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Macro-environment analysis of the corn ethanol fuel development in Brazil

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Abstract

In Brazil, the excess in corn production and the possibility to integrate it with sugarcane for the production of ethanol making use of the productive structure already available demonstrated a certain degree of feasibility in the utilization of corn kernel to increase the national production. Thus, this article proposed to analyze the potential opportunities and threats offered by the macro-environment for corn ethanol development in Brazil. The results show that the political and legal segments present more threats, while the economic segment presents the most significant opportunities. The environmental segment can also jeopardize corn ethanol opportunities, influenced by the country's current policy. Lastly, given the potential threats and opportunities encountered, corn ethanol was considered viable as a complement to sugarcane ethanol. Corn ethanol is a good alternative for reducing operational idleness during the inter-harvest sugarcane harvest as well as minimizing storage problems and collaborating with the region's producers in marketing in a less costly manner and with a higher profit margin. Finally, it was possible to show the current conditions of the macro-environment for the production of corn ethanol in Brazil and the importance of strategic analysis of the macro-environment.

Keywords: Corn ethanol; PESTEL framework; Marco-environment; Strategic analysis; Ethanol fuel.

1. Introduction

1.1. Biofuels in Brazil (ethanol from sugarcane)

The first fifteen years of the 21st century were marked by global concerns related to energy supply and the admission of approaching the effects of the climatic changes [1]. These factors aroused interest and generated significant investments in renewable

energy by the international community. However, the global energy matrix is still formed in almost its totality by fossil carbon sources – around 81% – while the renewable energy accounts for 14% of the total [2].

Oil accounts for 33% of the global energy matrix, it is a primary fuel source, and its prices are high [2]. In contrast, liquid biofuel is a direct substitute that has the potential to reduce transport sector emissions, oil imports, and contributes to rural development [1].

Brazil has the most sustainable energy matrix (renewable energy representing 43.5 %) [2], and is also the world's third most significant biofuels producer and consumer, only falling behind the United States and China. However, as opposed to other countries, Brazil can increase its biofuel production, not causing a seeming loss of food supply [3].

Studies undertaken by Brazilian Sugarcane Industry Association - Unica proved that in no other country in the world is ethanol produced as efficiently as in Brazil due to the quality of the raw-material and suitable climatic conditions [3].

While sugarcane ethanol has been produced since the early 20th century, its real success in the country starts in the 21st century. During the last century, the sector was not able to "boom", as the effects of CO₂ emissions during fossil fuels burning on humankind's wellbeing were still not realized. Although scientists had already been warning about the consequences of the GHG increase in the atmosphere, no country has adopted a single restrictive measure. Additionally, ethanol was not competitive from the economic standpoint, which required subsidies for its penetration into the domestic marketplace [4].

The sector's success resulted from the advances in technology, the State incentives for strengthening the use of renewable energy, and the introduction of flex-fuel vehicles, which boosted the sugar-alcohol sector. Also, mostly on account of reducing production costs (about 70%) and the frequent rise in oil cost, turning this kind of fuel highly competitive in the internal and external market [5].

1.2. Macro-environment influence for biofuels

Organizational environments influence the organizations, and the managers need to continually assess the influence of these environments to make better decisions. Three organizational environments can be identified. The internal environment assesses

an organization's resources and capabilities. In the external environment, the sectorial environment or industry (where partner organizations and competitors interact) and the macro-environment can be identified. The latter has the potential to influence and even to subject organizations and economic sectors [12].

The macro-environment can be organized in segments such as political, global, economic, technological, legal, ecological, socio-cultural, demographic, among others, is possible in each one of these to identify factors that will specify the characteristics and the influence of the macro-environment [6].

The importance of assessing the influence that the macro-environment has on the development of biofuel markets can be noted, albeit partially, in previous work such as this: Landry and Bento [7], who assessed public policies aimed at defending externalities affecting the biofuels sector in the United States; Everard et al. [8], showing that for the increase in clean energy consumption there is a need to institutionalize pro-environmental values aimed at changing social norms and behaviors; Weil et al. [9], who addressed the development of the biofuels market in the United States from the perspective of the dynamics of technological evolution; and Fertel et al. [10], who analyzed the importance of a coherent governance structure to promote a cleaner energy sector.

Just as organizations and economic sectors are not unaware of the characteristics and contexts of the external environment in which they operate, the existing segments of the macro-environment interact and influence each other, leveraging the strength they will exert on an organization or economic sector. In this sense, it is understood that a novelty of this research is to show the possibility of carrying out an analysis highlighting the integration between the macro-environmental segments.

From another perspective, although primarily a source of influencing factors, the macro-environment, under certain conditions, can also be affected by a large company or by dominant economic sectors. In this sense, Moreira et al. [11] and Eckert et al. [21] can be cited, which shows the relationships of the Brazilian corn ethanol industry with its external environment. This perspective also delimits the difference in this study's approach, which focuses on the strength coming from the macro-environment and directed to the corn ethanol industry.

When considering strategic options for the growth of Brazilian ethanol production, using corn as raw material, identifying the potential opportunities and threats that the macro-environment offers are fundamental, therefore, this research aims

to identify and analyze the macro-environmental factors that can influence the corn ethanol industry's development in Brazil.

2. Corn ethanol fuel industry in Brazil

Brazil holds third place in productivity ranking and the second place in worldwide corn exports, falling behind the United States only. Ninety-six million metric tons are expected for the 2018/2019 crop [17]. Currently, corn highlights as the second most significant crop growing for Brazilian agriculture. Data from the National Supply Company - Conab show that this cereal stood for 34.5% of all grain production in the 2017/2018 crop, with a yield of 80.7 million metric tons [18].

The State of Mato Grosso is the most significant corn producer in Brazil, producing 31.31 million metric tons, representing 31.3% of the 2018/2019 crop domestic production. One of the peculiarities of the corn produced in Mato Grosso is that it is featured as second-crop corn, also known as the "petite crop". At first, it was considered a risky activity by agronomists [19], but today represents 99.23% of all the corn produced in that State [18], and 73% of national production (Figure 1). This successful corn crop production is due to favorable climatic conditions and high-performance genetic material [20, 21].

Over fifteen years, Brazil saw its production evolve from 35 million metric tons, in a 12.3 million hectares plantation area, to more than 97.8 million metric tons in 17.59 million hectares, reaching a growth of 43.05% in the cultivated area, and more than 200% in production [22, 23]. These figures demonstrate the significant increase in the technological quality of corn crop in Brazil.

However, the increase in corn production, which at first met the already existing internal demand and also boosted the domestic product consumption, ended up implying in an excessive offer. This situation forced corn to be channeled through exportation, which is financially not attractive due to the logistical bottlenecks faced by the Brazilian corn [18].

The big issue in Brazilian logistics rests on the distances from the corn production areas to the ports and poor highway conditions [24]. The average distance between plants and ports in the State of Mato Grosso, Brazil's biggest corn producer, ranges around 1000 kilometers (Figure 2), and distance devaluates the product price [25]. Brazil's major transport modal (roadways) is also considered the most

burdensome, and this reduces Brazilian competitiveness in the international corn market compared to that of the significant grain-exporting countries [26].

The demand for fuel ethanol produced from renewable resources has been growing considerably in Brazil over the last few years, due to energy supply issues, the climatic changes, and oil prices. Besides, flex-fuel (double-fuel) vehicles fleet expanded by 250% over the last nine years and today account for 64.07% of the total motorcycles and lightweight vehicles in the country [26, 27]. A sizeable production is required to cope with the active fleet's size, which is worrisome, considering the persistent imbalance in the ethanol internal demand-supply equation, which calls for constant product imports to supplement the offer [28].

For a high-growth scenario, The Brazilian Company for Energy Research – EPE predicts the demand for ethanol fuel in Brazil to reach 50 billion liters in 2030, an increase of 87.5% over today's consumption [29].

As sugarcane ethanol mills operate with an average idle capacity of 4 months in the year, due to the sugarcane growing season and the lack of storage capacity, the ethanol industry has been studying alternatives to meet the growing demand.

Given the excess domestic corn supply scenario that lowers its price in Brazil, the grain has received attention to solve the mills' idleness and increase domestic ethanol production.

The Mato Grosso plants (called "flex distilleries/plants", because they processing either sugarcane or corn or sorghum), went through some adaptations required for corn processing, such as boilers (thermal energy generation), fermentation columns, distillers and ethanol alcohol stocking tanks [20, 30].

Usimat was a country pioneer in this segment, followed by the Porto Seguro and Libra plants, which adopted that production system [31]. The industrial processing of corn for ethanol manufacturing is new in the marketplace. However, due to the excellent corn productive stability and technological innovation, the ethanol production perspective for 2019 is 66% higher than in 2018 [17, 32].

Currently, nine corn ethanol plants operate in Brazil. Five of them are in the State of Mato Grosso, two in Goiás, one in São Paulo, and another in Paraná (Figure 3). The 2019/20 domestic production was of approximately 1.6 billion liters of ethanol, and this represents more than double the production of the previous harvest and almost 5% of the current national production (Table 1). Production is expected to continue to grow, because according to the National Corn Ethanol Union of Brazil, in 2018, there are 15

plant projects under construction and being licensed, most of them in Mato Grosso and some others in Goiás. Two of them in Mato Grosso (Sinop and Sorriso) and one of them in Chapadão do Céu, Goiás [34].

