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Review

Strategies to Ensure Fuel Security in Brazil Considering a Forecast of Ethanol Production

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Highlights:

- Sugarcane would not be enough to meet the ethanol targets set for Brazil
- Corn ethanol may be an attractive secondary feedstock to help supply the demand
- In Brazil, sugarcane ethanol has more advantages when compared to corn ethanol

Abstract: Ethanol production in Brazil started in the early 1930s due to laws created by the Brazilian government. However, ethanol production only increased significantly with the National Program of Ethanol implementation in 1975. This program was another action taken by the Brazilian government aiming to provide conditions for the development of the ethanol industry in the country. With the program, it was possible to achieve significant progress; however, it finished in the mid-1980s. Currently, ethanol is produced on a large scale by more than 300 sugarcane mills all over the country. In 2016, the Brazilian government provided another incentive for ethanol production by creating the RenovaBio Program, which aimed to reduce greenhouse gas emissions. Besides the environmental aspect, Brazil's ethanol industry needs to develop to supply future biofuel demand. According to the forecast provided in this paper, and considering technical, economic, and environmental aspects regarding the Brazilian ethanol industry, the current and only feedstock used is likely to be insufficient. Thus, the ethanol produced from corn would be an attractive secondary feedstock to complement sugarcane ethanol as the primary feedstock.

Keywords: ethanol production; Brazil; sugarcane; corn; forecast; greenhouse gas emissions

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1. Introduction

The Brazilian production of ethanol first became relevant in the early 1930s through decree no. 19717 on 20 February. According to this decree, adding anhydrous ethanol in the proportion of 5% of the gasoline became compulsory. In addition, it was compulsory that all vehicles belonging to public institutions run on ethanol or gasoline with 10% ethanol. Moreover, the cheaper freight for ethanol compared to that for gasoline transportation encouraged for ethanol production [1]. However, despite the beginning of its production in the early 1930s, it was only in 1975 that the Brazilian ethanol yield increased. The National Program of Ethanol was created in the same year through decree no. 76593 on 14 November [2–4]. This program fostered research on the development of ethanol and flex-fuel engines, which led to improvements in the expertise related to sugarcane cultivation and optimization of machinery and processes. These improvements resulted in ethanol production reaching 11.8 million cubic meters in the 1985/1986 harvest [5].

A few decades later, in the Brazilian harvest of 2017/2018, the ethanol yield was equal to 27,859 thousand cubic meters [6]. This volume of ethanol was provided by 342 sugarcane mills installed throughout the country [7–9]. It is essential to highlight that to produce such an amount of ethanol, Brazilian sugarcane mills used sugarcane mills exclusively [10]. However, in the last few years, some Brazilian facilities have started to use corn to produce ethanol. The corn ethanol yield began in 2012 in facilities located in Mato Grosso [11,12]. In 2018, the corn ethanol production in Brazil was 830 thousand cubic meters, representing a 58% increase compared to the volume produced in 2017 [13]. Such corn ethanol was produced by four facilities in Goiás and Mato Grosso states. In addition, two of these facilities are flex, which means they use corn and sugarcane to produce ethanol [13]. The increase observed in ethanol production in Brazil is impressive. In addition, there is considerable growth in the demand for this biofuel. The Brazilian ethanol market is expected to reach around 47.1 million cubic meters in 2028 [13]. It is crucial to meet this need; otherwise, it will be necessary to import fuel, increasing its price.

Concerns related to biofuel are not only due to the price to the final consumer. Ethanol plays a relevant role in reducing greenhouse gas emissions [14]. In 2017, the Brazilian government created RenovaBio, which aims to incentivise biofuel production to reduce carbon emissions, as agreed during the 21st Conference of the Parties (COP21) [12,15,16].

It is noteworthy that the capacity of companies to produce ethanol is very important. If biofuel producers fail to meet the demand, there might be negative impacts on both the economy and the Brazilian government's commitments. Therefore, it is necessary to study the ethanol market to identify if it will be possible to supply future demand. It is also important to provide alternatives to ensure the accomplishment of the main objective, which is to reach the volume of ethanol required for 2028. To verify whether the Brazilian facilities will meet future demand, it is essential to use the historical data on ethanol production in Brazil to provide a more reliable forecast [17]. The forecast based on these data aims to show if there is a trend for ethanol production in the future that might reach the volume of biofuel required for 2028. Besides the forecast, it is essential to include in the analysis economic, environmental, technical, and legal aspects [10,18,19]. Environmental aspects are relevant because even though the profitability of a business is crucial, a company must not harm the environment to increase its income. In addition, environmental factors may impact the economic aspects because they may influence, for example, the number of decarbonization credits (CBios) that the company may gain due to the RenovaBio Program [15,20,21]. Technical factors are significant because a technology that uses specific natural resources might be more efficient than another, for instance, in terms of productivity [18]. The economic aspects are significant because the better the economic performance of a company, the higher the chances of overcoming an economic crisis, or becoming more competitive among its competitors [22]. Understanding the legal element is crucial because it may show if there are laws that may benefit ethanol production.

