

Original Article

Impacts of RenovaBio and SARS-CoV-2 on Biofuels Production, Fuel Prices, and Economic Performance in Brazil

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Received: 16 February 2026

Revised: 26 March 2026

Accepted: 13 April 2026

Published: 27 April 2026

Abstract - The transportation sector in Brazil consumes over one-third of the national energy matrix, which makes biofuels critical for diversifying energy sources and reducing environmental impacts from fossil fuels. Proálcool started in 1975, and the National Biodiesel Production and Use Program (PNPB) began in 2004. These historical programs prepared the ground for biofuel production. Then, RenovaBio arrived in December 2016 as a more recent policy. When the SARS-CoV-2 pandemic arrived in March 2020, fuel supply and demand were significantly disrupted. This study examines production trends for ethanol (both anhydrous and hydrous) and biodiesel from 2012 to 2021, also using GDP data, to evaluate RenovaBio's role across three periods. Those periods are pre-pandemic (2012 to 2019), acute pandemic (2020), and post-acute (2021). The data come from the ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis) and the World Bank. The results show that the pandemic's negative effects largely outweighed any benefits from RenovaBio, although the program reduced some of the harm. Meanwhile, production of hydrated ethanol contracted, while production of anhydrous ethanol and biodiesel remained stable, even as fuel price increases favored gasoline. In 2021, there was a 3% reduction in the required biodiesel blend, slowing growth without affecting production, which remained close to previous years. Overall, these findings show the importance of policies like RenovaBio for meeting climate targets and the Sustainable Development Goals, while also pointing to the need for bigger changes to make biofuels more competitive and encourage continued investment.

Keywords - Biofuels Production, Covid-19, Energy Policy, RenovaBio, Sustainable Development Goals.

1. Introduction

The energy matrix is the combination of multiple sources available to a nation for its development. This matrix is composed of sustainable sources and others that impose environmental liabilities. Economic and technological development, as well as other sectors, depend on the energy supply.

The transportation sector in Brazil uses 34% of the country's total energy [1]. In this area, 73% of the energy comes from fossil fuels like gasoline and diesel, while 23% comes from biofuels. This large use of oil affects both Brazil's trade balance and its environmental conditions. However, the effects on trade deficits and pollution are different because reliance on oil impacts each in different ways.

Since 1975, Brazil has been promoting biofuels, initially with the Proálcool Program. Then, in 2004, the National

Program for the Production and Use of Biodiesel (PNPB) was created. Both programs were designed to incorporate more biofuels into the national energy matrix, reduce oil imports, and address environmental challenges, reinforcing the role of biofuels in Brazilian energy policy.

The RenovaBio program, launched in December 2016 and regulated by Law No. 13,576/2017, was designed to encourage low-carbon fuels, cut greenhouse gas emissions, and meet global climate goals [2,3]. The program was still being implemented when the SARS-CoV-2 pandemic began in March 2020, disrupting energy markets and fuel supply and demand. Liquid fuels were hit harder than other types.

The COVID-19 pandemic brought major changes to daily life, such as travel restrictions, remote work, and reduced mobility, directly affecting fuel use and biofuel production. In Brazil, these changes made existing problems in the biofuels sector worse, like price swings, lower demand, and labor shortages. Rather than introducing new



problems, the pandemic intensified existing weaknesses. RenovaBio may have contributed to maintaining biodiesel production and supporting the ethanol market, although biodiesel and ethanol were affected differently by the crisis [4].

Research on biofuels and energy policy in Brazil is growing, but most studies look at policies like RenovaBio or the economic effects of COVID-19 on their own. This separation limits the understanding of how policy design performs under stress conditions. There are few studies that examine how decarbonization policies and global shocks interact over time, and not much attention has been given to how these combined effects change production and prices in Brazil's biofuels sector. This indicates a literature gap. This study addresses this gap by jointly evaluating the implementation of RenovaBio and the impacts of the SARS-CoV-2 pandemic within a unified temporal framework. This approach allows a more integrated understanding of policy performance under external shocks.

The timeframe is divided into three phases: pre-pandemic (2012–2019), the acute pandemic in 2020, and the final phase in 2021, the post-acute pandemic. This study evaluates how RenovaBio and the SARS-CoV-2 pandemic jointly influenced biofuel production, fuel prices, and Brazil's economy, focusing on the interaction between policy incentives and external demand shocks. Using data from the Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP) and the World Bank, the analysis covers 2012 to 2021.

The study examines the production of both types of ethanol (anhydrous and hydrous) and biodiesel, along with Brazil's GDP, to assess how RenovaBio supported biofuels and lessened the effects of the pandemic, with different magnitudes across fuel types due to distinct market conditions.

By studying these factors, this research shows how energy policies can help make biofuels more competitive, support economic recovery, and achieve the Sustainable Development Goals (SDGs), especially SDG 7, SDG 9, and SDG 13. The findings offer useful advice for policymakers and stakeholders to improve current policies and create a stronger, more sustainable energy sector. The conclusions of the analysis relate to public policies.

2. Materials and Methods

This analysis uses data from the Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, ANP, obtained through the Brazilian Open Data Portal, Portal Brasileiro de Dados Abertos 2022a, b. The biofuels production series is available for different periods, with biodiesel data from 2005 to 2021 and ethanol data for anhydrous and hydrous forms

from 2012 to 2022. Because the full historical series is not complete for both fuels over the same interval, the study focuses on 2012 to 2021, the period for which comparable data are available for all variables analyzed.

The original production data are reported in cubic meters. For this study, the values were converted to thousands of cubic meters, while preserving all digits used in the calculations. Fuel sale price data were collected for the same period. These data are published every six months in spreadsheets covering all gas stations in Brazil, generating about 1.5 gigabytes of information for the period studied.

A descriptive time-series approach guides the analysis, in which biofuel production, fuel prices, and macroeconomic performance are examined jointly. The variables considered include the production of anhydrous ethanol, hydrous ethanol, and biodiesel, together with the average prices of gasoline, common diesel, S10 diesel, and ethanol, as well as gross domestic product as an indicator of economic performance. This approach makes it possible to identify patterns and co-movements over time, without establishing causal relationships.

Because the collected datasets on production and sales prices were large, data processing and visualization were performed using Microsoft Power BI, which enabled integration, filtering, and summarization of the information used to generate the figures. The base data for the figures are available in Appendix A of this study. Notably, the price data use the term ethanol, while the production data use the term hydrous ethanol.