Table 1. Brazilian ethanol production from corn and sugarcane

Production (10³ liters)	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
Corn ethanol	104,972.5	163,053.8	140,308.8	513,377.5	791,400	1,677,181
Sugarcane ethanol	28,659,923.7	30,461,524.5	27,807,523	27,237,654	32,266,000	34,000,000
Total Brazil	28,764,896.2	30,624,578.2	27,947,831.8	27,751,032	33,057,400	35,677,181

(Source: Based on data from Conab, 2020 [22])

3. PESTEL framework

The PESTEL framework (an acronym for political, economic, social, technological, environmental and legal) through a sequence of stages allows the analysis of the macro-environment in which the organizations are inserted and the identification of potential threats and opportunities present in each of its segments [6, 12].

In the political segment, factors may be identified, related to political approaches and policies implemented by a particular government that administers the local, regional, or national environment into which the organization is inserted. As for the social segment, factors are found, such as work conditions, public health, miscegenation, gender issues, physical handicaps, culture, and social behavior.

Through the economic segment, it is possible to understand the conditions under which a particular organization was created and verify the economic course into which that organization will or may come to compete.

The technological segment is determinant for organization or sector competitiveness, given the availability, propagation, and diversification of technology. It can offer advantages or disadvantages to the production processes of specific organizations or areas in the utilization of raw material, among others. In the ecological segment, tendencies and changes in the physical environment in which the organization operates are set forth.

Lastly, the legal segment brings forward regulations that must be followed in the area in which the organization or sector takes part. These regulations may be temporally beneficial or disadvantageous to the organization or industry, depending mainly on the

interests of the administering government that, at times, represents the interests of the members of the society, while, on occasions, defends the attention of the rulers themselves solely [6, 12].

The PESTEL framework has been used in studies of the macro-environment of some energy systems, as in the waste-to-energy incineration industry in China [13], ocean energy in the European Union [14], geothermal energy in China [15] and the hydrocarbons sector in Cyprus [16]. In these works, the main factors were identified within the six segments, which influence the current development of the energy systems.

4. PESTEL analysis of corn ethanol fuel in Brazil

It is a qualitative, descriptive, and document research. For using the PESTEL framework, a continuous analysis flow was proposed, based on [6, 12, 14, and 15] the analysis process was divided into four stages (scanning, forecast, association, and interpretation) (Figure 4).

The identification of current and potential future macro-environmental factors was carried out through documentary (government and industry data) and bibliographic research. The identified factors were evaluated based on their direct and indirect relationship with the Brazilian corn ethanol sector. Finally, the relationship between each macro-environmental factor and the sector studied was interpreted as a potential opportunity or threat to the development intentions of Brazilian corn fuel ethanol.

4.1 Political Segment

Although a precursor in the ambitious and large-scale production of fuel ethanol, Brazil lost its position to the United States (Figure 5), which has already firmed its position as the great nation in the sector and is increasingly parting from its closest competitor [35].

Among the several factors that lead the United States to take this leap in ethanol production, particular emphasis has been given to the active participation of the American Federal Government. They acted through the allocation of resources to research, innovation, and technology, as well as through the granting of subsidies that allow producers and refineries to add ethanol to gasoline and the imposition of financial barriers to the product importation. These moves allowed the development of a

competitive marketplace for their biofuel, despite it presenting less productivity and higher manufacturing costs than those in Brazil, for instance [35].

In Brazil, it is clear that the higher provision of natural resources is not enough to make ethanol compete with fossil fuels. Government support, technological advances, and scientific development are equally important in this process for gaining competitiveness. As they were when the country created its *Proálcool* (*The National Alcohol Program*) through which several public policies oriented towards the ethanol sector, similar to those adopted by the American Government, were created and allowed for the Brazilian ethanol production to grow fivefold between 1975 and 1979 [35].

However, while United States ethanol production is encouraged with investments by the public and the private sector, in Brazil, Government has been giving low priority to ethanol, and that goes against the allegations in favor of sustainable development and less dependency on fossil sources claimed by the country [35]. The production of corn ethanol, for example, is not the subject of any specific public policy [36].

Without State support to ethanol production, institutions had to adapt themselves as of the 1990 decade [37]. The Brazilian government that used to adopt several policies that contributed to the growth of ethanol production now plays the role of mere sector regulator, employing indirect investments in the sector as well as in research and development (R&D), leaving the initiatives relative to the sector's expansion to the plants themselves.

To place ethanol as a competitive product in the fuel market, while the private sector seeks technological innovations that make the industrial process more efficient, thus decreasing production costs, the government is committed to adopting stricter environmental rules and leveraging the R&D process [37].

However, since 2016 - the year in which the proposed constitutional amendment number 241 was approved, which provides for a freeze on Brazilian government spending for the next 20 years - public investment in R&D has been substantially reduced in all sectors, including biofuels [38, 39, 40]

Furthermore, the ethanol sector overview points at an inertial process in which agents seem to be used to times of active State intervention. Even years after deregulation, ethanol prices and production volumes continue to be defined based on marketplace stimuli and influenced by specific government incentives [41].

Thus, the lack of specific public policies for the incentive to corn ethanol production may discourage private investments and even cause to halt the development process.

Even though, and as mentioned before, corn ethanol is not the specific objective of any public policy. However, the use of corn for ethanol production is increasing, 1.95 million tons in 2018/19 and 4.1 million tons in 2019/20, it benefits from agricultural and ethanol fuel policies [42], which are efficient and continuously contribute to the segment's technological and productive improvement [43] (Figure 6).

Table 2 presents a synthesis of the potential impacts identified in the current macro-environment of Brazilian corn ethanol from the political segment.

Table 2. Macro-environmental political segment synthesis

Political segment	Impact synthesis
Sugarcane ethanol and agricultural policies	Indirect potential opportunity
Absence of specific policies for the corn ethanol sector	Direct potential threat
National policies for fossil fuels	Indirect potential threat
Policies for technological development and improvement of the environmental profile could contribute to the national and international competitiveness of the sector	Indirect potential opportunity

4.2 Economic Segment

Factors like the prohibition against the use of gasoline additives such as methyl *tert*-butyl ether (MTBE), the expected GHG reduction to satisfy the Kyoto Protocol agreement, and the continuous growth of the Brazilian flex-fuel vehicles fleet, point to a scenario of growth for the biofuel sector. The sector that then began to invest actively in its productive capacity saw its expectations deterred.

The 2008 international crisis caused the industry to be drastically affected by credit restrictions. Since 2009, the investments in new plants have decreased, and the sector began facing the closure of several units [44]. This scenario was aggravated by government price control policies implemented during Dilma Rousseff's Government, which kept the oil price below its market worth, making it impossible for ethanol to compete with gasoline directly.

With the end of gasoline prices control, higher renewable energy production and the Paris Agreement that aims at the end of GHG, an increase of more than 30% in the

fleet of flex-fuel vehicles are expected until 2026 [45], and this would cause the demand for ethanol in Brazil to grow remarkably.

According to estimates by the Brazilian Sugarcane Industry Association – Unica, until 2020, Brazil would need 100 new ethanol plants to cope with the rising demand for renewable fuel [46]. The focus on corn emerges within this demand expansion scenario and a threefold increase in grain production in the country's central-west region scrubland over the last ten years that still did not obtain a response suitable to the internal market.

As with the excess of production, it became necessary to find solutions for grain utilization that were profitable to the producers, since the inefficient transport conditions account for an operational cost of more than 26%, devaluating the product price and not allowing the Brazilian corn to compete in the international market [24].

Corn ethanol production comes to supplement supply. Integration between sugarcane and corn ethanol can offer significant economic leverage about independent units [47]. So the corn will play an even more critical role in the so-called flex plants during the sugarcane off-season [44], between December and March, thus ending idleness and reducing the industrial structure fixed costs through the synergy created by the combined operation between workforce and other production factors.

The expectation is more investments in the area for the flex plants, the expansion of the already existing structures, and new ventures. On the other hand, some plants produce alcohol exclusively from corn, the so-called full distilleries whose grinding and production capacity are higher than those of flex technology [32].

An economic feasibility study, based on the budget for corn ethanol plants, shows that R\$ (BRL) 31,605,597.87 is required to adopt a sugarcane ethanol plant flex-fuel plants, and the return on the value is an average of 3 years [48].

In the 2018/19 harvest, the total cost of producing corn ethanol in flex-fuel plants was, on average, R\$ (BRL) 1,709.07 per cubic meter, 4.49% lower than the cost of sugarcane ethanol plants, which was R\$ (BRL) 1,789.40 per cubic meter. The price of the corn (R\$ (BRL) 1,243.51 per cubic meter of ethanol) was 11% lower than the sugarcane price (R\$ (BRL) 1,404.08 per cubic meter of ethanol). Consequently, the profit margin for corn ethanol production was 23.9%, and for sugarcane ethanol production 19.41% in the same period [49].

The State of Mato Grosso turned out to be ideal for plant installation [32], and it is not by chance that five out of the nine of the corn ethanol plants are located there. At the

same time, corn consumption there is low, around 13% of the total production [50]. This scenario allows the grain to be offered at a low price, and the primary consumer is the DDGS (Dried Distiller Grains with Solubles) intended for animal feed [32].

Distillery grains as a source of animal feed are an excellent strategy for cost reduction at the feedlot, and one expects a more excellent supply of distiller's grains for 2019 already. For each metric ton of corn, 401 liters of ethanol and 323 kilograms of DDGS are produced. The energetic, protein, and digestible phosphorus values of DDGS mark it as an alternate food with great potential to substitute corn and soybean in animal feed. Part of the animals' diet may certainly include DDGS without risk of performance damage [51].

