, the numbers to the left of the parentheses refer to the position that nations occupy in the classification of world production and the percentages as far as the production quota of the countries is concerned.

TABLE 5. CLASSIFICATION OF BIOFUEL PRODUCTION AND MAIN RAW MATERIALS.

Classification	Raw material	Country
1. (34.1%)	Rapeseed oil / waste cooking oils	EU
2. (19.5%)	Soy oil	USA
3. (12.3%)	Palm oil	Indonesia
4. (12.0%)	Soy oil	Brazil
5. (6.6%)	Soy oil	Argentina
6. (3.6%)	Palm oil	Thailand
7. (2.2%)	Waste cooking oils	China
8. (1.4%)	Palm oil	Colombia
9. (0.7%)	Canola oil / soybean oil	Canada
10. (0.4%)	Waste cooking oils	India
11. (0.03%)	Soy oil	Paraguayan

Source: Authors based on [52].

Identify the Position of the Agents in the Market in the SC

This section is in charge of identifying the position in the market supply, regarding the importance of biofuel companies.

TABLE 6. LARGEST BIOFUEL COMPANIES BY MARKET CAPITALIZATION.

N°	Company	Market Cap	Country
1	Cosan	\$7.45B	Brazil
2	Verbio	\$4.43B	Germany
3	Renewable Energy Group	\$3.08B	USA
4	Montauk Renewables	\$1.74B	USA

5	Green Plains	\$1.66B	USA
6	Gevo	\$0.79B	USA
7	REX American Resources	\$0.50B	USA
8	FutureFuel	\$0.43B	USA
9	Green Plain Partners	\$0.33B	USA
10	Aemetis	\$0.33B	USA
11	Tidewater Renewables	\$0.32B	Canada
12	Cielo Waste Solution	\$0.12B	Canada

Source: Authors based on [53].

Three companies stand out for their size: Cosan, Verbio and Renewable Energy Group. Cosan's weight in the market is significant since it has been able to take advantage of its position as a palm producer to satisfy a large domestic demand for biodiesel. Verbio's situation is different, it supports its biodiesel production on rapeseed produced in Europe to satisfy high German consumption, the main promoter of cleaner production in the world. For its part, the Renewable Energy Group leads US companies in the production of biodiesel based mainly on soybeans.

Carry out a Description of the SC Logistics System

This section is in charge of studying the organization of the logistics process of the SC, which was divided into three different phases. (Fig. 4) shows the links and the different links that make up the SC of biodiesel.