The analysis is organized into three periods: pre-pandemic from 2012 to 2019, acute pandemic in 2020, and post-acute in 2021. This organization makes it possible to identify changes in production and price behavior associated with both the introduction of RenovaBio and the impacts of the SARS-CoV-2 pandemic, as well as to evaluate trends and possible links between policy incentives and market conditions.

During the initial processing, records not relevant to this study were removed, and inconsistencies in the regionalization of some states in the data for 2020 and 2021 were identified. Data on GDP were collected from the World Bank, with Brazil, the United States, the European Union, and China selected for the same period covered by the ANP dataset. Once the data were treated, they were organized into electronic spreadsheets, which supported the figures and simplified tables used in the analysis.

Differences between datasets require aligned time periods, without modification of the original values, in order to preserve comparability across the series. As the analysis is descriptive, the results are treated as associations and do not

represent direct causal relationships. Even with these limitations, the dataset allows the identification of the main trends and sector responses over the period.

This study uses a descriptive approach to examine patterns and trends over three periods. The variables considered in the analysis include biofuel production (anhydrous ethanol, hydrous ethanol, and biodiesel), expressed in thousands of cubic meters, average retail fuel prices (gasoline, ethanol, S500 diesel, and S10 diesel), and GDP as an indicator of economic performance. Econometric models are not used, so the results show associations rather than causal relationships. Factors such as international oil prices, exchange rates, and changes in domestic or foreign policy may affect the results.

3. Results and Discussion

This study examines events between 2012 and 2021, grouped into three key periods related to the SARS-CoV-2 pandemic declared on March 11, 2020. The period from 2012 to 2019 is defined as pre-pandemic, 2020 represents the acute period, and 2021 is defined as post-acute rather than post-pandemic. As of January 2023, the World Health Organization had not declared the end of the pandemic. Across these three periods, the production of ethanol (anhydrous and hydrous) and biodiesel is evaluated, together with the sales values of gasoline, common diesel (also called S5000), S10 (a formulation with lower pollutant emissions), and ethanol (hydrous, according to ANP labeling).

3.1. Pre-pandemic Period (2012–2019)

During the pre-pandemic period, from 2012 to 2019, the Brazilian government launched its newest biofuel incentive program, *RenovaBio*, in December 2016, which was implemented in December 2017 [2,5]. Between its launch and implementation, only biodiesel exhibited a positive market response, which may reflect a response to the program and anticipation of its potential effects, although

other market factors may also have contributed. For hydrous ethanol and biodiesel, 2018 marked the rise in production (Figure 1). Although this section covers events from 2012 to 2019, Figure 1 illustrates the entire historical series up to 2021, providing relevant data for the subsequent sections, where it is analyzed in the following sections.

Through Figure 1 and Table 1 of Appendix 1, from 2012 to 2018, anhydrous ethanol showed stable production levels. Hydrous ethanol exhibited a consistent growth trend, except in 2016 and 2017, when no direct correlation with anhydrous ethanol production was observed. In 2018, hydrous ethanol recovered its growth curve with a 40% increase over the previous year. In 2018, there may have been a greater allocation of inputs to hydrous ethanol due to the 20% reduction in anhydrous ethanol production. *RenovaBio* was regulated by decree in March 2018, which may be associated with the 19.6% increase in biodiesel production during the 2017–2018 biennium (Figure 2) [2,5]. The 2018–2019 biennium marks the beginning of a slowdown in biodiesel production, indicating an adjustment after a period of high production. Nevertheless, production levels remained positive.

Figure 2 demonstrates percentage variations by biennium, revealing moments of growth and retraction due to various factors beyond the scope of this study. Evaluating the types of ethanol, only in the 2012/13 and 2018/19 biennia was the production of both ethanol types increasing, while in the other periods there was alternation between them. The 2016/17 biennium was marked by a decline in the production of both types of ethanol, and this trend occurred in the 2019/20 biennium. This decline may reflect early market adjustments and may have been intensified by subsequent measures implemented to mitigate the effects of the COVID-19 pandemic, which reduced fuel consumption and, consequently, the production of both ethanol types.

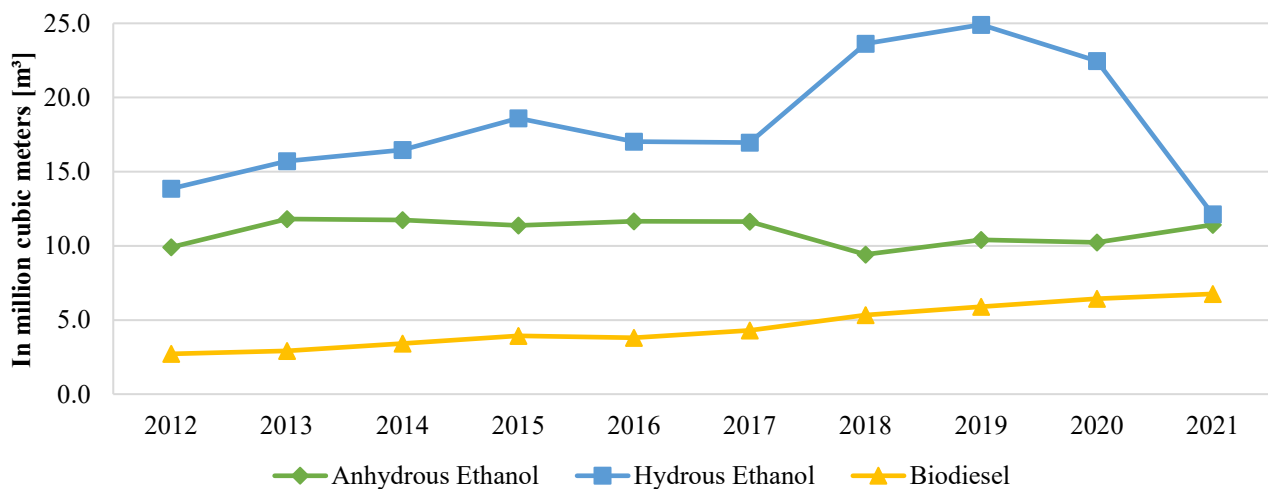


Fig. 1 Biofuels production curves between 2012 and 2021 (million m³)