The by-product also enriches the process and becomes economically advantageous, as studies indicate that this raw material (DDGS) is intended for cattle raising in the several Brazilian States. Once its exportation is encouraged, it would bring annual revenue of R\$ (*BRL*) 1.2 billion [25, 45]. In 2018, its price could range from 31.8% to 63.6% of that of soy [52].

A study conducted by the Initiative for Land Utilization and by *Agroicone*, in 2018, shows that the operation of a corn ethanol plant with an annual production of 500 million liters of ethanol is capable of generating a total output in the value of R\$ (*BRL*) 2.5 billion and an increase in GDP of R\$ (*BRL*) 910 million. Virtually 80% of these values are restricted to the State of Mato Grosso and may generate an increase of up to R\$ (*BRL*) 73 million in tax collection [53].

On what depends on the grain's agricultural production, economic strengthening shall continue. Corn production may grow by 12.6% in 2018/2019 when compared to the last season and is estimated to reach 90.95 million metric tons, equivalent to an excess of 10.16 million metric tons over the previously harvested 80.78 million metric tons [52].

This large corn production expected in Brazil is a factor that shall maintain the cereal costs at levels lower than those in 2018 [52], thus allowing for the reduction or even the extinction of ethanol imports, which is based on the prices discrepancy [44]. Therefore, ethanol production from the cereal shall become even more viable.

In 2024/2025, the State of Mato Grosso is expected to produce 38 million metric tons of corn [45] and that in ten years, the state shall be consuming at least 10 million metric tons from its total production to produce at least 4 billion liters of ethanol [33].

Table 3 presents a synthesis of the potential impacts identified in the current macro-environment of Brazilian corn ethanol from the economic segment.

Table 3. Macro-environmental economic segment synthesis

Economic segment	Impact synthesis
Increase in the price of oil and its derivatives	Indirect potential opportunity
National and international economic crises	An indirect and direct potential threat
Vehicle fleet growth trend	Indirect potential opportunity
Sustainable growth of the agricultural frontier and grain production, such as corn	Direct potential opportunity
Seasonal and industrial complementarity between corn and sugarcane crops	Direct potential opportunity

4.3 Social Segment

The continuous countryside mechanization process is excluding the rural worker from the value chain [55]. However, it is expected that the corn ethanol production increase and the implementation of new plants [34] shall generate mass employment in the producing region.

During the investment cycle that encompasses the period from start-to-end new plant construction, it is expected to create 8.5 thousand direct and indirect employments and 4.5 thousand jobs at the start of the plant operation [53].

The relationship between criminality and employment show that labor market opportunities affect the other costs of implicit dedication to illegal activities. That is, the lesser the chance an individual has for finding a job in the legal work market, and the higher are the incentives for him to enter and stay in crime [56].

Thus, one expects that with the decrease of unemployment, in the areas where corn ethanol plants will be installed, the rate of criminality shall follow suit. It is worth mentioning that from the two plants expected to open between 2019 and 2020, one of them is located in Sinop [34], the most crime-stricken city in the State of Mato Grosso [54].

Due to the accelerated corn production at levels much higher than required, top stocks caused a lack of space for grain storage. The lack of silo space has forced the producers to keep the corn in the field, exceeding its harvest point, which results in a more significant appearance of fungi that spread toxic chemical substances to human beings and cause the presence of certain kinds of cancer [57].

In addition to the serious public health issue, such fungi also cause direct losses to corn production and productivity. With the increase of ethanol production, a reduction in corn stock levels is expected, which shall facilitate grain storage, thus avoiding all risks inherent to the delay in harvest time [57].

Over the last years, Brazil has demonstrated a more significant concern and has been internationally recognized in terms of adopting government measures that seek the elimination of child labor, achieving a reduction of 70% over the last 20 years. Despite this progress, 2.5 million children are still exploited [58], and it is in the field that child labor appears as higher [59].

There are currently considerable concerns about the regression and a return to the increase in those figures since the number of child labor inspections registered between January, and July 2019 is the second smallest over the last ten years [60]. Recently, President Jair Bolsonaro stated his position favorable to child labor. For example, he said that he was by no means harmed by having harvested corn at ages nine and ten [61]. Nonetheless, several studies demonstrate that child labor is harmful to children's health and safety [62] and associate it with school drop-offs [63].

Therefore, the increase in corn production, aiming at satisfying its growing demand for ethanol production, when linked to those circumstances that characterize a possible decrease in child labor regulation, may lead to its considerable increase.

Differently from the United States, where corn ethanol production resulted in the price increase of food in Mexico in 2007 [64], in Brazil, only 2% of the total corn demand goes to human consumption [65].

The lack of corn supply for animal feed production, which could raise the prices of food that is part of the Brazilian daily diet, is overcome by the ethanol production itself, which generates the DDGS by-product, that is already in use by the meatpacking plants [66].

Table 4 presents a synthesis of the potential impacts identified in the current macro-environment of Brazilian corn ethanol from the social segment.

Table 4. Macro-environmental social segment synthesis

Social segment	Impact synthesis
A large number of poorly trained people seeking employment	Direct potential opportunity and threat
Negative impacts on public health due to problems in the production chain	Indirect potential threat

Leniency with the increase of child labor	Indirect potential threat
Absence of conflict between food and fuel production	Direct potential opportunity

4.4 Technology Segment

As opposed to the United States, where corn ethanol plants operate year-round, in that same period, the Brazilian sugarcane ethanol plants remain idle for four months in their biofuel production. Differently from the corn kernel, sugarcane cannot be stored, and during the inactivity of Brazilian plants, ethanol presents a significant price rise.

From the development of a new corn fermentation process (based on the utilization of yeast cells that were left from sugarcane fermentation) that allows integrating corn starch with sugarcane molasses, a series of advantages are being offered to the conventional Brazilian plants that operate solely on sugarcane. While the fermentation process takes 45 to 60 hours in American plants, the new Brazilian fermentation that combines sugarcane with corn takes around 34 to 36 hours, on average 66% faster than the American fermentation [47].

This new technology allows the utilization of the same sugarcane distilling process (Figure 7), expands the activity period of the Brazilian plants over the entire year, reduces fixed costs, increases ethanol production through only incremental investments, improves the country's energy security, and keeps ethanol price-stable year-round [19].

From the two processes employed to obtain ethanol from corn, wet milling, and dry milling, corn ethanol Brazilian plants, which in their majority are located in the central-west region, have the utilization expertise for dry milling. Although the process does not provide the most extensive variety of co-products like oil, starch, and carbonic gas, it allows a lower bioethanol final costs as it is through that process that DDGS, a highly demanded co-product [66].

The corn ethanol production that in 2019/20 was around 1.67 billion liters [22] will remain restricted to the total consumption of ethanol in the central-west region, of 3.6 billion liters per year [67]. In a promising scenario for corn ethanol, in which there is the opportunity to sell it to other States and even to the international market, logistics issues reappear as a threat.

According to The National Transport Confederation, in 2018, only 12.4% of the Brazilian road network is paved, meaning that from the 1.7 million kilometers of roads, only 213.4 thousand are paved. The central-west region is the second most burdensome

of the country in terms of transport conditions, presenting an infrastructure density of Just 7.3% [68].

Distant from the significant Brazilian ethanol consumption centers and the exportation ports, the distribution of the corn ethanol from central-west to the other Brazilian States and foreign countries can fuel prices might rise [69].

Conversely, an alternative that enables ethanol transport through different routes has been studied and gradually implemented by the state-owned *Petróleo Brasileiro S/A (Petrobrás)* partnering with several private companies to distribute the biofuel at a lower cost with fewer transportation risks. The solution devised by these companies involves the utilization of pipelines, which make up a logistics solution considered to be one of the most efficient and less costly [70].

However, the transport modal mostly utilized by the plants is still the roadways one. The alternative found to avoid a logistical bottleneck caused by the expansion of corn ethanol market turns out to increase investments in pipelines and the escalation of their utilization.

Table 5 presents a synthesis of the potential impacts identified in the current macro-environment of Brazilian corn ethanol from the technology segment.

Table 5. Macro-environmental technology segment synthesis

Technology segment	Impact synthesis
Technological development for the industrial integration of sugarcane and corn	Direct potential opportunity
Logistical problems for transport and production flow in the country	Direct potential threat

4.5 Ecological Segment

Sugarcane ethanol was already considered as a well-established process in the country, reaching excellent productivity levels (Figure 8). However, an intense pressure put on the industrial sector to reduce environmental impact portrayed a scenario that demanded a more socially and environmentally responsible production process, as did the fast-growing demand that exceeded the sugarcane ethanol production capacity [71].

The increasing demand for ethanol and the consequent opportunity for more production did not mean that it would be fabricated through more efficient and environmentally responsible means. Even though increasing ethanol production through sugarcane and corn means a reduction in gasoline consumption [19], the global

contribution of corn ethanol to the reduction of GHG is not significant [66]. On the contrary, flex plants have several environmental disadvantages when compared to plants that operate only with sugarcane [19].

A fuel's energy balance may be seen as the ratio between the provided clean energy versus the fossil energy consumed in a particular production system. From that ratio, one may determine the feasibility of obtaining power through the many possible technologies.