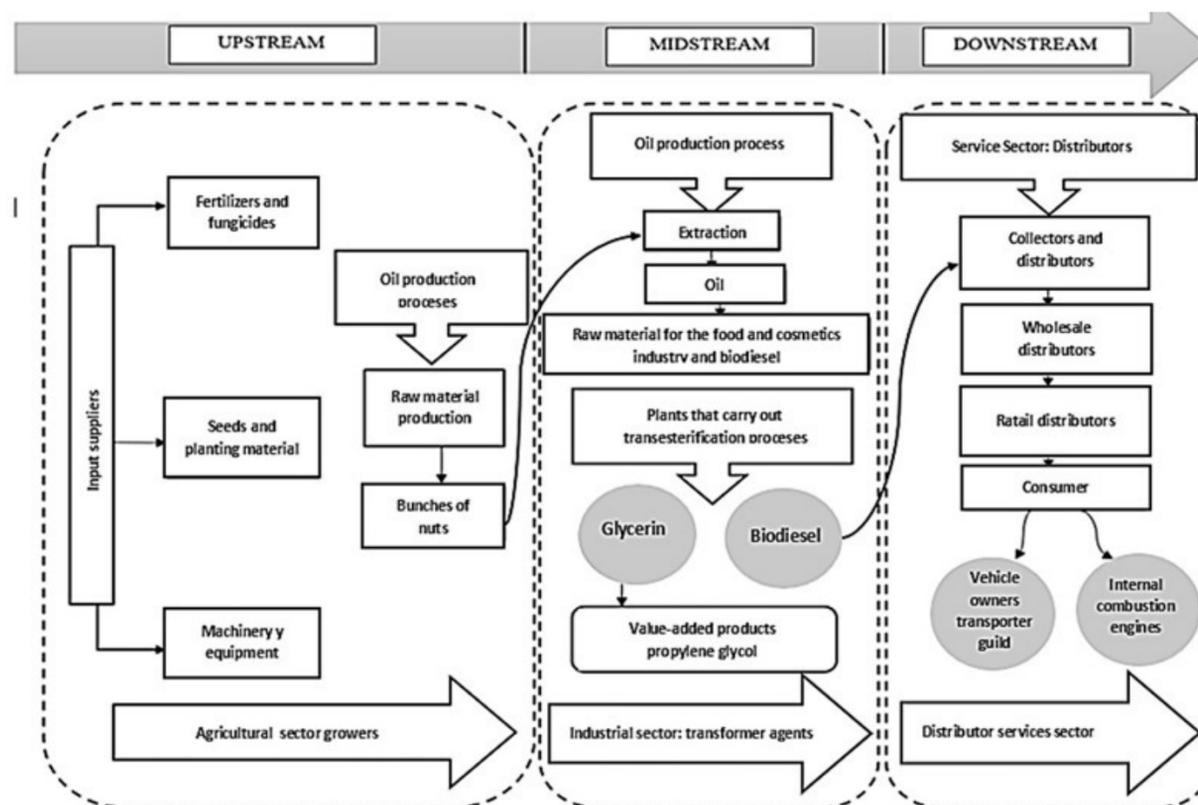


Fig 4. Configuration of the biodiesel supply chain.

Source: Authors.

In this SC it is possible that all the stages are carried out by a single company, however, in practice, the SC is shared between large and small biomass producers, biomass processors, product carriers between the production centers and the oil refineries [54]. Each of the phases of the SC is detailed below.

Upstream phase

It is associated with the first phase of added value that begins with the cultivation activities related to the preparation of the land and that goes up to the harvest. The added value focuses on the development of agribusiness capacities through GAP (Good Agricultural Practices) and biotechnology. The links of this phase are:

Input suppliers link: They are in charge of supplying inputs to growers, among their activities are the provision of seeds, seedlings, fertilizers, agrochemicals, machinery and agricultural tools. It should be noted that the majority of members of this link do not participate exclusively in the SC of study, but rather, due to their trade name, they focus on all agricultural SCs and more specifically on the agrochemical SC.

Growers: Participate in this link from the small farmer to the large estates dedicated to the development of the crop with different means of production, ranging from traditional labor-intensive methods to more technical processes with the use of agro-industrial machinery.

Midstream phase

It is associated with the second phase of added value, it focuses on the development of agribusiness capabilities, through good logistics practices and biotechnology, which allow the achievement of safety and quality standards during storage and transportation of the product. The links of this phase are:

Industrialists dedicated to the extraction of oil: They are the extractors and purifiers supplied by the collection centers near the crops or places of production. It is necessary to comment that in this link the extracted oil is shared between the biodiesel SC, the food industry (if the oil is edible) and the cosmetics industry.

Industrial Plants: They produce biodiesel from methods of physicochemical transformation of crude oil (transesterification). In this link, companies are identified as belonging to economic conglomerates due to the level of investment necessary for their progress.

The two activities that make up the phase could be integrated into a single link.

Downstream phase

It is made up of the companies that participate in the distribution and sale to biofuel users: storage and blending plants, distribution centers and service stations. The main players in this phase are world leading companies in the production and refining of fossil fuels, such as YPF, Shell, Esso, Petrobras, among others.