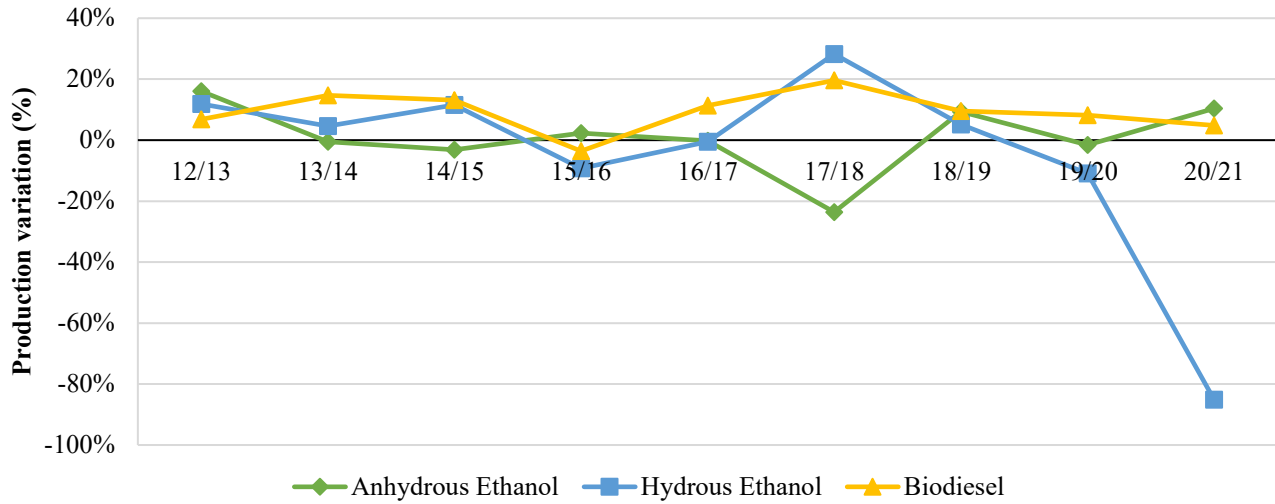


Fig 2 Percentage changes in production in each biennium from 2012 to 2021

The analysis aligns with the IEA report, which stated that global biofuel production grew at an average rate of 5% per year from 2010 to 2019, and it was expected that from 2019 to 2030 demand would triple in the transport sector [6]. In the case of Brazilian biodiesel, which from 2012 to 2019 had only one year with growth below 5% (biennium 2015/16, reduction of 3.6%), ethanol production showed varying growth rates. On average, hydrous ethanol grew by 7.38%, while anhydrous ethanol grew by only 0.05%, below the global average (Figures 1 and 2), in line with the trends reported by the IEA [6].

3.2. Acute pandemic period (2020)

With the declaration of the SARS-CoV-2 pandemic on March 11, 2020, many activities shifted to remote work, reducing fuel demand for car and motorcycle fleets [7].

Figure 3 compares the monthly biofuel production in 2019 and 2020. In the first four months of 2020, biofuel production was higher than during the same period in 2019, indicating an initially favorable scenario. The effects of the pandemic were already being felt worldwide before the official declaration, starting with the first cases reported in Wuhan, China [8].

Among the biofuels studied, biodiesel showed the smallest changes, possibly due to the positive effects of *RenovaBio*, a program that has been expanding since 2017, and the nature of the biodiesel market. Figure 3 also shows that until May 2020, ethanol production was higher than in 2019. From April, production declined sharply, immediately after the pandemic declaration. These drops may be associated with lower demand and worker shortages. Hydrous ethanol production remained below 2019 levels until December, while anhydrous ethanol varied month to month, with growth from February to October 2020. In the

last three months of 2020, production approached 2019 levels but declined again in December.

The reduction in ethanol production was accompanied by a price increase, which may have reduced the competitiveness of this biofuel compared to gasoline [9].

In the United States, during the acute phase of the pandemic, there was a reduction in ethanol prices, while this effect was not observed in the European market. There, ethanol prices were influenced by the supply and demand of sugar and corn, used for both biofuel and food production. In Europe, ethanol prices were mainly influenced by the costs of artificial fertilizers and corn [10].

Figure 3 reflects a global reduction in biofuel production, with different patterns across regions [8,10]. Europe's ethanol market remained stable, while Brazil presented greater variation.

The international drop in oil prices during the acute phase of the pandemic reduced the competitiveness of biofuels and the demand for inputs such as corn and oilseeds [11]. This effect also extended to other agricultural products.

Global biofuel demand in 2020 declined by 8%, mainly due to the effects of the pandemic [6]. In Brazil, the ANP reduced greenhouse gas targets in the transport sector and lowered the mandatory biodiesel blend from 13% to 10% in response to rising costs.

The data suggest that this reduction did not lead to a clear and lasting decline, although short-term adjustments may reflect supply constraints and market expectations. In contrast, countries such as Indonesia, Colombia, and Argentina postponed the implementation of biofuel policies [6].

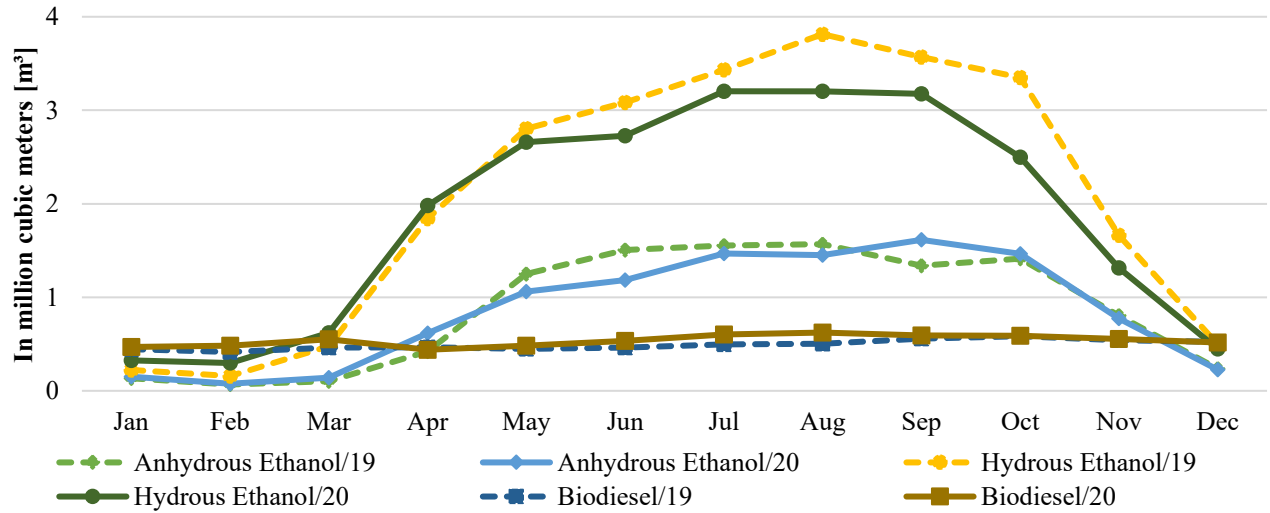


Fig. 3 Monthly production of biofuels in 2020 compared to 2019 (in m³)

3.3. Post-Acute Period of the Pandemic (2021)

After the acute phase, Figures 1 and 2 show that anhydrous ethanol increased significantly, surpassing 2019 levels by 10.4%, which was the best performance among the three biofuels. Biodiesel grew more moderately at 4.8%. Hydrus ethanol, in contrast, fell to its lowest point in the entire study period, dropping 85.1% after two years of reduced production.