Studies on the energy balance and carbon footprint in the production of liquid biofuels are many and varied. The results are different, influenced by the type of raw material (corn, sugarcane juice, sugarcane molasses, sugar beet, cassava, and others) and production conditions (agricultural inputs, industrial processes, and others) [86]. Under Brazilian conditions, a study showed that corn ethanol has a positive energy balance and that in the agricultural phase, inputs represent the main energy cost (herbicides, pesticides, fertilizers, and others). In the industrial phase, the highest cost is represented in the hydrolysis/saccharification/juice treatment operations [87].

Water consumption is of particular importance where water scarcity is a prevalent issue and can be a limiting factor. Approximately, to produce a liter of ethanol using corn, 2,600 liters of water are consumed, using sugar-beet is consumed 1,300 of water, while using sugar cane 200 liters of water are consumed. Thus, in Brazil, although there is a large availability of water resources compared to other countries, the expansion potential of the corn ethanol industry may be impaired [86, 88]

While corn ethanol provides something between 1.9 and 2.3 clean energy units for each fossil energy unit consumed, sugarcane ethanol can provide up to 9 clean energy units for each fossil energy unit [19]. However, as shown in a study on corn ethanol in the United States, energy and environmental indicators are improving (between 1990 and 2010 the production and use of corn ethanol emitted 44% less GHG, consumed 54% less fossil energy, and needed 44% less agricultural land) [89]. It means that Brazilian corn ethanol has a long way to go, mainly in an expansion scenario and in the face of sugarcane ethanol, which uses less water and agricultural inputs.

The GHG balance is obtained through the ratio between the greenhouse effect gases absorbed and those emitted during the entire biofuels lifecycle, which goes from the extraction of natural resources through the final product utilization and availability [19].

Corn ethanol accounts for just 21% of GHG reduction in the United States, while sugarcane ethanol, considered an advanced fuel, reduces those emissions by 61% [72]. It is happening because corn ethanol production process includes a step additional to those required by other raw materials, the starch hydrolysis used in obtaining glucose, and spends an average of 4 MJ of energy for each liter of ethanol produced [66].

Sugarcane ethanol stands out in the world in terms of sustainable biofuels capable of mitigating GHG adverse effects. Supply the international market with corn ethanol from the Brazilian central-west, in addition to infrastructure and logistics competitive disadvantages, may face an absolute opposition by the part of foreign consumers due to its smaller environmental benefits when compared to sugarcane ethanol [19].

Differently from the self-sufficient sugarcane ethanol plants that count on the reuse on the bagasse from the sugarcane itself for electricity generation, corn ethanol plants require external thermal sources that usually resort to eucalyptus biomass.

Should the amount of sugarcane bagasse generated by the plants not be enough to keep them operating throughout the whole year, there might be a possible encouragement to eucalyptus production, which would lead to an increase in the eucalyptus planted area near the plants. This move could result in a reduction in the areas of permanent protection (APP) or incentivize deforestation in other areas. In both cases, the country's relevant authorities' monitoring and inspection would be required [73].

Table 6 presents a synthesis of the potential impacts identified in the current macro-environment of Brazilian corn ethanol from the ecological segment.

Table 6. Macro-environmental ecological segment synthesis

Ecological segment	Impact synthesis
Life cycle and carbon footprint of corn ethanol	Indirect potential threat
The country's concern to reduce the consumption of fossil fuels	Indirect potential opportunity
International pressure to improve the social and environmental profile of biofuels	Indirect potential opportunity and threat

4.6 Legal Segment

Since 1972, several countries have been meeting in a diplomatic effort to adopt measures for decelerating climatic changes jointly. Treaties derived from these meetings

organized by the UN demonstrate the relevance of the progress achieved worldwide in environmental issues [74].

In 2015, during the 21st Climate Change Conference (COP21) at the United Nations Framework Convention on Climate Change (UNFCCC), 195 countries signed the last international treaty between nations, the Paris Agreement, which was enforced in 2016. This new agreement has as main objective the intensification of the global response to the climatic changes threat and the strengthening of the countries' ability to deal with the impacts caused by those changes [75].

The Paris Agreement States as its main objectives: to keep a global temperature rise below 2 degrees Celsius above pre-industrial levels; to pursue efforts to limit the temperature increase to 1.5 degrees Celsius above the pre-industrial levels; to have all countries involved, not just the developed ones, so that the agreement objectives may be reached; to support the less industrialized countries in their emissions adaptation; to allow States to define their voluntary goals and commitments, in the form of the so-called intended Nationally Determined Contributions (iNDCs) through which they will present the contribution considered as viable, taking into account their social and economic conditions; and to regularly follow-up on the progress of the countries and their goals [75].

The Brazilian iNDC (intention) became an NDC (commitment) in 2016, pledging to reduce, from sustainable renewable energy, GHG in 37% through 2025 and 43% up to 2030 in terms of 2005 levels [75].

To comply with the commitments assumed in the Paris Agreement, Brazil launched the *RenovaBio* program in 2017 through Law Number 13.576 to define a new legal framework for biofuels [76].

The existence of a demand for ethanol and an abundant corn supply alone does not guarantee investment decisions for ethanol production from that grain. According to the Head of Embrapa Maize and Sorghum, Antonio Purcino, during a debate at the São Paulo Ethanol Summit in 2019, *RenovaBio* proves to be an essential driving element for the increase of ethanol and corn supply [77].

The sugar-energy sector tends to benefit most from *RenovaBio*, which shall trigger a new cycle of sugarcane and corn ethanol [78].

Insensitive to the benefits that might come from corn ethanol through the *RenovaBio* program, the current Brazilian president has lately threatened to break the

international agreement, in the belief that it puts at risk the Brazilian sovereignty and hinders the country's economic development [79].

In addition to those threats, the current Brazilian president has proved to be indifferent to subjects related to climatic changes and has boycotted some UN-sponsored events on the subject that should have taken place in Brazil [80].

However, what worries more is the fact that since he took over the Government in January 2019, funds earmarked for fighting climatic changes have dropped 95%, putting several Federal Government environmental programs at risk, as *RenovaBio* itself [81].

Brazil's possible evasion from the Paris Agreement and the dismantling of *RenovaBio* shall imply in a threat to corn ethanol, would then rely solely on private economic interests for the incentive to its production.

Table 7 presents a synthesis of the potential impacts identified in the current macro-environment of Brazilian corn ethanol from the legal segment.

Table 7. Macro-environmental legal segment synthesis

Legal segment	Impact synthesis
Commitments made by Brazil to objectively and planned to reduce its GHG emissions, and the approval of <i>RenovaBio</i> program	Indirect and direct potential opportunity
The divergent stance of the current government concerning laws and agreements based on sustainable development	An indirect and direct potential threat

5. Discussion

When viewed individually, the ecological and social segments play a supporting role in the positive influence of corn ethanol development in Brazil. In contrast, the political and legal segments represent the potential greatest threats, due to the absence of factors that directly and indirectly influence the corn ethanol sector, as well as the antagonistic stance of political actors in the face of the sustainable development challenges.

The economic segment offers more opportunities and presents itself as the real determinant of corn ethanol's recent development. In the technological segment, the country's inefficient transportation conditions make it impossible to expand the product and the production areas.

The macro-environment influence on the possibilities of development of Brazilian corn ethanol was also identified through the analysis of the interaction between the six macro-environmental segments (Figure 9).

The economic segment, which provides financial alternatives for corn and fuel ethanol producers, may allow the mills to overcome in the short term the threats posed by the technological segment, which is characterized by the country's poor logistical infrastructure. However, the economic segment's opportunities are threatened by the political and legal segments, which signal the continued absence of public policies and legal norms in favor of biofuels.

The economic segment also affects the possibility of opportunities arising in the social segment by increasing interest in the corn ethanol industry's development, especially in groups that interact directly with the production chain, as they see the opportunity for improvements in household income and employment conditions.

In the ecological segment, the forces that seek to influence organizations and economic sectors to adhere to sustainable development guidelines currently do not represent direct and explicit opportunities for the corn ethanol sector. However, the positive economic effect that can serve a more sustainable energy matrix could impact the political segment, at least in the discourse presented by the current government, notably guided by economic issues.

Table 8 compares the results of this research, with studies focusing on the macro-environment of the Brazilian corn ethanol sector.

Table 8. Comparing macro-environment analysis of corn ethanol sector

Other macro-environment analysis of corn ethanol	Contrasted Reference	This macro-environmental analysis of Brazilian corn ethanol
<p>The article takes an approach to the influence that corn ethanol production has on the social and ecological segments. From the current corn ethanol industry in the center-west of Brazil, GHG emissions from corn ethanol are higher than from sugarcane. However, when the dominant ethanol production technology used in the United States is adapted to Brazilian conditions, corn ethanol emissions are closer</p>	<p>[11]</p>	<p>Using the PESTEL tool, the article performed an integrated macro-environmental analysis, in addition to social and ecological factors, it also addressed economic, technological, political and legal factors that influence corn ethanol production in Brazil.</p> <p>Regarding the socio-environmental factors, the papers present similar results. In both papers, factors such as the emission of GHG higher than</p>

<p>to sugarcane emissions. The use of eucalyptus instead of natural gas as a thermal source for generating energy from corn is an essential determinant for the corn ethanol sustainability produced in the country.</p>	<p>sugarcane ethanol and the use of eucalyptus instead of natural gas as a thermal source for energy generation from corn are pointed out. In the present work, however, it was raised that this use of eucalyptus may also mean a reduction in areas of permanent prevention (APP). Besides, it was also raised the possibility of the general public rejecting the consumption of corn ethanol, given the higher emission of GHG than sugarcane ethanol.</p>
<p>This article analyzed factors mainly related to operational and logistic feasibility for corn ethanol production in Brazil, such as the availability of raw materials, production costs, and necessary technology. The results confirm the operational viability of biofuel production and place it as a possible stabilizer of ethanol supply in the country.</p> <p>As far as logistic viability is concerned, the work was only carried out in the discussion of short-term viability, in which logistic deficits are circumvented because there is only local production and distribution.</p>	<p>In addition to economic and technological factors, this article also addresses political, legal, social, and ecological factors.</p> <p>In this article, the same discussions were raised regarding the availability of raw materials, production costs, and the necessary technology that also confirms the operational viability.</p> <p>Concerning ethanol supply, although the same conclusion about the capacity of corn ethanol to positively influence its stabilization, previously this work also identifies the current instability as a factor that influences the production of corn ethanol.</p> <p>As for logistic feasibility, the article discusses both short-term and long-term aspects. It is essential to point out that in the long term, logistic deficits are once again, a factor that negatively influences the distribution of biofuel to other regions.</p>

[25]

Table 9 compares the results of this research, with studies focusing on the PESTEL analysis for the macro-environment of other energetic systems.