Provide a Diagnosis of the CS through the Application of an Analysis (SWOT)

The production of vegetable oils used for biodiesel is presented below:

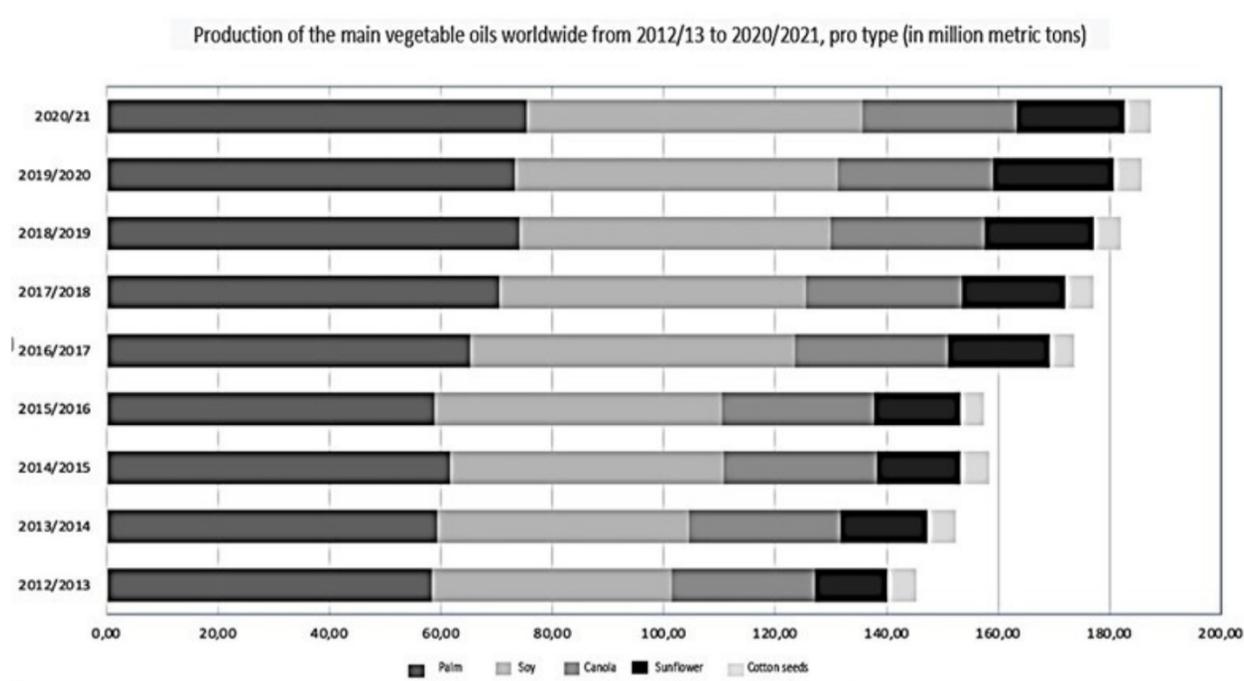


Fig 5. World production of vegetable oils between 2020 and 2021.
Source: [52].

The production of liquid biofuels has increased considerably in the last twenty years, growing 928% between 2000 and 2019. The countries that produce biodiesel focused on soybean oil are the US, Argentina, Brazil and Paraguay. Rapeseed oil as a production input is very popular in the EU, while palm oil is widely used in Brazil, Colombia, Indonesia and the rest of Southeast Asia [50], [55], [56].

The foreign trade of biodiesel represents 17% of world consumption, with a volume that exceeds 8,000,000 m³. (Table 7) presents the global biodiesel market.

TABLE 7. IMPORTS AND EXPORTS (2020).

Region	Country	Imports (Tons)	Exports (Tons)
America	USA	674,145	539.425
	Canada	518,219	487.447
	Peru	97,827	
	Colombia		5.338
	Brazil		3271
Asia	China	89,612	911.334
	Malaysia	173,772	401.651
	South Korea		191.546
	Taiwan		58.910
	Indonesia		33.908
	Türkiye		16.858
	India		11.901
	Japan		8057
Africa	Nigeria	4,339	
	Morocco		7.759
Europe	Holland	3,968,095	4.751.266
	Belgium	2,804,044	3.223.728
	Germany	1,483,526	2.412.153
	France	1,206,472	552.468
	Sweden	365,784	13.711
	Bulgaria	420,302	422.645
	Austria		288.531
	Poland		364.749
	Norway	213,149	
	Czech Republic	176,629	162.395
	Swiss	130,982	
	Slovenia	129,569	
	Slovakia	113.415	65.529
	Ireland	149.231	17.981
	Hungary	104.354	64.187
	Lithuania	86.577	126.011
	Denmark	88.155	
Portugal		64.499	
Greece		22.766	

Source: Authors based on [57].