In brief, this study aims to verify if sugarcane, which is the traditional feedstock used to produce ethanol, will be able to supply future ethanol demand. Another objective is to provide an alternative that may allow for increasing biofuel production and a more attractive strategy for supply. The strategy presented has economic, environmental, technical, and legal elements.

2. Methodology

The methodology of this paper consists of four aspects. Firstly, it was essential to analyze the current situation of sugarcane crops in Brazil because they are the main feedstock for Brazilian ethanol production. To do so, it was necessary to identify which regions cultivate sugarcane, what amount is produced, and what the leading state producers are. In addition, it was essential to identify what products are obtained from the sugarcane to analyze if there is competition between them. Another important aspect regarding the products derived from sugarcane was to analyze the trends regarding the amount produced of each product, and if some of these products should be given priority.

The second aspect was to identify alternative feedstocks for ethanol production and to select the most promising according to the Brazilian scenario. Regarding this alternative feedstock, it was important to analyze the amount produced in Brazil, its main uses, and in what regions it is produced. The third aspect required was comparing sugarcane and the alternative feedstock to produce ethanol in Brazil to verify the best source and, therefore, the feedstock to be considered the primary option.

The fourth aspect necessary was to evaluate if the main feedstock selected from the comparison done in the third aspect would be enough to supply ethanol demand in the future. To do this evaluation, it was necessary to collect historical data on Brazilian ethanol production. These data were input into Oracle© Crystal Ball software. In the software, it was necessary to use the Predictor tool, provide data attributes, select forecasting methods, and choose the error method to rank them.

The historical data were classified in years, since they had ethanol production for each year. In addition, the seasonality option was selected for AutoDetect even though there is no seasonality influencing the data because no constant seasonal aspects increase or decrease sugarcane production. In the option events, three events were included: the end of the ProAlcool program in 1985, the beginning of Flex Fuel cars in 2003, and the RenovaBio program in 2016 [5,23]. These events were included because they influenced Brazilian ethanol production or had the potential to influence it for many years.

Regarding forecasting methods, nonseasonal methods and Arima were assessed to choose the best method. The Mean Absolute Percent Error (MAPE) and Theils' U were used to choose which methods were best, and the standard forecasting technique was used because it was assumed every datum had the same relevance.

3. Theory

3.1. Sugarcane Crops in Brazil

Currently, there are plantations of sugarcane all over Brazil; however, the most significant crops are concentrated in the northeast, southeast, and central-west regions. Regarding the leading producers, in the 2018/2019 harvest, the leading state producers in the northeast were Pernambuco and Alagoas. In the central-west, Goiás was the leader in production, and in the southeast, where the most extensive national production is located, São Paulo state had the most significant production, followed by the state of Minas Gerais [24].

Regarding sugarcane production, in the 2018/2019 harvest, the amount of sugarcane produced was 625,963 thousand tons, representing a 1.2% decrease compared to the previous harvest [25]. To understand the reasons for this decrease, it is vital to analyze the factors influencing the production, i.e., productivity and harvested area.

In the sugarcane area harvested in 2018/2019, there was a reduction of 1.3% compared to the harvest in 2017/2018. This was the second decrease in a row considering the area cultivated. Moreover, this situation has been occurring since the 2016/2017 harvest, and it is due to a number of factors [25]. First, there has been a shortage cultivation area. The expansion of a specific crop depends on the willingness of farmers [24], and to decide a crops' expansion it is necessary to choose between two different crops [26]. Such a decision is complicated because it involves risks and costs. Specifically, for sugarcane, the investments and costs related to producing this plant are 2.5 higher than those required to produce soybean [26].

Secondly, in some regions, contracts between sugarcane mills and farmers were not renewed due to the significant distance between the farms and processing areas, or the low profitability of these contracts. Difficulties in using machines to harvest sugarcane are another reason to end contracts [25]. Moreover, a risk related to these contracts is the non-payment or delay in the payment to farmers [27,28]. Another reason for the decrease in the area of sugarcane harvested in Brazil is the necessity to renew the crops, with more areas for new seeds [25]. Financial issues also have motivated the decrease in the sugarcane cultivation area [29]. Many factors have contributed to worsening these issues, such as lack of rain, governmental policies to control gasoline prices, low sugar prices, the necessity for imported products, and an increase in the dollar exchange rate.

The average productivity for sugarcane crops all over Brazil in the 2018/2019 harvest was 72,671 kg per hectare. This value is similar that for harvests in 2016/2017 and 2017/2018. However, even this might seem satisfactory, since there was no reduction in the last three harvests, current productivity is lower than it was in the past. For instance, in the 2009/2010 harvest in São Paulo state, the leading state producer in Brazil, the average productivity reached almost 90,000 kg per hectare, but in the 2018/2019 harvest, the productivity was around 76,000 kg per hectare. Such a decrease from the 2009/2010 harvest to the 2018/2019 harvest almost happened in other states. For example, in Paraná, the decrease was 19,000 kg per hectare, and in Alagoas the difference was even higher at 26,000 kg per hectare [25]. Among the reasons for the reduction in productivity are lack of investment, low renewal of crops, and rainfall reduction [30].