Table 9. Comparing PESTEL analysis in energetic systems

Macro-environment factors of other energetic systems	Contrasted reference	This macro-environmental analysis of Brazilian corn ethanol
<p>The political segment was identified as the central influencer in transforming a favorable macro-environment to develop the treatment of urban solid waste in China. For this reason, the study suggests policies, laws, and public-private partnerships to strengthen economic, technological, social, and ecological segments.</p>	<p>[13]</p>	<p>It was not possible to determine the main segment of the macro-environment that influence Brazilian corn ethanol fuel development. The macro-environment presents itself in a diverse, situational, and integrated way; however, the political segment was also pointed out as one of the most influential, and similarly, the adoption of public policies was suggested especially concerning improving transport conditions.</p>
<p>In order to develop technologies for harnessing ocean energy in Europe, several macro-environmental factors have been identified, the importance of which depends on the point of view of each stakeholder. For example, from technology developers, technological and economic factors will be more critical; from investors, economic factors will be fundamental; from the general public, the main factors will be ecological and social. Finally, it is relevant to mention the influence between the segments of the macro environment.</p>	<p>[14]</p>	<p>Macro-environmental segments are interrelated and influence each other. The analysis and interpretation of this macro-environment can present important strategic alternatives for decision-makers.</p> <p>Similarly, it was pointed out that for investors, the economic factors are the most relevant; for the general public, the main factors are ecological and social. Beyond that, about the agents belonging to the public service, the most significant concern should be with factors present in the technological and ecological segment.</p>
<p>The development and use of geothermal energy in China is primarily driven by the relevant economic, environmental, and social benefits due to the ability to promote increased private investment in the economy, job creation, as well as the reduction of greenhouse gas emissions. Such development, however, is confronted by negative factors related mainly to the political segment, due to the lack of specific public policies.</p> <p>Concerning the role the state</p>	<p>[15]</p>	<p>Similarly, the economic segment was pointed out in this article as being the one that currently positively drives the development of corn ethanol in Brazil. The same social and ecological factors were identified, such as employment generation and GHG emissions reduction; however, it was considered that these factors are more influenced by the development of biofuel than influencing in themselves.</p> <p>The works are also similar in pointing out the lack of specific</p>

<p>should play in stimulating the use of geothermal energy in China, it is recommended to promote research and development of essential equipment and technologies.</p>	<p>public policies and in highlighting the importance of public investment in research and development and its neglect.</p>
<p>The development of the hydrocarbon sector in Cyprus is mainly a function of ecological factors, given the purpose of obtaining a more sustainable energy matrix. The political and legal segments have expressly supported this development since the country joined the European Union in May 2004. This country has committed itself to its policies and solid legislative framework that regulates all critical issues of hydrocarbon exploration and exploitation, such as licensing, health, and safety, as well as environmental protection issues.</p> <p>Although the entire national territory belongs to the EU, the country is divided into two main parts, the southern part, which is under the control of the recognized Republic of Cyprus, and the northern part, which is under Turkish military occupation. The unstable political structure of the northern part of the country is proving to be a threat to the development of renewable energy at the national level.</p> <p>Regarding the social issues influencing the hydrocarbon sector, oil and gas extraction activities encounter social resistance and have a high risk of health and safety at work, as they are linked to high injury and fatality rates.</p>	<p>[16]</p> <p>Contrarily, the development of corn ethanol in Brazil is mainly due to economic factors and private interest.</p> <p>This article warns about the lack of public policies that encourage the development of biofuel and a more sustainable energy matrix in general. Besides, recent deficiencies in the political and legal framework are pointed out, such as possible violations of international environmental agreements and severe reductions in funds to combat climate conditions.</p> <p>The development and distribution of corn ethanol to other regions of Brazil are also threatened, however, fundamentally by technological factors, due to inefficient countries' transportation conditions, which have been pointed out as those that should be prioritized in the adoption of public policies.</p> <p>In the social sphere, influenced by the ecological segment, a possible resistance in the consumption of ethanol from corn was also highlighted, due to the low amount of clean energy released in the biofuel production process when compared to sugarcane ethanol.</p>

6. Practical implications, suggestions, and limitations

6.1. Practical implications

The PESTEL analysis of the Brazilian corn ethanol macro-environment identified opportunities and threats for this sector's current and future development. Therefore, it is understood that this research results can influence strategic decision-making, both by private and public agents. In this sense, it is possible to suggest:

6.2. Suggestions for investors

First, it is important to stress that corn ethanol should not be seen as a competitor or substitute for sugarcane ethanol, but as a complementary product that will help meet the growing national demand for fuel ethanol.

In general, the owners of flex-fuel vehicles in Brazil - the country's largest consumers of ethanol - choose between ethanol and gasoline based on a balance between the price of these fuels and their energy performance (consumers tend to replace ethanol when its price exceeds 70% of the price of gasoline) [82].

A significant drop in total ethanol production during the inactivity of sugarcane mills can be observed, which corresponds to the agricultural commodity's inter-harvest period, which grants a seasonal nature to the product supply.

The seasonal nature of the sugarcane ethanol supply, caused by the inter-harvest period, means that ethanol's price tends to exceed 70% of the gasoline price, causing a drop in ethanol consumption. Thus, increasing corn ethanol production during the sugarcane inter-harvest period will reduce variations in ethanol prices due to seasonality and the consequent drop in ethanol consumption.

For investors, flex-fuel plants, adapted to produce sugarcane and corn ethanol, have economic and operational advantages over plants that produce corn ethanol exclusively.

Due to the current surplus in corn production in the country, their competitive profile in ethanol production has improved compared to sugarcane. Notwithstanding, this would tend to change in a scenario of increased demand for corn to produce ethanol, and there may be price increases on the grain. This possible scenario may be better transited through flex-fuel plants due to choosing between two raw materials.

6.3. Suggestions for public policy

Although the current supply and transportation structure allows ethanol to be sold at all country's service stations, its consumption is concentrated near the central producing regions, which reach few Brazilian States [83].

After leaving the plant, ethanol generally follows two paths: direct transportation to the distributors and then from there to the resale stations; and road transportation to collection terminals located in the central producing regions, only to be then transported to the distributors who supply the consumer stations [84].

Given the concentration of production, most Brazilian States' great distance to the largest ethanol producers increases the product's transaction costs, causing ethanol's price at gas stations in several States to comfortably exceed 70% of gasoline price. This trend is made worse by the poor condition of the country's road transport infrastructure.

Thus, since the Midwest region is the most viable region for corn ethanol production, and there is no prospect of improvement in national transport conditions, supply and demand tend to remain concentrated. Therefore, the possibilities for a sustainable future for fuel ethanol will depend, among other things, on better and more significant public investment in transport conditions and forms, which include the expansion of pipeline networks.

6.4. Limitations and future research agenda

Despite the importance of analyzing the macro-environment and the relevance of the PESTEL tool to meet this challenge, it is understood that the integrated diagnosis of all organizational environments will increase the chances for decision making with greater confidence, whether for private or public agents. The macro-environmental analysis should be contrasted with the firms' analyses and the competitive environment of the fuel ethanol sector itself, where all players and their competitive dynamics will be identified and studied.

7. Final considerations

Through this research, it was possible to characterize, present the associative dynamics and the importance of the macro-environment as an influencing force in developing the corn ethanol sector in Brazil.

One can also gather the importance of constant monitoring and evaluation by the macro-environment stakeholders vis-a-vis the organizational strategy and the

competitive dynamics. In particular, in the renewable energy sector, such as corn ethanol, this continuous analysis will evaluate and even create potential opportunities and threats to its development.

Ultimately it is concluded that corn ethanol is a supplementary alternative over the long journey of efforts that renewable energies will have to embark on to contribute with sustainable development effectively. Despite the threats to the macro-environment, Brazil offers opportunities strategically taken by the ethanol sector.

