TECHNICAL NOTE

Analysis of Current Biofuels Outlook – Year 2023

AUGUST 2024

MINISTÉRIO DE MINAS E ENERGIA

GOVERNO FEDERAL
BRASIL
UNIÃO E RECONSTRUÇÃO

epe
Empresa de Pesquisa Energética

20 anos

TECHNICAL NOTE EPE/DPG/SDB/2024/03

Director of Oil, Gas and Biofuels Studies
Heloisa Borges Bastos Esteves

Executive Coordinator
Angela Oliveira da Costa

Technical Coordinators
Angela Oliveira da Costa
Rachel Martins Henriques
Rafael Barros Araujo

Cover Images
1. Developed by Racool_studio in Freepik.

Secretary Technician
Raquel Lopes Couto

Intern
Anderson Luiz Silva Pelluso

Technical Translation
Dan Abensur Gandelman
Vinicius Folly Barbosa

Technical Team
Ana Paula Oliveira Castro
Angela Oliveira da Costa
Arthur Cortez Pires de Campos
Bruna Souza Lopes Graça
Dan Abensur Gandelman
Danielle Borher de Andrade
Danilo Perecin
Ederaldo Godoy Junior
Euler João Geraldo da Silva
Guilherme Correa Naresse
Juliana Rangel do Nascimento
Leônidas Bially Olegario dos Santos
Letícia Gonçalves Lorentz
Marina Damião Besteti Ribeiro
Paula Isabel da Costa Barbosa
Rachel Martins Henriques
Rafael Barros Araujo

PUBLIC VALUE

EPE CONDUCTS STUDIES AND RESEARCH TO SUPPORT THE FORMULATION, IMPLEMENTATION, AND EVALUATION OF BRAZILIAN ENERGY POLICY AND PLANNING.

WITH THIS STUDY, EPE PROVIDES TRANSPARENCY AND REDUCES INFORMATION ASYMMETRY BY PRESENTING DATA AND FACTS THAT CAN HELP INFORM DEBATES ABOUT ENERGY TRANSITION EFFORTS IN BRAZIL.

THIS TECHNICAL NOTE PRESENTS A SYNTHESIS OF THE MOST RELEVANT EVENTS IN THE RENEWABLE FUELS MARKET THAT OCCURRED IN THE YEAR PRIOR TO ITS PUBLICATION, ASSISTING IN UNDERSTANDING THE FACTORS IMPACTING THIS SECTOR.

Document Identification and Revision History

Field of Study

Oil, Gas and Biofuels Studies Division (DPG)

Oil Products and Biofuels Studies Department (SDB)

Study

Analysis of Current Biofuels Outlook

Revision	Date of Issue	Description
r0	20/08/2024	Original publication in Portuguese
r0	13/09/2024	Original publication in English

Acknowledgements

Agência Nacional de Petróleo, Gás Natural e Biocombustíveis – ANP
(National Agency of Petroleum, Natural Gas and Biofuels)

Associação Nacional dos Fabricantes de Veículos Automotores – ANFAVEA
(National Association of Automotive Vehicle Manufacturers)

Banco Nacional do Desenvolvimento Econômico e Social – BNDES
(National Bank of Economic and Social Development)

Centro de Tecnologia Canavieira – CTC
(Sugarcane Technology Center)

Companhia Nacional de Abastecimento – CONAB
(National Supply Company)

Ministério da Agricultura, Pecuária e Abastecimento – MAPA
(Ministry of Agriculture, Livestock and Supply)

Ministério de Minas e Energia – MME
(Ministry of Mines and Energy)

União da Indústria de Cana-de-Açúcar – UNICA
(Sugarcane Industry Union)

Fundação Instituto de Pesquisas Econômicas – Fipe
(Economic Research Institute Foundation)

Centro de Estudos Avançados em Economia Aplicada – CEPEA / ESALQ /USP
(Center for Advanced Studies in Applied Economics)

Presentation

The Energy Research Office presents its fifteenth edition of the Analysis of Current Biofuels Outlook, focusing on the year 2023. Published annually, this report consolidates the most relevant facts regarding biofuels that occurred in the year prior to its release. It is issued after the conclusion of the sugar-energy crop season and the consolidation of statistics from the most important sector agencies.

The main topics covered are the supply and demand for ethanol and its production and transport infrastructure, the Otto cycle market, the role of bioelectricity in the national energy matrix, the biodiesel sector, biomethane, the international biofuels market, innovations and emerging perspectives for biofuels, mitigated emissions by using these renewable energy sources, and the monitoring of the National Biofuels Policy (RenovaBio).

In this edition, besides evaluating the major events of 2023, the document includes an article on “Low-Intensity Land Use Techniques in Biofuels Production,” which explores methods to maximize biofuels production without the need to expand new agricultural areas or compete with food production, thereby also contributing to the reduction of greenhouse gas emissions.

Table of Contents

List of charts

List of tables

List of figures

1. Ethanol supply

In 2023, the sugar-energy production reached record levels in both sugarcane crushing and sugar production, driven by highly favorable weather conditions. Sugarcane processing amounted to 713 million tons, an increase of 19.7% compared to 2022. Sugar production grew by 26.0%, totaling 45.8 million tons, due to the high price levels in the international market. Regarding ethanol, 29.5 billion liters were produced from sugarcane, and when combined with the 5.8 billion liters of corn-based ethanol (a 40% increase), the total reached 35.3 billion liters (15.3% higher than in 2022). The totals for hydrous and anhydrous ethanol were 21.5 and 13.9 billion liters, respectively (MAPA, 2024). Hydrous ethanol: Contains around 5% water, used in flex-fuel vehicles as a standalone fuel. Anhydrous ethanol: Contains less than 1% water, suitable for blending with gasoline to enhance octane and reduce emissions.

Otto cycle fuel consumption reached a historic high of 59.1 billion liters of gasoline equivalent, continuing the growth trend observed since the second half of 2022, even with the reintroduction of federal taxes (EPE, 2024).

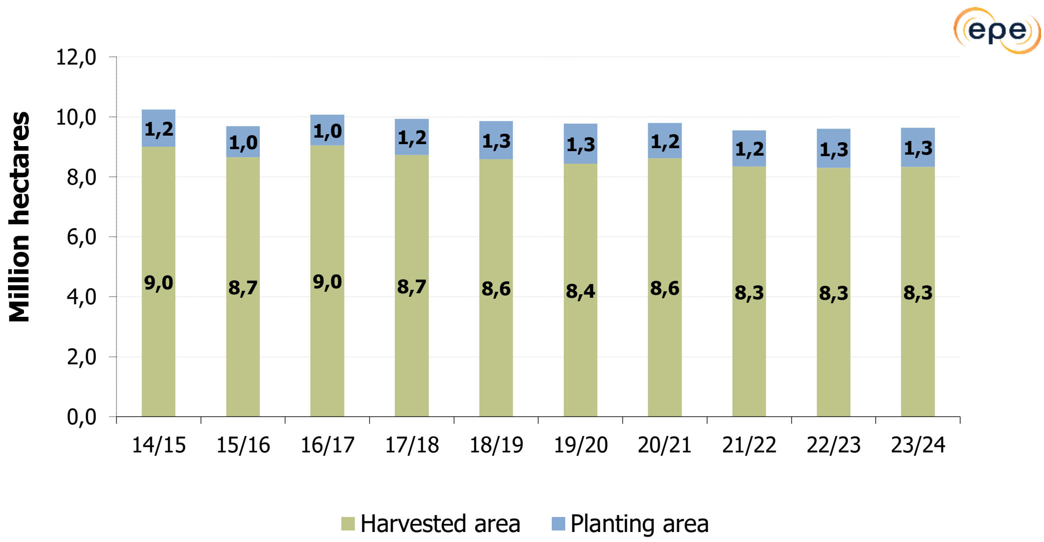
Favorable weather conditions, though less intense than those observed in the 2023/24 harvest, suggest positive prospects for 2024/25. Sugar production is expected to continue benefiting from its higher profitability and existing contracts. Corn ethanol is maintaining its growth trend (CONAB, 2024a, 2024b).

1.1. Area, Agricultural Productivity, and Sugarcane Yields

Area

The total harvested area of sugarcane in the 2023/24 harvest was 8.3 million hectares (Mha), remaining virtually stable over the past three years. In the period indicated in Chart 1, there is a trend of reduction in this area between the 2016/17 and 2021/22 harvests, generally explained by competition with temporary crops such as soybeans and corn. The planting area was 1.3 Mha, with declines in the Northeast and South regions being offset by increases in the Southeast and Central-West regions (CONAB, 2024a, 2024b).

Chart 1 – Harvested and Planting Area of Sugarcane in the Sugar-Energy Sector (Brazil)



Source: EPE based on CONAB (2024a, 2024b).

For the 2024/25 harvest, CONAB estimates that the harvested area will increase, totaling 8.7 million hectares (4.1%), due to the expansion of sugarcane fields (CONAB, 2024a, 2024b).

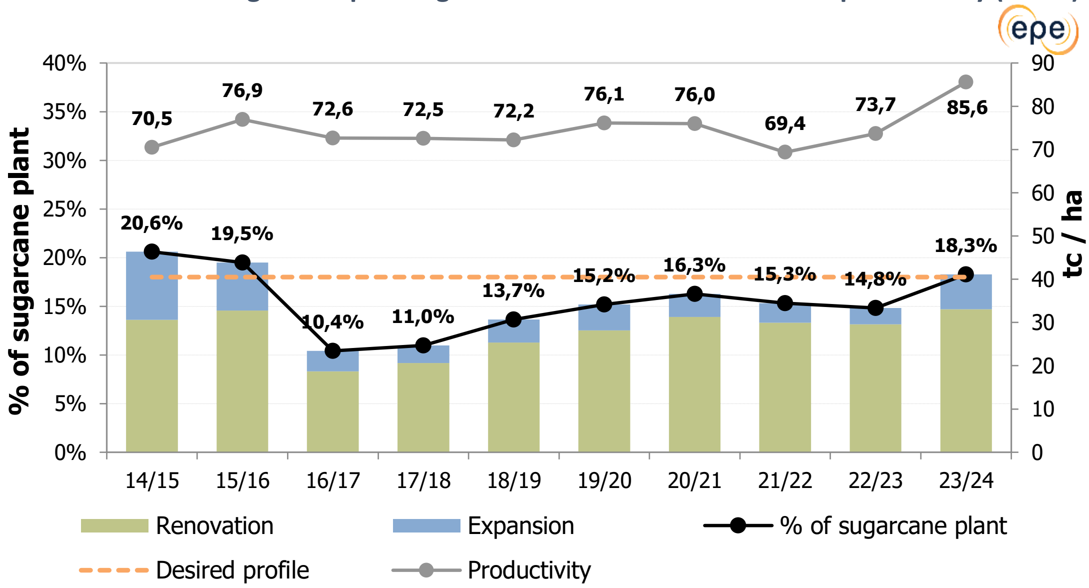
Agricultural Productivity

The average agricultural productivity of the Brazilian sugar-energy sector in the 2023/24 harvest was 85.6 tons of sugarcane per hectare (ts/ha), an increase of 16.2% compared to the previous harvest (73.7 ts/ha). This significant growth was due to favorable weather conditions. The Central-South region, which accounted for 91% of total production, showed an 18.2% increase (88.2 vs. 74.6 ts/ha), while the North-Northeast region saw a decrease of -1.4% (64.8 vs. 65.8 ts/ha) (CONAB, 2024a, 2024b).

Evaluating the performance of sugar-energy production also requires checking the distribution of sugarcane cultivation areas, which are categorized as: reformed, under reform, in expansion, and ratoon cane[1]. The ideal proportion of planted cane[2] (planted cane/total cane) is 18%, which corresponds to a renewal of the sugarcane field after five harvests (UNICA, 2014, 2017).

Chart 2 shows the evolution of the proportion of planted cane in the total sugarcane harvested in Brazil, excluding the area of cane under renovation (CONAB 2024a, 2024b).

Chart 2 – Share of sugarcane planting in the total harvested area and productivity (Brazil)



Source: EPE based on CONAB (2024a, 2024b) and UNICA (2014, 2017)

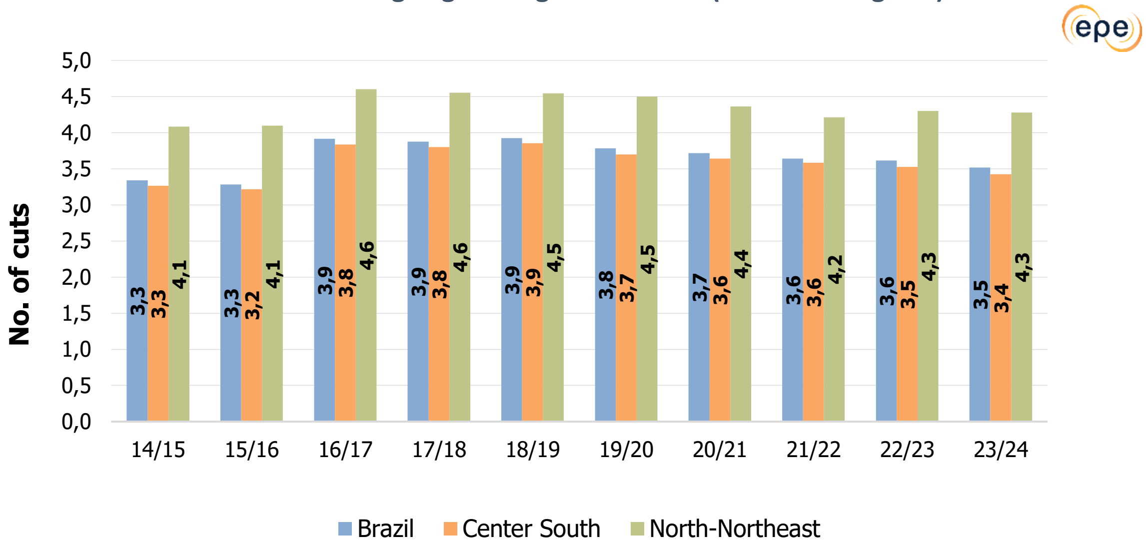
The proportion of planted cane in the total cane increased since the 2017/18 harvest. However, starting from 2021/22, it experienced a decline that continued through the 2022/23 cycle. In 2023/24, its share of the total cane was 18.3%, surpassing the ideal 18%.

[1] The reformed area is that which was recovered in the previous year's harvest and is available for harvest. The area under reform is that which will not be harvested, as it is in the recovery period for replanting sugarcane or other uses. The expansion area is the class of sugarcane fields that is available for harvest for the first time. The ratoon cane area is that which has already gone through more than one harvest.

[2] The planted cane area is the sum of the reformed and expansion areas.

The average age[3] of Brazilian sugarcane fields decreased by 2.6% this harvest. Chart 3 shows that this indicator was 3.3 cuts between the 2014/15 and 2015/16 harvests and increased to 3.9 from 2016/17 to 2018/19. Starting from 2019/20, a downward trend was observed, reaching the current value of 3.5. There is also a significant difference between the North-Northeast and Central-South regions.

Chart 3 – Average age of sugarcane fields (Brazil and regions)



Source: EPE based on CONAB (2024a, 2024b).

For the 2024/25 harvest, CONAB estimates productivity at 79.1 ts/ha, a decrease of 7.6% compared to 2023/24 (CONAB, 2024a, 2024b).

Sugarcane Yield (TRS[4]/ts)

The sugarcane yield in Brazil for the 2023/24 harvest was 137.7 kg TRS/ts, a decrease of 0.8% compared to the previous year (138.7 kg TRS/ts[5]), marking a decline for the third consecutive year. This decrease was influenced by a 0.9% reduction (140.8 kg ATR/ts) in the Central-South region. In the North/Northeast region, there was a 3.1% increase (125.7 kg ATR/ts). The main factors affecting this indicator are weather conditions, age of the crops, mineral and vegetal impurities, and the mechanization of planting and harvesting (CONAB, 2024a, 2024b; DATAGRO, 2024a).

As shown in Chart 4, in the 2023/24 harvest, mechanization of harvesting in Brazil increased to 92%. In the Central-South region, mechanized harvesting remained at 99%, while in the Northeast, it increased from 26% to 27%. In the North region, this indicator reached 100% in 2016/17 and has remained at that level (CONAB, 2024b, 2024c). In the Central-South region, planting mechanization was 67%, close to the previous harvest. This followed a period of decline observed between 2018/19 and 2021/22, during which efforts were focused on recovering productivity and reducing costs (due to high seed consumption and planting failures with the use of machinery), as well as increasing the use of the “meiosi” technique during that period (CTC, 2024; UDOP, 2019). The lag between planting and harvesting was 32 percentage points (CTC, 2024).

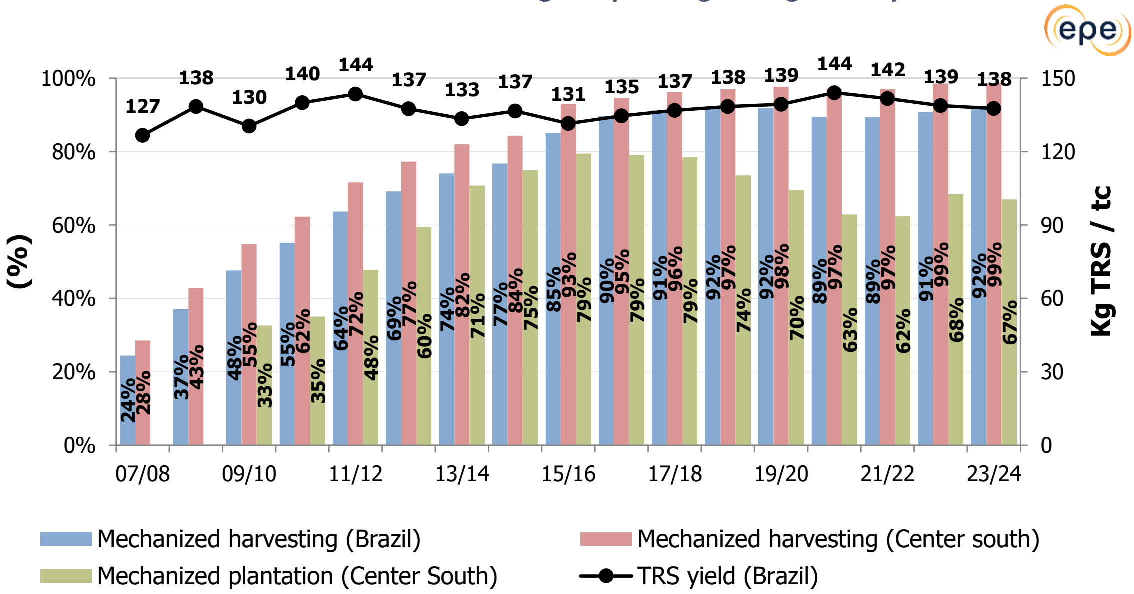
[3] The higher the average cutting stage (age of the sugarcane field), the smaller the area with newer cane, and consequently, the lower the average productivity, as productivity decreases with each harvest.

[4] Total Recoverable Sugar.

[5] Starting from the 2022/23 harvest, as yield data is no longer published by CONAB, the source has been changed to DATAGRO.

Mechanized harvesting in the Central-South region accelerated, increasing from 28% in 2007/08 to over 90% of the area within just 8 years (2015/16). In recent years, the yield has been at levels close to those observed at the beginning of this process.

Chart 4 – Mechanized harvesting and planting vs. sugarcane yield



Note: Harvest data (Brazil and Central-South) was extracted from CONAB (2024a, 2024b), while planting mechanization data was obtained from mills associated with CTC (2024), which represent only a portion of the sugar-energy sector and do not include suppliers.

Source: EPE based on CONAB (2024a, 2024b), CTC (2024), DATAGRO (2024a) and UNICA (2013, 2014, 2017).

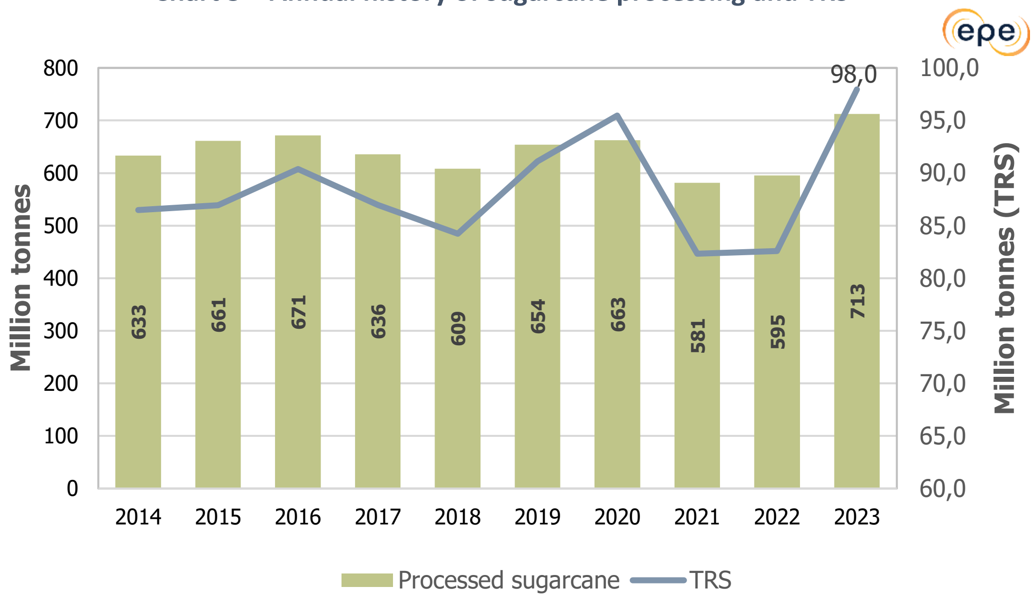
In the 2023/24 harvest, the total impurity content was 8.9%, an increase of 1.0 percentage point compared to the previous harvest. Vegetal impurities remained at 7.9%, while mineral impurities were at 1.0% (CTC, 2024).

The yield for the 2024/25 harvest is estimated to be around 138.2 kg TRS/ts, a growth of 0.4% compared to 2023/24 (DATAGRO, 2024a).

1.2. Sugarcane Processing

The total processed sugarcane reached 713 million tons in 2023, 19.7% higher than in 2022, as shown in Chart 5. This marks a significant recovery after a period characterized by adverse weather conditions in the main producing states (MAPA, 2024). TRS reached 98 million tons due to the high availability of sugarcane.

Chart 5 – Annual history of sugarcane processing and TRS



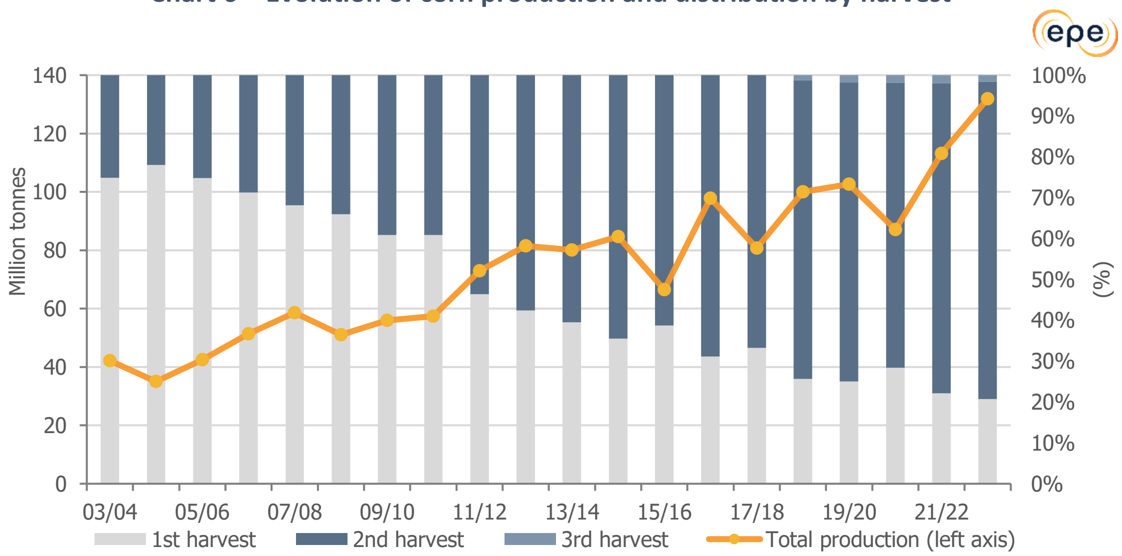
Source: EPE based on MAPA (2024).

From the crop year perspective, the processed sugarcane in 2023/24 (713 million tons) grew by 16.8% compared to the 2022/23 period (611 million tons), according to CONAB (2024a, 2024b).

1.3. Corn Processing

National corn production in 2023 (2022/23 harvest) was 131.9 million tons, according to Conab (2024c), representing a 17% increase compared to the previous year. Of this total, 77% was produced in the second harvest, a practice that has been expanding and driving the growth of corn supply in the country, as shown in Chart 6.

Chart 6 – Evolution of corn production and distribution by harvest

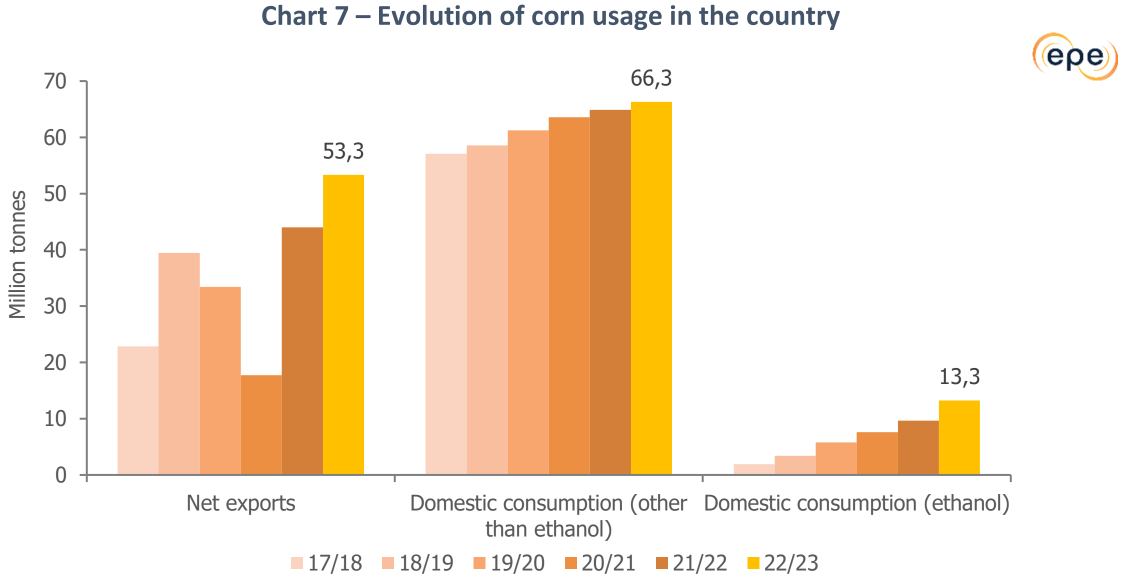


Source: EPE based on CONAB (2024c).

Domestic corn consumption was 79.6 million tons, including the portion used for ethanol production, and net exports totaled 53.3 million tons, a 21% increase, as shown in Chart 7. For the first time, in the 2022/23 harvest, Brazil became the world's leading corn exporter (USDA, 2024a).

The amount of corn processed for ethanol production nearly quadrupled in four years. From 3.4 million tons in 2019, it reached 13.3 million tons in 2023, representing 10% of production and 17% of domestic corn consumption that year (ANP, 2024a; CONAB, 2024c).