Similar patterns were observed as government rules lowered demand for fossil fuels and affected prices and production of alternative fuels like biofuels [12]. Local market conditions in each country may have also affected these results, limiting overall biofuel growth.

Projections suggested that biofuel production and demand would recover in early 2021, but this recovery did not materialize [12]. Still, some positive trends appeared. Biodiesel showed higher production from January to May

and again in October, and anhydrous ethanol had six months of higher production, from February to May through September. Hydrus ethanol showed no improvement, staying below 2020 levels throughout the year, as seen in Figure 4.

In 2020 and 2021, biodiesel remained relatively stable, with changes in April and June. Anhydrous ethanol varied across months, with changes in August and January.

Hydrus ethanol varied over the year, with the largest difference in October and the smallest difference between 2020 and 2021 in February. For ethanol (anhydrous and hydrus), production was higher from April to November.

Sugarcane harvesting occurs at different times depending on the region of the country, taking place from April to November in the Central-South Region and from November to April in the Northeast Region [13].

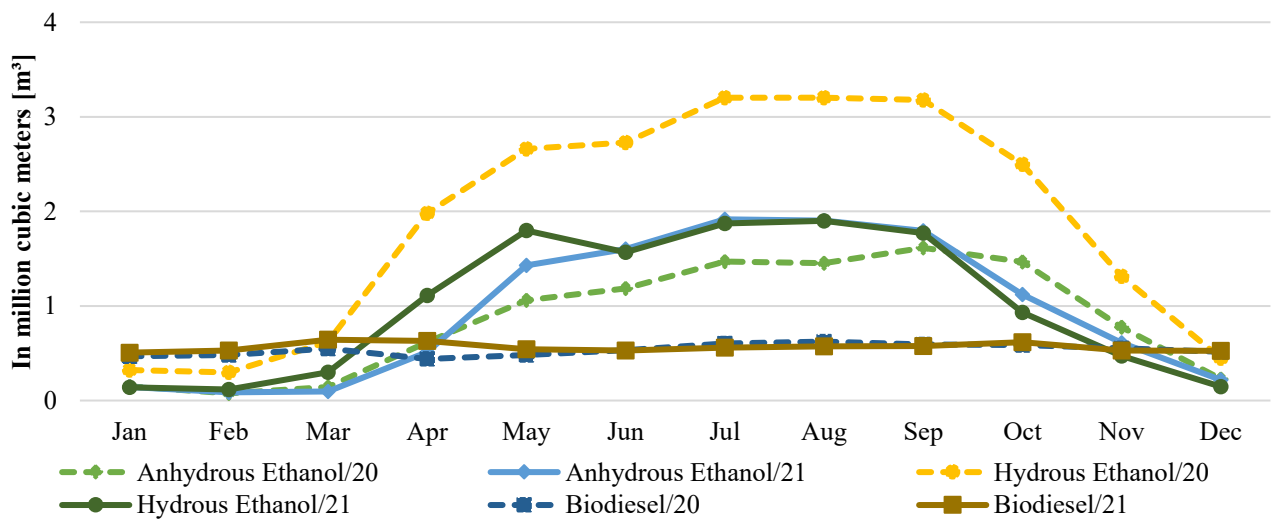


Fig. 4 Monthly production of biofuels in 2021 compared to 2020 (in m³)

The interval between harvesting and production confirms the months in which increases or reductions in production predominantly occur [13]. For every 1% increase in economic globalization, a 0.021% growth in biofuel consumption is observed, with developing countries showing higher demand for biofuels [14].

Internationally, a sharper decline was recorded in the early quarters, followed by a recovery that varied for each fuel. It was expected that prices would return to pre-pandemic levels within two years, provided there was no new wave of the pandemic [15]. In 2021, compared to 2020, there was a 5.9% increase in fuel sales, reaching 139.5 billion liters, although still below 2019 levels [16].

GDP grew by 4.6% in 2021, offsetting the losses of 2020, driven mainly by the services and industry sectors [17]. In the same period, agriculture recorded a slight decline of 0.2%, its first decrease since 2016.

Although biodiesel production did not decrease and only showed a slower growth rate, it remains lower than total ethanol production, which may be partially associated with the implementation of RenovaBio, alongside other market factors, although differences in feedstock availability and market demand may also have influenced this outcome.

3.4. National and International Markets

As seen in previous sections, fossil fuels and biofuels remained stable until the end of 2019, when, internationally,

conditions began to change as the pandemic spread. This section presents an overview of Brazil, along with general data from countries with policies similar to RenovaBio.

Using data from the ANP, Figure 5 presents the average price curves of fuels in Brazil, where both common and S10 diesel follow the same price trend. In general, the four fuels analyzed follow a common trajectory, although in distinct price ranges up to 2019.

In 2020, ethanol approached diesel (common and S10), nearly converging in 2021. These data are consistent with an association between rising ethanol prices and reduced competitiveness relative to gasoline, as well as with patterns observed in major biofuel markets under pandemic-related demand shocks [9,18].

Nationally in Brazil, fossil fuel prices have always been higher than ethanol prices, except in 2012, when common diesel cost R\$ 2.08 and ethanol cost R\$ 2.10. Before the pandemic, 2012, 2013, and 2016 were the years with the smallest price differences between common diesel, S10, and ethanol. After the pandemic, these differences became minimal, with ethanol slightly below both types of diesel.

The largest price difference between ethanol and gasoline occurred in 2018, in the pre-pandemic period, reaching R\$ 1.32. In 2021, at the peak of fuel price increases, the difference was R\$ 1.22.