In Brazil, there is a link between the economic situation and the decrease in sugarcane production. First, an economic situation in which there was an increased level of indebtedness and negative income of sugarcane mills, associated with the preference of the Brazilian banks for higher liquidity and more strict rules for borrowing financial resources, led to little chance of obtaining credit. When the sugarcane mills had fewer chances of financing their crops, farmers chose to reduce the expansion rate and not to renew or invest in the plantations. These factors contributed to a decrease in productivity and production [11,15,31]. Furthermore, climate change badly affected sugarcane crops, and a decrease in rainfall may have led to less production of sugarcane [30].

3.2. Products Manufactured from Sugarcane

The main products obtained from sugarcane processing are ethanol and sugar [15,32,33]. Figure 1 shows a simplified diagram outlining production of both products.

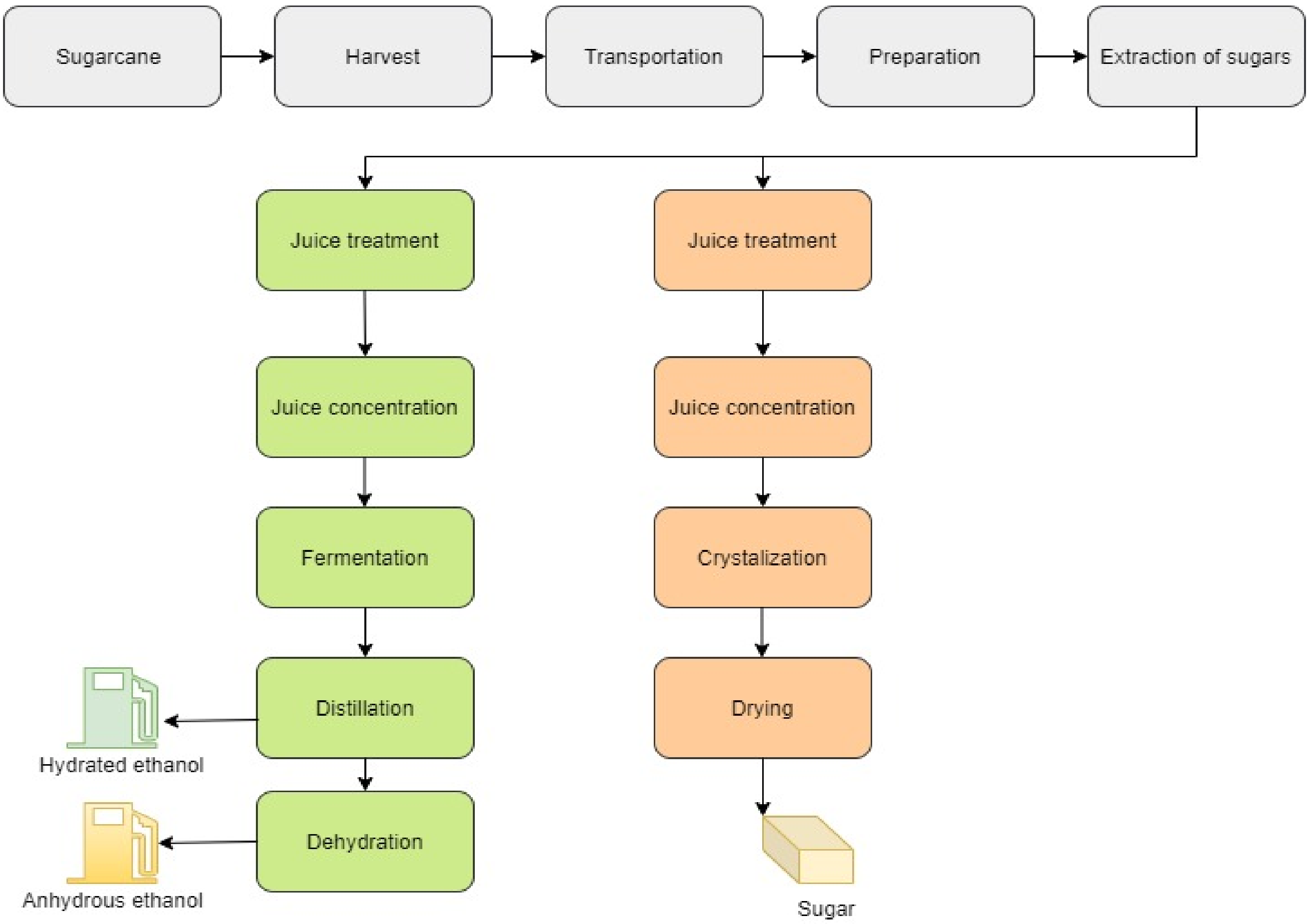

Figure 1. Production of ethanol and sugar from sugarcane.