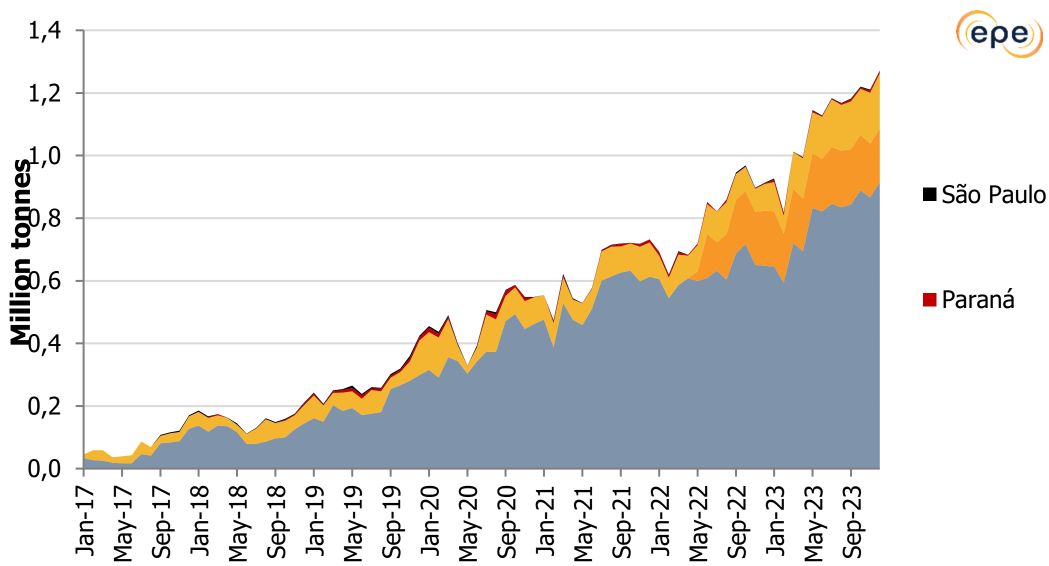
Chart 7 – Evolution of corn usage in the country



Source: EPE based on CONAB (2024c).

In 2023, for the first time, the monthly mark of 1 million tons of corn dedicated to ethanol production was surpassed. The state of Mato Grosso remains a standout, accounting for 72% of the corn processing for ethanol in the country, as observed in Chart 8

Chart 8 – Monthly corn processing for ethanol production by State



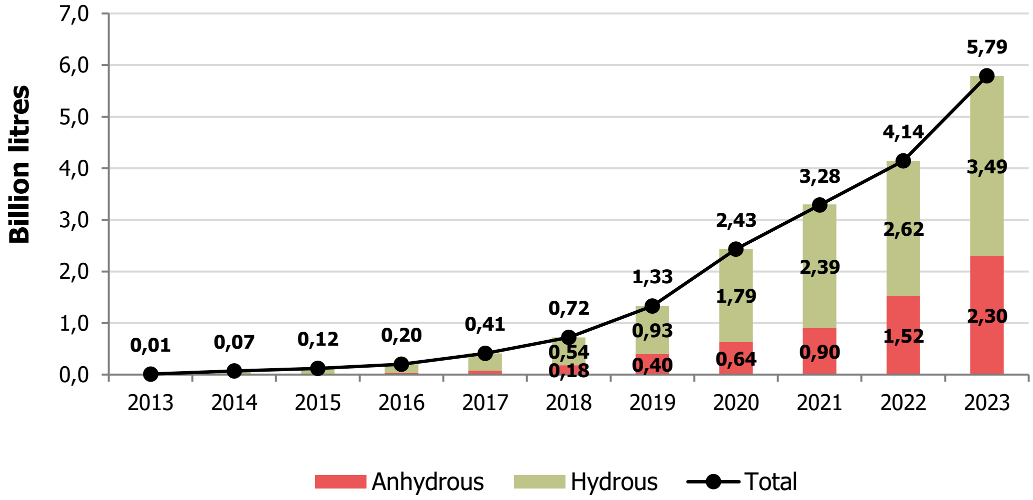
Source: EPE based on ANP (2024a).

Estimates say that by-products obtained from corn-based ethanol production, DDGS (Dried Distilled Grains with Solubles) and oil, totaled approximately 3.0-4.8 million tons and 200-290 million liters, respectively. DDGS is used as animal feed supplement, while the oil is used for human consumption and industrial purposes, including biodiesel production. Revenue from these by-products varies but can represent up to 25% of the total revenue from corn processing in the mills.

1.4. Total ethanol production

Corn-based ethanol continues to show significant growth, with production reaching 5.8 billion liters in 2023, a 40% increase compared to 2022, as shown in Chart 9. Most of the production facilities are concentrated in the states of Mato Grosso and Goiás.

Chart 9 – Brazilian corn ethanol production

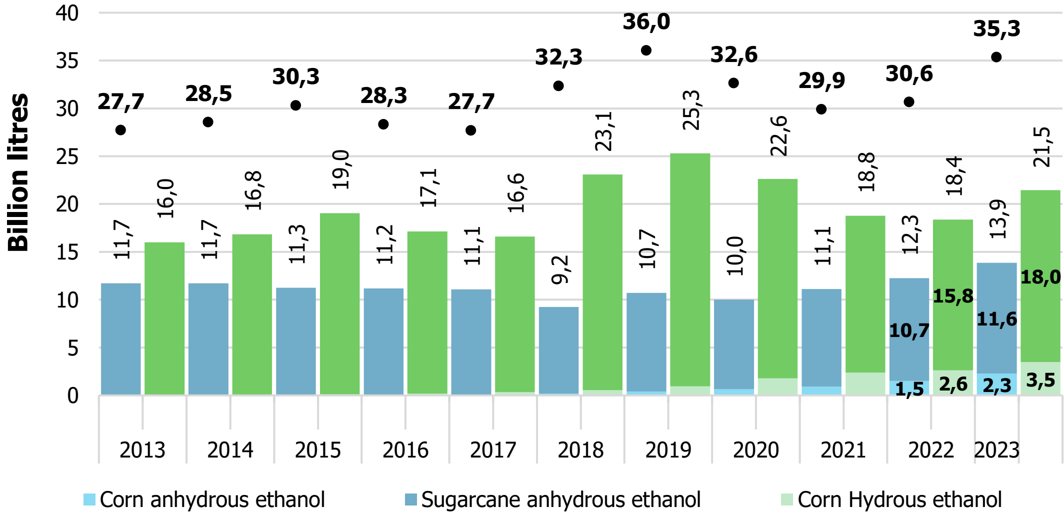


Source: EPE based on UNICA (2024).

From the perspective of the sugarcane harvest year, the value recorded in 2023/24 was 4.9 billion liters. Estimates for the next harvest indicate that corn-based ethanol production will reach 7.0 billion liters, representing a 43% increase. This reaffirms its potential within the biofuel sector and Brazil's energy matrix (CONAB, 2024a, 2024b).

In 2023, ethanol production from sugarcane was 29.5 billion liters. When combined with corn-based ethanol, the total reaches 35.3 billion liters, divided into 21.5 billion liters of hydrous ethanol (a 16.8% increase) and 13.9 billion liters of anhydrous ethanol (a 13.1% increase). Thus, the total volume produced was 15.3% higher than in 2022, as illustrated in Chart 10 (MAPA, 2024).

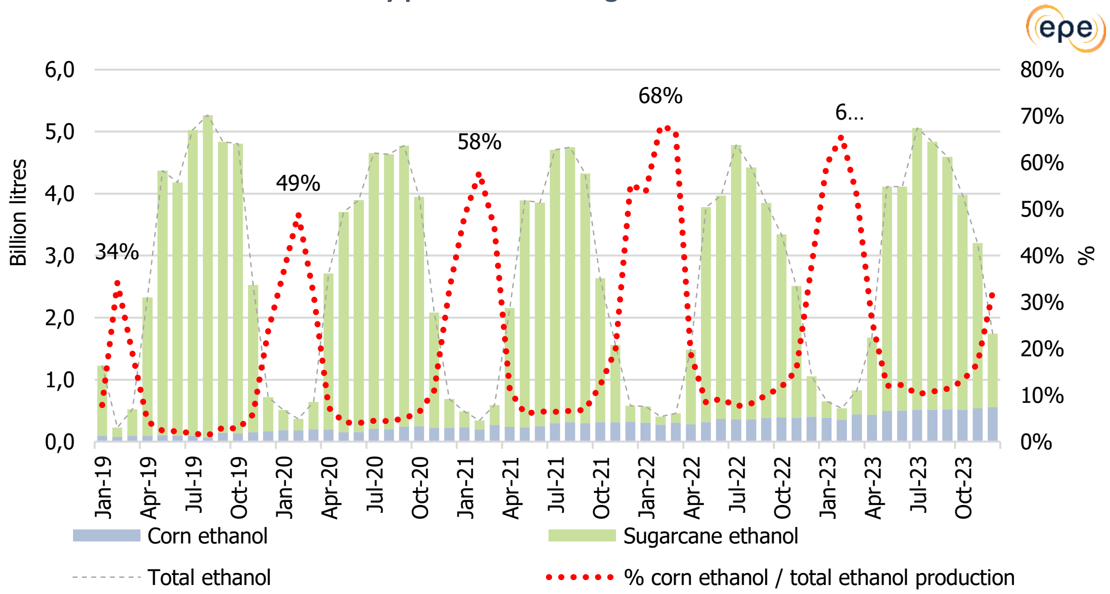
Chart 10 – Total Brazilian ethanol production (from sugarcane and corn)



Source: EPE based on MAPA (2024) and UNICA (2024).

From Chart 11, it is possible to observe the gradual increase in corn ethanol production and its importance during the off-season for sugarcane in the Central-South region (December to March). Between 2019 and 2023, its share of total production increased from 34% to 66%.

Chart 11 – Monthly production of sugarcane and corn ethanol



Source: EPE based on MAPA (2024) e UNICA (2024)

In general, sugarcane mills have increased their focus on sugar production due to its profitability in the international market. Meanwhile, corn ethanol has provided the necessary support to maintain the supply of this biofuel throughout the year, especially during the off-season.

Ethanol production for other uses totaled 1.1 billion liters, 16.0% lower than in 2022 (EPE, 2024). Hydrous ethanol constitutes the largest portion of production, and its primary application is as an antiseptic.

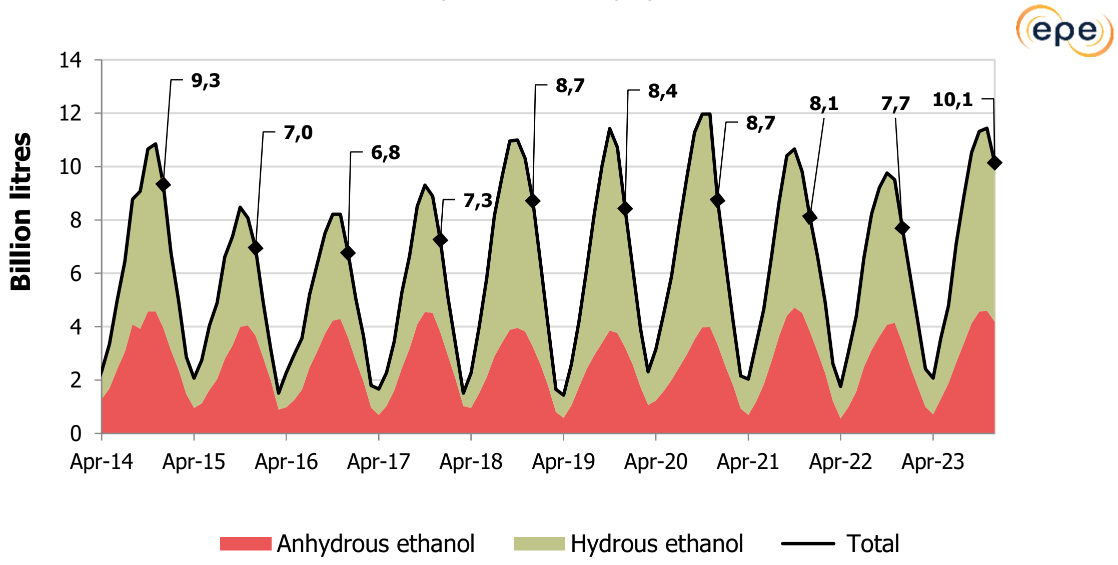
Ethanol Inventory

Chart 12 shows the historical variation in the monthly physical stock[6] Chart 12 shows the historical variation in the monthly physical stock of ethanol reported to MAPA. It reveals that the ending stock[7], on December 31, 2023, was 10.1 billion liters of ethanol, 31.7% higher than in 2022. From this amount, 4.2 billion liters were anhydrous ethanol, representing a 23.3% increase compared to December 2022. Conversely, hydrous ethanol saw a 38.4% increase in stocks, which supported its consumption during the sugarcane off-season.

[6] Physical stock refers to the actual volume stored in the production unit's tanks, including the volume that has been sold but not yet withdrawn.

[7] Ending stock refers to the stock stored in the production unit's tanks at the end of the calendar year.

Chart 12 – Monthly evolution of physical ethanol stocks



Source: EPE based on MAPA (2024).

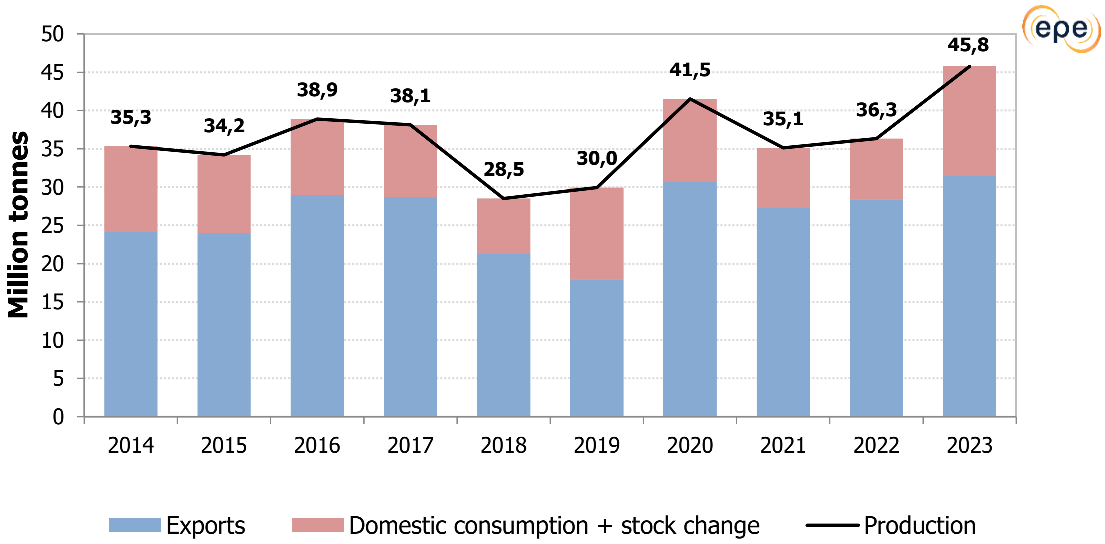
The rules regarding the mandatory stock of anhydrous ethanol are established by ANP Resolution No. 719, dated February 22, 2018 (ANP, 2018). According to this resolution, the mandatory minimum stock of anhydrous ethanol for production units is 25% by January 31 and 4% by March 31 of each year, relative to the total sold in the previous calendar year. For distributors, it is 10 days of sales, with ANP authorized to extend this to 15 days if necessary for supply during the off-season. The available stock of anhydrous ethanol observed on March 31, 2023, at production units was 1.3 billion liters (MAPA, 2024), a volume that meets ANP requirements.

With the greater availability of ethanol in 2023, the total volume of the biofuel (both hydrous and anhydrous) consumed was 6.3% higher than in 2022. This increase was due both to the higher demand for anhydrous ethanol for gasoline type C and to the recovery in the share of hydrous ethanol. These points will be analyzed in detail in Section 2.2 of this study. (MAPA, 2024; EPE, 2024).

1.5. Sugar production

In 2023, Brazilian sugar production reached a historic high of 45.8 million tons (26.0% higher than in 2022), due to favorable weather and market conditions. Exports totaled 31.4 million tons (a 10.8% increase), while the "domestic consumption + change in stocks" component showed an increase of 6.4 million tons, as illustrated in Chart 13 (MAPA, 2024).

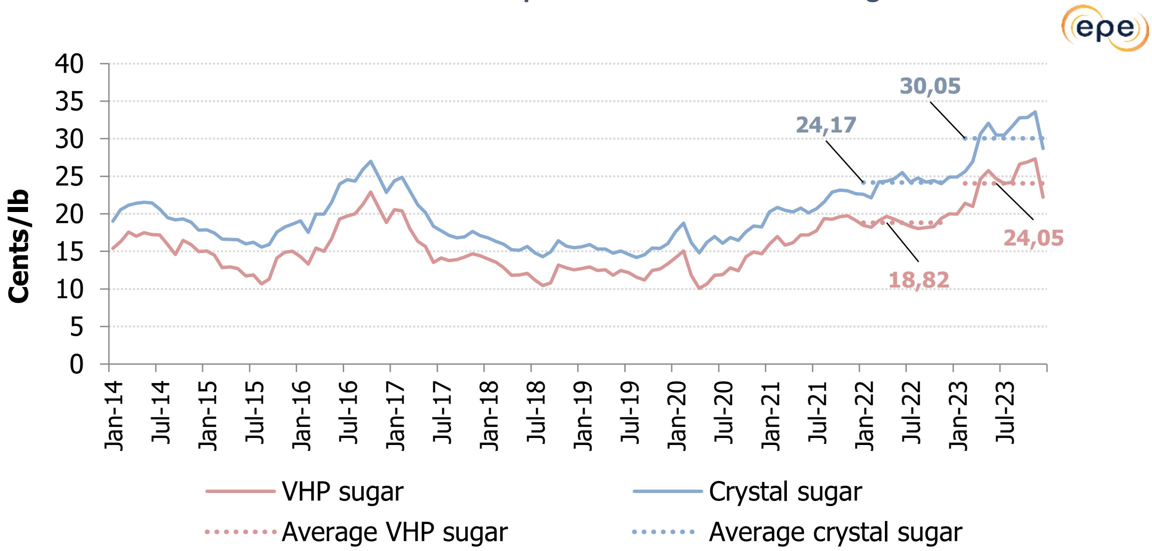
Chart 13 – Brazilian sugar production and exports



Source: EPE based on MAPA (2024).

Regarding the average prices of VHP and refined sugar, there was an increase of 27.8% and 24.3%, respectively, compared to 2022, as observed in Chart 14. Between January and December 2023, VHP and refined sugar prices rose by 11.4% and 15.3%, respectively, despite a decline in December. This trend is a result of maintaining global stocks at low levels (USDA, 2024b).

Chart 14 – International prices of VHP and refined sugar

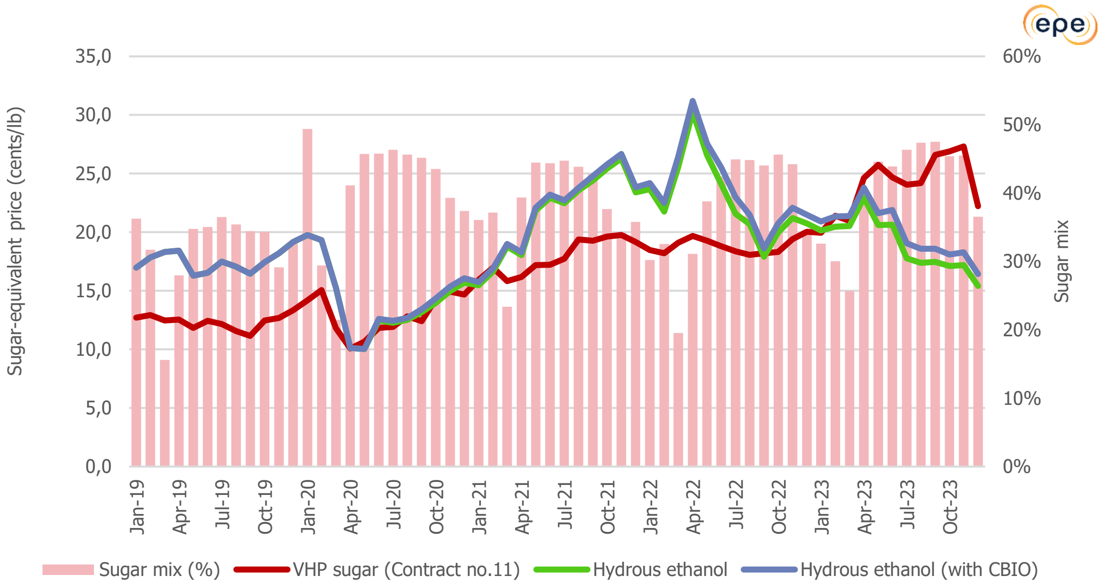


Note: VHP Sugar: Contract #11; Refined Sugar: Contract #5.

Source: EPE based on USDA (2024b)

The global sugar supply and demand balance has shown a deficit since the 2019/20 season, except for 2021/22, when there was a small surplus, with the stock-to-consumption ratio around 42% over the last four cycles. Since 2020, there has been a shift in the mix towards the production of sweeteners, driven by the rising price of sugar in the international market. In 2023, there was a significant divergence between the commodity's price and that of hydrous ethanol. The variation in market prices for sugar and ethanol (both with and without the contribution of CBIO) is presented in Chart 15.

Chart 15 – Mix and prices of sugar and hydrous ethanol (w/CBIO)



Note: The price of hydrous ethanol refers to the value in the domestic market (São Paulo), according to CEPEA/ESALQ (2024a).

Note: To determine the added value from CBIO, the financial value and quantity traded each month were considered, with an eligible volume of 90% and the average NEEA for May 2024. This value was added to the price of hydrous ethanol at the mill (São Paulo) (ANP, 2024b; CEPEA/ESALQ, 2024a).

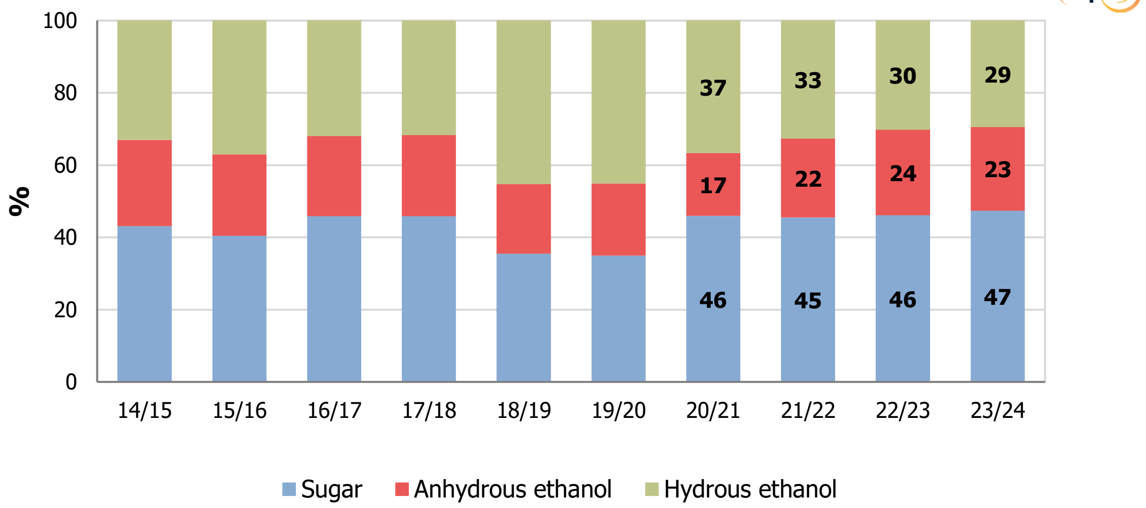
Source: EPE based on BC (2024), CEPEA/ESALQ (2024a), EPE (2024a), MAPA (2024), UDOP (2024) and USDA (2024b).

The global 2022/23 season experienced a supply/demand deficit of 100,000 tons of sugar, with a stock-to-consumption ratio of 41.9%. For the 2023/24 season, the expectation is a deficit of 1.6 million tons and a ratio of around 41.0%. Prospects for the next season (2024/25) indicate a slight surplus, based on production forecasts from major producers such as Brazil, Thailand, India, and the European Union (DATAGRO, 2024b).

1.6. Production mix

In 2023, the percentage of TRS allocated to ethanol production was 53%, 1.0 percentage point lower than in 2022, as shown in Chart 16. With the continued attractiveness of sugar in the international market, the allocation for sugar production reached 47%. It is noteworthy that Brazilian mills have consistently allocated the majority of TRS to ethanol throughout the analyzed period.

Chart 16 – Production mix (sugar vs. ethanol)



Source: EPE based on CONAB (2024a, 2024b) and DATAGRO (2024a).

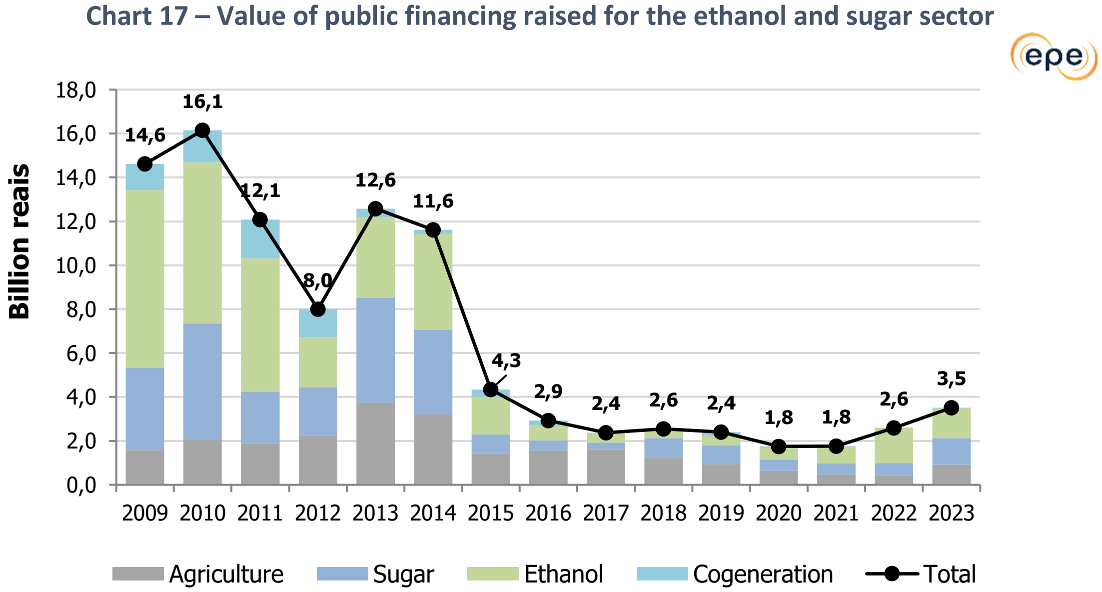
In the 2023/24 season, the remuneration for TRS in the state of São Paulo was R$ 1.203/kg TRS (CONSECANA, 2022), a slight decrease of 0.8% compared to the 2022/23 season.

1.7. Funding Mechanisms

The BNDES offers various financing lines for the ethanol and sugar production sectors, including RenovaBio, Finem, Finame, Fundo Clima, and Prorenova.

Chart 17 shows the total value contracted (current, in 2023 reais) by the ethanol and sugar sector with BNDES, including the agricultural component of sugarcane. In 2023, total investments through BNDES reached R$ 3.5 billion, nearly 40% higher than the previous year, continuing the growth observed in 2022. This amount represents 21.8% of the historical peak investment in the sector, which was R$ 16.1 billion in 2010.

Chart 17 – Value of public financing raised for the ethanol and sugar sector



Note: The ethanol sector includes the raw materials sugarcane, corn, and others

Source: EPE based on BNDES (2024a).

Launched in 2020, BNDES RenovaBio focuses on improving energy-environmental efficiency and certification for biofuel production units. Companies that achieve at least half of the target improvement in the "liters/CBIO" indicator will receive a reduction in the Bank's basic interest rate. The initial budget was R$ 2 billion, which has been increased to R$ 3.5 billion, with R$ 1 billion already approved for thirteen ethanol plants (BNDES, 2024b).

In another initiative for investments in the biofuel sector, the Ministry of Mines and Energy (MME) approved the issuance of incentivized debentures through Ordinance No. 252, dated June 17, 2019 (MME, 2019). With this instrument, companies can raise capital in the financial market to invest in renewing sugarcane plantations and their industrial facilities. By the end of 2023, 24 companies had their debenture issuances authorized by the MME, and approximately R$ 13 billion had been raised (MME, 2024a; NOVACANA, 2024a).