Sustainable development of the SC

Sustainable development factors have been the subject of high dynamics in the literature since [58]. In this line, particular aspects of biofuel production and management deserve special attention, as is the case of biomass management, transportation, conversion, distribution and consumption of biofuels, likewise, the importance of planning decisions in biorefinery design. According to [2] the main aspects involved in the logistics management of bioenergy SCs are: harvesting, storage, transportation, pretreatment and system design. In this regard, [59] developed a multi-objective framework to classify different raw materials based on their

potential to achieve sustainability goals and concluded that currently, as shown in (Table 3), research points towards more sophisticated raw materials.

Comparison between different types of vehicles

Environmental impact: The study [60] analyzes the environmental impact of three types of vehicles: with internal combustion engines, electric-hybrid (50% gasoline and 50% electricity) and electric. The categories considered in the study were: global warming, abiotic deterioration, terrestrial ecotoxicity and deterioration of the ozone layer. (Fig. 6) shows the comparison between vehicles. As far as biodiesel is concerned, it shows good performance in 3 of the 4 indicators, except for global warming, due to the deforestation process that monoculture implies, it is necessary to attack this practice to make biodiesel more attractive as a competitive alternative. environmental and sustainability.

Performance: Study [61] made the comparison between the hill-climbing performance of a four-wheel drive (4WD) hybrid electric vehicle and a combustion engine 4WD vehicle, based on simulation results.

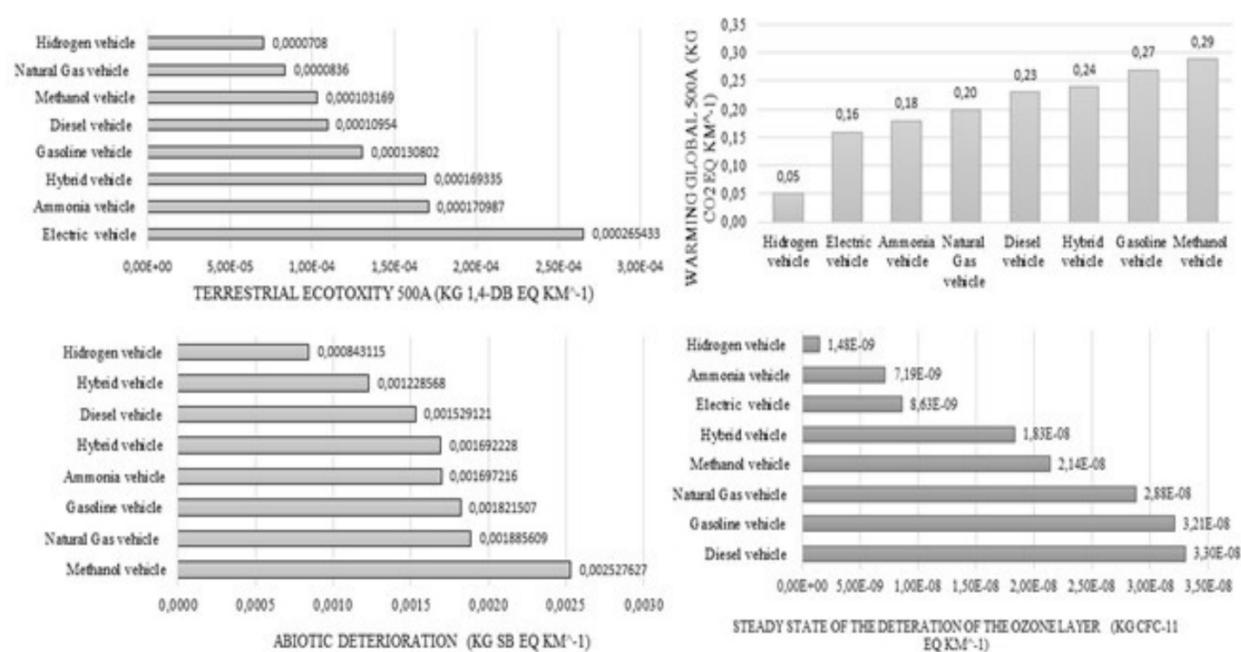


Fig. 6 Environmental impacts on different vehicles.
Source: Authors based on [60].