According to Figure 1, to obtain sugar and ethanol, some stages are shared, and companies must choose between sugar and ethanol since both are derived from the juice recovered from the sugarcane. This is interesting because it indicates competition between ethanol and sugar production, and the decision is made according to economic factors, such as market value [34].

In the 2013/2014 harvest, the amount of sugarcane used to produce sugar and ethanol was almost the same. However, this proportion has been changing over the years, and in the 2018/2019 harvest, the proportion was almost 40% to produce sugar and 60% to produce ethanol. It is expected that in the 2023/2024 harvest, less than 40% of Brazil's sugarcane will be used to produce sugar [35–37]. This is based on reducing sugar prices due to the surplus of this product in the world market.

3.3. Sugar-Related Health Risks

Sugar consumption in excess may lead to higher cancer risk because it causes insulin-glucose dysregulation, oxidative stress, inflammation, and body adiposity. It is necessary to advise the population to reduce sugar consumption because it may lead to obesity and affect cardiometabolic health, which are some of the factors that increase the risk of cancer [38]. Furthermore, there is an association between sucrose intake and consumption of products such as sweet buns and cookies, leading to a higher risk of endometrial cancer [39].

Considering the potential risk of cancer due to the consumption of sugar in excess, some regulations have been created to decrease sugar consumption. For example, in Brazil, some policies aim to promote restrictions on the sale of sugar-sweetened beverages (SSB) in schools [40]. This restriction considers not only that SSB damages children's health but also because children may adopt the habit of eating unhealthy food [41]. Another restriction is related to advertisements or promotion of unhealthy food. Companies must not take advantage of children's innocence to increase sales of these products, and must not stimulate negative habits such as consuming such unhealthy products [40].

Besides Brazil, 13 other countries in Latin America have adopted policies to reduce sugar consumption. Other Latin American countries follow the same policies used in Brazil, but they also apply SSB taxes [40,42,43]. The taxation on SSB is also present in other countries such as Finland, France, Hungary, Latvia, Fiji, Nauru, Samoa, and French Polynesia [44,45]. Another aspect interesting about these initiatives is their effectiveness. The taxation on SSB may be helpful to improve public health due to less consumption of SSB, and the population may tend to drink healthier beverages such as fruit juice [46]. In addition, the income from SSB taxes may be used for the benefit of the population, for instance, to improve the health sector [47].

3.4. Legal Aspects Related to Sugarcane Production

Sugarcane production in Brazil might be negatively affected because of legal factors, especially those related to its harvest. Currently, Brazil has two ways of harvesting sugarcane: the manual and the mechanical method [48–50]. The main difference between these methods is that manual harvesting requires burning because there is the risk of cutting workers that are responsible for cutting the plant [51]. In addition, there are several negative consequences related to burning, for example, greenhouse gas emissions, flora and fauna affected by the high temperatures and smoke, and sugar loss [52–54].

Considering the issues caused by burning sugarcane crops, law no. 11241, established on 19 September 2002, was created to prohibit this practice [55,56]. According to this law, in areas where it is possible to use machines, it will be illegal to burn sugarcane crops after 2021 [28,57,58]. In addition, in regions where mechanical harvest is not possible due to topography, it will be prohibited to burn sugarcane crops after 2031 [58,59].

Analyzing the prohibition terms of São Paulo state law, it is interesting to identify the percentage of areas using the mechanical method and the manual one. In crops, in the central-south region, only a small percentage of crops still involve manual harvesting. On the other hand, in Brazil's north and northeast regions, the percentage of farms using manual harvesting is significant at around 80%. In addition, since the 2014/2015 harvest, the percentage of manual harvesting has not changed considerably [25].

Two reasons for the slow reduction in manual harvesting in the north and northeast regions are the topography and the availability of workers. Due to the uneven surface, the topography makes it difficult to use machines in the sugarcane crops. Furthermore, it is essential to highlight that prior burning is not compulsory. Therefore, not every area that uses manual harvesting burns the crops. However, few workers accept harvesting a crop that is not burned, it is more difficult to harvest the sugarcane when it is not previously burned, which leads to more incidences of prior burning in areas with manual harvesting [28,57,58].

Nineteen years have elapsed since the law that prohibits burning in sugarcane harvesting until 2021 was passed, and more than 70% of the producers in the north and northeast do not use mechanical harvesting. This may mean that most producers will not have changed to mechanical harvesting by the end of 2030, mainly because in most of these regions, it would be necessary to change the local topography. Even though the law mentioned is only for cities in São Paulo, it shows that producers in the north and northeast are not concerned about following trends that lead to change in this practice. In addition, it is likely that environmental laws have become more strict in terms of sustainability and therefore affect some sugarcane crops that still use the burning method in the harvest [60].