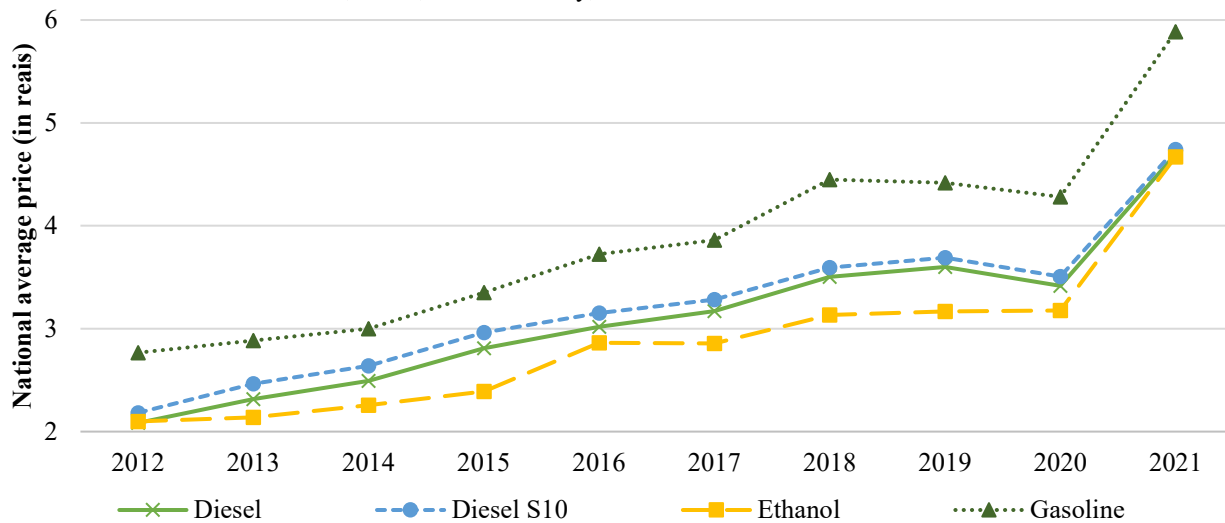


Fig. 5 Growth curves of fuel prices in Brazil between 2012 and 2021 (in reais)

Figure 6 shows the ratio between the price of hydrous ethanol and gasoline (common), a metric considered favorable to biofuels when below 70% [9]. This ratio is also displayed at fuel stations according to Bill 4525/2016, which establishes that retail sellers of automotive fuels must display the percentage ratio between the prices of hydrous ethanol and gasoline.

In 2018, ethanol use was most favorable according to this metric. After that, gasoline becomes the recommended choice under this metric. In 2021, when the ratio nearly reached 80%, gasoline was the preferred alternative.

The result observed in 2018 may be linked to hydrous ethanol production being the highest so far, only exceeded in

2019, while anhydrous ethanol, which is mixed into gasoline, had its lowest recorded production, leading to more hydrous ethanol being sold directly. In 2021, anhydrous ethanol went

over 11 million cubic meters, while hydrous ethanol dropped to its lowest level, about half of what was produced in 2019, the peak year with the third-best ratio.

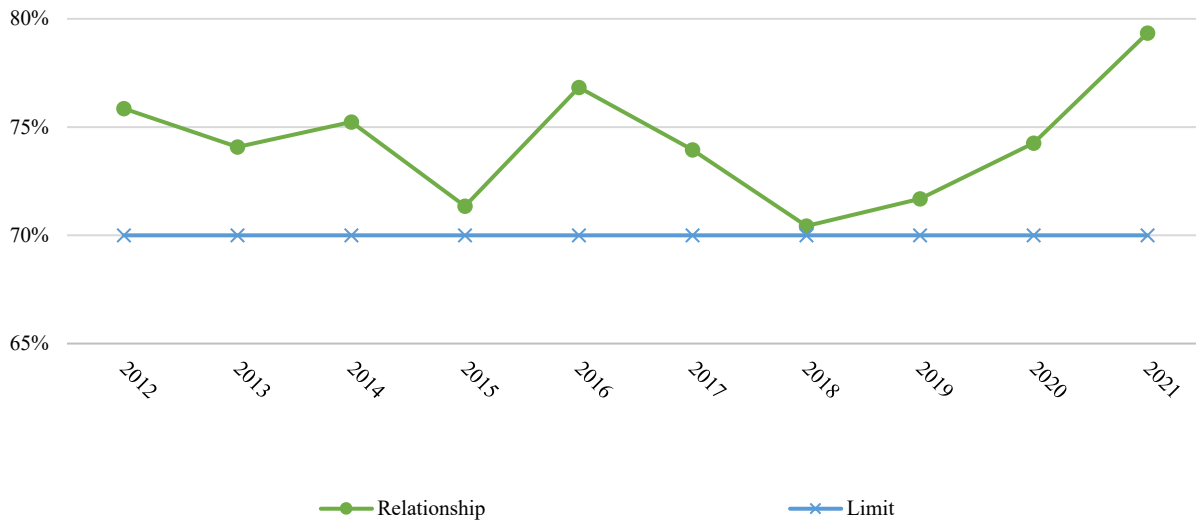


Fig 6 Ratio between the national average prices of ethanol and gasoline

Brazil is strongly influenced by foreign pricing in biofuels due to the pricing policy adopted by Petrobras for oil and derivatives, which considers macroeconomic variables such as commodity futures contracts, exchange rates, international parity, port bureaucracy, and taxation [3].

ethanol production, behind the United States, which is the largest producer, consumer, and exporter [9].

The rise in ethanol prices may be associated with a loss of competitiveness relative to gasoline [9]. After 2018, the relationship between the prices of these fuels deteriorated at the national level, reducing ethanol adoption.

The BRICS countries (Brazil, Russia, India, China, and South Africa) have their own incentive programs for biofuels but face challenges such as limited cultivation areas and raw material supply; among these, Brazil stands out as an industrial model for sugarcane [19].

Between 2010 and 2019, biofuels grew in the global market at an average rate of 5% per year, and demand was expected to triple from 2019 onwards due to the transportation sector [6]. Brazil ranks second globally in

In Brazil, ANP data for September and part of October 2020 were unavailable during data collection, causing gaps in Figures 7 and 8. The official pandemic declaration on March 11, 2020, serves as a reference point for interpreting these figures.