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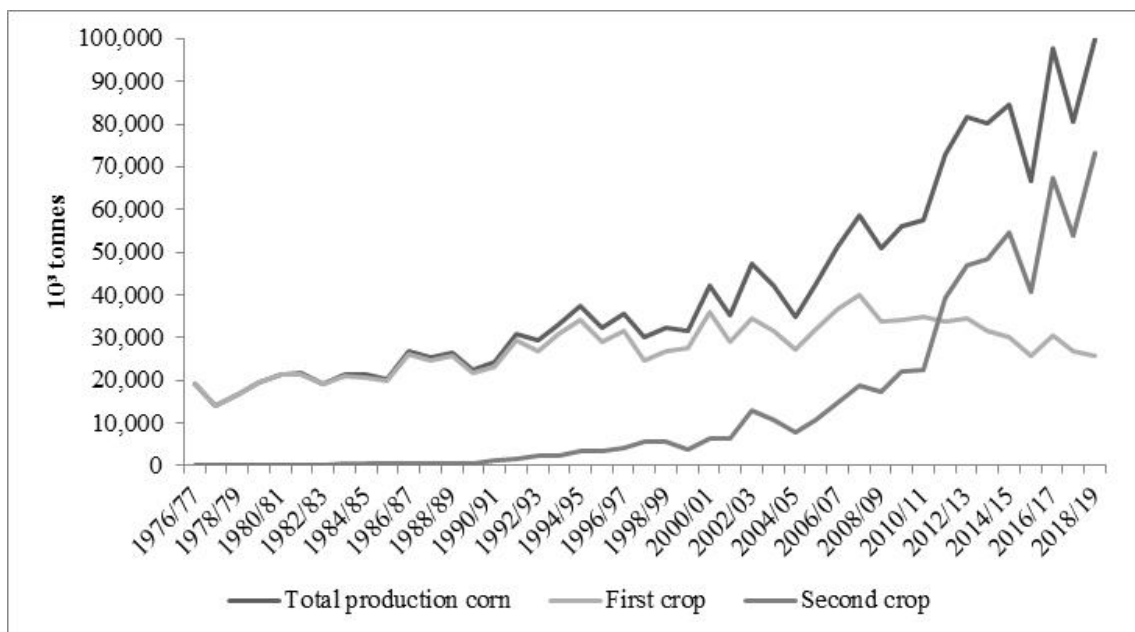
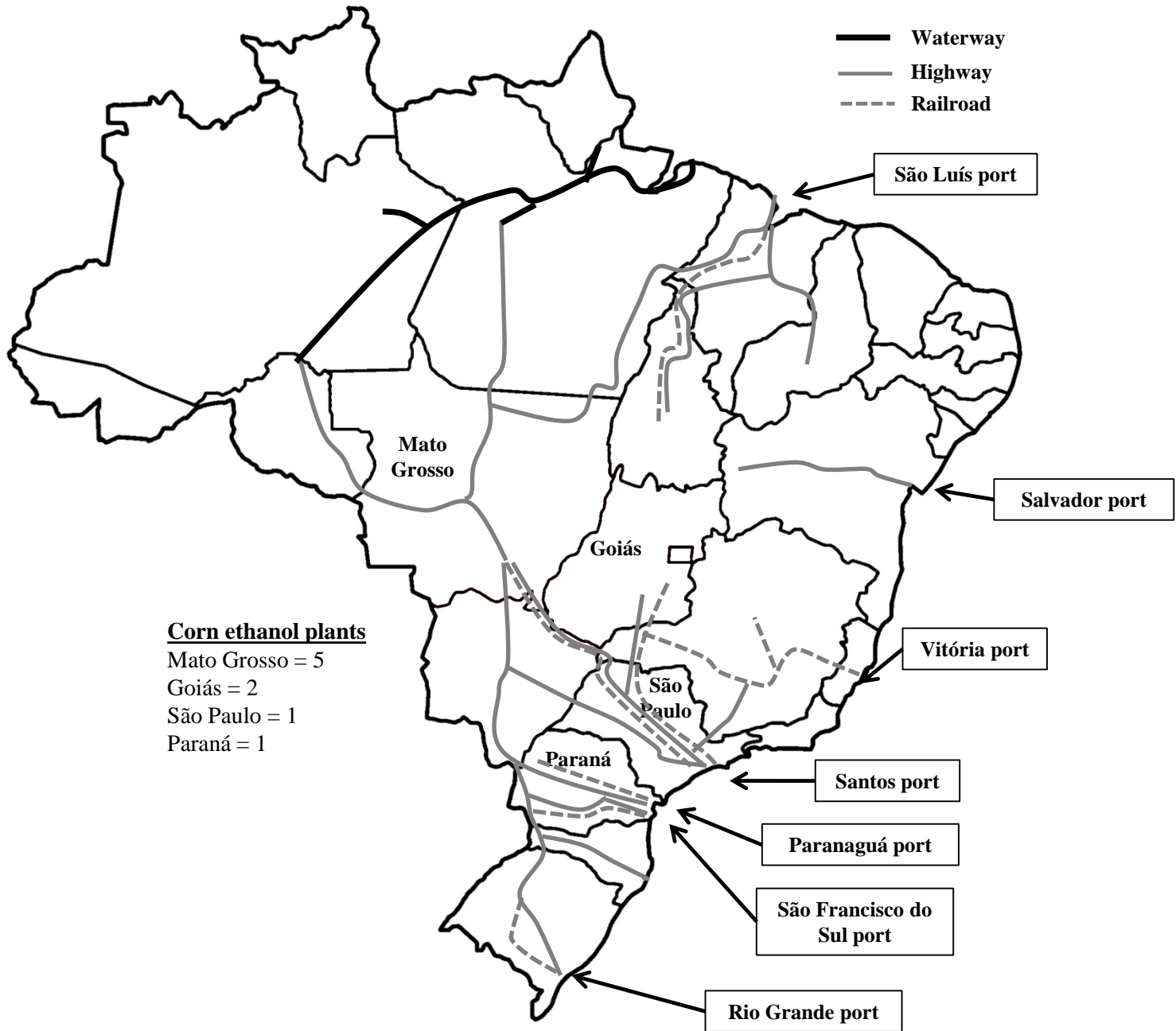


Fig. 1. Evolution of Brazilian corn production - 1st and 2nd crops

(Source: Based on data from Conab [22])



— Waterway
 — Highway
 - - - Railroad

São Luís port

Salvador port

Vitória port

Santos port

Paranaguá port

São Francisco do Sul port

Rio Grande port

Mato Grosso

Goiás

São Paulo

Paraná

Corn ethanol plants
 Mato Grosso = 5
 Goiás = 2
 São Paulo = 1
 Paraná = 1

CAPTION

Fig. 2. Transport logistics in Brazil and corn ethanol producing states

(Source: Based on data from Péra e Caixeta, 2018 [85])

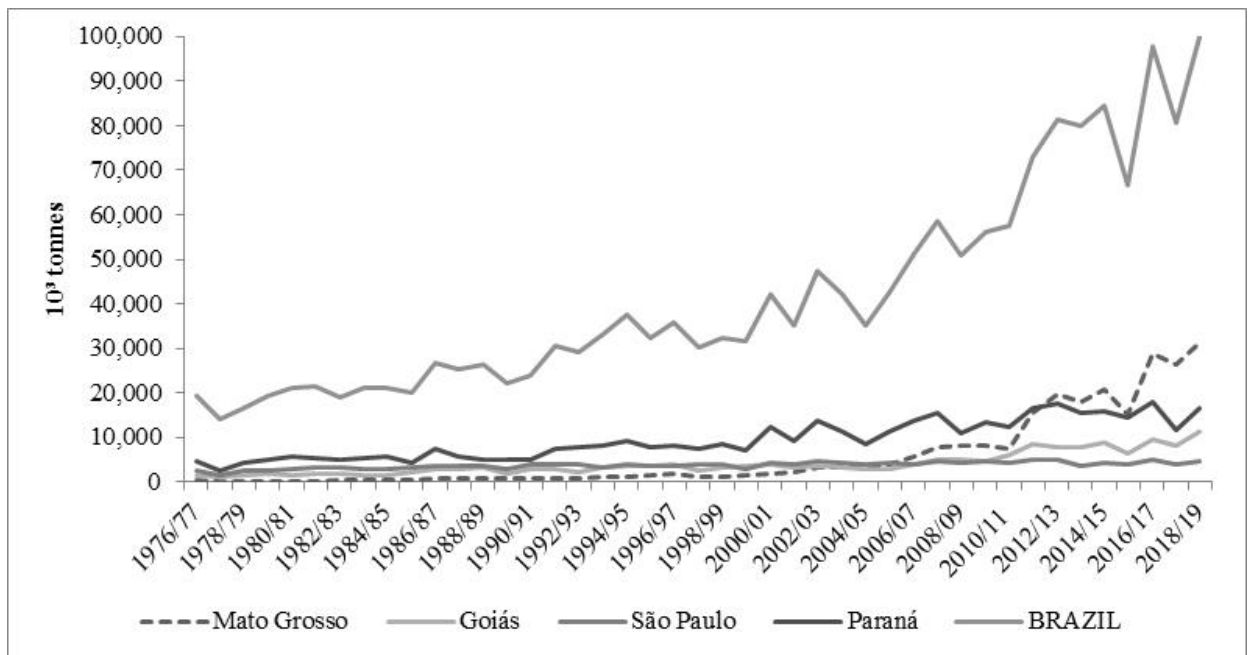
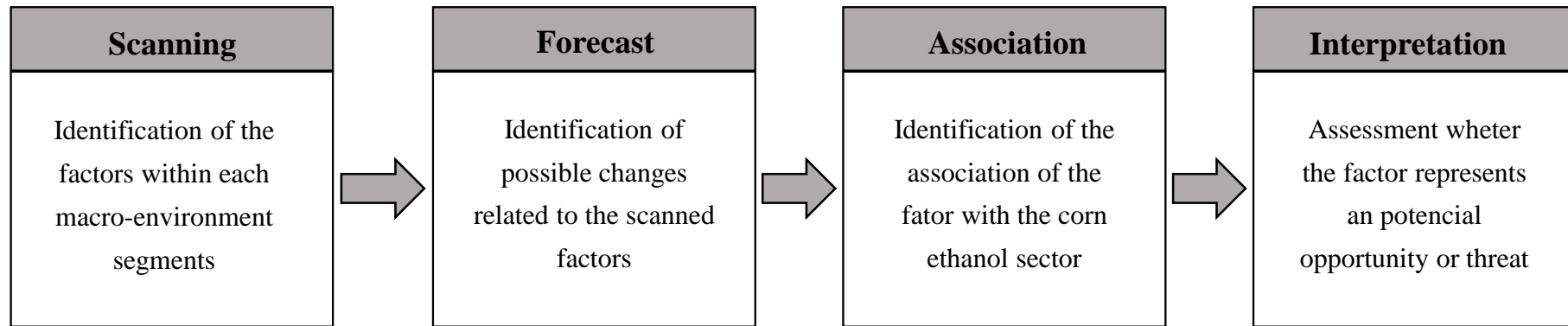