As mentioned, greenhouse gas emissions are an important issue related to sugarcane burning. The emission avoided using mechanical harvest is 1223.6 kg CO_2eq ha^{-1} yr^{-1} [61]. In addition, the Brazilian government signed an agreement during COP21 to reduce its emissions to 43%, based on the levels measured in 2005, by 2030 [62,63]. Two possible consequences of such a scenario may be the creation of federal laws to prohibit sugarcane crop burning, to fine producers that use this practice, or to award lesser gains from selling decarbonization credits (CBios) in the stock market. Therefore, producers may have less profitability due to the payment of fines or because they can sell fewer CBios. In the worst-case scenario, in which a federal law is created, they will not be allowed to burn the sugarcane. This situation may lead to the acquisition of expensive machines and consequently increase the sugarcane production costs. A possible outcome of this is that sugarcane producers facing difficulties may resort to other agricultural activities. This change is not attractive to the ethanol market in Brazil because the north and northeast produced almost 2 billion liters of ethanol in the 2018/2019 harvest. Even though the main producing region is the central-south area, with 28.5 billion liters in the same harvest, the north and northeast regions would undoubtedly contribute to achieving future demands [25].

3.5. Alternative Feedstocks to Produce Ethanol

Considering the abovementioned issues related to sugarcane production and its negative impact on the ethanol market, it is essential to consider another alternative, for example, corn ethanol. Furthermore, since bioethanol is an exciting alternative to fossil fuels, it is essential to have more feedstock options to supply the demand [32,64]. Adding another source for ethanol production may increase the fuel's relevance and create a more stable ethanol market [65].

It is important to understand that around the world there are other sources besides corn that are used to produce ethanol; for example beet pulp, sweet sorghum, wheat, cassava, and lignocellulosic biomass [65–67]. Even though there are other sources used to produce ethanol in other countries, in this article the suggested second feedstock to produce ethanol in Brazil is corn because corn is the second most important crop considering the area harvested, and Brazil is one of the main players in the corn world market [11,68,69]. In addition, Brazil has advanced technology in agriculture, which has resulted in Brazil achieving an almost 50% average gain of productivity in grains [11].

3.6. Brazilian Corn Market

The corn crop in Brazil has a unique characteristic that differs from the corn crops in other locations. Usually, corn producers grow only one crop a year; however, in Brazil, farmers can grow two [70–72]. The first crop, which is also called the summer crop, starts with planting between September and December, and is harvested between January and April. Most of the first crop production is to supply the domestic market. The second crop, or winter crop, started in the 1980s, is planted between January and March and harvested between May and August. The winter crop mainly supplies the international market [73].

In Brazil, corn crops are grown all over the country; however, higher production levels are found in the central-south region. The leading producer is Mato Grosso state, with 26.1 million tons of corn harvested in 2017/2018. The second-largest producer in the same harvest was Paraná state, with 13.5 tons. Considering national corn production, in the 2017/2018 harvest, 85 million tons were produced. Such production resulted from an area planted of 16.67 thousand hectares. These values represent the summer and winter crops [74].

Corn is crucial for Brazil because the country is one of the largest corn consumers in the world. Most of this production is used for feed purposes, mainly because in recent years the population’s income has been rising; therefore, there has been a growing domestic demand for meat, such as swine and broiler meat [11,68,69]. Due to the demand for corn for animal feed, the first crop is destined for animal feed and second crop is mostly for exportation [11,68,69].

Part of the total corn production can be stored. For example, in the corn harvest mentioned previously, 12.7% was stored. The amount of corn stock varies from harvest to harvest. For instance, in the 2014/2015 harvest, the stocks reached 17.2 million tons, and in the 2015/2016 harvest, only around 6.8 million tons were stored [75]. Stocks are created because production exceeds the demand for corn.

Regarding storage, related costs and commodity prices, are important. Maintaining stocks requires insurance, taxes, and the opportunity cost of the capital invested in maintaining the product stocked [76]. Furthermore, when producers choose to keep their products in stock, aiming to sell them in the future, they are taking the risk of price variation making it difficult to know whether storage is economically viable [77]. Besides the risk related to price, farmers also face other risks such as weather conditions and plagues [78,79]. Another critical aspect is transportation. Even though there have been tremendous technological improvements in Brazilian agriculture, the country faces issues with logistics, which is a limitation for this business [80].

Considering the risks of losing money due to the price variations of corn and the costs of maintaining stock, it would be interesting for farmers to have an application for the corn stored. Therefore, an attractive product to be produced from corn might be ethanol. In addition, from corn processing to obtain ethanol, there are by-products such as Distillers Grains (DGS) with soluble compounds that are sources of proteins and fat [81]. DGS can be used for cattle feed and have advantages such as low cost compared to other sources of protein and fat, and this product can be produced without affecting human food production [82–84].