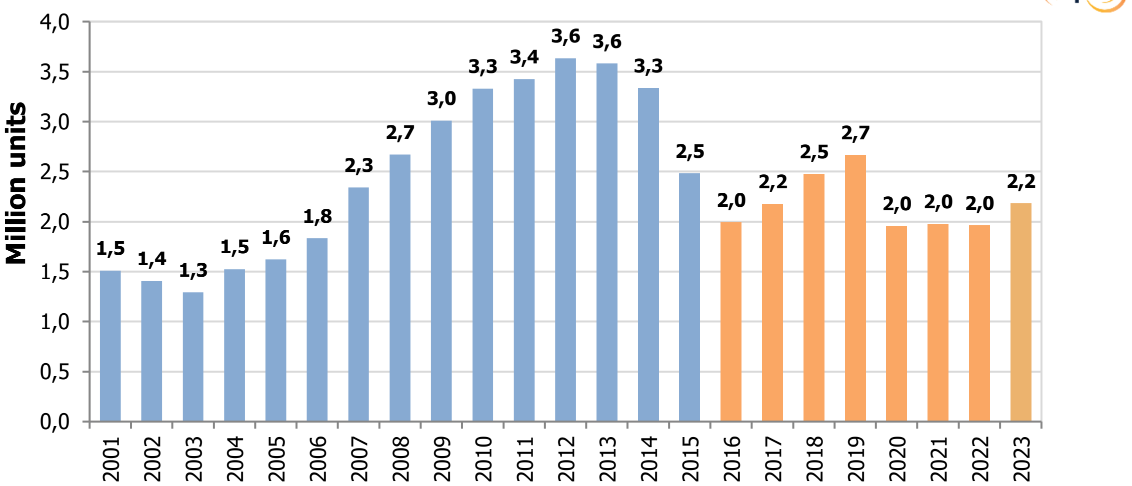
2. Otto cycle demand

The total energy demand of light Otto cycle vehicles in 2023 was 59.1 billion liters of gasoline equivalent (EPE, 2024). This represents a 6.6% increase compared to the previous year, continuing the growth trend observed in 2022. The licensing of light vehicles also saw an increase compared to 2022, as shown in Chart 15. This section will also provide a brief analysis of the economic situation to contextualize the macroeconomic and political environment affecting changes in the automotive sector in the country.

2.1. Licensing and fleet of light vehicles and motorcycles

In 2023, approximately 2.2 million new light vehicles were licensed in Brazil, marking an 11.2% increase compared to the previous year (ANFAVEA, 2023). Despite this growth, the number of new vehicle licenses has not yet returned to pre-pandemic sales levels, as shown in Chart 18.

Chart 18 – Light vehicle registrations



Source: EPE based on ANFAVEA (2023)

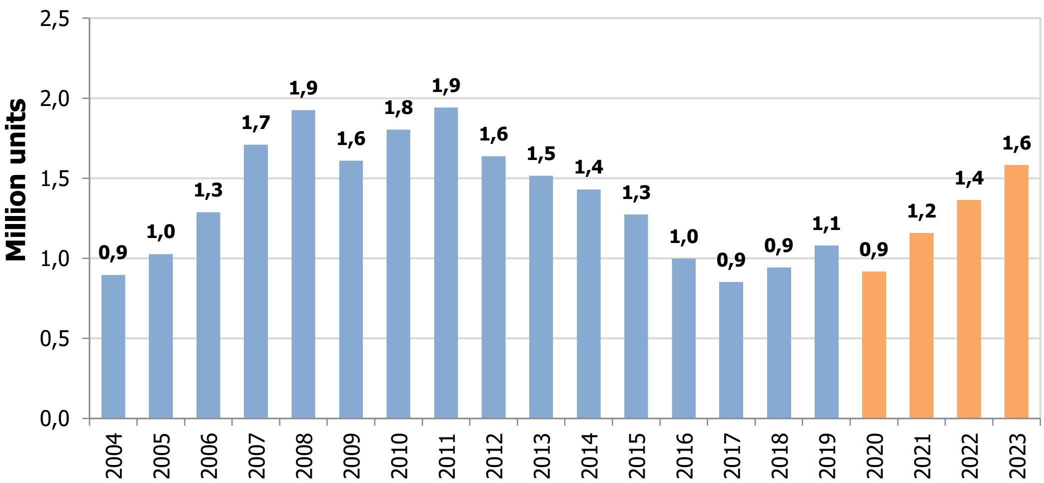
Of the total light vehicle licenses, 79% were automobiles and 21% were light commercial vehicles. In terms of fuel type, flex-fuel vehicles accounted for 83.0% of the total licenses, followed by diesel-powered vehicles with 9.9%. Gasoline-powered vehicles represented 2.8% of the licenses, while electrified vehicles (electric, hybrid, and plug-in hybrid) reached 4.3%, a significant increase from 2.5% in 2022. Regarding engine size, vehicles with engines up to 1.0 liters were licensed the most (54.9%), surpassing those with engines between 1.0 and 2.0 liters (43.2%) for the second consecutive year (ANFAVEA, 2023).

It is important to note that, among the total number of new vehicles licensed in Brazil, the share of vehicles purchased by rental companies has been increasing. According to a report by the Brazilian Association of Car Rental Companies (ABLA, 2024), these companies licensed 590,870 new models, which corresponds to 27.1% of all cars and light commercial vehicles licensed in Brazil in 2023. The sale of used vehicles in 2023 was 8.7% higher than in 2022, reaching 14.4 million units, and represented 86.2% of total vehicle sales (new + used). In contrast to 2022, there was a 3.5% increase in the sales of relatively new used vehicles (0 to 3 years) in 2023, reaching 2.2 million units. Similarly, there was a 9.6% increase in the sales of older used vehicles, reaching 12.2 million units (FENAUTO, 2024).

Regarding motorcycles, in 2023, nearly 1.6 million new units were licensed, a 16.1% increase compared to the previous year, according to data from FENABRAVE (2024). As shown in Chart 19, this marks a return to levels seen in 2012, consolidating a growing trend in motorcycle acquisitions, which has begun to emerge in the post-pandemic period.

The high price of light vehicles, coupled with the practicality of motorcycles in daily use, can be significant drivers of their increased acquisition. The rise in the number of delivery workers, especially since the pandemic, and the low maintenance and fuel costs of motorcycles also support this trend.

Chart 19 – Motorcycle registrations



Source: EPE based on ANFAVEA (2023)

Fleet

As a result of the licensing observed in recent years, the Brazilian fleet of Otto cycle light vehicles is estimated to having reached 39.7 million units, remaining at the same level as the previous year, with flex-fuel technology representing 84.5% of the total.

Regarding the motorcycle fleet, in 2023, it totaled 33.0 million units, showing a persistent growth trend since 2012. Regionally, there is a predominance of motorcycles in the Southeast region (38% in 2023). However, there is also an increase in the fleet in the Northeast region, reaching 29%. The Central-West and North regions each account for 10% (ABRACICLO, 2024).

The rental sector closed 2023 with a fleet of 1,570,820 light vehicles, surpassing the 1.5 million mark for the first time. This represents a 9.5% increase compared to the previous year. Additionally, of the 26,423 active rental companies in the country, 77% specialize in car rentals, while 23% focus on other means of transportation.

With the stagnation in the licensing of new vehicles in recent years, the aging process of the Brazilian fleet remains at high levels. In 2023, the average age of cars and light commercial vehicles was 10 years, while for motorcycles, it solidified at 8 years and 4 months (SINDIPEÇAS, 2024). Historically, over the past 10 years, there has been an increase of about 2 years in the average age of these vehicles.

2.1.1. Vehicle Licensing and Fleet Characterization

Electrified Vehicles

The number of electrified vehicles increased from 49,000 units in 2022 to 93,000 in 2023, representing a 90.7% rise in registrations. This year, as in 2022, the sales of this category of vehicles surpassed those of gasoline-powered ones by 64% (ANFAVEA, 2023). The sales of electrified vehicles grew in all regions of the country, with the Southeast leading, accounting for more than half of the total sales in Brazil. São Paulo stands out as the main state purchasing vehicles in this category (34.91% of the total), followed by Rio de Janeiro (7.35%) and Minas Gerais (6.83%).

Rental companies also increased their acquisitions of electric cars and light commercial vehicles, with an 81.6% growth compared to the previous year, totaling 8,426 units. These companies registered 19.6% of all licensed electric light vehicles, representing a significant share of the total.

In 2023, the price of electrified vehicles remained high compared to the average prices of entry-level internal combustion vehicles[8], with the lowest-priced models around R$ 125,000. However, 40 manufacturers currently offer 254 different models of electrified vehicles in the country, which increases the availability of these automobiles and intensifies competition among manufacturers (EPBR, 2023). The expected increase in the import tax on electric, hybrid, and plug-in hybrid vehicles, set to begin in January 2024, may be a factor explaining the increase in sales observed in 2023 (MDIC, 2023).

However, according to research led by various consultancies, there has been a shift in projections by manufacturers and companies in the electric vehicle sector: the share of these vehicles in the national market for cars and light vehicles is expected to increase by up to 26%. Additionally, there is a noticeable environment of positive expectations regarding market growth over the next five years, as evidenced by the significant investments made by major manufacturers in the country (FECOMBUSTÍVEIS, 2024a).

[8] In comparison, the cheapest electric vehicle in the country (R$119,990.00) is 54% more expensive than the average price of the cheapest conventional vehicles sold in Brazil (R$69,990.00) (FIPE, 2023).

On the other hand, the report released by AUTODATA (2024a) highlights challenges that must be overcome for the more pronounced adoption of these new technologies. Among them is the need for a domestic supply of key components for the national production of electric vehicles, such as batteries and their cells, which are predominantly produced in China. Another important issue is the lack of widespread charging infrastructure across the country, which hinders the broader adoption of these vehicles (AUTODATA, 2024b).

Despite the significant share of electrified vehicles in licensing in recent years, national peculiarities must be considered. The predominance of biofuels for powering light vehicles has contributed to a high and consistent level of renewability in the transportation matrix, reaching 23.8% in 2023 (EPE, 2024).

Economic Context

The vehicle financing market grew by 10% compared to 2022, which equates to 541,000 more financed units[9]. Most of the funds were directed towards the acquisition of used cars, which increased by about 7.6% (B3, 2024). Meanwhile, the availability of credit for financing new vehicles also saw growth compared to 2022, rising by 9% (ANEF, 2024).

The expansion of the financing market, along with the increase in vehicle registrations in 2023 and the rise in investments from major manufacturers in the country, may be associated with several macroeconomic and microeconomic phenomena and factors, such as: GDP growth; increased availability of credit; reductions in interest rates for vehicle purchases; and a decline in loan delinquency rates.

The country's Gross Domestic Product (GDP) grew by 2.9%, marking the third consecutive year of growth since the COVID-19 pandemic. From a demand perspective, this increase was significantly influenced by rising export rates (9.1%) and household consumption (3.1%) (IBGE, 2024a). Per capita GDP showed an even greater increase, growing by 7% compared to the previous year.

The SELIC rate, which is the benchmark interest rate for the Brazilian economy[10], was reduced in 2023[11]. Due to low inflation during the period, it resulted in one of the highest real interest rates applied globally. It's worth noting that high interest rates tend to divert investments towards financial applications rather than economic activities, impacting the overall economic outcome. Additionally, the interest rate serves as a basis for taking out loans. For example, the average interest rate for financing new and used vehicles also decreased throughout the year, dropping from 2.15% per month in January to 1.91% in December (BC, 2024), which could explain the increased economic activity in the country.

The exchange rate also shows a favorable trend, particularly regarding private investment. Although it remains high[12], it decreased by 3.3% compared to last year, reaching R$ 4.9/USD in December.

---

[9] Includes light and heavy vehicles, as well as motorcycles, both new and used.

[10] Due to this characteristic, it is the guiding rate for all interest rates in the country; that is, its movements—whether ascending or descending—tend to influence changes in all Brazilian interest rates.

[11] The COPOM (Monetary Policy Committee of the Central Bank of Brazil) reduced the SELIC rate by two percentage points from January to December 2023, ending the year at 11.65%.

[12] Since 2019, the nominal exchange rate (which is the most used by economic agents, as it represents the cost of one currency in relation to another) has been above R$4.00 in relation to the US dollar.

A major driver of GDP growth, the increase in household consumption can be significantly explained by improved credit conditions, growth in employment rates and real wages, and a reduction in inflation. Regarding employment levels, according to the PNADC (Continuous National Household Sample Survey – IBGE), 2023 showed the lowest unemployment rate in the country since 2015. In the last month of the year, the unemployment rate reached 7.4%, marking a significant decrease from the beginning of the year, when it was 8.4% in January. Compared to 2022, this rate dropped by 25%.

On the other hand, the level of delinquency in financing specifically for vehicle purchases was high in 2023, reaching a peak of 5.65% in May, close to the levels seen in 2013. However, this percentage decreased over the year, ending with an annual average of 5.19%.

Finally, there was a reduction in inflation levels, with the accumulated IPCA (Broad Consumer Price Index), which measures the price variation of a basket of products and services consumed by the population, closing the year at 4.62%, staying within the inflation target set by the National Monetary Council (CMN). This index is significantly lower than the 5.79% observed at the end of 2022.

Public Policies and Sector Investments

As part of Brazil's neoindustrialization project, the country is advancing with public policies aimed at reviving the development of the national industrial sector. This is demonstrated by the reimplementation of the import tax on electric vehicles and the creation of programs such as the National Green Mobility and Innovation Program, MOVER.

This new federal mobility program was enacted in June 2024, expanding sustainability and innovation targets for the automotive sector in the country, thereby providing greater confidence and attracting investments to the national territory. It succeeds other similar programs launched since 2010, such as Inovar-Auto (2012) and Rota 2030 (2018), which had already set goals that ensured national directions for the sector[13].

Among its objectives, MOVER mandates the expansion of the automotive industry's presence in the country, encourages the production of new technologies, promotes the use of biofuels and other sustainable, clean alternatives, and increases mandatory sustainability requirements for vehicles sold. A key innovation is the measurement of carbon emissions "from well to wheel," considering the entire lifecycle of the energy source used[14]. The program also includes the creation of the National Fund for Industrial and Technological Development (FNDIT). Additionally, it is a comprehensive policy that covers agricultural and road machinery.

Its guidelines could drive greater adoption of electric mobility and the use of biofuels such as ethanol and biodiesel. The main pillars include market regulation and the tax regime for vehicles, with clear goals for energy efficiency, material recyclability, accessibility, and the establishment of green taxation, among others. Additionally, it promotes investment in local R&D with tax benefits and encourages the industrial and technological development of auto parts and materials suppliers.

[13] Especially regarding the reduction of carbon emissions.

[14] There is also an estimate to expand this measurement by 2027 to include a "cradle to grave" analysis, covering the full lifecycle of the energy source used. This would include processes related to the production and disposal of vehicles and generation systems.

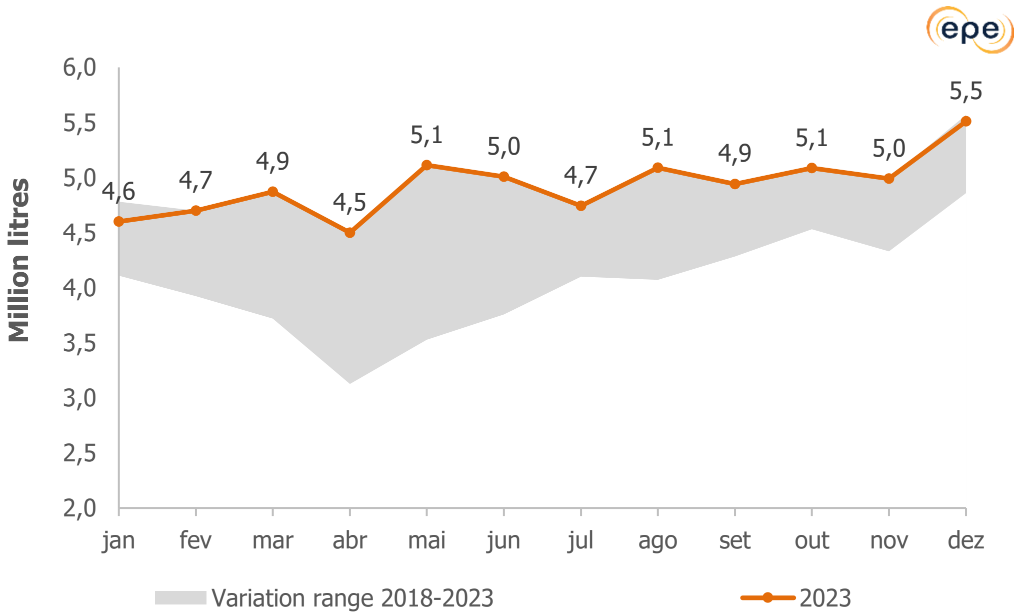
With this favorable political and macroeconomic environment (as analyzed above) encouraging and inducing local investment, some results of this combination are already observable. For instance, vehicle manufacturers are projecting investments on the order of R$95 billion for the 2021-2030 cycle (AUTODATA, 2024c). Similarly, the auto parts sector is also showing optimism, increasing its projections for 2024 by 3%, reaching approximately R$6.1 billion (VALOR ECONÔMICO, 2024).

2.2. Otto cycle fleet fuel demand

As previously mentioned, the total energy demand for light Otto cycle vehicles in 2023 was 59.1 billion liters of gasoline equivalent (EPE, 2024). This represents a 6.6% increase compared to the previous year, continuing the growth trend observed in 2022. As explored in the previous section, macroeconomic indicators point to a resurgence in national productive activities, indicating that the negative effects of the post-pandemic period are becoming increasingly distant.

The exemption from PIS/Pasep and Cofins for gasoline and ethanol, which was originally set to last until December 2022[15], was extended until February 2023 through Provisional Measure No. 1,157/2023 (BRASIL, 2023a). Subsequently, Provisional Measure No. 1,163/2023 established the partial reinstatement of these taxes until June of the same year (BRASIL, 2023b). From July onwards, the full collection of federal taxes was resumed. Meanwhile, ethanol prices decreased, while gasoline prices increased by 6.8% between January and December 2023. However, compared to the average prices in 2022, gasoline type C saw a decrease of 12.8%, and hydrous ethanol dropped by 19.2%, as will be detailed in the next chapter. Despite the reinstatement of taxes and the rise in gasoline prices throughout 2023, the demand for both fuels continued to grow, albeit with different shares. The monthly demand trend in 2023 compared to the five-year average can be observed in the chart below. Further details on the impacts on final fuel prices are discussed in Section 3 of this document.

Chart 20 – Otto cycle demand – range variation from the last 5 years vs. 2023

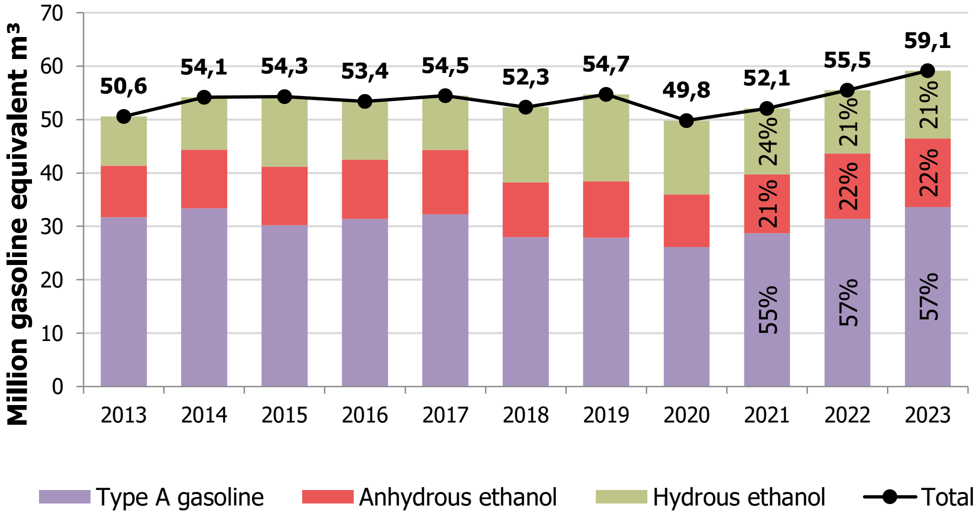


Source: EPE based on EPE (2024a) and MAPA (2024)

[15] Provisional Measure No. 1,118/2022 (BRASIL, 2022c), later converted into Complementary Law No. 194/2022 (BRASIL, 2022b).

The energy distribution remained nearly constant across all fuels, with gasoline type A at 57%, anhydrous ethanol at 22%, and hydrous ethanol at 21%. As a result, total ethanol fuel maintained its 43.2% share in 2023, sustaining the renewability of the Otto cycle matrix (EPE, 2024), as shown in Chart 21. The reasons for this behavior will be explored in greater detail in the next section of this document.

Chart 21 – Otto Cycle demand and share of different fuels

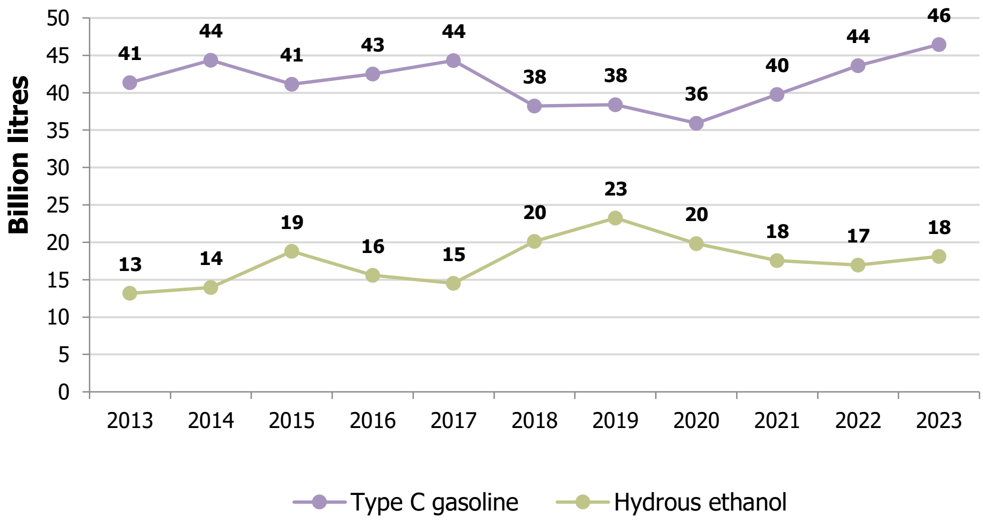


Note: The demand data exclude the portion related to CNG (Compressed Natural Gas).

Source: EPE (2024).

The demand for hydrous ethanol in 2023 totaled 18.1 billion liters, representing a 6.9% increase compared to the previous year, while the consumption of gasoline type C reached 46.5 billion liters, 6.5% higher than observed in 2022 (EPE, 2024), as illustrated in Chart 22.

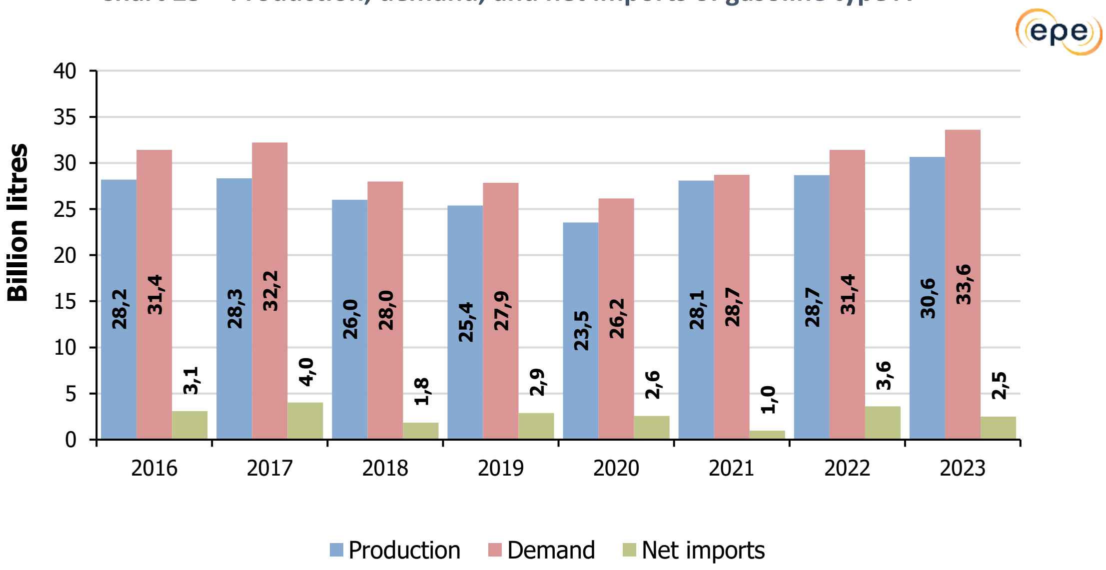
Chart 22 – Annual demand for hydrous ethanol and gasoline type C



Source: EPE based on EPE (2024a).

Chart 23 shows the evolution of demand, production, and net imports of gasoline A for the period 2016-2023.

Chart 23 – Production, demand, and net imports of gasoline type A



Source: EPE (2024a).

In 2023, the national demand for gasoline type A increased by 6.9% compared to the previous year, reaching 33.6 billion liters, and its production also grew by 6.9%, reaching 30.6 billion liters. The trade balance for gasoline type A showed a net import of 2.5 billion liters, a 30% reduction compared to the previous year (EPE, 2024). The amount of oil processed at refineries grew by 3.5% compared to 2022 (ANP, 2024c). While the demand for fossil diesel increased by 1.8%, its production by the national refining sector grew by 3.8% (more details in Chapter 6).

3. Economic Analysis

The year 2023, continuing the trend from the previous year, maintained the economic recovery following the COVID-19 pandemic. As highlighted in Chapter 2, many indicators showed an improvement in the country's macroeconomic environment, leading to increased investments and higher demand in the transportation sector from all economic agents.

For the analyses in this chapter, the reference prices are considered at constant December 2023 values, weighted by volume.

3.1. Otto cycle fuel prices

In 2023, the fuel tax burden underwent changes in the measurement of ICMS[16] rates on fuels. These changes, initially proposed in 2022 through Complementary Law No. 192 and later by Complementary Law No. 194, began to take effect in March 2023, standardizing ICMS values across the entire country. These changes will be further explored in section 3.2.

[16] As is customary, the National Council for Financial Policy (Confaz) publishes the Reference Prices for Fuels each month, establishing the Weighted Average Price to the Final Consumer (PMPF), which serves as the basis for ICMS tax collection.

In 2022, PIS/Pasep, COFINS, and CIDE were reduced to zero starting in the second half of the year, leading to a decrease in average fuel prices. In March 2023, a Provisional Measure was enacted that partially[17] reinstated these contributions until the end of June. From the second half of the year onwards, the full collection of these federal taxes was resumed.

Observing the price trends throughout 2023, there was a 6.8% increase in the average price of gasoline between January and December, while ethanol showed a decrease of 12.8% over the same period. Consequently, the absolute price difference between gasoline type C and hydrous ethanol widened from R$1.22 in December 2022 to R$2.09 in December 2023. When comparing the annual average prices of gasoline C and hydrous ethanol between 2022 and 2023, decreases of 12.8% and 19.2%, respectively, were noted, even with the reinstatement of taxes. The combined data reveal an average ratio of 68% between the price of hydrous ethanol and fossil fuel in 2023, which favors the consumption of the biofuel, a topic that will be explored further throughout this chapter.

As described in Item 1, this year saw a record in sugarcane crushing and sugar production at sugar-energy mills across the country. This phenomenon was driven by favorable climatic conditions. Corn ethanol production continues its growth trajectory, surpassing the previous year's output by approximately 40%, positioning itself as an increasingly significant alternative in the Brazilian biofuel market.

As in 2022, sugar maintained its attractiveness in the international market. Major exporters like India and Thailand experienced reduced harvests, leading to a decrease in global sugar supply. This, coupled with the decline in ethanol prices in the domestic market, prompted mills to prioritize sugar in their production mix.

In May 2023, Petrobras revised its international price parity policy, which previously tied domestic prices to those in the global market[18]. With this change, the company adopted a new pricing strategy that, while still considering international prices, also incorporates other indicators for valuation[19]. This shift allows Petrobras to set more competitive prices in the market, granting the state-owned company greater autonomy.