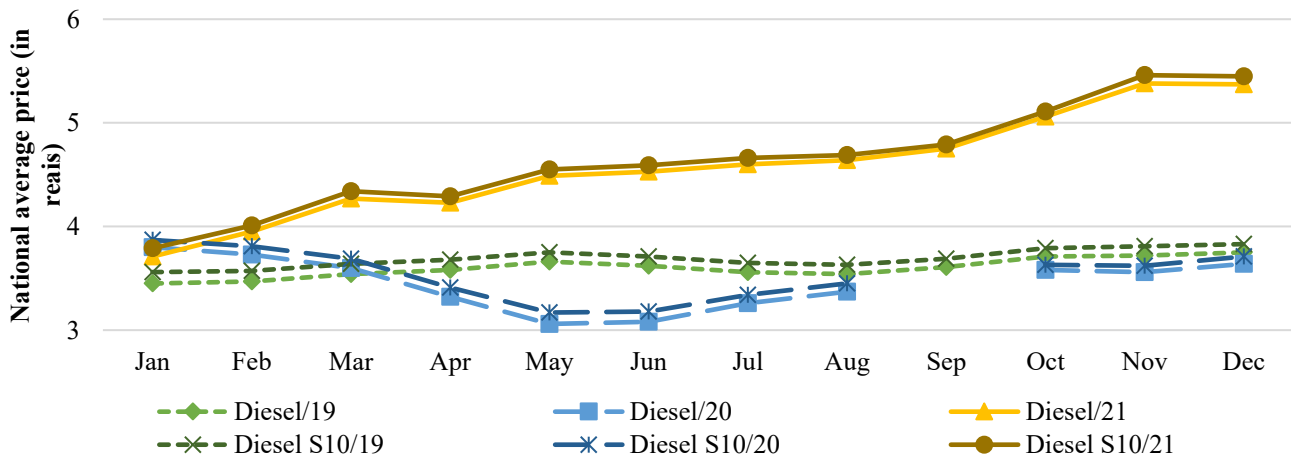


Fig. 7 Consumer prices from 2019 to 2021 - Regular diesel and S10

Figure 7 shows that common diesel and S10 prices rose slightly from January 2019 until March 2020, except between July and September. Prices then dropped below 2019 levels before recovering later in 2020. In 2021, prices increased again, peaking in November. S10 remained consistently more expensive than common diesel.

The prices of ethanol and gasoline show similar behavior, despite occurring at different levels (Figure 8), due to the mandatory blending of anhydrous ethanol into Brazilian gasoline. The production of the two types of ethanol is competitive, with one increasing as the other decreases. The only exception occurred in 2021, when

hydrous ethanol reached its lowest level in the 2019–2021 period, nearly equaling anhydrous ethanol (Figure 3).

In February 2019, ethanol prices started steadily rising until May 2020, when they dropped to R\$ 2.86, about the average price in 2016. After hitting the lowest value in the 2019–2021 period, ethanol prices went up again, reaching R\$ 5.54 in November 2021, close to the national average gasoline price of R\$ 5.89. Gasoline prices for 2021 and 2022 were expected to range between R\$ 4.00 and R\$ 5.00, and ethanol prices between R\$ 3.00 and R\$ 4.00 [20], but the values observed in 2021 exceeded these projections.

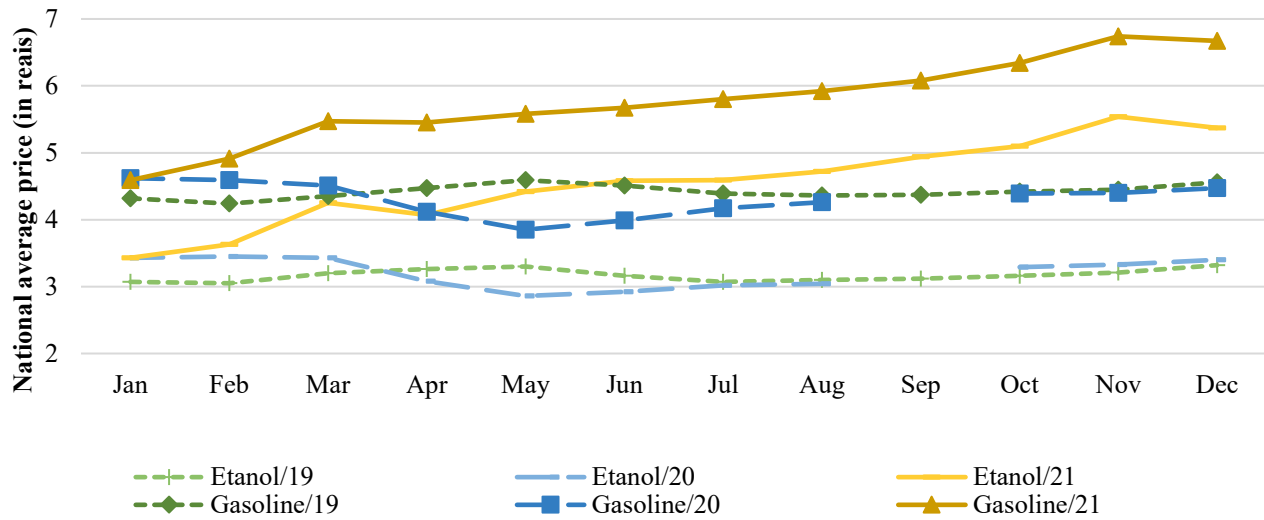


Fig. 8 Consumer prices from 2019 to 2021 - Ethanol and Gasoline

In the cities of Riyadh and Jeddah, Saudi Arabia, pandemic containment measures reduced urban circulation compared to 2019, followed by a decline in fuel prices starting in January due to dynamic pricing and pandemic effects [21]. A similar pattern occurred in Brazil, although the price decline began in April 2020. In May 2020, the lowest prices for all fuels shown in Figures 7 and 8 were recorded, followed by a recovery cycle reaching minimum values in January 2021. Fuel consumption recovery varies according to the size of each economy, which directly affects GDP [15].

The global economic recession caused by SARS-CoV-2 led to lower prices for products like meat and dairy, and also affected biofuels and their raw materials, such as corn in the US and rapeseed in Europe, along with oil prices [11].

In 2021, global investment in biofuels reached US\$ 8 billion, with much of it coming from the United States and Brazil through RenovaBio [18]. This investment may have contributed to the upward trends observed in Anhydrous Ethanol and Biodiesel (Figure 1). These results suggest

uncertainty about whether RenovaBio can sustain growth in biodiesel and anhydrous ethanol while supporting recovery in hydrous ethanol production, or if conditions similar to the acute phase will persist.

The program is positively assessed in the literature, highlighting its role in strengthening the biofuels market, introducing carbon pricing in Brazil, and contributing to greenhouse gas emissions, while also showing that more improvements are needed [3].