It is evident that the performance of the hybrid electric vehicle is better than the conventional one, except at the beginning of the climbing action due to the dependence on the electric battery. The cars of the future must not only be quieter and cleaner, but also more powerful.

Next, (Table 8) presents the synthesis of the SWOT analysis, in order to diagnose the context of the SC of biodiesel

TABLE 8. SWOT ANALYSIS OF THE SC OF BIODIESEL.

WEAKNESSES	OPPORTUNITIES
<ul style="list-style-type: none"> - Lack of investment for research and development of advanced biofuels and for the improvement of current ones. - High logistical and production cost of commodities throughout the SC of the supply. - Sustainability difficulties in aspects such as monoculture, the use of chemicals and food risk. 	<ul style="list-style-type: none"> - The growing importance of awareness favorable to the use of renewable energy. - The positive environmental image due to the reduction of greenhouse gases - It is an environmentally more sustainable alternative to fossil fuels, without major technical changes. - The use of clean energy constitutes a new source of growing demand. - High potential for scientific and technological development for the development of more environmentally friendly crops and oils.

STRENGTHS	THREATS
<ul style="list-style-type: none"> - Incorporation of non-productive areas with the use of soils not suitable for food production. <ul style="list-style-type: none"> - Revaluation of the land. - Good quality biodiesel obtained. - Job creation in rural communities. <ul style="list-style-type: none"> - High supply of biomass. - High offer for biofuels. - Accumulation of experience in the development of commodity crops. - It is a hybrid alternative that has shown to be profitable, even in monocultures, and has the potential to be sustainable and sustainable. 	<ul style="list-style-type: none"> - Fires, pests and diseases in crops. - Climatic risks such as droughts, floods, damaging winds and frosts. - Labor force shortage and negative social phenomena. <ul style="list-style-type: none"> - Currency changes, costs, biofuel prices. - Future impact on water and soil resources due to inappropriate use of agrochemicals. <ul style="list-style-type: none"> - Loss of biodiversity due to planting (monocultures). - Competition with other cleaner energy sources, specifically electric and hydrogen-powered cars.

Source: Authors.

III. CONCLUSIONS

The demand for biofuels for transport shows a complex competitive landscape, on the one hand, the demand for cleaner energy will grow in the coming years, but on the other it will face increasingly serious competition from other energy alternatives. The possibility of biodiesel becoming a lasting alternative in an increasingly competitive market will depend on research that contributes to making the production of its crops that serve as raw material more environmentally friendly, that is, reducing the water footprint that avoids monoculture and minimizes the use of chemicals; this both in traditional crops and in the one focused on the development of new generations of biofuels, in short, more productivity and kindness to the environment. Another aspect related to competitiveness is that in the face of a supposed expansion of demand, more solidity must be developed in the SC both in its efficiency and in its logistical and productive capacity. Despite this, the biofuels industry currently has a strong position due to its advantages over the pure electric alternative, its relationship with the oil industry and hybrid locomotion, and the little development of the hydrogen alternative. This situation will change over time. Time implies that its sustainability is based on the possibilities that research and innovation in the petrochemical, cosmetic and food industries can offer it in the face of competition.

The research perspectives of this work are focused, on the one hand, on the theoretical development of the characterization and its impact on the management of supply chains, and on the other hand, on the development of works in the management of the agrofuels chain that require as a basis the perspective and context provided by this study of a strategic nature, which is expected to be a relevant reference document for any prospective study for the development of the chain studied here.

CRedit AUTHORSHIP CONTRIBUTION STATEMENT

A. Espitia-Cubillos: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing, Review & Editing, Visualization, Supervision, Project administration, Funding acquisition. **C. López-Ramírez:** Methodology, Formal analysis, Investigation, Writing, Review & Editing, Visualization. **R. Garcia-Caceres:** Conceptualization, Methodology, Validation, Supervision.

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