With the new policy adopted by Brazil's main gasoline and diesel producer, fuel prices remain highly dependent on the company's movements. Throughout 2023, the retail price of gasoline type C, adjusted to December 2023 constant values, experienced fluctuations, ending the year with an increase of approximately 6.8% (ANP, 2024h; IBGE, 2024a). These fluctuations also reflect economic uncertainties stemming from the U.S. economic slowdown and China's economic growth, as well as ongoing impacts from the conflict in Ukraine, which affect international commodity prices, including gasoline. The reinstatement of taxes on these fuels outweighed the impact of these factors on pricing, contributing to the price increase.

[17] The same Provisional Measure that reintroduces taxes on fuels also sets new values for PIS and COFINS for the sale and import of gasoline and ethanol. For gasoline, PIS is set at R$ 83.84/m³ and COFINS at R$ 386.16/m³, totaling R$ 0.47 per liter. For ethanol, there are three different charging schemes: producers and importers pay R$ 3.60/m³ for PIS and R$ 16.40/m³ for COFINS, while cooperatives pay R$ 1.64/m³ for PIS and R$ 7.53/m³ for COFINS (BRASIL, 2023b). However, the CIDE charged on gasoline remained at zero until the second half of 2023.

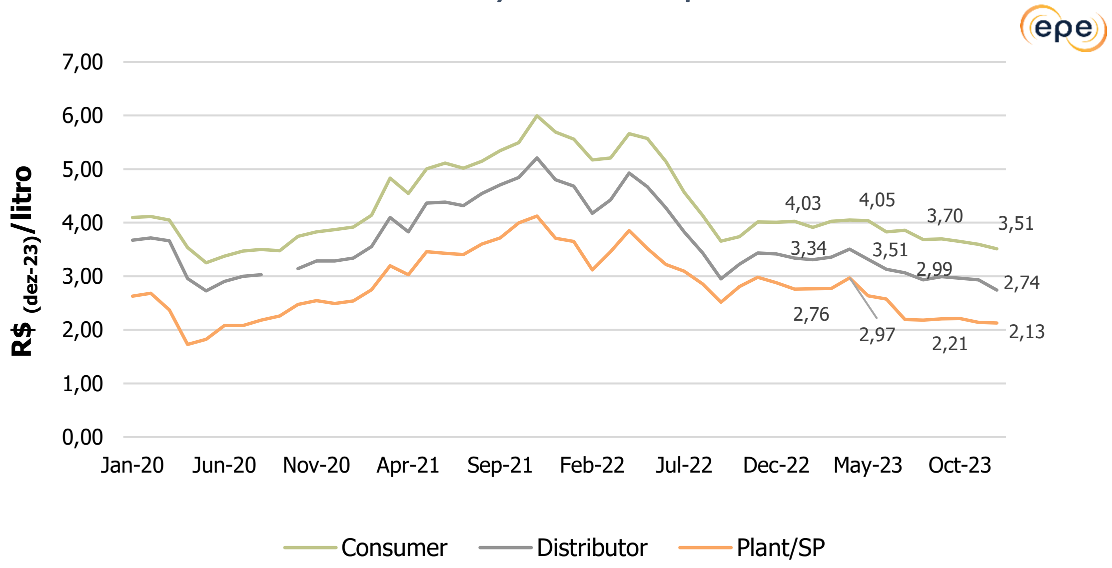
[18] The price of gasoline and diesel sold by Petrobras to distributors was determined by import and logistics costs, considering the exchange rate of the dollar and the price of Brent crude oil.

[19] According to Petrobras, the new model now considers what is referred to as the "alternative cost to the customer," which looks at other suppliers of the same and/or similar products. It also considers the "marginal value to the company" to safeguard its production, import, and export conditions (PETROBRAS, 2023a).

Thus, with a 6.6% increase in the Otto cycle fuel demand compared to the previous year, the consumption of hydrous ethanol rose by 6.9%, while the consumption of gasoline type C increased by 6.5% (EPE, 2024).

Chart 24 presents a comparison of the average prices of hydrous ethanol for consumers (Brazil), at distributors (Brazil), and at mills (São Paulo), weighted by volume and adjusted for inflation using the IPCA to reflect constant December 2023 values.

Chart 24 – Hydrous ethanol prices



Source: EPE based on ANP (2024c) and CEPEA/ESALQ (2024a).

In 2023, the difference between the maximum and minimum prices of hydrous ethanol to consumers (recorded in April and September, respectively) was R$0.54 per liter. This difference was significantly smaller than that observed in 2022 (R$2.00 per liter) and even smaller than that in 2021 (R$2.08 per liter), resembling the values seen in 2020 (R$0.89 per liter).

The price of hydrous ethanol, in constant terms (December 2023), returns to levels observed before the pandemic and prior to the conflict in Ukraine, when the liter of the biofuel cost less than R$4.00 on average. This reduction can be attributed to the record increase in sugarcane milling and the rise in ethanol[20] production in the country, as well as the gradual reintroduction of taxes throughout 2023.

Comparing month by month between 2023 and 2022, the maximum difference in resale margin occurred in July, reaching R$0.77 per liter (about 25% lower than in 2022). Notably, the average annual resale margin for hydrous ethanol in 2023 was R$0.69 per liter, 7.8% below the average observed in 2022 (R$0.75 per liter)[21]. Conversely, the average distribution margins reached R$0.67 per liter, a reduction of 15.3% compared to 2022.

The annual average prices of hydrous ethanol and gasoline type C for consumers, weighted by volume and in constant values, are shown in Table 1, along with the relative price (EP/GP) and their respective variations.

[20] Not only derived from sugarcane, but also from corn, as noted in Chapter 1.

[21] In constant December 2023 values.

Table 1 – Annual average prices of hydrous ethanol, gasoline type C, and relative price (EP/GP)

Year	Hydrous (R$dez23/l)	Var. (% p.a.)	Gasoline type C (R$dez23/l)	Var. (% p.a.)	EP/GP	Var. (% p.a.)
2014	3.51	-1.1	5.10	-1.9	0.69	0.8
2015	3.51	0.1	5.26	3.2	0.67	-2.8
2016	3.79	8.0	5.33	1.3	0.71	6.3
2017	3.71	-2.0	5.26	-1.4	0.71	-0.4
2018	3.90	5.0	5.92	12.7	0.66	-6.7
2019	3.77	-3.3	5.68	-4.0	0.66	0.6
2020	3.40	-10.0	4.93	5.58	0.69	3.9
2021	4.95	45.7	6.73	36.5	0.73	6.1
2022	4.70	-5.1	7.02	4.4	0.73	0.3
2023	3.79	-19.2	5.58	-12.8	0.68	-7.3

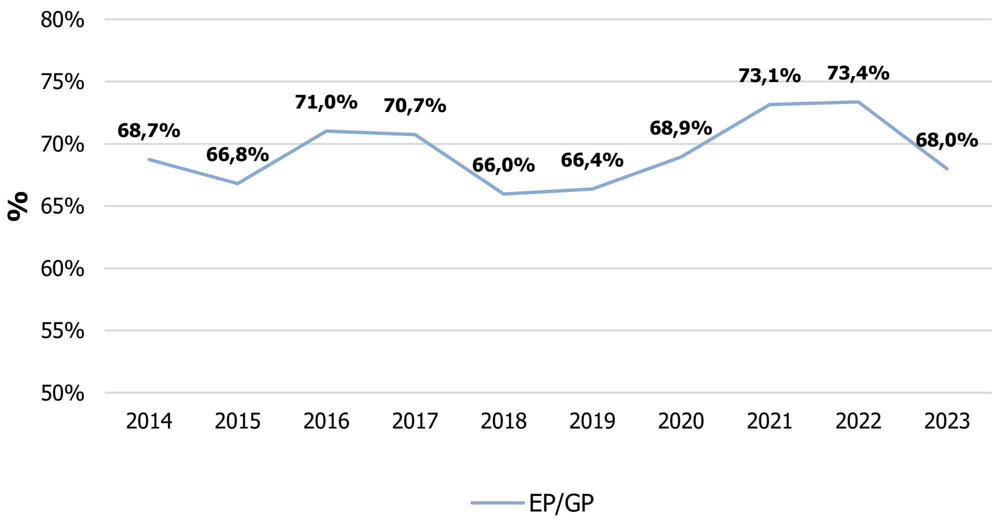
Note: The prices were weighted by volume and deflated by the IPCA, relative to December 2023.

Source: EPE based on ANP (2024c); BC (2024).

Throughout 2023, the price of hydrous ethanol followed a similar trend to that of gasoline type C, showing somewhat more pronounced variations but in a manner consistent with previous years. Its average retail price was R$ 3.79 per liter, a decrease of 19.2% compared to 2022, while gasoline type C dropped by 12.8%, reaching R$ 5.58 per liter. Consequently, the average relative price (EP/GP) for 2023 decreased to 0.68, below the threshold value (0.70), which is more favorable for the consumption of hydrous ethanol.

Chart 25 illustrates the variation in the annual average relative price (EP/GP) since 2014.

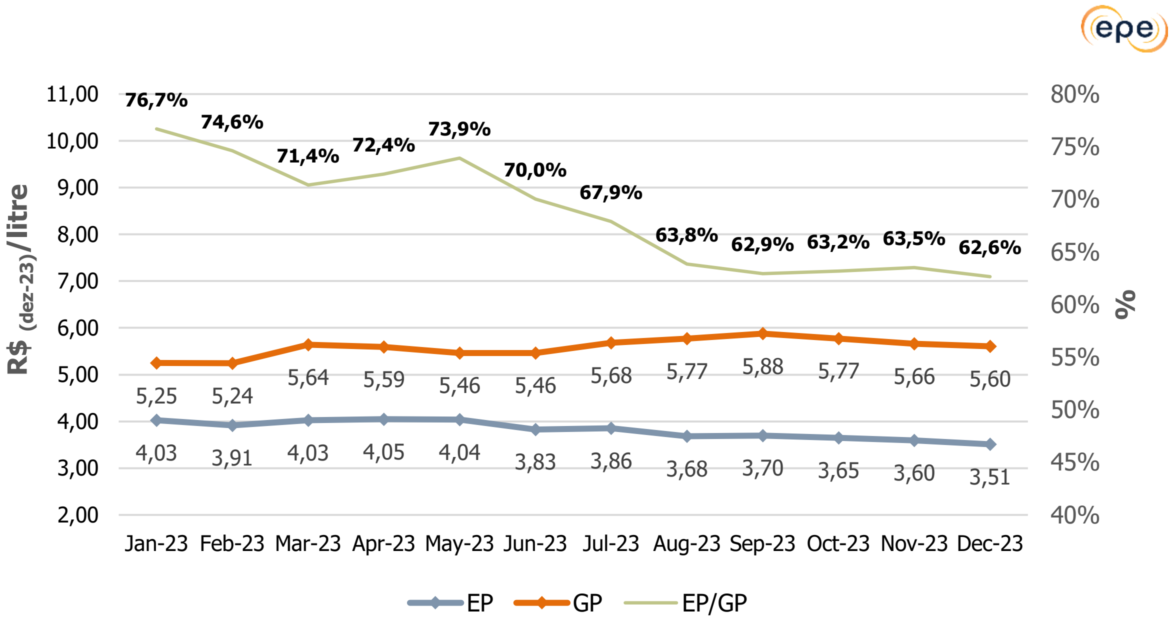
Chart 25 – Price ratio between hydrous ethanol and gasoline type C (EP/GP)



Source: EPE based on ANP (2024c).

The monthly analysis conducted throughout 2023 indicates that, starting from July, hydrous ethanol became competitive, reaching even more favorable levels for its acquisition, as shown in Chart 26. This year, more states exhibited favorable EP/GP ratios for the consumption of the biofuel compared to the previous year. In 2022, only SP, GO, MT, and MG showed positive values for ethanol. In 2023, the list expanded to include the six largest ethanol-producing states in the country—SP, GO, MT, MS, MG, and PR—which together represent 39%, 15.5%, 15%, 11%, 9%, and 3.5% of total production, respectively, as well as Ceará. Although Ceará does not have a history of ethanol production, the favorable PE/PG ratio in this northeastern state can be explained by the high gasoline prices at local stations, making ethanol a more advantageous option by comparison.

Chart 26 – EP, GP and monthly EP/GP ration in 2023



Source: EPE based on ANP (2024c).

3.2. ICMS in Otto cycle fuels

In March 2022, Complementary Law No. 192 was enacted, modified by Provisional Measure 1.118/2022 (BRASIL, 2022a), which defines the fuels subject to changes in ICMS incidence and the details of these changes. These changes include, among other points, a uniform tax rate across the entire national territory and the establishment of a fixed rate per unit of measure (liter for diesel, gasoline, and anhydrous ethanol; and kilogram for LPG)[22]. It is important to recall that, as noted in previous reports, the tax was previously charged as a percentage, varying between 17% and 22% (EPE, 2023). Although published in 2022, its implementation only took effect in the following year, in March 2023.

[22] This incidence measure is called an *ad rem* rate. Prior to this law, the tax collection model was *ad valorem*, which consisted of a percentage based on the average distribution price of fuels at gas stations.

More recently, in March 2023, the National Council of Tax Policy (Confaz) established ICMS Convention No. 12, which addressed the monophase tax regime[23] to be applied to transactions involving gasoline type A, anhydrous ethanol fuel, and diesel. The increase resulting from the application of new rates was set to begin only in the second semester due to the noventena[24]. As mentioned, the tax incidence will be ad rem, uniform across the entire national territory, and will be calculated regardless of the purpose of the transactions, even if initiated abroad (CONFAZ/MF, 2024b).

Starting in 2023, all tax changes, which are now determined by Confaz rather than by each state individually, led to an increase or stabilization in ICMS rates on gasoline and ethanol for most federal entities. Regarding gasoline, since June 2023, all states have had the same "ad rem" value of R$1.22/liter, which remained until December of the same year. When comparing this value with those practiced up to the last month before the new tariff mode came into effect (May 2023), some states saw a reduction in ICMS on gasoline: Alagoas, Amazonas, and Piauí. All other states experienced an increase in the valuation percentage (EPE, 2024).

However, still in October, the Council approved new changes to the rates: for gasoline, the ICMS will increase by R$0.15, reaching R$1.37 per liter; for diesel, the increase will be R$0.12, reaching R$1.06 per liter. These latest changes took effect from February 2024.

Regarding ethanol, when comparing values from May 2023[25] with those from 2022, five states showed an increase in the tax on the biofuel: Acre, Alagoas, Amazonas, and Tocantins, with an increase of 2%, and Sergipe with 5.7%. For the calculation of the second half of the year, with the implementation of the new tariff model on gasoline, a larger number of states showed an increase in the ethanol tax: eleven states ended the year with higher values than those seen in May (Acre, Alagoas, Amapá, Minas Gerais, Pará, Paraíba, Rio Grande do Norte, Rondônia, Roraima, Sergipe, and São Paulo).

The average *ad rem* ICMS value for common gasoline during the year 2023 was R$1.12 per liter. Although hydrous ethanol continues under the *ad valorem* regime, when calculating the tax on hydrous ethanol in an isonomic manner, the average corresponding *ad rem* ICMS value for the biofuel was R$0.68 per liter throughout the year 2023.

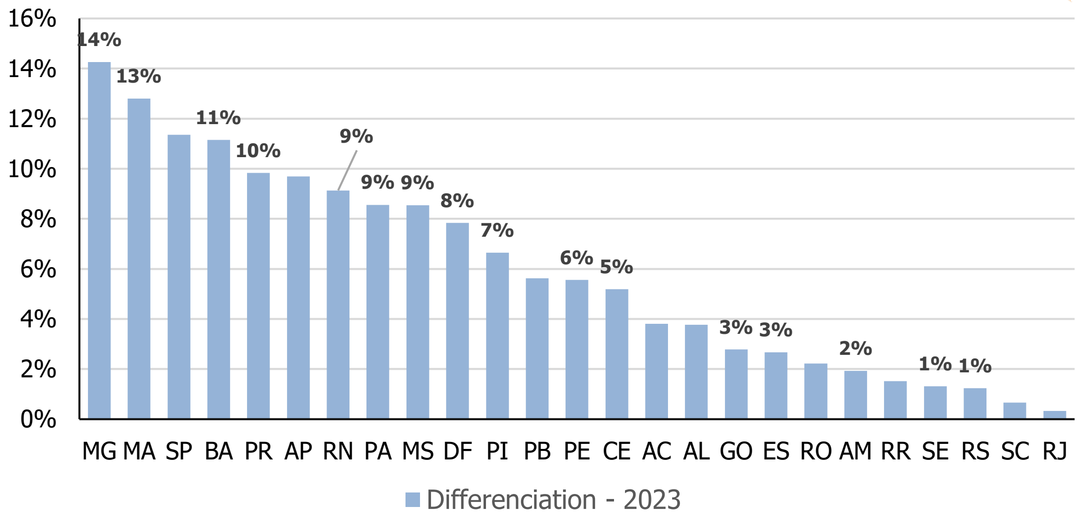
Chart 23 shows the differentiation of the *ad rem* rates for gasoline and ethanol, which were in effect throughout the second half of 2023.

[23] Tax incidence at a single stage of the fuel supply chain.

[24] The noventena is a period during which, according to the Constitution, entities can only begin collecting taxes 90 days after the publication of the instituting law.

[25] May 2023 was selected due to the start of the *ad rem* rate for gasoline from June of the same year, as detailed in the previous paragraphs.

Chart 27 – Tax differentiation - ICMS "ad rem" (*) (Gasoline type C vs. hydrous ethanol) 2023



Source: FECOMBUSTIVEIS (2024b) and CONFAZ/MF (2024a; 2024b).

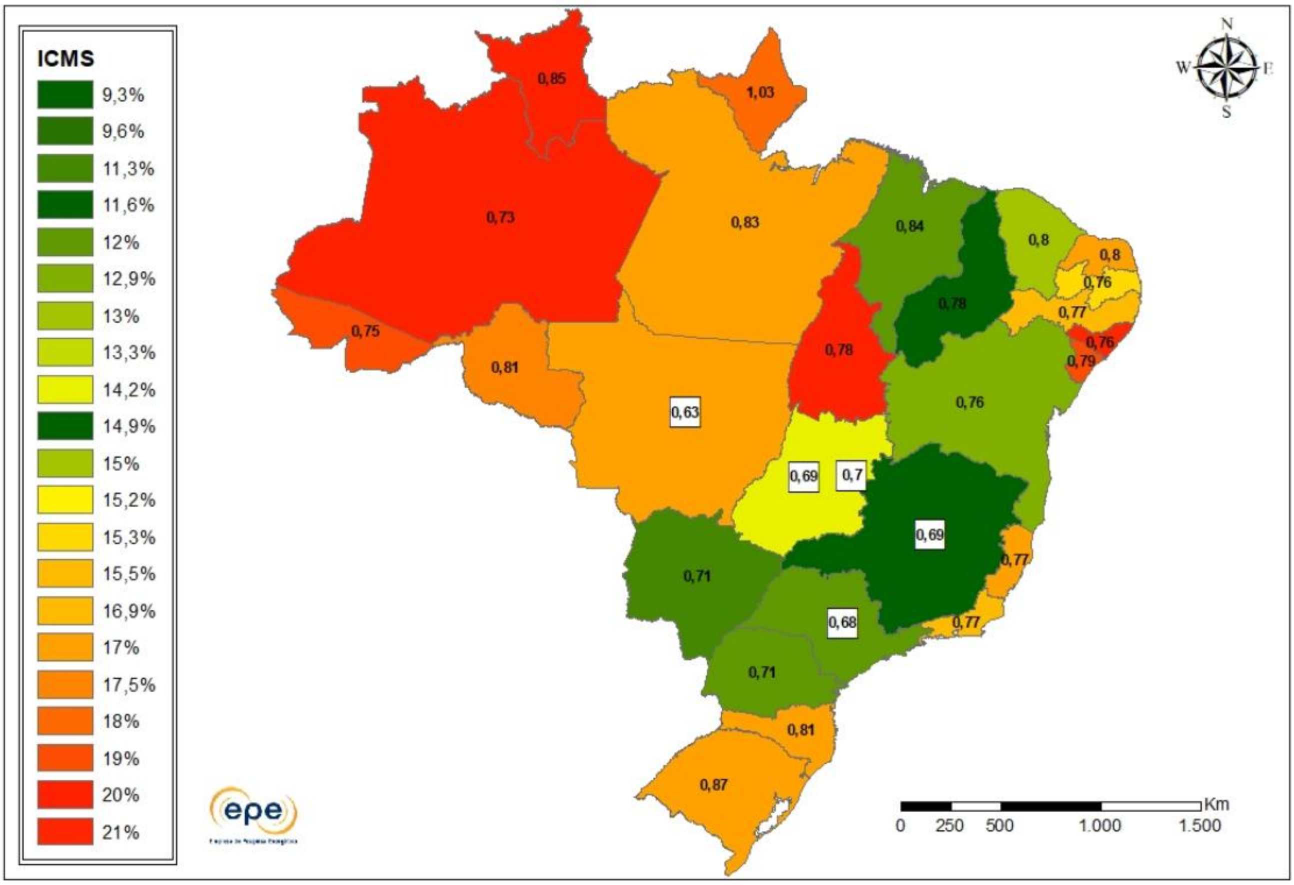
(*) This calculation was performed using the *ad rem* values divided by the most recent PMPF for gasoline in May 2023 (the last month of PMPF for gasoline type C) and compared with the ICMS values for ethanol, which were obtained in a similar manner.

It can be observed from Chart 23 that the three states with the greatest tax differentiation between ethanol and gasoline in the "pre-ad rem rate" period—Minas Gerais, São Paulo, and Maranhão—remain the leaders in variations between the two fuels. Since this is a relatively recent change, it is not yet possible to observe significant differentiation in taxation[26].

Figure 1 illustrates the relationship between ICMS taxation and the competitiveness of hydrous ethanol in Brazilian states in 2023.

[26] The frequency of changes to the PMPF (Weighted Average Consumer Price) remains biweekly, excluding gasoline type C and diesel, whose last PMPF was published at the end of May 2023, according to CONFAZ/MF (2024b). The PMPF is significant as it serves as the basis for calculating ICMS.

Figure 1 – ICMS rate for ethanol and EP/GP ratio by State in 2023



Source: EPE based on ANP (2024c), CONFAZ/MF (2024a) and FECOMBUSTÍVEIS (2024b).

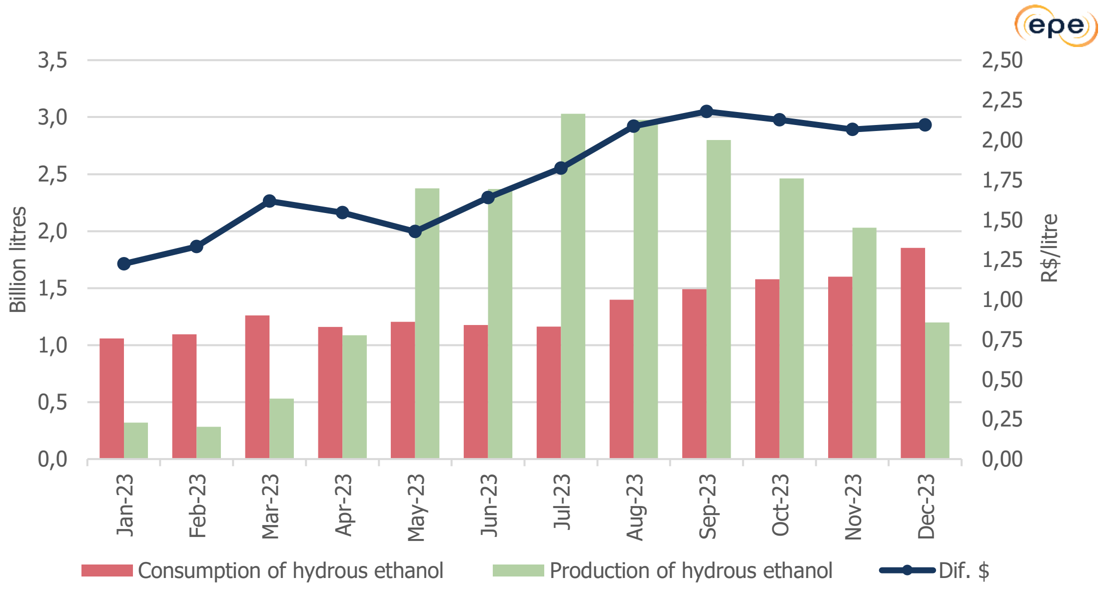
In 2023, the average PE/PG ratio for Brazil was 68%. The state of Mato Grosso had an annual average ratio of 62%, remaining the lowest in the country. In São Paulo, the largest producer and consumer[27], the average ratio was 67% (the ICMS rate for ethanol was the third lowest nationwide, at 12%). The least competitive states continue to be Amapá and Rio Grande do Sul, where the price of hydrous ethanol reached, on average, 103% and 86% of the price of gasoline C, respectively. Roraima, with a ratio of 84%, is the third state with the least advantage for hydrous ethanol. In all three states, the price of the fossil fuel remained below that of the biofuel every month of the year. The national average price in 2022 was R$ 6.02, while in 2023, it decreased to R$ 5.50. Similarly, for ethanol, the average price was R$ 4.41 in 2022, dropping to R$ 3.73 in 2023.

Special Topic on Hydrous Ethanol Prices

In addition to the price ratio between gasoline type C and hydrous ethanol serving as an indicator to guide consumers in choosing between these fuels, the price differential is also significant. Chart 28 compares the difference in prices (GP-EP) with the monthly production and consumption of hydrous ethanol.

[27] São Paulo accounted for 38.7% of the national production and 35.7% of the consumption of both anhydrous and hydrous ethanol in Brazil, in 2023 (MAPA, 2024).

Chart 28 – Difference between gasoline type C and hydrous ethanol prices | Ethanol fuel production and consumption – Brazil

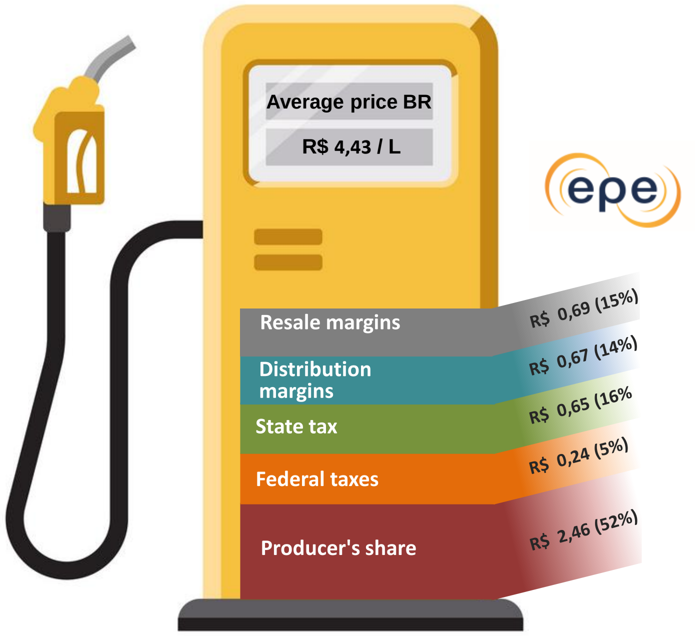


Source: EPE based on ANP (2024c).

According to economic theory, the prices of a product are determined by the balance between supply and demand. However, Chart 28 presents a higher degree of complexity by incorporating supply (production), demand (consumption), and not the price of the biofuel itself, but the difference between the price of regular gasoline and the price of hydrous ethanol. Given that the hydrous ethanol market consists of millions of consumers but only thousands of distributors and just over three hundred producers, price formation power tends to be in the hands of the latter. Thus, with other conditions being equal, or "ceteris paribus," an increase in production brings more ethanol to the market, which exerts downward pressure on the biofuel prices, leading to an increased PG-PE difference. It has been noted that it takes one to two months for increased hydrous ethanol production to impact prices. Specifically, the rise in production from April 2023 only began to affect ethanol prices starting in June 2023. Additionally, the price of gasoline C increased in July of the same year, as shown in Chart 26. On the other hand, according to economic theory, lower prices attract higher consumption. Thus, a larger price difference tends to promote the consumption of hydrous ethanol, as shown by the periods from August 2023 to December 2023. In summary, higher production tends to lower the price of the biofuel, which in turn increases the price difference. Consequently, a greater GP-EP price difference tends to encourage higher ethanol consumption.