Between 2012 and 2021, the Brazilian economy declined by 22.67%, followed by the European Union (2.06%) and the United States (1.50%), while China grew by 2.86% [22].

In 2021, the economies that had declined showed recovery, with the European Union reaching 10.71% and the United States 11.76%, both surpassing 2019 levels. Brazil grew by 11.07%, although this did not fully recover the 2019 level. China recorded a 20.74% increase in GDP compared to 2020.

As discussed in Section 3.2, Europe and the United States reduced biofuel production during the acute phase of the pandemic, indicating economic slowdown [10,11].

In Brazil, 34% of total energy consumption is allocated to the transportation sector [1]. This sector accounted for R\$ 284,471.00, R\$ 273,239.00, and R\$ 283,181.98 in 2019, 2020, and 2021, respectively [23], corresponding to a 3.95% decline followed by a 3.64% recovery. In 2021, activity remained slightly below 2019 levels, consistent with national GDP behavior.

After the pandemic, global biofuel markets stabilized, with demand recovering and average annual growth rates of about 3.2% for ethanol and 2.7% for biodiesel [24–27]. Policies like the US Renewable Fuel Standard and updates to the EU Renewable Energy Directive continue to shape the market. In Brazil, RenovaBio and the CBIO market support biofuel production and emission targets, though regulatory structures vary across countries. Recovery patterns differ across regions and follow differences in policy frameworks and market conditions.

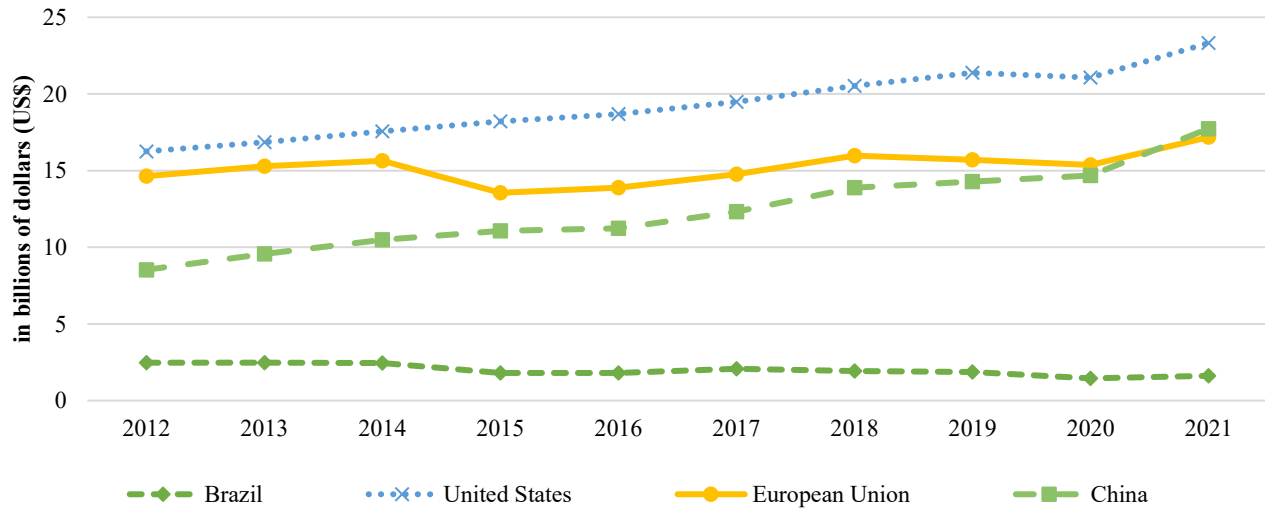


Fig. 9 GDP values in the main economies covered (in billions of dollars)

4. Conclusion

Historically, Brazil has adopted policies aimed at promoting biofuel production, starting with the Proálcool program in 1975 under the government of Ernesto Geisel and later with the launch of RenovaBio in 2016, which became the National Biofuels Policy (Law No. 13.576/2017). Despite these developments, Brazil remains the second-largest ethanol producer in the world, behind the United States. Biodiesel, in turn, showed steady growth over the period from 2012 to 2021.

This study evaluated the dynamics of ethanol and biodiesel production, as well as the relationship between biofuels and the prices of gasoline and diesel. For this purpose, data from the ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis) and the World Bank on Brazil's GDP and other major economies were analyzed, with these economies selected due to their own biofuel incentive programs, such as RenovaBio, or due to the effects of the pandemic. The analysis was divided into three periods: pre-pandemic (2012-2019), acute pandemic period (2020), and post-acute pandemic period (2021), allowing for the evaluation of trends and associations.

From this analysis, the following patterns were observed for fuels and their market as a whole:

- Anhydrous ethanol, more sensitive to production variations, showed growth after the pandemic. This movement may be linked to gasoline demand, since it is blended with this biofuel. Even with pre-pandemic instability, production reached levels close to the best years on record (Figure 1).
- Hydrous ethanol did not follow the same path. During the acute phase of the pandemic, production declined sharply and, in 2021, reached the lowest level observed in the series. The alternation between ethanol types, shown in Figure 2, does not point to a single explanation. Part of this behavior may be related to the role of anhydrous ethanol in gasoline blending, but pricing conditions and supply constraints also need to be considered when interpreting these changes.
- Biodiesel followed a more stable path during the period. Even with the economic slowdown, production continued to increase. The reduction in the required blend in 2021 may be part of this behavior, although other adjustments in the market also need to be considered. Evidence from Figures 3 and 4 suggests that the monthly variation in biodiesel production remained lower than that observed for ethanol.

- Brazil's GDP did not fully return to 2019 levels, unlike the United States, European Union, and China (Figure 9). The transportation sector, which depends heavily on fuel, was strongly affected, with impacts on demand and prices. There was some recovery in 2021, but it did not fully make up for the drop in 2020, as explained in Section 3.4.

RenovaBio may have played a role in stabilizing the biofuels market, although this relationship cannot be interpreted as causal. There are still uncertainties regarding the competitiveness of hydrous ethanol and its role in Brazil's energy security. Changes in incentives can affect how biofuels compete with fossil fuels and change the country's energy mix.

At the global level, policies like the Renewable Fuel Standard in the United States and the Renewable Energy Directives in the European Union work in different ways, making direct comparisons difficult. Still, they provide useful examples for understanding how policy design affects market behavior.

The SARS-CoV-2 pandemic caused major economic effects worldwide, as reflected in fuel demand and overall

economic activity. In Brazil, transportation data and GDP show that levels before the pandemic had not fully returned by 2021.