On aspect of DGS in cattle feed is the positive results of adding this product to the animals’ diet [85–87]. For example, a study that included DGS in Holstein cows’ diet found an increase in milk yield [88]. However another study concluded that the inclusion of DDGS did not influence milk yield or the milk composition [89]. It is possible that farmers can increase their profit by selling ethanol and DGS as cattle feed.

Another possibility for corn farmers is to produce ethanol [90,91]. This is interesting because the ethanol market in Brazil will benefit from the RenovaBio Program [19,84,92]. The RenovaBio Program was created in 2016 to incentivize biofuel production by 2030 [19,84,92,93]. In addition, this program aims to provide more stability for the biofuels market and to attain the commitments agreed upon at COP21 (21st Conference of the Parties) [94]. From this program, biofuel producers will receive a document corresponding to a certain amount of CBios based on their efficiency in biofuel production [19,84,92]. These CBios can be sold on the stock market, and be another source of income for farmers [15,16,62]. This is an interesting opportunity for farmers to explore because due to incentives to reduce carbon emissions, the biofuels market has the potential for significant development and to receive investments [95].

An interesting measure that can be taken to improve net energy balance and reduce greenhouse gas emissions in corn ethanol plants is the cogeneration of electricity [96]. The biomass obtained after ethanol production, such as the corn stover and DGS, can be used to generate electricity, which may reduce the use of coal and lead to less greenhouse gas emissions [97].

The production of corn ethanol is still in the beginning phases. Currently, there are five plants in operation, and another six are still projects in the final stages of conclusion [92]. Some facilities can produce ethanol using more than one feedstock, such as sugarcane and corn.

4. Results and Discussion

4.1. Corn and Sugarcane Ethanol

With the possibility to produce ethanol from two different feedstocks, it is crucial to evaluate which feedstock has more advantages. Table 1 compares corn and sugarcane ethanol, considering technical, economic, and environmental factors.

Table 1. Comparison between corn and sugarcane as feedstock for ethanol production.

Factors	Corn	Sugarcane
Cost per liter (USD 1.00 equal to R$5.00)	Between R$0.97 and R$1.84 (hydrated ethanol) [93].	R$1.80 for anhydrous ethanol and R$1.71 for hydrated ethanol [98].
Stock	Possible to stock for several weeks [99].	Must be processed immediately after the harvest [99].
Fermentation time	45 to 60 h [100].	6 to 12 h [100].
Productivity (liters per ton of feedstock)	400 L of ethanol per ton of corn [95].	70 to 85 L of ethanol per ton of sugarcane [95].
Productivity (tons of feedstock per hectare)	5.5 tons per hectare [74].	77 tons per hectare [101].
Volume of pesticides	7.4 L per hectare [102].	4.8 L per hectare [102].
Volume of water	2570 L per hectare [103,104].	2516 L per hectare [103,104].
GHG emission	15 to 20 g equivalent of CO_2/MJ [99].	20 g equivalent of CO_2/MJ [22].
Plant working days	345 days per year [99].	Between 200 and 240 days per year [95].
By-product	DGS [101].	Vinasse [36,105,106].

Analyzing the comparison presented in Table 1, corn seems more attractive in certain aspects, while sugarcane has an advantage in others. Regarding the cost per liter, corn ethanol has a related cost varying from R$0.97 to R$1.84. A cost of R$0.97 is considered the best-case scenario [93]. When analyzing the period each feedstock can be stored, there is considerable dissimilarity; corn can be stored for several weeks, whereas sugarcane cannot. The reason is that after the sugarcane is harvested, there is a loss of recoverable sugar triggered by microorganisms [107].

Regarding fermentation time, it is clear that sugarcane has an advantage. The faster fermentation when using sugarcane as feedstock is due to the higher cell concentration [99]. Another reason is that it uses yeast to recycle cells, whereas corn fermentation does not occur because of a higher concentration of solids [108,109]. A faster fermentation process may result in more effective production, fewer costs, and more ethanol production in less time.

Considering the amount of ethanol that can be produced from a ton of feedstock, there is a considerable difference between corn and sugarcane, with corn having the advantage [11]. For example, one ton of corn produces almost five times more liters of ethanol than one ton of sugarcane. However, when analyzing the quantity of feedstock produced per hectare, sugarcane seems much more promising. Furthermore, considering both productivities, sugarcane ethanol has an environmental advantage because it can produce more ethanol per hectare. This is relevant due to issues related to food security and competition for agricultural land [110].

Another aspect compared was the volume of pesticides used in corn and sugarcane crops. In this aspect, sugarcane crops have a slight advantage [31]. Such a factor is essential because pesticides are associated with serious human health issues and are harmful to the environment [111].

Regarding the volume of water required for each crop and the greenhouse gas emissions to produce ethanol, there is no considerable advantage between the feedstocks analyzed. On the other hand, regarding the number of days a facility can work using both feedstocks, there is a noteworthy difference. A facility using corn can work more days during the year. The reason is that corn can be stocked, as mentioned previously [99].