As highlighted in the sections on ICMS, taxes, as well as distribution and resale margins, are significant components in the formation of the hydrous ethanol price. Figure 2 illustrates the price formation of hydrous ethanol for Brazil on average for the year 2023.

Figure 1 – Consumer price formation of hydrous ethanol in Brazil in 2023



Source: EPE based on ANP (2024c) and CEPEA/ESALQ (2024a).

Figure 2 records the average price of hydrous ethanol for the national market at R$ 4.43 per liter. The largest portion of this price is the producer's share, accounting for about 52% of the final average price, or approximately R$ 2.48 per liter. Federal taxes (PIS and Cofins) and state tax (ICMS) make up about 5% and 16% of the final price, respectively, or R$ 0.24 and R$ 0.65 per liter, on average nationally. As previously shown, distribution and resale margins accounted for 14% and 15% of the final average price, respectively, or R$ 0.67 and R$ 0.69 per liter. In comparison to the average price structure of regular gasoline, hydrous ethanol has lower federal and state taxes (around 21% for ethanol versus about 35% for regular gasoline) and higher resale and distribution margins (approximately 31% for ethanol compared to about 16% for the fossil fuel). Finally, the producer's share is higher for ethanol (52% compared to 35% for regular gasoline), with gasoline C also including an anhydrous ethanol component that represents about 14% of the final price of the petroleum derivative (EPE, 2023; ANP, 2024c; PETROBRAS, 2024b; BRASIL, 2023b).

4. Production Capacity and Ethanol Supply Chain

4.1. Production Capacity

In 2023, two sugar-energy plants were established, with no reactivations[28] or shutdowns. By December, there were 360[29] operational units corresponding to an effective milling capacity of approximately 870 million tons (MAPA, 2024). With a milling of 713 million tons, the industry's occupancy rate for the year was 82% of this capacity.

[28] In the current accounting, three units producing aguardente and/or ethanol for other uses are considered. Units producing non-cane-derived ethanol and those that were shut down and resumed operations within the same calendar year are not included.

[29] This total includes the corn ethanol flex units.

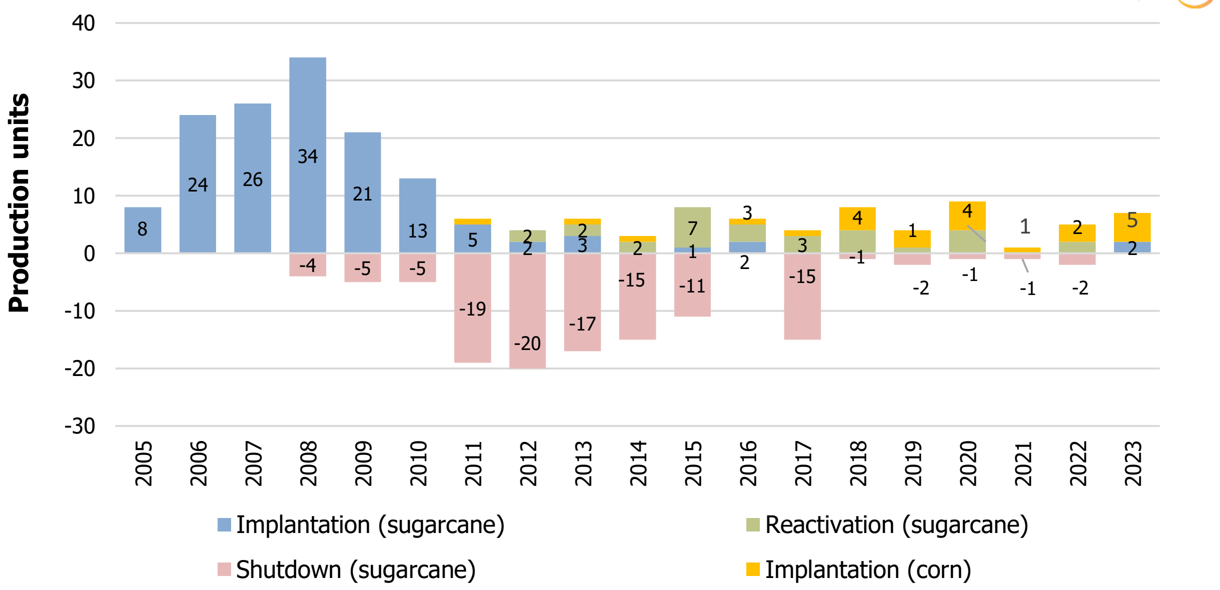
Regarding corn ethanol, in 2023, there were 24 operational units (13 full and 11 flex). The total processing capacity was 18.3 million tons per year, with an ethanol production capacity of 7.1 billion liters. Four new plants were established during the year.

There are still three units producing ethanol from cereals (excluding corn) and soybeans, with one of these units starting operations in 2023.

Considering these inputs for ethanol production, there were a total of 387[30] ethanol production units in operation as of December 2023.

Chart 29 shows the flow of ethanol production units between 2005 and 2023. Regarding sugarcane mills, many began operations between 2005 and 2010, but several ceased operations by 2017. Since then, some units have been reactivated, and only two new plants have been established. The nominal milling capacity of sugarcane is estimated to having increased by approximately 166 million tons over the period, considering the units installed, deactivated, and reactivated. The entry of corn ethanol plants began in 2011 and gained significance from 2018, with a growing trend since then, becoming important for national capacity. More recently, projects using other cereals, such as wheat, and soybeans have emerged as additional options for biofuel supply.

Chart 29 – Progression of sugarcane and corn ethanol plants in Brazil



Note: Units using soybeans and other cereals as raw materials are accounted for along with those using corn.

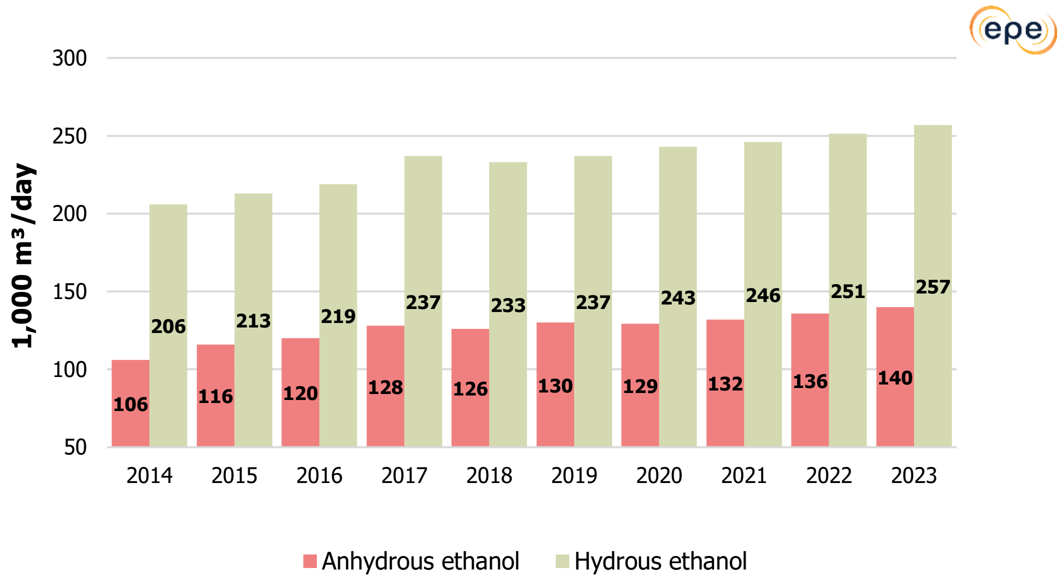
Source: EPE based on MAPA (2024) and UNICA (2014).

Additionally, there were 19 requests[31] for the construction of new plants, which will add a capacity of 6,900 m³/day for anhydrous ethanol and 8,600 m³/day for hydrous ethanol. There were also 49 units indicating plans to expand their production capacity for these biofuels (ANP, 2024a). Chart 30 shows the evolution of installed ethanol production capacity in Brazil since 2014, highlighting an increase of 51,000 m³/day for hydrous ethanol and 34,000 m³/day for anhydrous ethanol.

[30] There are also six small-scale units that produce ethanol from rice, potatoes, and other residues.

[31] The authorizations include units for ethanol production from sugarcane (five units, with three already operating and producing sugar, ethanol for other uses, and/or aguardente), corn (eleven units), wheat (one unit), and cereals (two units) (ANP, 2024a).

Chart 30 – Evolution of installed ethanol production capacity in Brazil



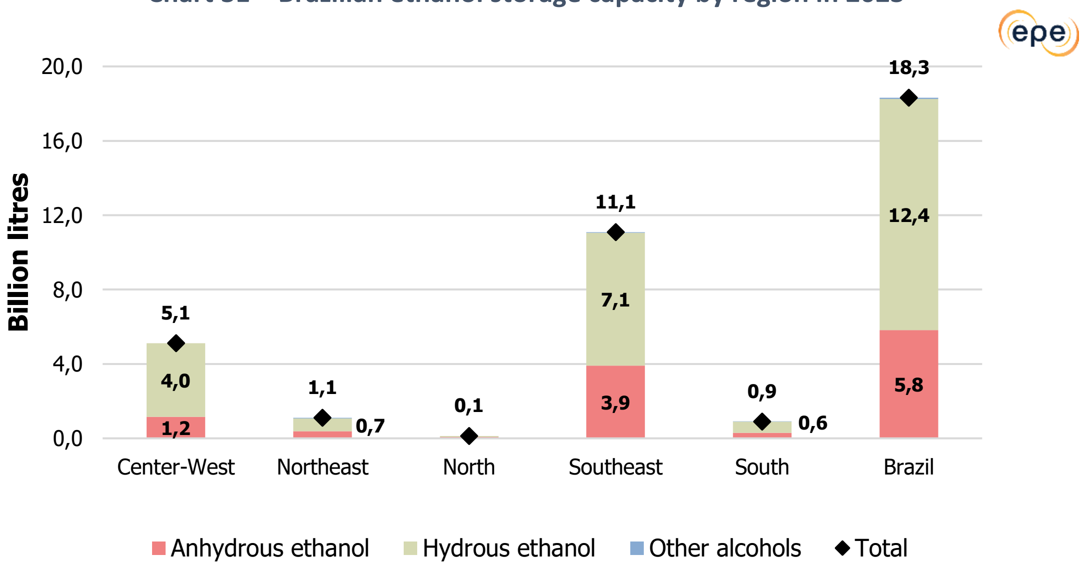
Source: EPE based on ANP (2024a).

MAPA oversees the operations of units in the sugar-energy sector, including those dedicated to sugar production. ANP, on the other hand, regulates the units authorized to commercialize anhydrous and hydrous ethanol, even if they are not operational on a given date. The discrepancies between the reports of the two entities are due to their different objectives.

4.2. Tanking

In 2023, Brazil registered an ethanol tanking capacity of 18.3 billion liters, with 12.4 billion liters for hydrous ethanol, 5.8 billion liters for anhydrous ethanol, and 65 million liters for other alcohols. Among the regions, the Southeast stands out with 11.1 billion liters (61%), reflecting its alignment with the largest volumes produced and consumed there. Chart 31 presents Brazil's tanking capacity by type of ethanol and by region.

Chart 31 – Brazilian ethanol storage capacity by region in 2023



Source: EPE based on ANP (2024a).

4.3. Pipelines

Most of the ethanol distribution in Brazil is carried out by road transport. However, there are alternative transportation methods with lower greenhouse gas emissions per volume transported, such as pipelines and railways. Figure 3 presents Logum's integrated logistics system for ethanol, which consists of its own pipelines and the use of existing ones, with a final extension of 1,400 km and a maximum annual transport capacity of up to 9 billion liters of ethanol (LOGUM, 2023).

Figure 2 – Integrated logistics system for ethanol

Source: (LOGUM, 2023b)

The sections of the pipelines currently in operation are:

i. Owned pipelines: Ribeirão Preto (SP) – Paulínia (operational capacity of 2.8 billion liters/year); Uberaba (MG) – Ribeirão Preto (SP) (operational capacity of 1.8 billion liters/year), and Guararema (SP) – Guarulhos (SP) – São Caetano do Sul (SP) – São José dos Campos;

ii. Subcontracted pipelines: Paulínia (SP) – Barueri (SP); Paulínia (SP) – Rio de Janeiro (RJ).

The storage capacity of the tanks (useful volume) at the operational terminals of the system is 617 million liters. In 2023, the volume of ethanol transported was 4.3 billion liters, 22% more than the previous year (LOGUM, 2024).

In July 2023, Logum completed the expansion between Guararema and São José dos Campos to serve the Vale do Paraíba and the northern coast of São Paulo. The company expects to handle up to 9 billion liters of ethanol per year by 2030, with its operational system fully functioning and improvements being implemented (UDOP, 2023).

4.4. Ports

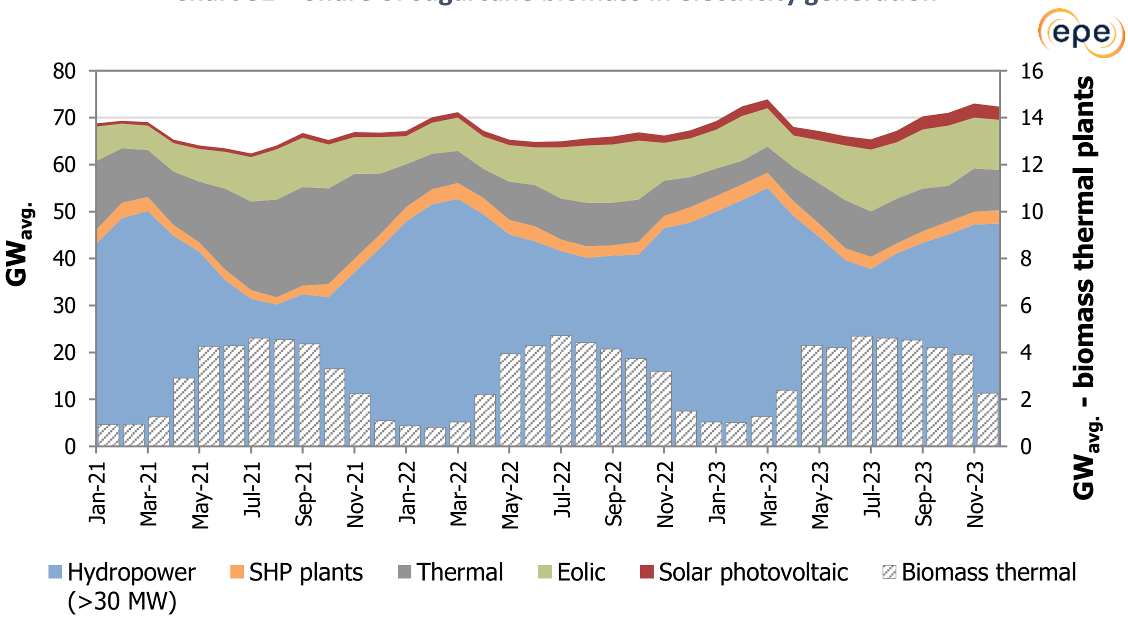
In 2023, Brazilian ethanol transactions were predominantly maritime (99.8% of exports and 100% of imports). The Port of Santos (SP) accounted for 89.6% of exported volumes, followed by the Port of Paranaguá (PR) with 7.6%, and the Port of Rio de Janeiro (RJ) with 1.4%. The Port of Suape (PE) (82.3%) was the main entry point for imported ethanol, followed by the Port of Rio Grande (RS) with 16.8% (ME, 2024).

5. Bioelectricity

Biomass thermal generation plays an important role in the national energy landscape. In 2023, there was a 10.1% increase in the amount supplied compared to 2022. Bagasse remains the most used fuel for exporting energy to the National Interconnected System (SIN), accounting for 74.5% (a 2.5% increase), followed by black liquor from the paper and pulp industry with 18.6%, and biogas from urban waste with 3.6%, as described in section 5.2.

In 2023, the share of energy exported from sugarcane in the national electricity matrix was 3.4%. Sugar-energy mills injected 2.4 GW on average into the National Interconnected System (SIN), which is 14% higher than in 2022, reversing the previous downward trend. Chart 32 shows the seasonal share of sugarcane biomass in electricity generation for 2022/2023. It highlights the complementarity with hydropower, as the increase in bioelectricity generation occurs during the harvest period, which coincides with the dry season (CCEE, 2024a).

Chart 32 – Share of sugarcane biomass in electricity generation



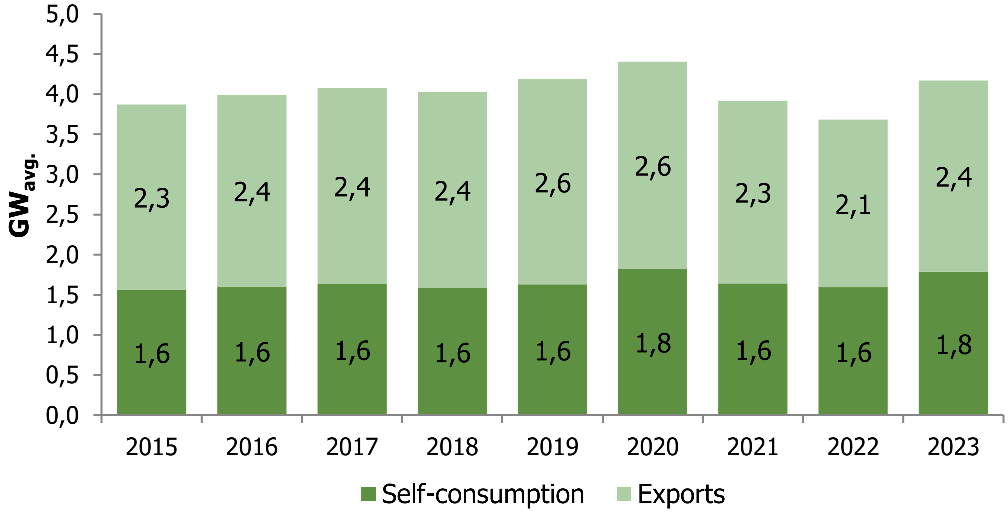
Source: EPE based on-CCEE (2024a).

5.1. Exportation and Commercialization of Energy

In addition to energy self-sufficiency, sugarcane biomass plants are characterized by their supply of energy to the SIN[32]. According to Chart 33, there was a decline in electricity generation from this source in 2021 and 2022, with a return to previous levels in 2023. The share of energy used for self-consumption remained stable during this period.

[32] Sugar-energy plants sell electricity in both the Regulated Contracting Environment (ACR) and the Free Contracting Environment (ACL). In the ACR, operations for buying and selling energy are concentrated through auctions, including new energy auctions, reserve (LER) auctions, and alternative sources (LFA) auctions. The auction model is designed to ensure greater transparency and competition in energy commercialization. In the ACL, generation, trading, importation, exportation agents, and free consumers operate under bilateral contracts for the sale and purchase of energy, which are freely negotiated, and distributors are not permitted to acquire energy in this market. Additionally, there is the Incentive Program for Alternative Sources of Electric Energy (PROINFA), established in 2004 (CCEE, 2024a; ELETROBRÁS, 2018).

Chart 33 – Self-consumption and exported energy by sugarcane biomass plants



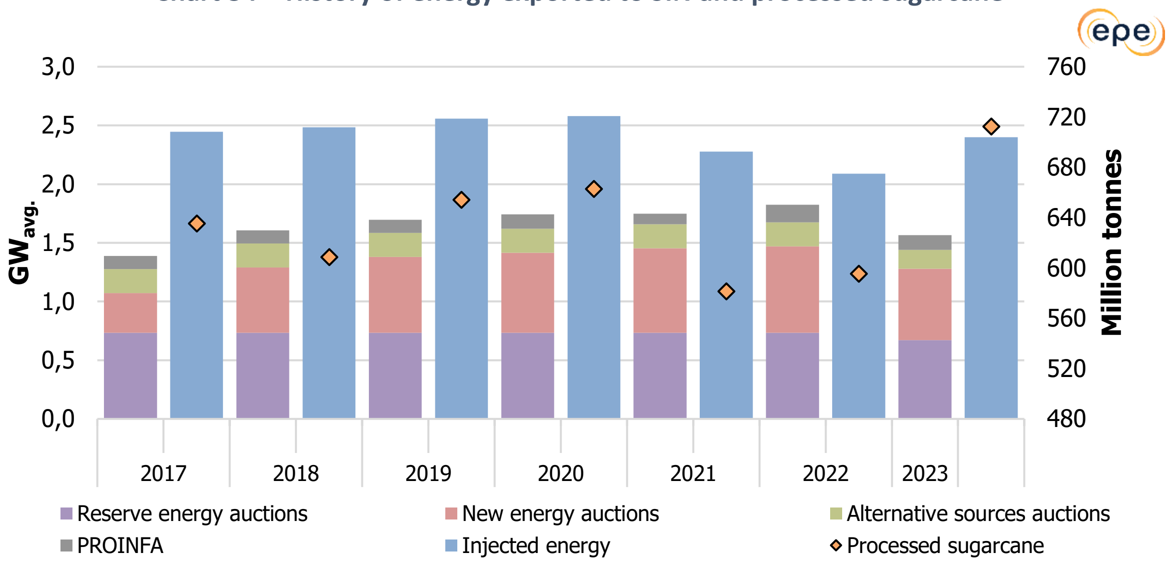
Source: EPE based on CCEE (2024a); EPE (2024a).

Among the 360 sugarcane biomass plants operating in 2023, 249 sold electricity, five more than the previous year. Of those exporting energy to the SIN, some operate exclusively in the ACL (62%) or in the ACR (5%), while the remaining (33%) sell in both contracting environments. There is a noticeable increasing preference for selling energy in the ACL, as well as an expansion of renewable sources such as wind and solar power. As in previous years, there has been reduced demand in ACR auctions, particularly due to low demand from distributors. The new characteristics of the energy commercialization model have focused on capacity and reserve auctions, a profile that does not favor sugarcane bioelectricity plants. One of the main factors explaining this trend is the increase in distributed generation and the growing share of the ACL in the consumer base.

The previously dominant business model in the electric sector was largely based on centralized energy auctions. To increase the competitiveness of biomass-derived sources and stimulate the growth of bioelectricity in Brazil's electricity matrix, the federal government promoted the creation of regulatory mechanisms and incentive policies, such as specific auctions. In 2008, the first reserve energy auction (LER, 2008) was held, focusing exclusively on biomass. During this auction, over 590 MW on average were contracted, the highest value recorded, with the start of operations scheduled for 2009 and 2012.

As of October 2023, sugar-energy plants had contracts amounting to 1.7 GW on average. There were small increases in biomass energy in the auctions held in 2021 and 2022. For the year 2023, there were no auctions for new energy acquisitions in the regulated market (CCEE, 2024a). Chart 34 highlights the volume exported to the SIN (ACR and ACL) from these units, the total contracted by auction type, and the processed sugarcane in recent years. In 2023, there was a 20% increase in the amount of processed sugarcane, with details provided in Chapter 1 of this publication. There was also a 14% increase in energy injection into the SIN, which reflected a higher share of biomass in the electricity matrix.

Chart 34 – History of energy exported to SIN and processed sugarcane



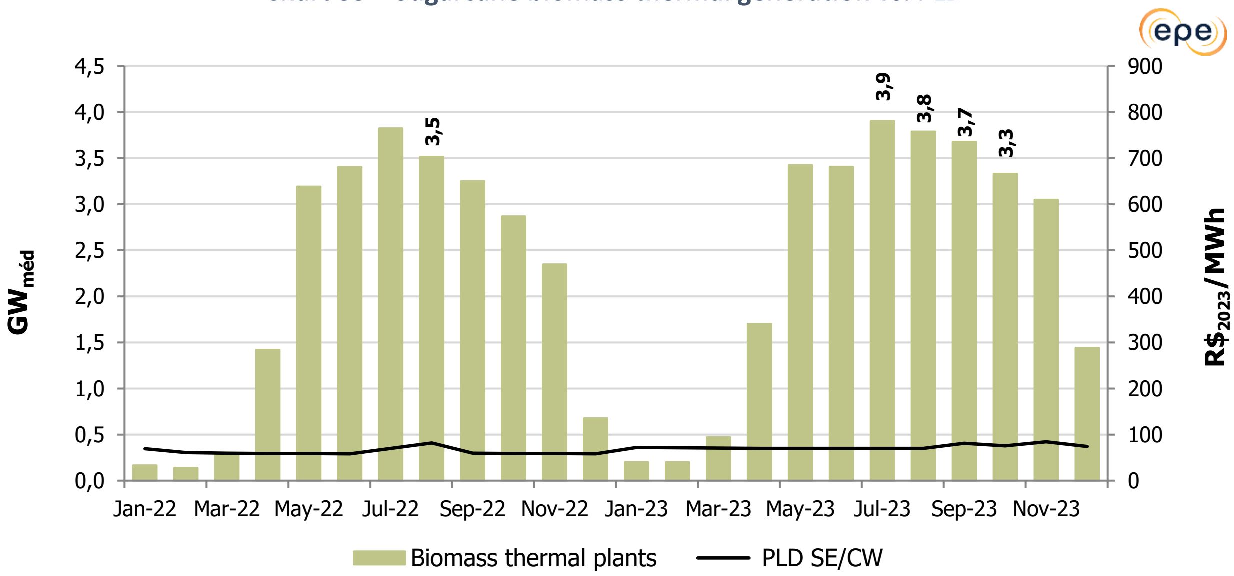
Source: EPE based on-CCEE (2024a); MAPA (2024).

In 2023, there was a significant reduction in the participation of thermal power plants in meeting the load compared to 2022 (MCTI, 2021). The favorable hydrological scenario, accounting for about 70% of electricity generation, along with the significant contribution of wind power (15% of the total), are part of the explanation. Additionally, there was an expansion in installed capacity, with wind and solar sources accounting for 69% and 25%, respectively, of this expansion, which reached 20 GW, including distributed generation.

Chart 35 illustrates the monthly injection of energy into the SIN from sugarcane biomass thermal plants versus the PLD (Settlement Price of Differences) in constant values. Throughout the observed period, the PLD remained close to the minimum value for the entire year, influenced by various factors such as changes in the electricity market, increasing inclusion of mini and micro distributed generation, the rise in bilateral contracts in the Free Contracting Environment (ACL), stable electricity demand, and the large supply of renewable sources such as hydropower and wind. This trend observed in 2023 is similar to that of 2022, when the PLD value did not align with the seasonality of biomass thermal generation. The values set by CCEE for the PLD in 2023 were R$678.3/MWh as the upper limit and R$69.0/MWh as the lower limit (increases of 4.9% and 23.9%, respectively)[33] (CCEE. 2024b). Over the past 5 years, the PLD value has increased by 38.2%, which is 5.06% above the inflation rate for the same period.

[33] The limit values for the PLD defined for the year 2024 were R$716.8/MWh and R$61.07/MWh, representing increases of 5.7% and decreases of 11.5%, respectively, compared to the previous year. The highest hourly PLD recorded was R$1,404.77/MWh, which is 5.9% higher than the value registered in 2022. For 2024, the maximum hourly value for this indicator is R$1,470.57 (ANEEL, 2023; CCEE, 2024b).

Chart 35 – Sugarcane biomass thermal generation vs. PLD



Note: The PLD is calculated for the submarkets N, NE, S, and SE/CW. In this chart, the value used for comparison is that of the SE/CW submarket.
Source: EPE based on CCEE (2024b).

Units had been showing a trend toward increasing efficiency in the export of electricity per ton of cane processed, although a recent stagnation was observed. Several factors explain this trend, and its reflections may be related to the amounts financed through BNDES funding lines. The amounts requested by plants from this bank for bioelectricity have been low in recent years, amounting to R$35.5 million in 2023, an increase compared to 2022 and 2021, which had the lowest historical amounts of R$5.9 million and R$34.1 million, respectively. However, this value still represents 53.7% of what was available in 2020, R$66.1 million, and 24.7% compared to 2019, R$143.4 million (BNDES, 2024a).