The analysis describes what happened, so the results indicate connections rather than cause-and-effect relationships. Further research using updated data is needed to see how long these effects will last. The effects on RenovaBio and similar policies also need more study, especially to support the design of more resilient energy policies under external shocks.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Funding Statement

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

Acknowledgments

The authors would like to thank the institutions and contributors who supported this research.

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Appendix 1

Table 1. Values in Fig 1 - Biofuels production curves between 2012 and 2021 (million m³)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
A	9.91	11.81	11.74	11.39	11.66	11.64	9.42	10.39	10.23	11.42
H	13.85	15.72	16.47	18.61	17.03	16.95	23.62	24.91	22.45	12.13
B	2.72	2.92	3.42	3.94	3.80	4.29	5.34	5.90	6.43	6.76

A: Anhydrous Ethanol; H: Hydrus Ethanol; B: Biodiesel

Table 2. Values in Fig 2 - Percentage changes in production in each biennium from 2012 to 2021

	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
AE	16.1%	-0.6%	-3.1%	2.4%	-0.2%	-23.6%	9.4%	-1.6%	10.4%
HE	11.9%	4.6%	11.5%	-9.3%	-0.5%	28.2%	5.2%	-10.9%	-85.1%
B	6.9%	14.7%	13.1%	-3.6%	11.4%	19.6%	9.6%	8.2%	4.8%

AE: Anhydrous Ethanol; HE: Hydrus Ethanol; B: Biodiesel

Table 3. Values from Fig 3 - Monthly production of biofuels in 2020 compared to 2019 (in m³)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A/19	135	67	104	423	1,248	1,504	1,553	1,569	1,338	1,412	806	235
A/20	151	76	142	616	1,060	1,185	1,469	1,451	1,614	1,465	775	227
H/19	223	159	477	1,843	2,804	3,082	3,431	3,814	3,569	3,349	1,664	496
H/20	324	298	620	1,982	2,659	2,728	3,202	3,202	3,177	2,499	1,315	449
B/19	447	415	462	465	448	462	495	503	558	584	540	523
B/20	468	483	550	440	481	533	602	623	594	588	554	516

A/19 e A/20: Anhydrous Ethanol in 2019 e 2020; H/19 e H/20: Hydrus Ethanol in 2019 e 2020; B/19 e B/20: Biodiesel in 2019 e 2020.

Table 4. Values from Fig 4 - Monthly production of biofuels in 2021 compared to 2020 (in m³)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A/20	151	76	142	616	1,060	1,185	1,469	1,451	1,614	1,465	775	227
A/21	143	87	95	510	1,429	1,600	1,916	1,902	1,795	1,120	609	217

H/20	324	298	620	1,982	2,659	2,728	3,202	3,202	3,177	2,499	1,315	449
H/21	141	117	298	1,112	1,798	1,568	1,873	1,900	1,772	933	471	146
B/20	468	483	550	440	481	533	602	623	594	588	554	516
B/21	507	529	643	631	542	528	561	572	575	618	528	526

A/20 e A/21: Anhydrous Ethanol in 2020 e 2021; H/20 e H/21: Hydrous Ethanol in 2020 e 2021; B/20 e B/21: Biodiesel in 2020 e 2021.

Table 5. Values in Fig 5 - Growth curves of fuel prices in Brazil between 2012 and 2021 (in reais)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
D	2.08	2.31	2.49	2.81	3.02	3.17	3.50	3.60	3.42	4.69
S	2.18	2.46	2.64	2.96	3.15	3.28	3.59	3.69	3.51	4.74
E	2.10	2.14	2.26	2.39	2.86	2.86	3.13	3.17	3.18	4.67
G	2.77	2.89	3.00	3.35	3.73	3.86	4.45	4.42	4.28	5.89

D: Diesel S10; S: Diesel S10; E: Ethanol; G: Gasoline.

Table 6. Values in Fig 6 – Ratio between the national average prices of ethanol and gasoline

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Relationship	76%	74%	75%	71%	77%	74%	70%	72%	74%	79%

Table 7. Values in Fig 7 – Consumer prices from 2019 to 2021 – Regular diesel and S10

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
D/19	3.45	3.47	3.54	3.58	3.66	3.62	3.56	3.54	3.61	3.71	3.72	3.75
D/20	3.80	3.73	3.60	3.32	3.06	3.08	3.26	3.37		3.58	3.56	3.64
D/21	3.71	3.95	4.27	4.23	4.49	4.53	4.60	4.64	4.75	5.06	5.38	5.37
S/19	3.56	3.57	3.64	3.68	3.75	3.71	3.65	3.63	3.69	3.79	3.81	3.83
S/20	3.87	3.81	3.69	3.41	3.17	3.18	3.34	3.45		3.63	3.62	3.71
S/21	3.79	4.01	4.34	4.29	4.55	4.59	4.66	4.69	4.79	5.11	5.46	5.45

D/19, D/20, D/21: regular diesel prices in 2019, 2020 e 2021; S/19, S/20, S/21: diesel S10 prices in 2019, 2020 e 2021

Table 8. Values in Fig 8 – Consumer prices from 2019 to 2021 - Ethanol and Gasoline

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
E/19	3.07	3.05	3.20	3.26	3.30	3.16	3.07	3.10	3.12	3.16	3.21	3.32
E/20	3.43	3.45	3.43	3.08	2.86	2.92	3.02	3.04		3.29	3.33	3.40
E/21	3.43	3.63	4.25	4.07	4.42	4.58	4.59	4.72	4.94	5.10	5.54	5.37
G/19	4.32	4.24	4.35	4.47	4.59	4.51	4.39	4.36	4.37	4.42	4.45	4.56
G/20	4.62	4.59	4.51	4.12	3.85	3.99	4.17	4.26		4.39	4.40	4.47
G/21	4.59	4.91	5.47	5.45	5.58	5.67	5.80	5.92	6.08	6.34	6.74	6.67

E19, E/20, E/21: etanol prices in 2019, 2020 e 2021; G19, G/20, G/21: etanol prices in 2019, 2020 e 2021

Table 9. Values from Fig 9 – GDP values in the main economies covered (in billions of dollars)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Brazil	2,465	2,473	2,456	1,802	1,796	2,064	1,917	1,873	1,449	1,609
United States	16,254	16,843	17,551	18,206	18,695	19,477	20,533	21,381	21,060	23,315
European Union	14,642	15,294	15,650	13,553	13,889	14,765	15,981	15,693	15,369	17,177
China	8,532	9,570	10,476	11,062	11,233	12,310	13,895	14,280	14,688	17,734