The last factor used to compare both feedstocks was the by-product obtained after the process to produce ethanol. Although the DGS from corn can be sold as cattle food, for sugarcane the by-product is vinasse. There are many possibilities for the reuse of vinasse to reduce its environmental impact [112]. One of the most common applications of vinasse is for fertigation, due to its levels of nutrients [113–115]. The use of vinasse in fertigation is interesting because it is a cheap source of nutrients for the soil [113,116]. Another use for the vinasse is to generate electricity. This can be done through the anaerobic digestion of vinasse, which results in biogas that can be used to generate electricity [117,118].

4.2. Forecast

To predict future ethanol production, it was necessary to use historical data. The data collected were from 1981 to 2019, as shown in Figure 2. To predict ethanol production for 2028, Oracle© Crystal Ball software was used.

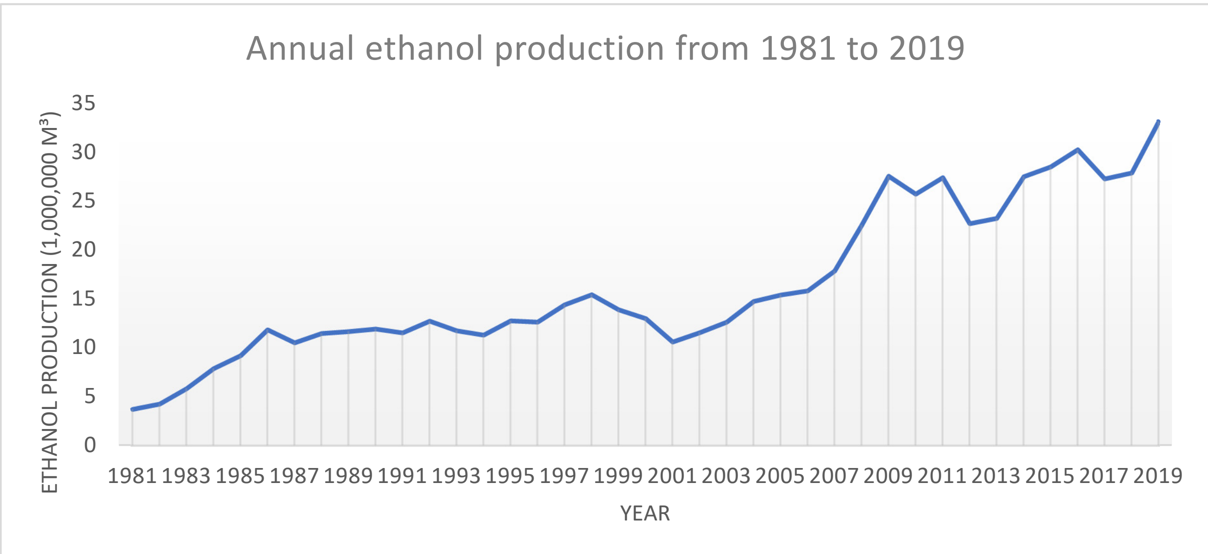

Figure 2. Annual ethanol production in Brazil from 1981 to 2019 [119].

After running the software with historical data and parameters set, predictions for ethanol production for the next 12 years were obtained for each forecasting method. To analyze these methods and choose the best model, two statistical parameters provided by the software, the Mean Absolute Percentage Error (MAPE) and Theil's U. The parameters obtained for the forecasting methods analyzed are shown in Table 2.

Table 2. Evaluation of each forecasting method considering different statistical parameters.

Forecasting Method	**Mean Absolute Percentage Error (MAPE)**	**Theil's U**
Double Exponential Smoothing	9.31%	0.9514
Damped Trend Non-Seasonal	9.32%	0.9514
ARIMA (0,1,0)	9.03%	0.8722
Single Moving Average	9.87%	1
Single Exponential Smoothing	9.87%	1.05
Double Moving Average	10.84%	1.05

To determine which method provided the best result, it was crucial to analyze the statistical parameters and compare them to ideal values for each parameter. For the Mean Absolute Percentage Error (MAPE), achieving values under 10% was necessary to validate the forecast [120]. Thus, the only unsatisfactory model, according to MAPE, was the Double Moving Average model. Considering Theil's U, values less than 1 indicate that the forecast is better than guessing [121]. Applying Theils' U, there were three models with values under 1: the Double Exponential Smoothing method, the Damped Trend Non-Seasonal method, and ARIMA (0,1,0). Therefore, only these three forecasting methods are valid, and the forecast for ethanol production for each method is provided in Table 3.

Table 3. Ethanol production forecast provided using Arima (0,1,0), Double Exponential Smoothing, and Damped Trend Nonseasonal methods.