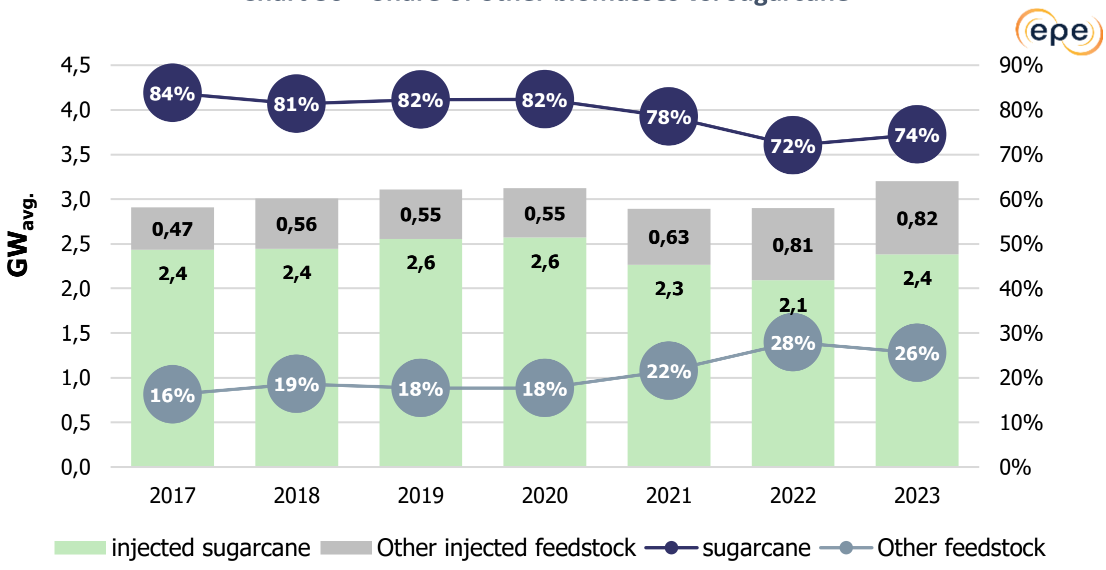
5.2. Bioelectricity from other biomasses

In the last two years, there has been an increase in the export of electricity from biomass, primarily driven by the rise in exports from the sugar-energy sector. In 2023, in addition to the previously mentioned by-products from sugarcane, 817 MW were injected on average into the grid from projects that use fuels derived from other biomass sources, whether animal or plant, remaining stable compared to 2022.

Electricity generation from these other biomass sources (excluding sugarcane) represented 1.2% of the power matrix in 2023. Notably, black liquor accounted for the largest share (595.5 MW_{avg}, 73%), largely driven by the growth in cellulose production over the past five years. Other significant contributors include biogas (115.4 MW_{avg}, 14%) and forest residues (50.1 MW_{avg}, 6%). Lesser contributors include elephant grass, charcoal, rice husks, oven gas, and firewood.

In 2023, the share of these sources in the total energy exported by biomass to the SIN was 26%, a decrease of 2% compared to the previous year. Although their contribution has decreased relative to 2022, approximately 300 MW_{avg} have been added over the last five years, as shown in Chart 36.

Chart 36 – Share of other biomasses vs. sugarcane



Source: EPE based on CCEE (2024a).

Unlike sugarcane, which has a well-defined seasonality and consequently a high variation in energy exported to the grid, energy generation from other biomass sources is generally more controllable and deterministic. This is primarily due to the ability to store the fuel. This attribute is important for the electric sector, contributing to increased energy security and system reliability during a period of significant challenges and structural changes in the generation park.

6. Biodiesel

In 2023, Brazil consumed 7.5 billion liters of biodiesel, a 19% increase compared to 2022 (EPE, 2024a). The mandatory biodiesel blend percentage with fossil diesel started the year at 10% by volume (B10) and increased to 12% in April 2023, maintaining this level thereafter (CNPE, 2023b).

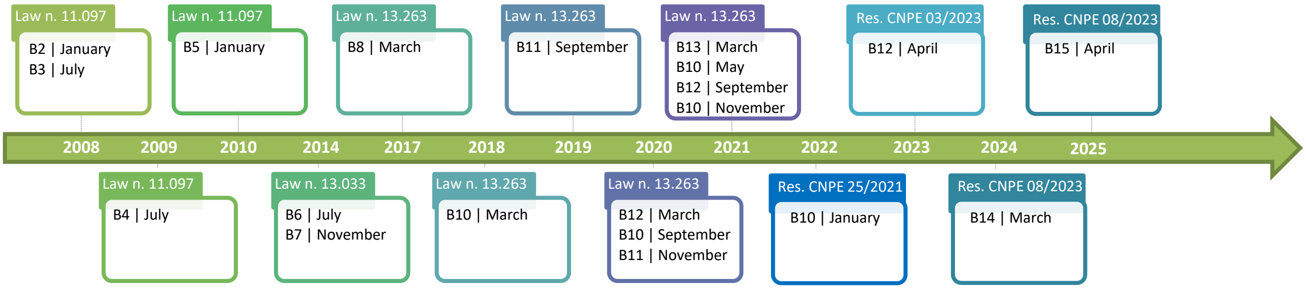
Since the inception of the National Biodiesel Production and Use Program (PNPB) in 2005, over 67.5 billion liters of this biofuel have been produced by December 2023. Comparatively, Brazil remains among the top three producers and consumers of biodiesel internationally. By December 2023, the national biodiesel sector had a total of 61 production plants, with a continued concentration in the Central-West and South regions of the country (ANP, 2024c).

6.1. Evolution of the Biodiesel Regulatory Framework

Since the mandatory use of biodiesel in blending with fossil diesel was established by Law No. 11,097/2005 (BRASIL, 2005), there has been a rapid evolution towards higher biodiesel content. The initial value was set at 2% by volume in 2008, reaching 5% by 2010, which was originally scheduled for 2013. In the following years, there was a gradual increase in the mandatory minimum percentages for diesel type B.

In 2021, the CNPE (Resolution No. 25) decided to maintain the biodiesel content at 10% in diesel type B for the entire year of 2022, aligning with societal interests by balancing measures to control prices with maintaining the National Biofuels Policy, thereby providing predictability, transparency, and legal and regulatory security to the sector. This percentage was maintained until March 31, 2023, through CNPE Resolution No. 12/2022 (CNPE, 2021b; CNPE, 2022a). In March 2023, CNPE Resolution No. 3/2023 modified the percentage to 12% starting from April 2023. On December 19 of the same year, CNPE Resolution No. 8 changed the evolution of the biodiesel blend percentage in diesel type B, establishing 14% starting March 2024 and 15% starting March 2025. The evolution of mandatory biodiesel blending percentages with fossil diesel is detailed in Figure 4.

Figure 3 – Evolution of the biodiesel legal framework



Source: EPE (2020).

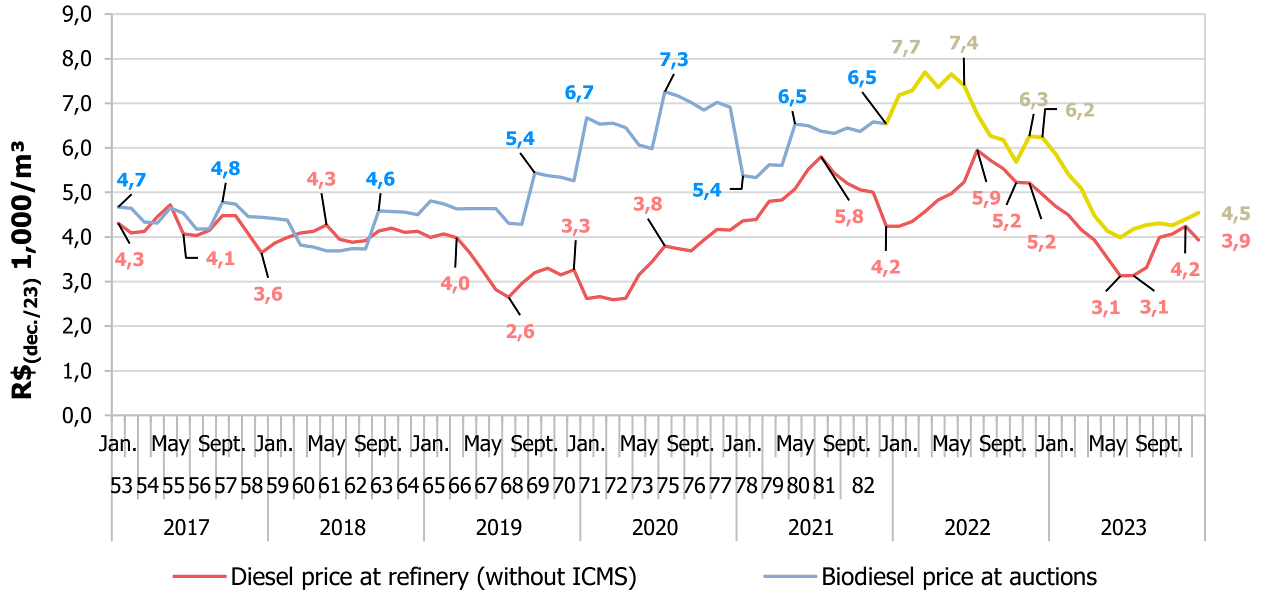
Although Law No. 13.263/2016 had already authorized the National Energy Policy Council (CNPE) to increase the biodiesel blend percentage up to 15%, if engine tests for this level were approved, this percentage will only be reached in March 2025 (BRASIL, 2016).

Law No. 11.097/2005 (BRASIL, 2005) provides a broad definition of biodiesel, describing it as any fuel derived from renewable biomass for use in Diesel cycle engines. Currently, ANP Resolution No. 798/2019 (ANP, 2019) is in effect, which specifies the biofuel as being composed of a mixture of fatty acid esters.

With the maturation of new technologies, it became necessary for regulations to allow the incorporation of such advancements, enabling the use of other renewable fuels derived from biomass in Diesel cycle engines, which can be blended with fossil diesel to create diesel type B. Thus, ANP Resolution No. 842/2021 (ANP, 2021a) establishes the specification for green diesel, as well as the quality control obligations that must be met by economic agents who market it within the national territory, opening the possibility for new biofuels to be included in the blend with diesel type A.

From 2007 until the end of 2021, the commercialization of biodiesel occurred through public auctions organized by ANP. Starting in January 2022, the commercialization system for this biofuel in the national market was changed through CNPE Resolution No. 14/2020. This regulation established that there would no longer be biodiesel auctions, and that commercialization would occur directly between producers and distributors (CNPE, 2020), with the relationship being regulated by ANP Resolution No. 857/21 (ANP, 2021b). Chart 37 presents the average prices of biodiesel and diesel type A.

Chart 37 – Average prices - biodiesel and diesel excluding ICMS



Source: EPE based on ANP (2024g).

CNPE Resolution No. 3/2015 (CNPE, 2015) established guidelines to authorize the commercialization and voluntary use of biodiesel in quantities exceeding the mandatory blending percentage with diesel oil[34]. These rules for optional biodiesel aim to leverage and stimulate conditions that could make it competitive with diesel oil, particularly in regions far from oil refineries and with abundant production capacity.

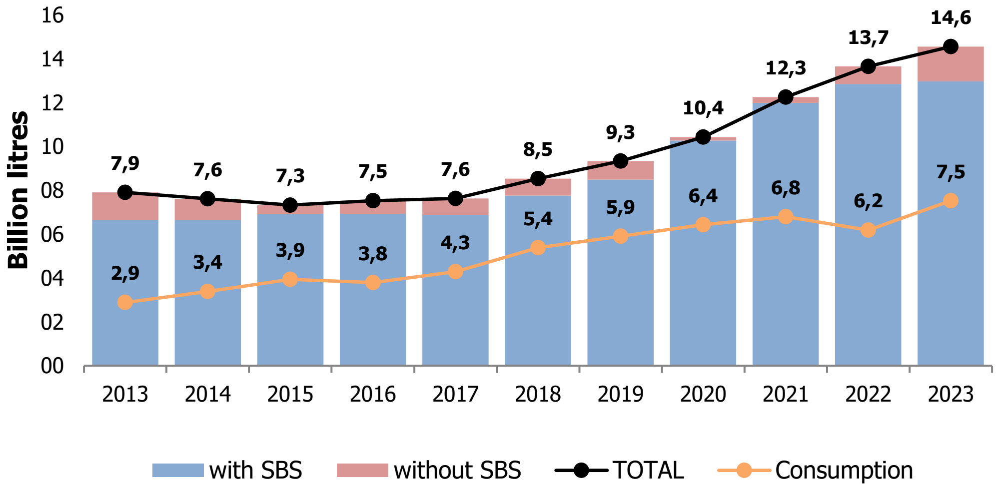
To decarbonize their logistical operations, some companies have started using pure biodiesel (B100) as a substitute for fossil diesel, both in their own fleet trucks (BIODIESELBR, 2024a; BIODIESELBR, 2024b) and in river vessels (ANP, 2024j). Additionally, there are initiatives to use the biofuel in maritime transport by blending it with fossil fuels (BIODIESELBR, 2024c).

6.2. Installed capacity and regional production

According to ANP data, as of December 2023, the installed capacity was 14.6 billion liters, distributed among 61 authorized production plants, with 53 holding the Social Biofuel Seal (SBS). Chart 38 shows the annual authorized capacity, distinguishing between plants with the SBS, as well as the annual consumption, illustrating the effect of overcapacity since 2008 (ANP, 2024f). It is noted that in 2023, the production of this biofuel accounted for 52.4% of the installed capacity in the country.

[34] The maximum percentages, by volume, for the addition of biodiesel to diesel oil are: 20% for captive fleets or road consumers served by a refueling point; 30% for railway transport; 30% for agricultural and industrial use; and 100% for experimental, specific, or other applications (CNPE, 2015).

Chart 38 – Authorized nominal capacity and biodiesel consumption in 2023

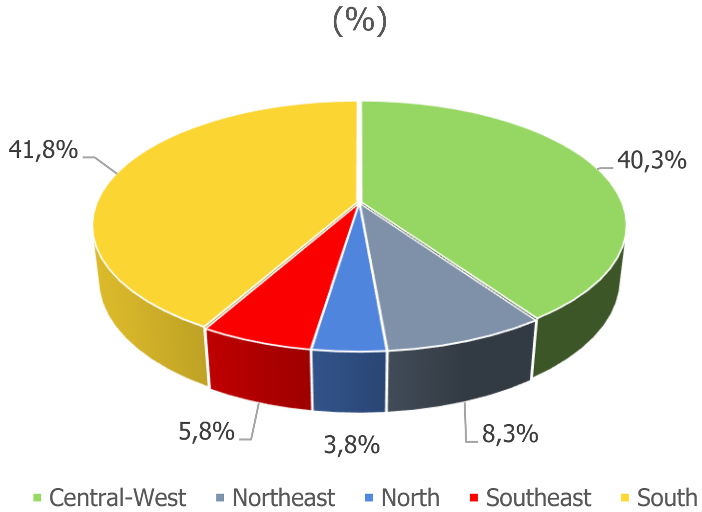


Note: The Social Biofuel Seal (SBS) is a distinction awarded to biodiesel production companies that use products from family farming in their production chain. The aim is to ensure income and promote social inclusion for producing families. Companies holding the SBS benefit from better financing conditions with financial institutions.

Source: EPE based on EPE (2023a); ANP (2024f).

The availability of major feedstocks, such as soybeans and tallow, in the Central-West and South regions, makes these areas the largest producers of biodiesel. In contrast, the highest consumption is concentrated in the Southeast region. Chart 39 shows the regionalized biodiesel production in 2023, with the highest concentration of production in the South (41.8%) and Central-West (40.3%) regions of the country.

Chart 39 – Regional biodiesel production in 2023

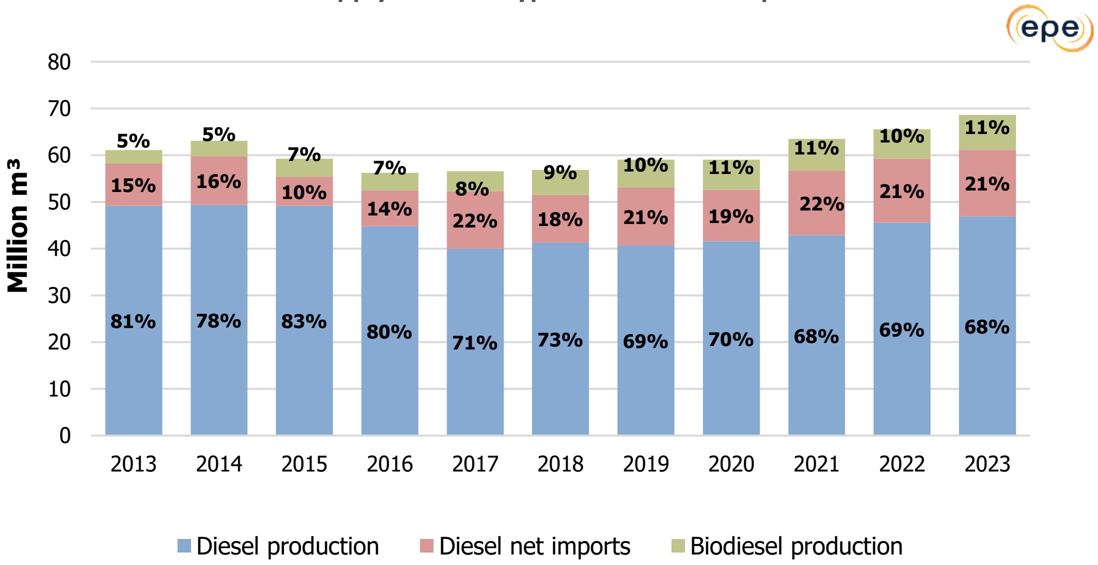


Source: EPE based on ANP (2024af).

The above landscape may change in the coming years due to the changes proposed by Resolution CNPE No. 03/2023 (CNPE, 2023a), which establishes that biodiesel purchases from the Social Biofuel Seal Program, originating from the North, Northeast, and Semi-Arid regions, should total at least 10% in 2024, 15% in 2025, and 20% in 2026.

Compared to 2022, there was a 3.8% increase in the production of diesel type A by the national park and a 9.0% decrease in net imports. Additionally, the production of the biofuel increased by 20.3% compared to the previous year, due to two factors: the increase in the mandatory percentage and the growth in demand for diesel cycle. Chart 40 shows the evolution of the production and importation of diesel type A and the supply of biodiesel.

Chart 40 – Supply of diesel type A and biodiesel production

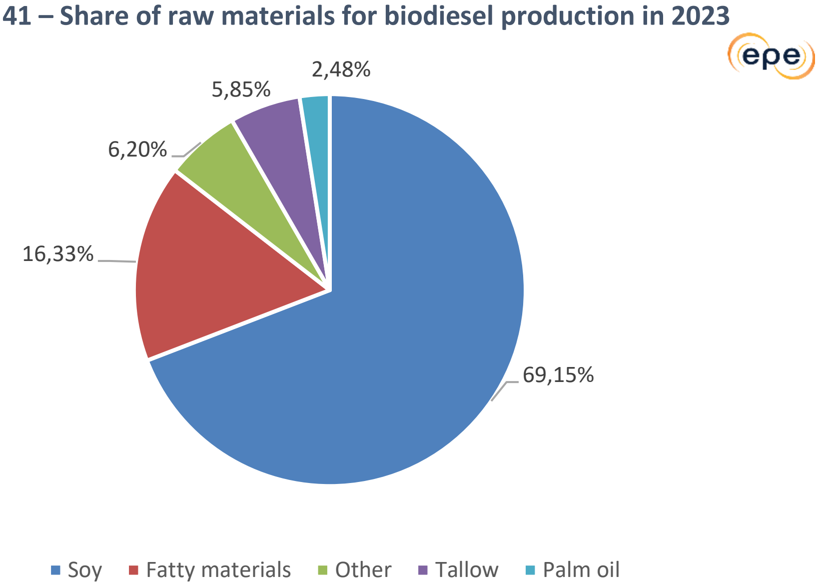


Source: EPE based on EPE (2024a).

6.3. Raw Materials for Biodiesel

As shown in Chart 41, soybean oil was the most important feedstock source for biodiesel production in 2023, totaling 5.2 billion liters (+23.8%), which corresponds to 69.2%. This was followed by other fatty materials with 16.3%. Beef tallow accounted for 5.9%, palm oil for 2.5%, and various other inputs represented 6.2%. The latter category includes used cooking oil, chicken fat, pork fat, and others (ANP, 2024f).

Chart 41 – Share of raw materials for biodiesel production in 2023



Source: EPE based on ANP (2024f).

Given the trends over recent years, it's expected that soybean oil will remain a major feedstock source for biodiesel production for a long time. However, to meet the anticipated increases in mandatory biodiesel percentages, which will contribute to a more renewable Brazilian energy matrix, there's a need for incentives to diversify the feedstock mix (ANP, 2024f; EPE, 2023). Like the case with beef tallow, other fats, such as palm oil and used cooking oils, are also likely to gain prominence in the long term.

In 2023, Brazil's soybean harvest was 158.7 million tons (compared to 129.9 million tons in 2022), representing a 22.2% increase compared to the previous year. Soybean oil production was 10.8 million tons, showing a 9.1% increase. Domestic processing grew by 5.5% compared to 2022 (ABIOVE, 2024).

The soybean processing capacity was 69 million tons annually, with an increase of 4.5%, according to the Brazilian Association of Vegetable Oil Industries (ABIOVE, 2024). Due to the current legislation favoring grain exports, this industry operates with idle capacity. Table 2 summarizes the situation of the soybean complex in 2022 and 2023.

Table 2 – Soybean complex [35]

Million tons	2022	2023	Δ % (2022-2023)
Soybean production	129.9	158.7	22.2%
Installed soybean processing capacity	66	69	4.5%
Soybean grain exports	78.7	101.9	29.5%
Processed soybeans	50.9	53.7	5.5%
Soybean meal produced	39.2	41.1	4.8%
Soybean oil produced	9.9	10.8	9.1%
Soybean oil exports	2.6	2.3	-11.5%
Soybean oil consumption for biodiesel	3.9	4.8	23.1%
Soybean oil consumption for food and other uses	3.4	3.7	8.8%

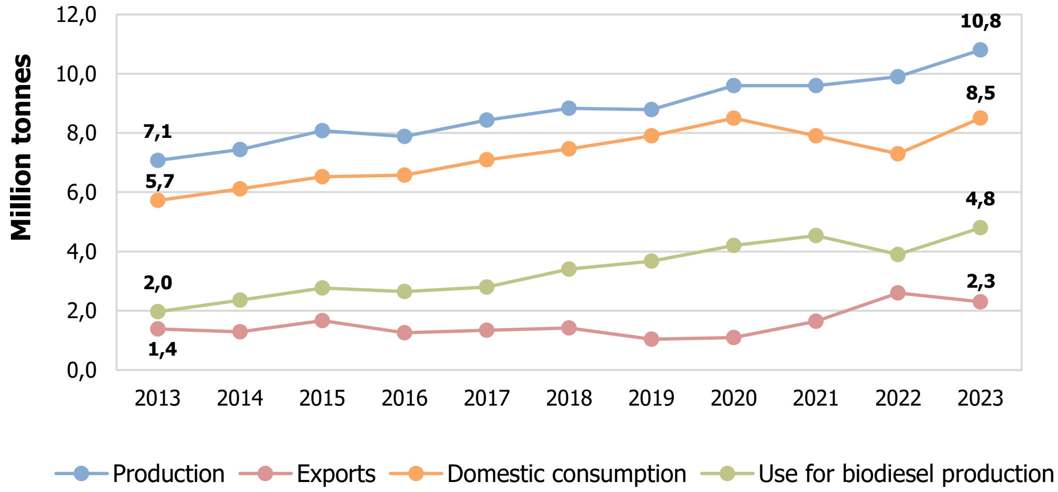
Note: The density considered for soybean oil was 0.92 kg/l.

Source: ABIOVE (2024) and ANP (2024f).

Chart 42 illustrates the behavior of the Brazilian soybean oil market since 2013.

[35] The values related to domestic consumption of "soybean seeds" and other uses were not considered.

Chart 42 – Soybean oil market



Note 1: Domestic consumption includes oil for biodiesel, food, and other uses.

Source: EPE based on ABIOVE (2024).

According to ABIOVE, the mass production of soybean oil increased by 52% between 2013 and 2023. This growth is much lower compared to that for biodiesel production, which, in absolute terms, increased from 2.0 million to 4.8 million tons, a 140% increase during the same period. Soybean oil exports in 2023 fell by 11.5% compared to 2022, due to higher domestic use for biodiesel production (ABIOVE, 2024).

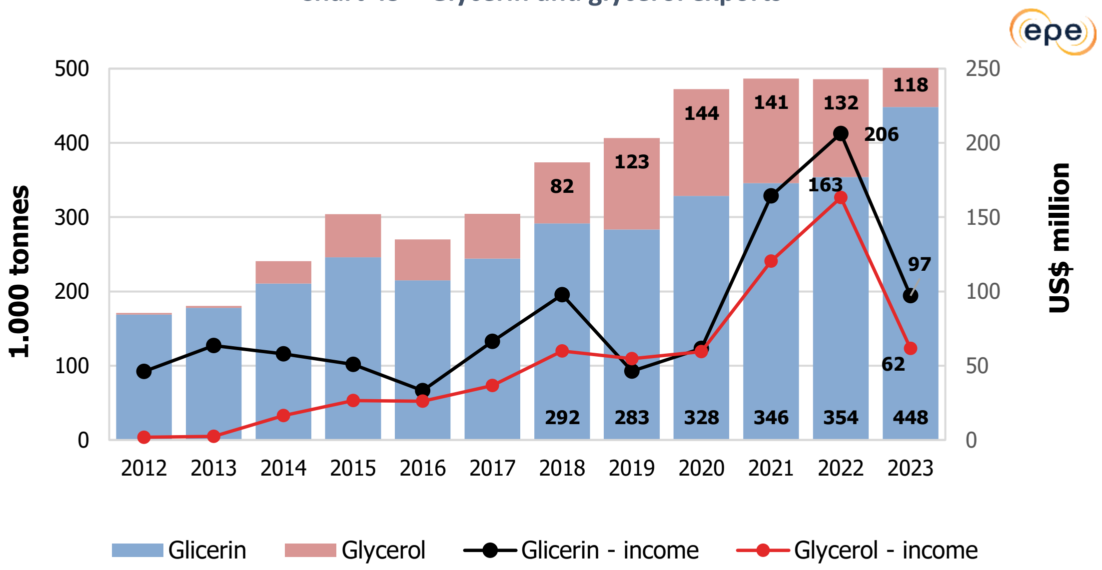
6.4. Biodiesel byproducts

Crude glycerin is a byproduct of the biodiesel production chain, representing approximately 10% by mass of the biodiesel produced. In 2023, it is estimated that 680,000 tons of crude glycerin were produced. Its total export was 16.6% higher compared to the previous year, as shown in Chart 43. The revenue from the export of crude glycerin amounted to US$ 97.1 million, which is 52.9% lower than the revenue in 2022.

Glycerol is a classification for refined glycerin, which commands better prices in the international market compared to crude glycerin. The number of plants installing equipment for its purification, aiming for better revenues, has been increasing continuously. The export of glycerol, which had been growing since 2013, declined in 2022 and continued the trend in 2023, totaling 118,400 tons, a decrease of 10.3%. The revenue amounted to US$ 61.6 million, a 62% drop compared to 2022 (ME, 2024).

China remains the largest destination for exports, accounting for 87% of crude glycerin and 35% of glycerol (ME, 2024).

Chart 43 – Glycerin and glycerol exports



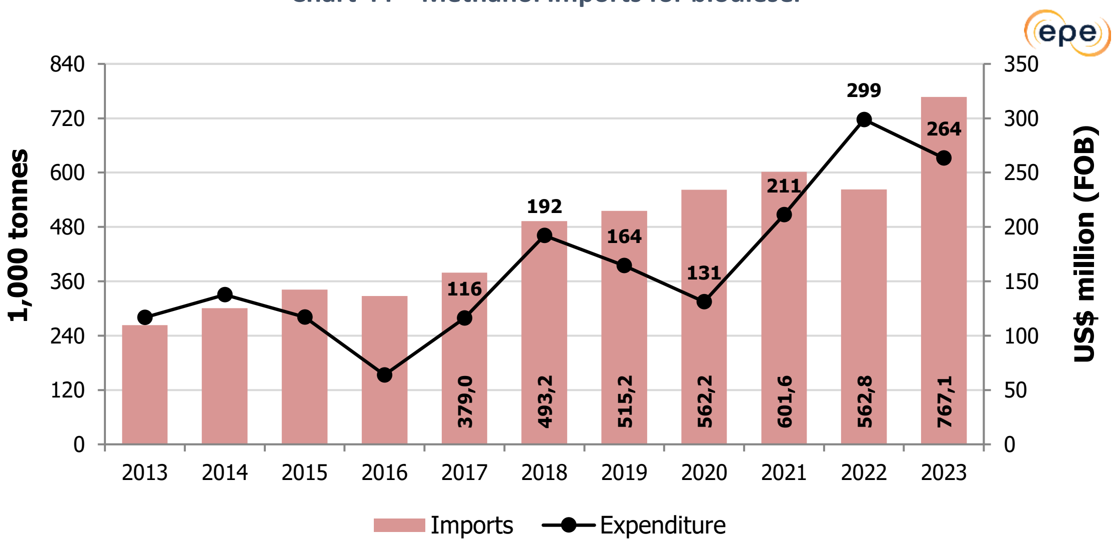
Source: ME (2024).