Fig. 3. Main corn ethanol producing states in Brazil

(Source: Based on data from Conab [22])



CAPTION:

Fig. 4. PESTEL analysis sequential stages

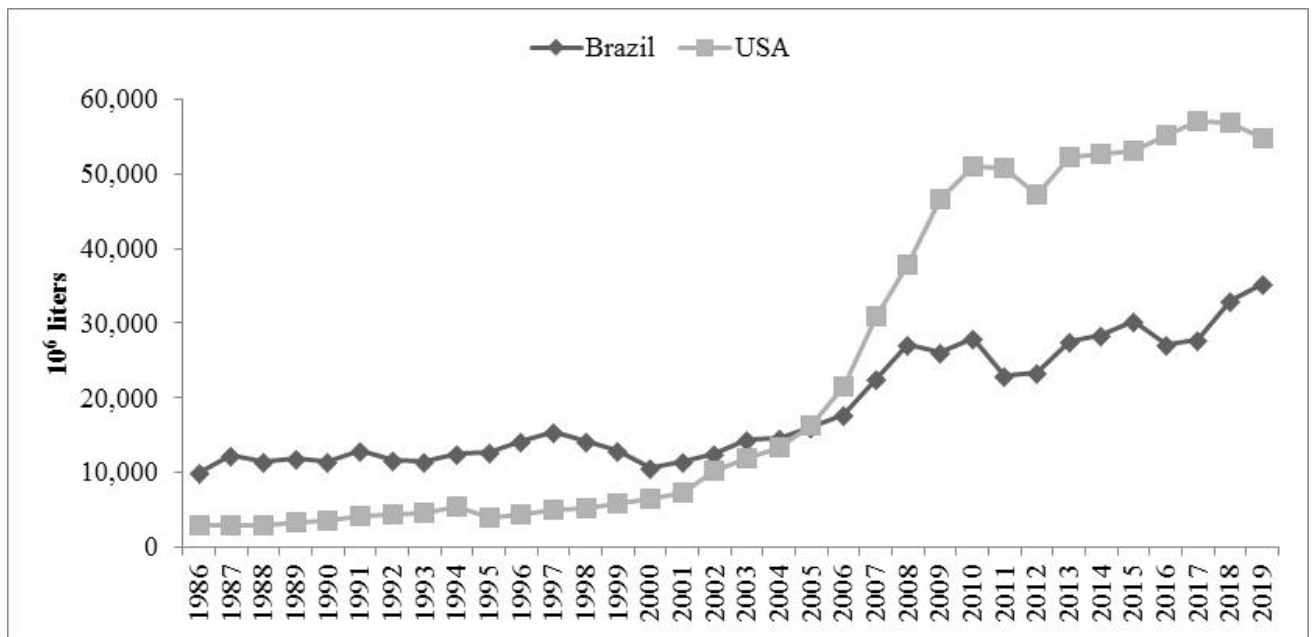


Fig. 5. Historical ethanol production in Brazil and United States

(Source: Based on data from Conab [22] and USDA [95])

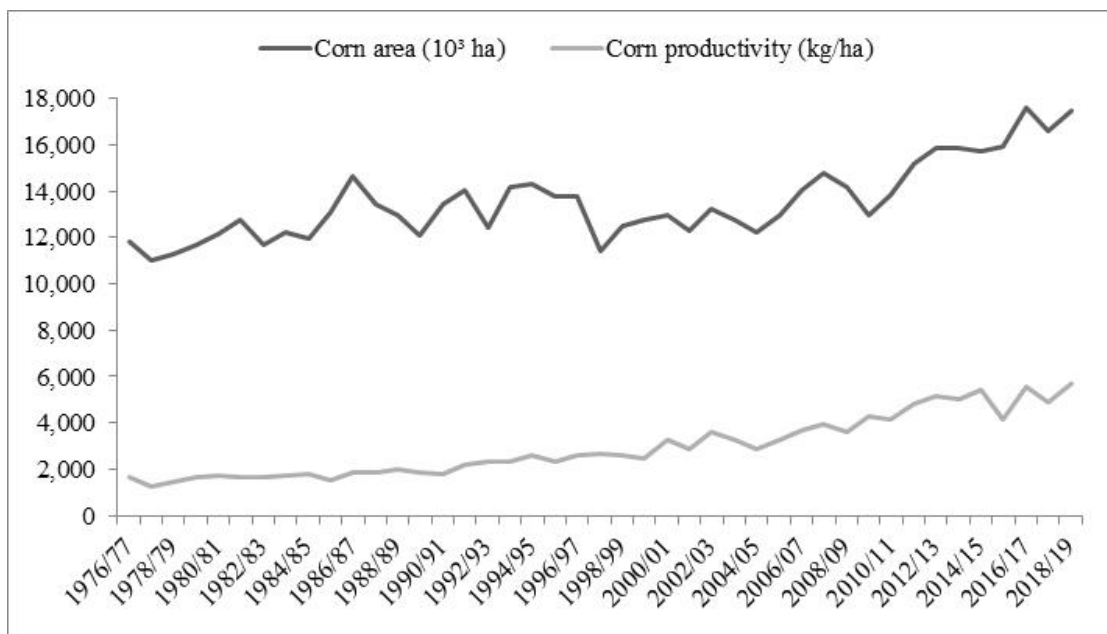
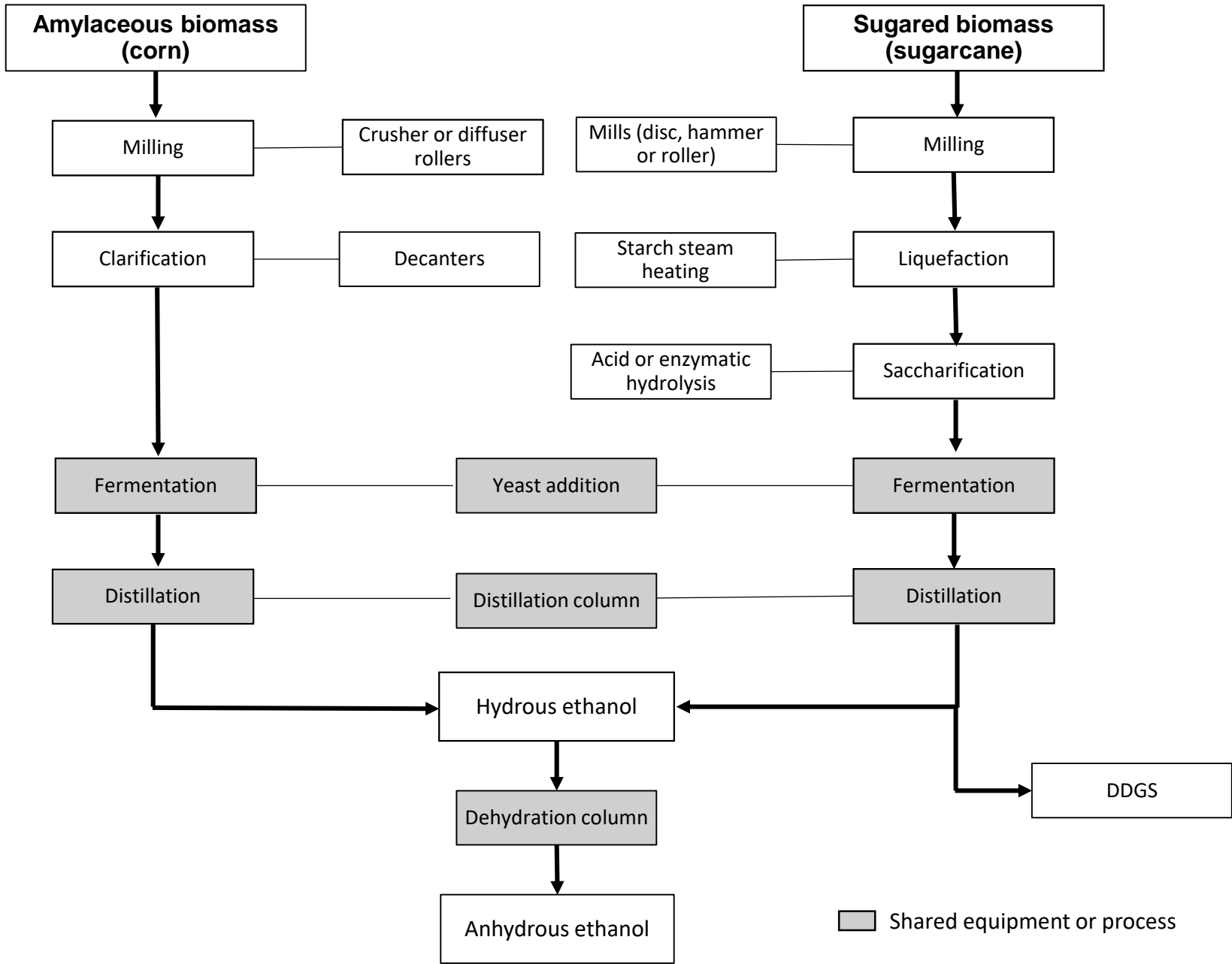