Year	**Arima (0,1,0) (1000 m^3)**	**Damped Trend Nonseasonal (1000 m^3)**	**Double Exponential Smoothing (1000 m^3)**
2020	34,639	34,017	34,021
2021	36,231	34,936	34,945
2022	37,879	35,854	35,869
2023	39,586	36,771	36,793
2024	41,351	37,687	37,717
2025	43,177	38,602	38,641
2026	45,065	39,516	39,565
2027	47,016	40,429	40,489
2028	49,033	41,342	41,413
2029	51,116	42,253	42,336
2030	53,267	43,164	43,260
2031	55,489	44,073	44,184

According to Table 3, the forecast provided by the Arima (0,1,0) method indicates that if the sugarcane mills in Brazil keep their current output, it will be possible to achieve the volume of ethanol demanded in 2028. In addition, Arima (0,1,0) shows that Brazilian ethanol production will exceed demand by 2 billion liters. On the other hand, the Double Exponential Smoothing and Damped Trend Nonseasonal methods suggest that considering historical data of ethanol production, it will not be possible to supply biofuel demand by 2028. Moreover, these two methods show that not even by 2031 would the country be able to produce 47.1 million cubic meters.

Because Arima (0,1,0) had the best results for the statistical parameters, this method provides the most accurate forecast. However, Arima (0,1,0) suggests that in 2028 the production will surpass the demand by only 2 billion liters, which is not a significant difference because it is only 4% above the volume required.

Furthermore, the forecast took into account ethanol production from 1981 to 2019 to verify the forecasting method's accuracy. The reason is that there is actual data for ethanol production in 2020 of 35,677 million cubic meters. Thirty-four million cubic meters were obtained from sugarcane and 1677 million cubic meters from corn [119]. Therefore, the forecast was accurate concerning sugarcane ethanol production in 2020. However, in the comparison between the results of the forecast methods to the actual ethanol production in 2020, it is noteworthy that there was no significant difference. Therefore, it is necessary to increase ethanol production in Brazil because there is no reasonable chances that it will meet future demand.

5. Conclusions

Regarding the Brazilian ethanol market, there is a well-consolidated sector with great potential and demand. This sector has received many incentives from the Brazilian government. In the beginning, most of the incentives were provided by the government to reduce dependency on fossil fuels. However, the motive for the incentives has recently changed, and the government understands that the ethanol industry can help the country reduce its greenhouse gas emissions. Carbon emissions are an important aspect because they are directly related to the commitment of the Brazilian government during COP21. The ethanol industry also plays a relevant role in fuel security. Therefore, it is essential to understand future demand and if current production methods are sufficient to supply this demand.

According to our forecast ethanol production from sugarcane alone cannot supply the demand for biofuel. Three forecasting methods were used, Arima (0,1,0), Double Exponential Smoothing, and the Damped Trend Non-Seasonal method. Arima (0,1,0) indicated that the sugarcane mills must maintain current production practices to produce 47.1 million cubic meters of ethanol in 2028. However, this method suggests that sugarcane mills will surpass the demand by only 4%. Thus, it would be advantageous to increase production to ensure achieving the objective.

The forecast obtained using the Double Exponential Smoothing and Damped Trend Nonseasonal methods suggests that the production observed from 1981 until 2019 will not be enough to supply the demand in 2028. Moreover, these methods indicate that Brazilian ethanol production will not reach 47.1 million cubic meters even by 2031,. Therefore, in 2028, it will be necessary to import

These methods indicate that importing around 6 million cubic meters would be necessary. The unfortunate thing about importing biofuel is that it may increase price, and the consumer might choose gasoline instead. Consequently, greenhouse gas emissions may not be reduced, and the Brazilian government may not fulfill its environmental commitments. Considering the significant risk of not supplying future demand, it is necessary to provide strategies to mitigate this issue.

An interesting alternative to increase ethanol production and improve the country's fuel security is to use another feedstock to produce biofuel. However, this decision needs to be carefully chosen because there are many issues related to using feedstock for biofuel production, such as food security. The use of corn to produce ethanol in Brazil is an attractive possibility. However, to avoid food security issues, corn ethanol should be considered a secondary feedstock. In other words, the production of corn ethanol should be used to fill the gap between the demand in 2028 and that from sugarcane ethanol production.

Future studies should aim to improve ethanol production in many different aspects, especially in ethanol yield and reduction of greenhouse gas emissions with economically viable solutions. Studies regarding the impact of ethanol production incentives on the economy and society are also relevant.

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Abbreviation

CAPES	Coordination of Superior Level Staff Improvement.
CBio	Decarbonization credit.
CO_2	Carbon dioxide.
COP21	21st Conference of the Parties.
DDGS	Dry Distillers Grains.
DGS	Distillers grains.
GHG	Greenhouse gases.
ha	Hectare.
Kg	Kilogram.
m^3	cubic meters.
MAPE	Mean Absolute Percentage Error.
MJ	Mega Joule.
R$	Brazilian currency.
SSB	Sugar-Sweetened Beverages.
yr	year.

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