6.5. Methanol

Methanol is a key input for biodiesel production through the esterification/transesterification process. The United States leads global production due to low natural gas prices, which are the primary raw material in its production process. In 2023, Brazil imported 767,100 tons of methanol for biodiesel production, with most coming from Trinidad and Tobago, Venezuela, and the United States. Chart 44 shows the amount of methanol imported specifically for biodiesel production and the associated expenditure. The total in 2023 was 36.3% higher than in 2022, with total spending amounting to $264 million (11.8% lower than in 2022) (ANP, 2024e; ME, 2024).

Methanol is a commodity, and thus its selling price is determined by the interaction between supply and demand in the global market. This factor represents a point of concern for the development of future domestic production.

Chart 44 – Methanol imports for biodiesel



Source: EPE based on ANP (2024f) and ME (2024).

7. Biogas

Increasingly relevant in the national energy scenario, biogas continues to grow its share in the domestic energy supply. From 2022 to 2023, biogas contribution rose from 438 thousand tons of oil equivalent (toe) to 460 thousand toe, compared to just 14 thousand toe in 2010 (EPE, 2024). For the coming years, positive prospects for this source are maintained, supported by regulatory advancements and increased visibility in public policies that enhance its prominence. These prospects are reflected in the development of new production units and signs of interest from demand-side agents seeking to decarbonize their activities.

Biogas is a versatile fuel that can be used locally as a source of thermal energy and for distributed electricity generation. Its treatment can produce a standardized biofuel known as biomethane, which is defined as the "gaseous biofuel consisting primarily of methane, derived from the purification of biogas," with quality regulated by ANP (ANP, 2022a; ANP, 2022b). Once it meets the Agency's requirements, it becomes interchangeable with natural gas—meaning it can replace or be mixed with this fuel in any proportions. This possibility opens up a broad market for the biofuel and allows it to be distributed through gas pipelines and other delivery solutions originally designed for fossil-based gas.

Similarly to other biofuels, biomethane can be used in the transportation sector. Therefore, for this document, the focus is primarily on biomethane and all the biogas produced internally in the production process of other biofuels, such as in the sugar-energy sector.

7.1. Biogas in the Electric Sector

Electricity generation from biogas is primarily divided between micro or mini distributed generation plants and those with registration or authorization from the National Electric Energy Agency (ANEEL).

Micro and mini distributed generation is characterized by the electricity compensation system, initially regulated by ANEEL in Normative Resolution No. 482 of 2012. Under this system, which allows for the generation of credits to offset consumption, the first biogas plants appeared in 2014. By the end of 2023, there were 131 MW of installed biogas power across 508 generating units, using various raw materials – animal waste, urban waste, agroindustry, and forestry. Compared to 2022, 59 new units were added with a total capacity of 13.2 MW (ANEEL, 2024a).

The compensation system includes the largest number of biogas plants, but the rules limit the installed capacity to 5 MW. On the other hand, generally, the plants not covered by the compensation system are larger. In 2023, according to ANEEL's Generation Information System (SIGA), biogas ended the year with 51 operating plants with registration or authorization[36], totaling 233 MW of regulated capacity. Most of this capacity, amounting to 193 MW, uses biogas from municipal solid waste as fuel (ANEEL, 2024b).

[36] The plants registered with ANEEL total 559 biogas plants for electricity generation in Brazil, with an installed capacity of 364 MW. It is worth noting that CIBiogás (CIBIOGAS, 2024) conducts its own survey of biogas plants in the country. For the year 2023, the Center reported 1,184 electricity generation units, including plants with isolated operations. In addition to these plants and those producing biomethane, there are also 128 plants registered using biogas for thermal energy and 6 for mechanical energy.

7.2. Biomethane

Throughout 2023, only one plant obtained ANP authorization to produce biomethane, adding 30,000 Nm^3/day to the national capacity (ANP, 2024i). By the end of the year, there were six plants authorized by the Agency[37], corresponding to a total production capacity of 417,113 Nm^3/day. Approximately 75% of this capacity was concentrated in two plants, both producing from urban waste, the feedstock for five of the six authorized plants, as shown in Table 3.

Table 3 – Biomethane plants with operational authorization from ANP, RenovaBio, and REIDI

Company	City	State	Capacity [Nm^3/day]	Feedstock	RenovaBio – NEEA [gCO_2eq/MJ]
COCAL ENERGIA	Narandiba	SP	27,112.8	Agroforestry and commercial	75.66
ENGEP AMBIENTAL	Jambeiro	SP	30,000	MSW in sanitary landfill	No
GÁS VERDE	Seropédica	RJ	204,000	MSW in sanitary landfill	76.73
GNR DOIS ARCOS	São Pedro da Aldeia	RJ	16,000	MSW in sanitary landfill	78.97
GNR FORTALEZA	Caucaia	CE	110,000	MSW in sanitary landfill	80.77
METAGÁS BIOGÁS	São Paulo	SP	30,000	MSW in sanitary landfill	No
Total (operational)			***417.113***		

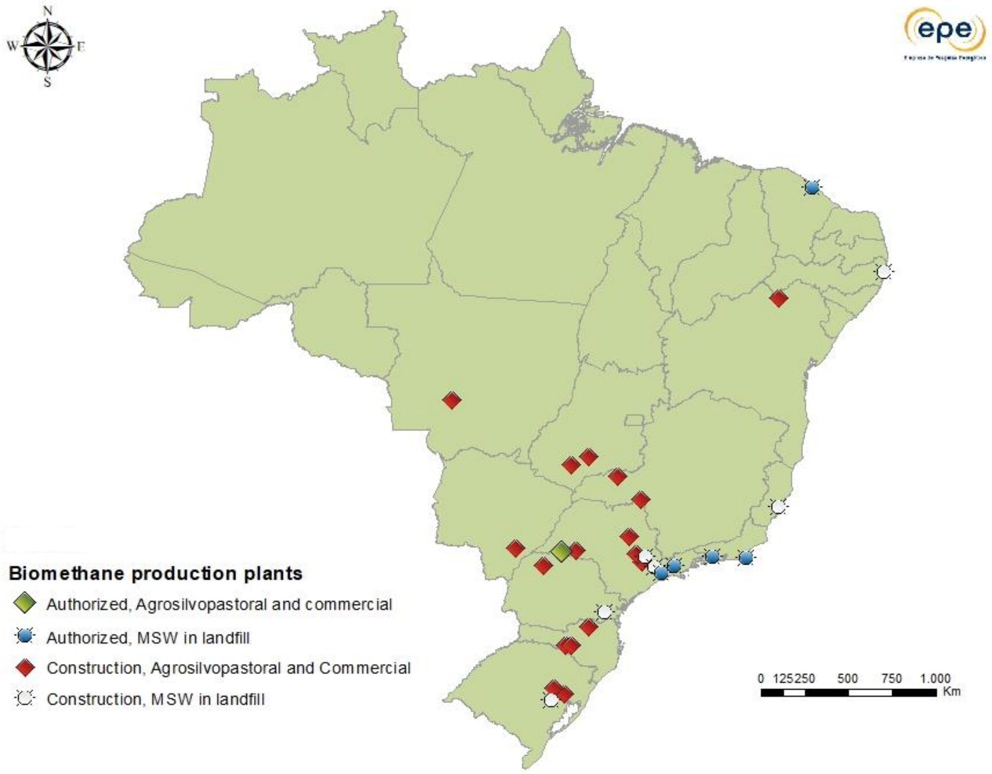
Note: Green marking refers to the plant from the sugar-energy sector. Status: June 2024.

Sources: ANP (2024b); ANP (2024i)

In June 2024, 24 plants were in the authorization process, all categorized as new construction. If completed, these plants would add 1,137,956 Nm^3/day to the national biomethane production capacity (ANP, 2024i). Figure 5 presents the biomethane production plants classified by type of authorization and feedstock.

[37] CIBiogás records (CIBIOGAS, 2024) for 2023 indicated 50 biometane plants, with 6 having ANP operation authorization, 21 in the authorization process, and 23 in non-commercial operation, producing the biofuel for self-consumption.

Figure 4 – Biomethane production plants



Source: EPE based on ANP (2024)

Of the six plants authorized by the ANP, four had valid RenovaBio certificates in June 2024, representing 86% of the production capacity. Of these certificates, one was obtained in 2021, while the other three were for recertification—one from 2023 and two from 2024 (ANP, 2024b).

Considering RenovaBio, on average, biomethane has the highest energy-environmental efficiency rating among biofuels, generating more CBIOs per megajoule (MJ) sold than ethanol or biodiesel. The average NEEA (energy-environmental efficiency rating) for the four valid certificates is 78.0 gCO2e/MJ. All the plants have 100% of their volume eligible for generating CBIOs, a unique feature among biofuels participating in this program (ANP, 2024b). Using the average rating of 78.0 gCO2e/MJ, it is estimated that RenovaBio could generate an additional revenue of about R$ 0.32 per Nm³ of biomethane, considering the CBIO price of R$ 113.67.[38].

7.3. Sugar-energy sector

The sugar-energy sector is unique for the development of biogas in Brazil, due to the high production potential from the residues of sugarcane processing and harvesting. At sugarcane mills, large-scale plants can be installed with various business models for utilizing biogas. This is due to its intrinsic flexibility and the available options within the context of a mill.

Among the operating models, there are projects for electricity generation from biogas, including a plant with a contract obtained through a regulated auction. In some cases, electricity generation is combined with biomethane production within the same mill.

[38] The CBIO price was assumed to be R$ 113.67, the average value recorded in 2023, and a CH4 concentration in biomethane of 96.5%. Taxes and other producer costs were not considered.

Producing biomethane, the only plant authorized by ANP in the sugar-energy sector operates connected to a dedicated pipeline, built with the purpose of supplying the biofuel to a region distant from the integrated natural gas network. In turn, the option of injecting biomethane into the existing grid is also expected to become a reality. There is a plant awaiting operational authorization, with supply contracts for industrial units via the free market, an environment characterized by direct negotiations between producers and consumers of gas. These contracts must comply with state regulations.

One of the alternative uses of biogas with potential environmental and financial benefits for the sugar-energy sector would be its purification and use as biomethane to replace diesel consumed in trucks and agricultural machinery. This model is planned for biomethane production units under construction, and its dissemination depends on the maturation of the use of gas-powered vehicles and their adaptation to the sector's activities.

7.4. Regulation and Public Policies

The regulatory and public policy environment related to biogas and biomethane has seen significant advancements in recent years. The 2023 edition of this document (EPE, 2023) revisits some of the key milestones for the sector's development, including quality resolutions for biomethane established by ANP, federal measures directed at or including biomethane, and state initiatives involving the role of regulatory agencies and natural gas distributors.

For the concessionaries, public calls continue to be used as a tool to promote biomethane and enable the procurement of renewable supply (EPE; CIBIOGÁS, 2023). Between 2023 and early 2024, results from previous calls were announced, and new tenders were published, including those by gas distributors from the states of Minas Gerais, Sergipe, and Paraná (COPERGÁS, 2023; GASMIG, 2023; SERGAS, 2024). The Paraná distributor, which received 14 supply proposals from 10 companies, repeated its experience from 2022 when its exclusive biomethane public call received 22 proposals from 12 suppliers (AEN-PR, 2023; 2024). During this period, the Rio Grande do Sul distributor and one of the companies operating in São Paulo also conducted open public calls for natural gas and biomethane (SULGÁS, 2023; COMGÁS, 2024).

At the federal level, in terms of taxation, there has been significant adoption of the “Regime Especial de Incentivos para o Desenvolvimento da Infraestrutura” (REIDI), which exempts producers from PIS and COFINS on revenues from certain acquisitions related to infrastructure projects. Since the introduction of incentives for biomethane production, at least 15 projects have received approval, reducing initial investment amounts (MME, 2022; BRASIL, 2024). Table 4 presents the segmentation by state of the new production capacity, highlighting the projects that have adhered to REIDI.

Table 4 – Biomethane production capacity, under development, and REIDI applicants

REIDI	Capacity [Nm³/day]										
	BA	ES	GO	MG	MS	MT	PE	PR	RS	SC	SP	Total
Yes			21.620	30.000		27.600	162.000	31.200	106.000	35.760	277.296	**691.476**
Unidentified	55.000	25.000		10.800	14.400			17.000	10.000	13.440	300.840	**446.480**
Total	**55.000**	**25.000**	**21.620**	**40.800**	**14.400**	**27.600**	**162.000**	**48.200**	**116.000**	**49.200**	**578.136**	**1.137.956**

Source: ANP (2024i), BRASIL (2024)

In terms of financing, the sector continues to benefit from advantageous conditions. Through BNDES, biogas projects in the sugar-energy sector have been able to secure funds from the Climate Fund.

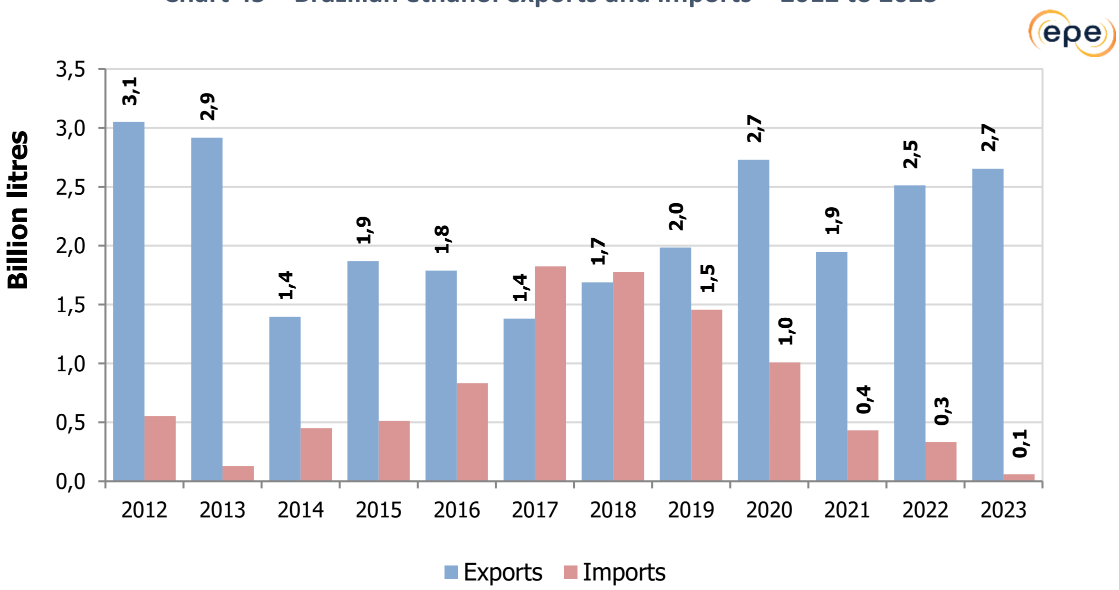
The year 2023 also saw the creation of the Working Group for the Gas for Employment Program, which was divided into five Committees. Committee 5, titled "Role of Natural Gas in the Energy Transition," has one of its two work fronts focused on "promoting strategies that contribute to making investments in natural gas consistent and reduce the final cost of the energy transition, and ensure that these investments are resilient." Integrating the supply of biomethane is a key part of achieving these goals, and the Committee proposes to explore synergies with the gas market.

8. International Biofuels Market

In 2023, global ethanol fuel production reached 112 billion liters, a 5% increase compared to 2022 (107 billion liters). The two leading market players, Brazil and the United States, continued to hold a significant share, accounting for 81% of the world's biofuel production (RFA, 2024).

This year, Brazil exported 2.7 billion liters (8% more than in 2022), while imports were 0.1 billion liters (67% less than in 2022) (Chart 45), resulting in a net export of 2.2 billion liters. The main destinations for the exported ethanol were: South Korea (868.2 million liters – 32.7%), Netherlands (624.4 million liters – 23.5%), United States (443.1 million liters – 16.7%), and the Philippines (113 million liters – 5.5%) (ME, 2024).

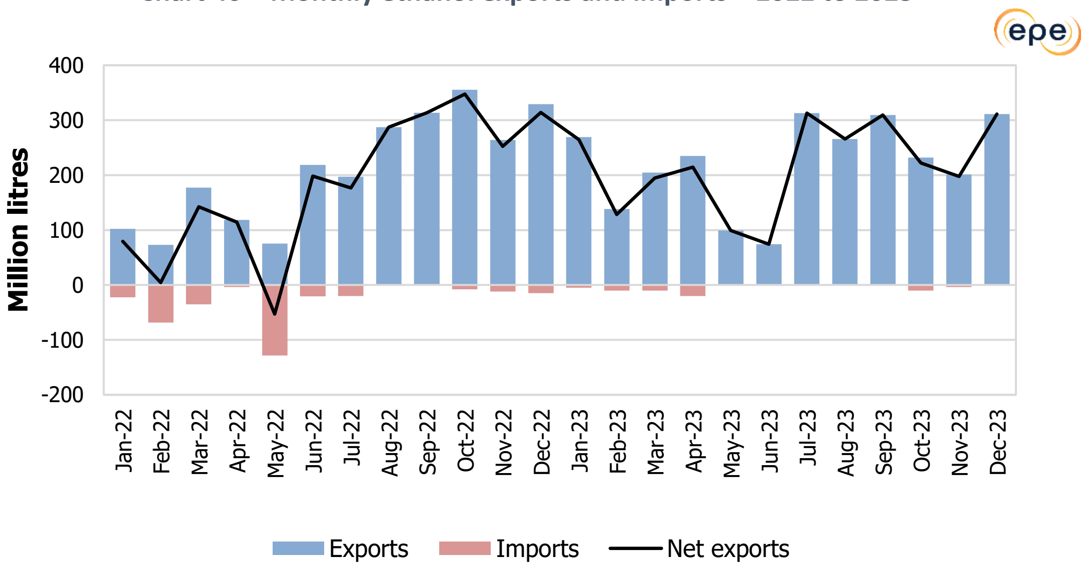
Chart 45 – Brazilian ethanol exports and imports – 2012 to 2023



Source: EPE based on (ME, 2024).

Starting in August 2017, through Resolution CAMEX No. 72 (ME, 2017) and Ordinance No. 547 (ME, 2019), imported volumes of ethanol fuel, up to a specified limit (quota), were exempt from the import duty (20%) until August 2020, with the exemption extended to December of the same year. At the end of 2020, the import duty was reinstated on the entire imported volume and remained in effect until December 31, 2021. On March 22, 2022, the government, through Resolution GECEX No. 317, reestablished an exemption from the import duty (18%) for all imported ethanol, a measure effective until December 31 of the same year (ME, 2022). At the end of December 2022, the Chamber of Commerce decided not to renew the import duty exemption. Therefore, starting in 2023, the import tariff for ethanol became 16%, according to Resolution Gecex No. 353, of May 23, 2022, remaining in effect until December 31, 2023. After this date, the duty rate returned to 18% (DIÁRIO DO COMÉRCIO, 2023). Chart 46 shows the monthly exports and imports of ethanol throughout the years 2022 and 2023.

Chart 46 – Monthly ethanol exports and imports – 2022 to 2023



Source: EPE based on ME (2024)

It is noteworthy that Brazilian ethanol-producing companies have been seeking new opportunities in the international market, considering the demand for sustainable aviation fuel (SAF) production from ethanol in other countries. Through the International Sustainability and Carbon Certification (ISCC)[39], which certifies that the production process meets international requirements for the production and supply of ethanol for SAF manufacturing, companies can access this restricted market, potentially increasing ethanol exports in the coming years (NOVACANA, 2024d).

In December 2023, representatives from the Brazilian government and the private sector participated in the Brazil-Japan Seminar on Sustainable Aviation Fuel in Tokyo to discuss the decarbonization of the aviation sector (UNICA, 2023). As a result, a commitment was established to promote the exchange of experiences on the topic and the development of the international market, as well as to discuss joint initiatives related to accelerating the decarbonization of the aviation sector (MRE, 2024). Japan has one of the most ambitious goals for SAF implementation, aiming to use 10% SAF in international flights at its airports by 2030.

Regarding biodiesel, global trade remained concentrated among Europe, Argentina, and the United States, with Brazil not having a significant share in the traded volumes. This year, the country exported 114 million liters and imported three million liters of biodiesel (ME, 2024).

8.1. United States

In 2023, the country produced 59.1 billion liters of ethanol fuel (a 2.0% increase compared to 2022), with 54.0 billion liters allocated to the domestic market (EIA, 2024a). Its demand, linked to gasoline through the E10 blend, has remained stable at around 50 billion liters, with the excess being directed to the external market (EIA, 2024b).

[39] The ISCC certification is a global system that covers the entire value chain of biofuels, from biomass cultivation to final consumption. The goal is to ensure that biofuels are produced sustainably, adhering to social, environmental, and economic criteria (ISCC, 2024).

This year, the country's ethanol exports totaled 5.4 billion liters, a 6.1% increase compared to 2022. The main destinations were Canada (44.7%), the United Kingdom (11.2%), the Netherlands (8.0%), South Korea (6.6%), and India (6.5%). Unlike previous years, Brazil represented less than 1.0% of U.S. ethanol exports, with only 0.5 million liters imported (EIA, 2024b). Regarding imports, 0.4 billion liters came from Brazil, a 7% decrease compared to 2022 (ME, 2024).

The United States primarily use biodiesel in the B20 blend[40]. In 2023, 6.4 billion liters were produced, and 7.3 billion liters were consumed, resulting in a net import of 0.9 billion liters (EIA, 2024a).

The EPA (Environmental Protection Agency) is responsible for setting the mandatory volumes for the RFS (Renewable Fuel Standard) each year, adjusting them from the original values. On December 1, 2022, the agency released the preliminary RFS volumes for the years 2023, 2024, and 2025 (EPA, 2023). Additionally, the agency proposed the creation of a new category of Renewable Identification Number (RIN) generated from renewable electricity used in electric vehicles. According to this proposal, the generation of e-RINs would be based on the amount of renewable electricity consumed by electric vehicles, with manufacturers responsible for generating credits through generation contracts and the insertion of electricity produced from biogas with qualified producers (EPA, 2023). In May 2023, a revision was proposed to amend the rules associated with e-RINs, shifting the credit generation responsibility from vehicle manufacturers to bioelectricity producers (ETHANOL PRODUCER, 2023).

On June 21, 2023, the proposed amendment to the volumes for 2023 to 2025 was formalized in the final rule, according to Table 5. In this amendment, e-RINs were not included, and the EPA committed to further evaluating the mechanisms for generating and incorporating these credits into the system (EPA, 2023).

Table 5 – RFS biofuel volumes for the 2023-2025 period (billions of liters)

Fuel	2023	2024	2025
Cellulosic biofuels	3.18	4.13	5.22
Biomass diesel	10.67	11.51	12.68
Advanced biofuels	22.49	24.76	27.75
Renewable fuels	80.2	81.54	84.53

Source: EPA (2023).

In August 2022, the Inflation Reduction Act (IRA) was enacted to reduce the U.S. federal budget deficit and, consequently, curb inflation. The act encompasses a broad range of measures aimed at lowering healthcare costs, funding federal revenue, and addressing climate change. In the latter segment, the law represents the largest investment in the country's history, allocating approximately US$400 billion in direct funds for clean energy projects. Of this amount, US$23.4 billion is earmarked for transportation improvements and electric vehicles (MCKINSEY & COMPANY, 2022).

Under the IRA, the United States aims to build a society based on clean energy and energy security, with a goal of reducing carbon emissions by at least 50% by 2030, aspiring to achieve a net-zero economy by 2050. Additionally, the federal administration also targets emissions-free electricity generation by 2035.

[40] B20 and lower blends can be used in current engines without modifications, provided they meet ASTM D7467 specifications. Higher blends, up to B100, are much less commonly used due to the lack of regulatory incentives and the requirement for special equipment both for storage and in the engines themselves (EERE, 2023).

8.2. European Union

The European Union is committed to greenhouse gas (GHG) mitigation and energy security goals and has established action plans with annual targets for 2020, 2030, and 2050. The Renewable Energy Directive – RED II (CE, 2009) set targets for 2020, known as the Triple 20, which were: a 20% reduction in GHG emissions compared to 1990 levels, 20% share of renewable sources in energy consumption, 10% share of renewables in automotive fuel consumption, and a 20% increase in energy efficiency compared to 1990. The bloc achieved and exceeded these targets in 2020, largely due to the Covid-19 pandemic containment efforts, which imposed restrictions on movement and gatherings.

In November 2023, revisions and amendments to the RED II directive were approved, resulting in Directive 2018/2418 (CE, 2023). The revised directive introduces more stringent measures for the use of clean energy sources to reinforce the commitment to achieving a climate-neutral society, meaning zero net GHG emissions (CE, 2023), and facilitates the entry of new technologies, such as hydrogen and renewable electricity, into various sectors. By 2030, the previous target of 32% renewable energy in final consumption is increased to 42.5%.

8.3. Other countries

In 2023, China was the fourth-largest producer of ethanol in the world, with 3.6 billion liters (RFA, 2024), all of which is used domestically. The country maintains an optional E10 blending program in 10 provinces and restricts ethanol fuel production to licensed plants that sell the biofuel to national distributors and refineries (USDA, 2023a). The Chinese government, through the 14th Five-Year Plan for 2021 to 2025, has shown interest in developing a clean biofuels industry, focusing on advanced technologies and new biofuels. However, no detailed implementation measures or policies have been announced since the plan's launch (USDA, 2023a).

Indonesia remained one of the world's major biodiesel producers in 2023, with an estimated production of 14 billion liters. The consumption of this biofuel in the country is driven by a blending mandate, which increased from 30% to 35% (B35) starting in February 2023 (USDA, 2023c). The Indonesian biodiesel program is funded by taxes on palm oil exports. Indonesian biodiesel exports in 2023 are estimated at 0.6 billion liters (USDA, 2023b).

South Korea imported 868 million liters from Brazil in 2023, making it the largest destination (32.7% of the exported volume) (ME, 2024). The country uses ethanol exclusively in the industry and food sector; however, the government is exploring its use as a fuel due to environmental benefits, improvements in air quality in large cities, and energy security.

In 2023, India became the third-largest producer of ethanol in the world, surpassing China with a production of 5.4 billion liters (RFA, 2024), primarily derived from the conversion of molasses. The Ethanol Blending Program, launched in 2003, facilitates the acquisition and conversion of by-products from the sugar industry into biofuel. The country, through the National Biofuels Policy of 2018, established the E10 ethanol blend starting in 2022 (USDA, 2023c), but only achieved the 10% ethanol content in total fuel consumption starting in November 2023 (BUSINESS STANDARD, 2024). The government had initially set a target for increasing the blend to E20 by 2030 but brought forward this milestone to 2025 through an amendment to the law in June 2022 (MPNG, 2022). The target for 2030 remains the introduction of the B5 biodiesel blend (USDA, 2023b).

India signed a Memorandum of Understanding with Brazil in January 2020 for mutual support in the development and promotion of biofuel production and use, as well as in utilizing by-products, based on the accumulated experience of both countries in the sector (BRASIL, INDIA, 2020). This agreement allows India to update its ethanol production facilities and develop technology for ethanol blending, promoting sector flexibility by alternating the use of sugarcane between sugar and ethanol. Potentially, the agreement would enable both countries to develop ethanol-based biorefineries.

Under this agreement, a partnership was formed between the Union of Sugarcane Industry (UNICA) and the Society of Indian Automobile Manufacturers (SIAM) to create a Virtual Center of Excellence (CoE). Established in a memorandum signed on April 22, 2022, and officially launched in January 2023, the CoE serves as a knowledge portal gathering information on technological advancements, technical standards, regulations, public policies, and sustainability related to biomass and bioenergy (UNICA, 2022; USDA, 2023b).