Fig. 6. Evolution of corn productivity and planted area

(Source: Based on data from Conab [22])



CAPTIONS

Fig. 7. Brazilian process of corn ethanol production

(Source: Copersucar,(2018 [90]; Bortoletto and Alcarde, 2019 [91])

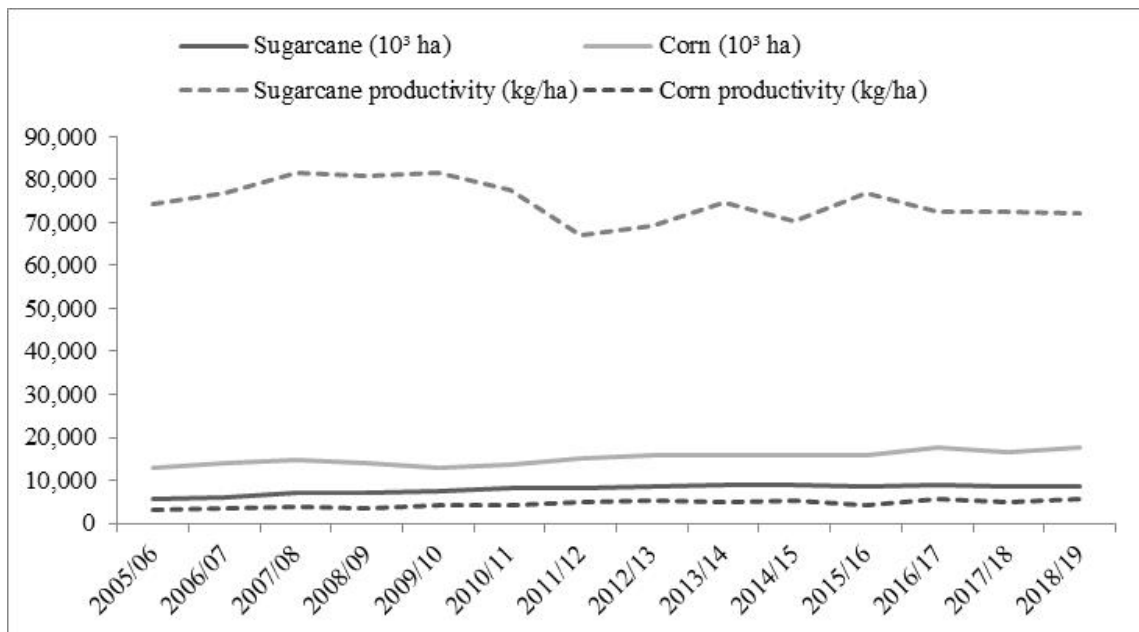


Fig. 8. Brazilian sugarcane and corn - Planted area and productivity

(Source: Based on data from Conab [22])

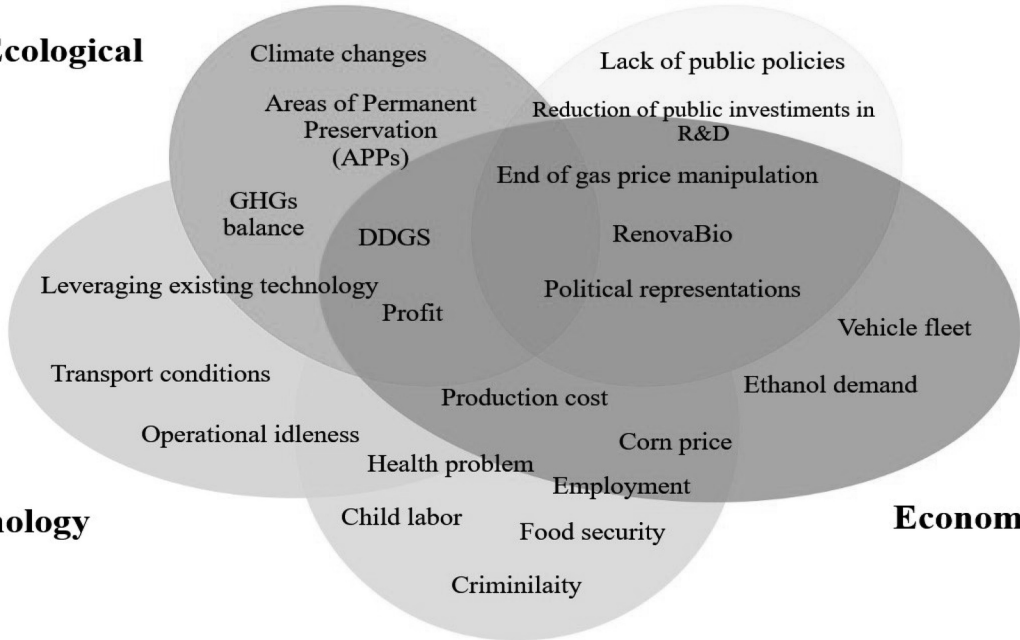
Political and Legal

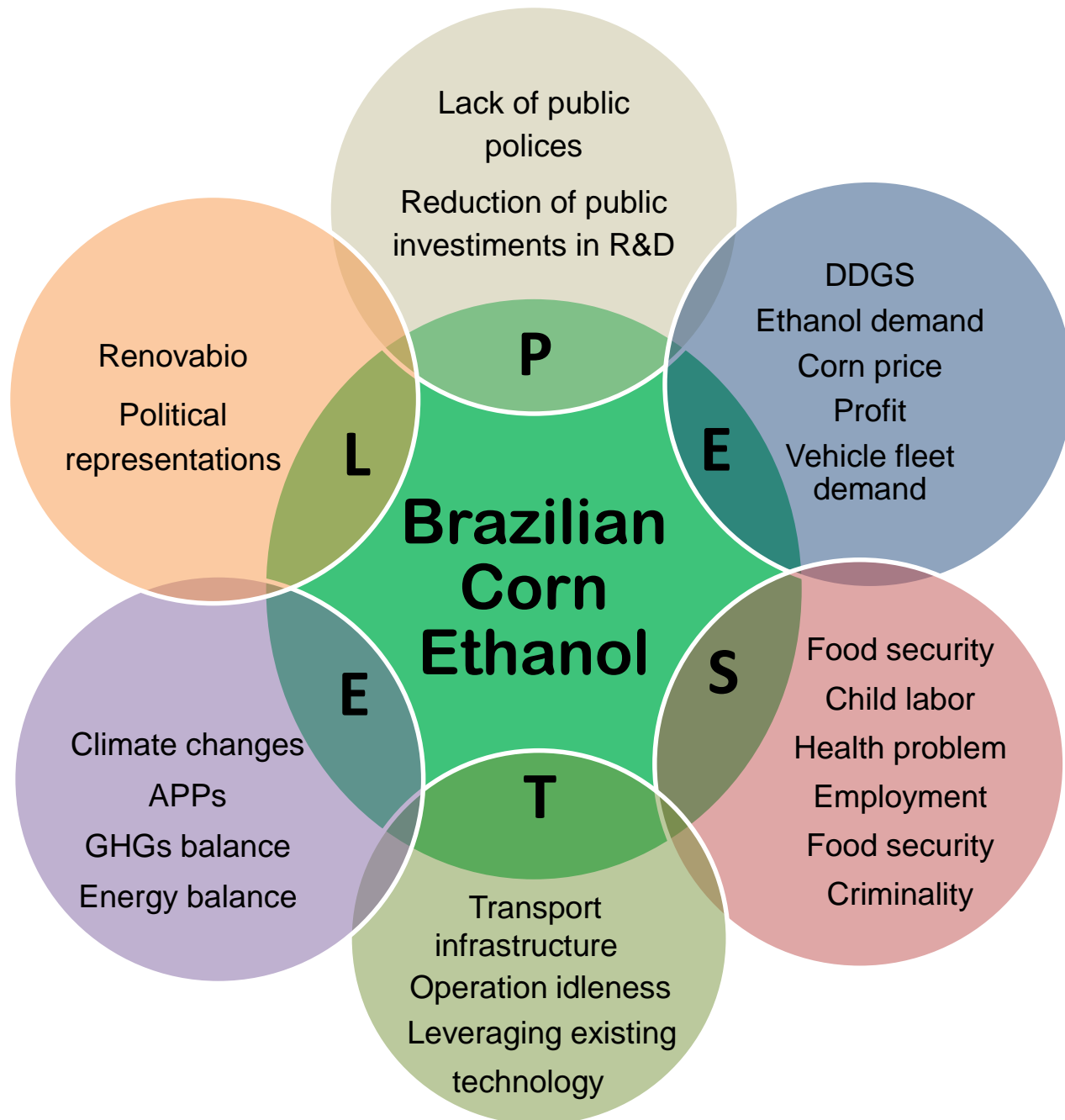
Ecological

Technology

Economic

Social





CAPTION

Graphical Abstract