9. Innovations and Emerging Perspectives for Biofuels

The National Energy Policy Council (CNPE), through Resolution CNPE No. 07, dated April 20, 2021 (CNPE, 2021a), established the Future Fuels Program and created the Future Fuels Technical Committee (CT-CF). The program aims to increase the share of sustainable and low-carbon intensity fuels by integrating various public policies, such as RenovaBio, the National Biodiesel Production and Use Program, the National Vehicle Labeling Program, and Rota 2030 (CASA CIVIL, 2021; CNPE, 2021a).

As a result of the studies conducted by the CT-CF, the federal government submitted to the National Congress Bill 528/2020, attached to Bill 4516/2023. The bill "*provides for the promotion of low-carbon sustainable mobility and the capture and geological storage of carbon dioxide; establishes the National Sustainable Aviation Fuel Program (ProBioQAV), the National Green Diesel Program (PNDV), and the National Decarbonization Program for Natural Gas Producers and Importers and the Biomethane Incentive Program*." The bill[41] also proposes changes to the maximum and minimum limits for the blend of anhydrous ethanol in gasoline C and the blend of biodiesel in diesel sold to final consumers. As of the end of June 2024, the bill was under consideration in the federal senate.

Bill No. 5174/2023, currently under consideration in the National Congress, establishes the Energy Transition Acceleration Program (Paten), which has three objectives: (i) to promote the financing of sustainable development projects, particularly those related to infrastructure, technological research, and technological innovation development; (ii) to connect funding institutions with companies interested in developing sustainable development projects; and (iii) to allow the use of credits held by private legal entities with the Union as a financing instrument. The bill creates the Green Fund, to be managed by BNDES, aimed at guaranteeing the risk of financing provided by financial institutions to companies with approved projects under Paten (Agência Câmara de Notícias, 2024).

The following presents an overview of new biofuels: lignocellulosic ethanol (E2G), green diesel, including Hydrotreated Vegetable Oil (HVO), SAF, sustainable marine fuels, and biomass-derived hydrogen.

[41] The bill also proposes amendments to Law No. 9,478/1997, including designating the ANP as the regulatory body for the synthetic fuels industry and for CO_2 capture and geological storage. It also defines Synthetic Fuel as that which is synthesized from technological routes, such as thermochemical and catalytic processes, and which can partially or fully replace fossil fuels.

9.1. Lignocellulosic Ethanol (E2G)

Currently, in Brazil, there are several commercial lignocellulosic ethanol (E2G) plants. GranBio operates the Bioflex-I biorefinery in São Miguel dos Campos (AL), which has a nominal capacity of 30 million liters per year. Additionally, Raízen has two plants: one in Piracicaba (SP) with a capacity of 42 million liters per year and another in Guariba[42], with a capacity of 82 million liters per year (GranBio, 2024; Raízen, 2024).

The Bioflex-I biorefinery was inaugurated in 2017 but has not produced lignocellulosic ethanol since the 2021/22 harvest. The company has announced plans to expand its production capacity to 60 million liters starting in 2026 (GranBio, 2024; Novacana, 2024b). In April 2021, the company obtained Roundtable of Sustainable Biomaterials (RSB) certification for the European Union's RED II directive, allowing it to export 2G ethanol to the EU. GranBio is also developing a project that integrates energy cane and conversion technologies for biogas and SAF (GRANBIO, 2024; NOVACANA, 2022c).

Currently, Raízen has five new lignocellulosic ethanol (E2G) projects under construction, each with a capacity of 82 million liters per year, as shown in Table 6. Additionally, the company has two more new projects with construction and operation schedules yet to be announced: one adjacent to the Santa Elisa plant in Sertãozinho-SP and the other adjacent to the Caarapó plant in Caarapó-MS. Raízen intends to market lignocellulosic ethanol internationally, where it already has long-term contracts.

Table 6 – Raízen's E2G units and projects

Related plant	City	State	Status	Annual capacity (million liters)	Operation start
Barra	Barra Bonita	SP	Under construction	82	2024/25
Univalem	Valparaíso	SP	Under construction	82	2024/25
Gasa	Andradina	SP	Under construction	82	2026/27
Vale do Rosário	Morro Agudo	SP	Under construction	82	2026/27
Tarumã	Tarumã	SP	Under construction	82	2026/27
Santa Elisa	Sertãozinho	SP	In design		T.B.A.
Caarapó	Caarapó	MS	In design		T.B.A.

Source: NOVACANA, 2022a; UDOP, 2024; RAÍZEN, 2023b; NOVACANA, 2024e.

Abroad, E2G projects by other companies have struggled to reach commercial production, and many plants have halted operations with no plans for resumption.

9.2. Other Inputs for Biofuel Production

Considering that the use of biofuels is one of the alternatives for decarbonizing the transport sector, there is a need to increase their production, which includes greater availability of raw materials. In parallel, the federal government has established guidelines to promote local development in the semi-arid regions of the Northeast (MME; MDA, 2023; MAD, 2024; SAF/MAPA, 2022).

[42] The construction was completed in October 2023, and the authorization for operation was granted by the ANP in March 2024.

In this context, the development of agave[43] cultivation in the semi-arid regions of the Northeast for ethanol production (both 1G and 2G) stands out. In 2022, Shell partnered with Unicamp (State University of Campinas) to launch the Brazilian Agave Development Program – BRAVE. The goal of this program is to develop processing routes for obtaining ethanol, biogas, and other by-products from agave (SHELL, 2023).

The initial phase of the BRAVE project (BRAVE Bio) focused on developing biological solutions to increase the productivity of agave cultivation. In 2023, Shell entered a partnership with SENAI CIMATEC to initiate the next phases of the program. These new phases aim to develop mechanization technologies for planting and harvesting (BRAVE Mec) and to enable the processing of different agave species (BRAVE Ind). These developments are expected to proceed in parallel over the next five years (SHELL, 2023).

9.3. Hydrotreated Vegetable Oil (HVO)

Green diesel, which includes HVO, is a renewable fuel composed of a mixture of hydrocarbons with a chemical composition similar to that of fossil fuels (drop-in[44]). It can be produced through various routes, such as the hydroprocessing of vegetable and animal oils, Fischer-Tropsch synthesis from renewable sources, as well as from fermentative processes, catalytic hydrothermal liquefaction of vegetable oil (raw or residual), animal fat, and fatty acids from biomass. Additionally, it can involve the oligomerization of alcohols (ANP, 2021a). Concurrently with HVO production, SAF, renewable naphtha, and biopropane can also be produced (EPE, 2020).

The Future Fuel Bill proposes the creation of the National Green Diesel Program (PNDV), which is part of the effort to transition to cleaner energy and reduce external dependence on petroleum-derived diesel by gradually incorporating green diesel into the country’s fuel matrix. To determine the mandatory percentage of renewable fuel to be blended with fossil diesel, the CNPE will assess the conditions of product supply, including raw material availability, production capacity, and location. Additionally, the CNPE will consider the impact of the mandatory minimum blend on the final consumer price and the competitiveness of domestically produced green diesel in international markets.

Three projects to produce both HVO and SAF have been announced (see item 9.5). As mentioned, the trend in Brazil, as in other countries, is for the pioneering units of this product to come from the conversion of conventional refineries into biorefineries processing vegetable oil (EPE, 2020).

9.4. Co-processing of Vegetable Oils

Additionally, Petrobras, through the BioRefining Program[45], aims to expand the production of Diesel R at the Presidente Getúlio Vargas Refinery (REPAR) in Paraná and to start co-processing for biofuel production at the Presidente Bernardes Refinery in Cubatão (RPBC), the Paulínia Refinery (REPLAN) in São Paulo, and the Duque de Caxias Refinery (REDUC) in Rio de Janeiro. In its roadmap, PETROBRAS estimates that production will reach 3.4 million m^3/year (PETROBRAS, 2024a).

[43] Agave is a plant from the semi-arid regions known for its high biomass productivity, drought resistance, and low nutritional requirements. As a non-food biomass source, the production of ethanol from agave does not face entry barriers in some countries or economic blocs.

[44] Drop-in biofuels are hydrocarbons that are functionally equivalent to those derived from petrochemicals and are fully compatible with existing petroleum infrastructure (EPE, 2020).

[45] The BioRefining 2030 Program is an initiative by Petrobras to promote the production of advanced sustainable biofuels, such as Diesel R and SAF, with an investment of R$ 600 million (PETROBRAS, 2022a).

Diesel RX is a fuel resulting from the co-processing of a percentage of vegetable oil with mineral diesel during the hydroprocessing (catalytic hydrogenation) stage at a refinery, producing a fuel with a low-carbon technology. In the Diesel RX nomenclature, the "X" refers to the percentage of vegetable oil used in the original blend (Diesel R5 = 5% vegetable oil mixed with mineral diesel).

9.5. Sustainable Aviation Fuels

For SAF, the International Civil Aviation Organization (ICAO/UN) has established an emissions reduction agreement with airlines called CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation). This scheme sets a carbon-neutral growth target for the aviation industry starting from 2020 but based on 85% of the 2019 emission levels due to the COVID-19 pandemic in 2020 (ICAO, 2024).

In addition to emission offsetting mechanisms and energy efficiency promotion, CORSIA includes the use of drop-in alternative aviation fuels, particularly those with processes certified by ASTM International (American Society for Testing and Materials International), as outlined in Table 7. The feedstocks used are defined as technologies undergo the approval process by the “Aviation Fuels” subcommittee of ASTM International (ASTM, 2020).

Table 7 – Approved technological routes for SAF production

Route Name	Feedstock	Maximum mix
HEFA-SPK	Fats, oils, and greases	50%
FT-SPK	Agricultural and forest residues, wood, and solid waste	50%
FT-SPK/A	Agricultural and forest residues, wood, and solid waste	50%
ATJ-SPK	Renewable raw materials (sugarcane, corn, or forest residues)	50%
SIP	Sugars	10%
CHJ	Oils and fats	50%

Source: (ASTM, 2020); (EPE, 2024)

Considering the technological processes certified by ASTM International and authorized for use in Brazil, as regulated by ANP, the following feedstocks can be utilized most promisingly, depending on their maturity for large-scale production (in alphabetical order): babassu, corn, forest resources (eucalyptus), macaúba (*Acrocomia aculeata* palm), palm, soy, and sugarcane.

There are industrial and economic challenges for SAF to be competitive with fossil jet fuel, both in Brazil and globally. Similarly to the biofuels that will be part of the Diesel cycle, the Future Fuel Bill also includes the National Sustainable Aviation Fuel Program in the Brazilian aviation market (ProBioQAV).

With the signals from CORSIA and ProBioQAV, some companies are focusing on building SAF production plants, often alongside HVO production. Generally, there is a growing movement towards biorefining.

In 2022, Petrobras announced a project to establish a SAF production unit at the Presidente Bernardes Refinery (RPBC) in Cubatão (SP), with a production capacity of 2.2 million barrels per year (350,000 m^3/year) of SAF and an equal amount of 100% renewable diesel, derived from the processing of up to 790,000 tons of feedstock per year (PETROBRAS, 2024a). Recently, the company revealed plans to convert the Riograndense Refinery in Rio Grande do Sul (RS) into a biorefinery by 2026 and to implement SAF and renewable diesel production at the Gaslub Complex in Rio de Janeiro after 2028. SAF production at Petrobras will use HEFA technology, utilizing soybean oil and beef tallow as feedstocks.

Also in 2022, a project was announced to build a biorefinery in Manaus for the joint production of SAF and HVO, using palm oil. The facility will have a production capacity of 500,000 m^3/year, to be shared between both fuels. It is estimated to be operational by 2025 and is expected to cost around R$ 2.5 billion to complete (BRASIL BIOFUELS, 2022).

ACELEN Renováveis has also announced an investment of R$ 12 billion over the next 10 years for the conversion of the Mataripe Refinery into a biorefinery, with a goal of producing 1 billion liters/year of renewable fuels (SAF and green diesel) by 2035. The project includes promoting the cultivation and development of macaúba as a feedstock and will use soybeans in the initial years of operation (ACELEN, 2024).

Additionally, there are two pilot projects resulting from a partnership between Brazil and Germany. The first is an initiative between the National Service for Industrial Training (SENAI) and the German Agency for International Cooperation (GIZ) for SAF production, to be installed at the SENAI Institute of Innovation in Renewable Energies (ISI-ER) in Fortaleza. This project is budgeted at R$ 4.5 million with a duration of two years and will use glycerin as a feedstock (APROBIO, 2022). The second project is a partnership between the German and Brazilian governments, academia, and the private sector to study the installation of a pilot plant in Ceará. This plant will use renewable electricity (from wind or solar sources) to produce hydrogen and SAF. Notably, it will be a mobile plant, capable of being transported to airports with supply challenges (GOVERNO DO ESTADO DO CEARÁ, 2020).

Recently, several companies have announced their intention to invest in SAF production using the ATJ (Alcohol to Jet) route (NOVACANA, 2024c; RAÍZEN, 2023a).

In December 2023, a meeting took place between representatives of the Brazilian government and private companies from the sugar-energy sector with officials from Japan's Ministry of Economy, Trade, and Industry (METI) to discuss the decarbonization of the aviation sector, focusing on the development of the ATJ (Alcohol to Jet) route using ethanol. Japan has set an ambitious target for SAF implementation, with a mandate of 10% SAF blending in aviation fuel used on international flights at Japanese airports starting from 2030. The demand for sustainable fuel could reach 1.7 billion liters per year, according to estimates (UNICA, 2023).

9.6. Renewable Hydrogen

In April 2021, CNPE Resolution No. 6 mandated the conduct of a study to propose guidelines for the National Hydrogen Program (PNH_2). The study involved institutions and stakeholders from both the public and private sectors, including the technical team from EPE. The proposal for the hydrogen program is based on three pillars: public policies, technology, and market. The goal is to integrate hydrogen into the Brazilian energy matrix and make it available for other uses, such as fertilizer production (CNPE, 2021a; MME, 2021).

Also in April 2021, Eletrobras, Siemens Energy, and CEPEL signed a memorandum for the joint development of pilot-scale studies to master the biomass hydrogen (H_2) cycle in Brazil, covering its production through to its consumption (ELETROBRAS, 2021).

In May 2022, Geo Biogas & Tech, in partnership with the Federal University of Paraná (UTFPR), announced that it had produced hydrogen from biomethane obtained through dry catalytic reforming of biogas, a product of vinasse biodigestion. According to the Brazilian Biogas Association (ABIOGÁS), Brazil has the potential to produce 20,000 tons per day of hydrogen from biomethane (NOVACANA, 2022b).

In January 2023, the commencement of hydrogen production in Brazil was announced with the H2V pilot project at the Pecém Thermal Power Complex (UTE Pecém) in Ceará. With an investment of R$ 42 million, the facility is the first in Latin America with a scale exceeding 1 MW (PECEM, 2023).

PNH_2 was officially launched on August 3, 2022, through Resolution No. 6/2022, along with the management committee - COGES-PNH_2. The program is based on six pillars: (1) strengthening scientific and technological foundations, (2) human resources training, (3) energy planning, (4) legal framework, (5) market opening and growth, and competitiveness, and (6) international cooperation. COGES-PNH_2 is responsible for coordinating and supervising the planning and implementation of the program (CNPE, 2022b).

In August 2023, the 2023-2025 Triennial Plan for the National Hydrogen Program was launched. This Triennial Plan established timelines, goals, investments, regulatory frameworks, and Brazil's priorities for structuring the hydrogen economy. By 2025, the goal is to deploy low-carbon hydrogen pilot plants across all regions of the country (MME, 2023b). By 2030, the objective is to position Brazil as the most competitive producer of hydrogen in the world, and by 2035, to establish low-carbon hydrogen hubs using wind, solar, and biomass sources. According to estimates from the MME, the country has the technical potential to produce 1.8 gigatons of hydrogen per year at a lower production cost (MME, 2023b).

In addition to several hydrogen production projects aimed at SAF production, export, and other uses (GOVERNO DO ESTADO DO CEARÁ, 2020; TRENDSCE, 2021), other similar production hubs are planned for the ports in Suape (PE) and Rio Grande do Sul (RS).

Bill No. 725/2022 (which is still under consideration in the Senate as of the publication date of this technical note)[46] stipulates that by 2032, a minimum of 5% hydrogen must be added to the gas pipeline network, increasing to 10% by 2050. Of this hydrogen, 60% must be sustainable—derived from energy sources such as solar, wind, biomass, biogas, and hydroelectric—during the initial period. From 2050 onward, the share of clean hydrogen should be 80%. This bill also amends Law No. 9.478 of 1997, the Petroleum Law, allowing this new fuel to be regulated by the ANP (SF,2022).

[46] As of the publication of this Technical Note, Bill No. 725/2022 was still under consideration in the Senate. It is worth noting that on July 14, 2024, the National Congress approved Bill No. 2308/2023, known as the Green Hydrogen Legal Framework. This legislation establishes the legal framework for low-carbon hydrogen, creates incentives for the hydrogen industry, and establishes the Special Incentives Regime to Produce Low-Carbon Hydrogen (Rehidro – Senado Federal, 2024). The bill was approved by the Chamber of Deputies, then by the Federal Senate with amendments and revisions, and has returned to the Chamber of Deputies (CN, 2024).

9.7. Sustainable Marine Fuels

The International Maritime Organization (IMO) has developed regulations and targets for the decarbonization of the maritime sector. The IMO 2023 Strategy has raised the ambition levels compared to the IMO Initial Strategy for reducing GHG emissions from ships. Following the revision of the Strategy, the total annual GHG emissions from shipping must achieve a 30% reduction by 2030 and an 80% reduction by 2040, compared to the 2008 baseline year. These targets can be met through further improvements in the energy efficiency of new ships and the adoption of zero or near-zero GHG emissions technologies and fuels (DGRM, 2023).

In December 2022, Petrobras conducted the first test of bunker fueling with renewable content in the country. A blend of 90% conventional or mineral marine fuel oil (bunker) and 10% biodiesel was used. In 2023, the tests were expanded to a mixture of 76% bunker and 24% biodiesel (BIODIESELBR, 2024c). The biodiesel used in the test was produced at Petrobras Biocombustível's Montes Claros (MG) plant from a mix of 30% beef tallow and the remainder from soybean oil (ANP, 2024d).

The aim of these tests is to assess the logistical challenges associated with blending biodiesel with marine fuel and the potential adverse effects that may impact ship operations. During the tests, performance and impacts on filters and purifiers are monitored. The test conducted in 2023 was deemed successful as no atypical occurrences were observed in the ship's engine or fuel treatment systems (BIODIESELBR, 2023; PETROBRAS, 2023b)

10. Greenhouse Gas Emissions

Brazil plays a prominent international role in discussions and negotiations on climate change. Over time, the country has developed a legal framework aimed at promoting the use of renewable sources, with a particular emphasis on biofuels. An important step in this direction was taken in December 2017 with the establishment of the National Biofuels Policy, a topic covered in Section 11 of this document.

The GHG emissions profile in Brazil differs from the global average. While in most countries the energy sector is the primary emitter, in Brazil, the combined sectors of agriculture, forests, and land use (AFOLU—Agriculture, Forestry, and Other Land Use) account for the largest share of gross GHG emissions. Recent data indicate that in 2020, land use changes represented 38% of emissions, largely due to deforestation; agriculture accounted for 28.5%; and the energy sector for 23.2% (MCTI, 2022). The share of each segment highlights that one of the major challenges for the country in combating climate change is to achieve zero deforestation, a commitment made in the Nationally Determined Contribution (NDC) to the Paris Agreement (BRASIL, 2023c).

However, even though the energy sector is not the primary contributor to national GHG emissions, it is still necessary to advance the transition with a focus on ensuring sustainability, energy access, and energy security. Brazil has several comparative advantages in this process, primarily due to its abundant renewable energy resources, both for electricity generation and for producing low-carbon intensity fuels. By leveraging these opportunities, the energy transition has the potential to catalyze technological and industrial development and to promote job and income generation for the population.

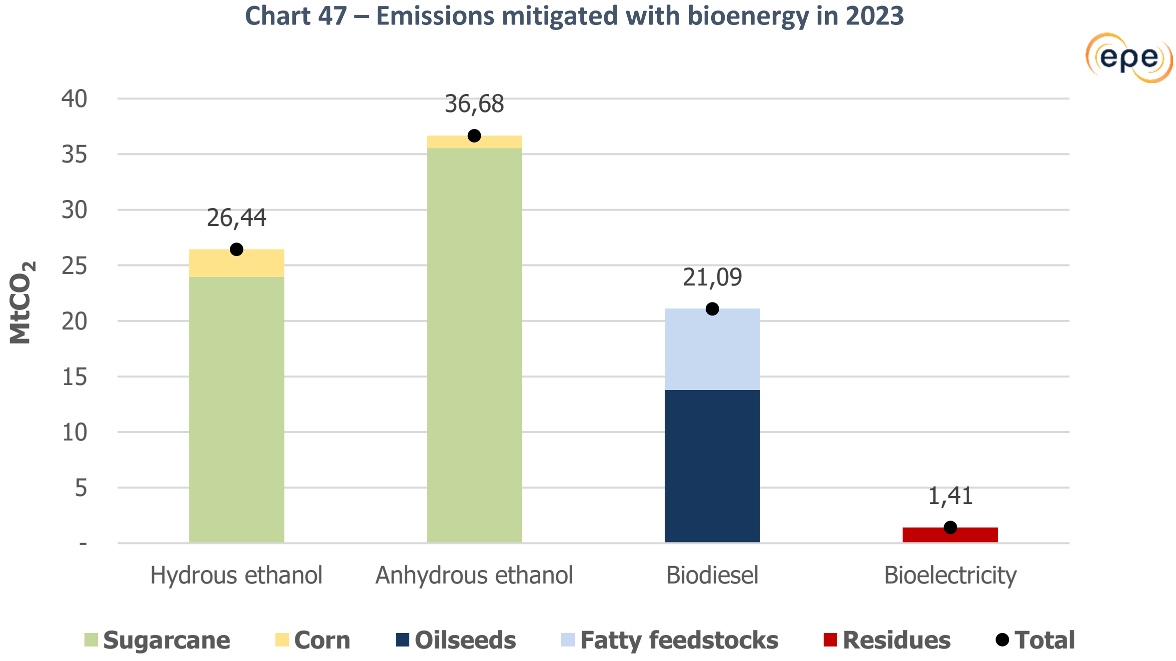
In this context, bioelectricity and biofuels already play an important role in the renewability of the national energy matrix. As discussed in previous chapters, both electricity generation at sugar-energy mills and the production of ethanol and biodiesel increased in 2023, leading to a rise in mitigated emissions through bioenergy.

In the electricity sector, bioelectricity accounted for 8.2% of the electricity generated in 2023, with the largest share coming from the use of sugarcane bagasse at ethanol mills. Additionally, electricity generation in the year was even more renewable than in 2022, with stable hydropower generation and increases in wind (+17.4%) and solar photovoltaic (+68.1%) generation. In contrast, there was a decrease in the share of natural gas (-7.9%) and oil-derived thermal power (-19.4%) (EPE, 2024). These changes resulted in an average emission factor for the National Interconnected System (SIN) of 0.0385 tCO_2/MWh, according to the Ministry of Science, Technology, and Innovation (MCTI, 2024). This factor is about 10% lower than the value recorded in 2022 and represents the lowest value in the last 12 years. Thus, the energy generated by sugar and ethanol mills in 2023, used for self-consumption and exported to the grid, contributed to avoiding the emission of 1.41 $MtCO_2$, 2.3% more than the mitigated emissions in 2022 (1.37 $MtCO_2$).

Regarding liquid biofuels, there was an increase in mitigated emissions due to the rise in production observed in 2023, as reported in previous chapters. The share of biofuels led to a 22.5% renewable profile in the transport matrix (EPE, 2024). Consequently, the emissions mitigated by using ethanol (anhydrous and hydrated from sugarcane and first-generation corn) and biodiesel, compared to their fossil equivalents (gasoline and diesel), totaled 84.2 $MtCO_2$ in 2023. This figure represents an 18.5% increase in mitigated emissions compared to the previous year's total (71.1 $MtCO_2$).

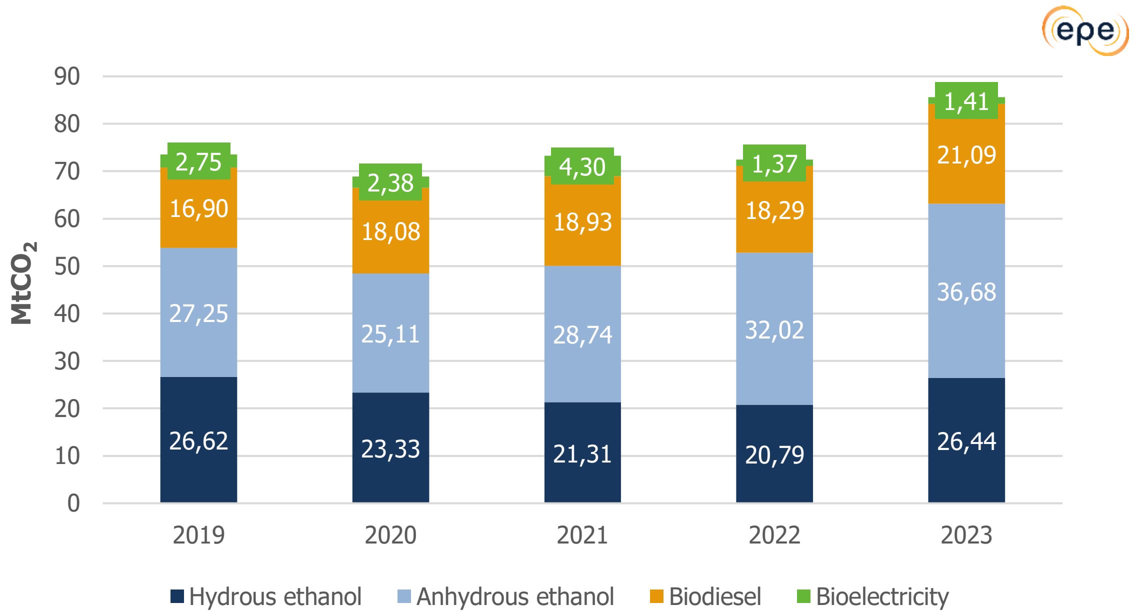
Chart 47 illustrates the mitigated emissions resulting from the use of biofuels and sugarcane bioelectricity in 2023, while Chart 48 presents the overview for the past five years. In 2023, the total mitigated emissions from bioenergy use amounted to 85.62 MtCO2, a figure that not only returns to pre-pandemic levels but also exceeds them by 16%. Bioenergy is expected to gain even more relevance with the advancement of the energy transition, particularly due to the potential to mitigate emissions with drop-in biofuels in hard-to-decarbonize sectors. This process is anticipated to be driven by the implementation of national and international regulations, such as the Fuel of the Future and the targets set by ICAO and IMO.

Chart 47 – Emissions mitigated with bioenergy in 2023



Source: EPE based on (EPE; FBDS, 2009); (EPE, 2024); (IPCC, 2006); (MCTI, 2024) and (ROSA, OLIVEIRA, COSTA, PIMENTEIRA, & MATTOS, 2003).

Chart 48 – Emissions mitigated with bioenergy in the last 5 years



Source: EPE based on (EPE; FBDS, 2009); (EPE, 2024); (IPCC, 2006); (MCTI, 2024) and (ROSA, OLIVEIRA, COSTA, PIMENTEIRA, & MATTOS, 2003).

11. National Biofuels Policy (RenovaBio)

Established by Law No. 13,576/2017 (BRASIL, 2017), the National Biofuels Policy (RenovaBio) acknowledges the strategic role of biofuels in the national energy matrix, focusing on fuel supply security and the mitigation of GHG emissions. The policy aims to increase the competitive participation of biofuels based on the establishment of annual targets for reducing the carbon intensity (gCO_2/MJ) of the transportation energy matrix over a minimum period of ten years, biofuel certification, and the Decarbonization Credit (CBIO).

By the end of 2024, RenovaBio will complete five years of full operation, considering the commercialization of Decarbonization Credits (CBIO) on the B3 trading platform as a milestone.

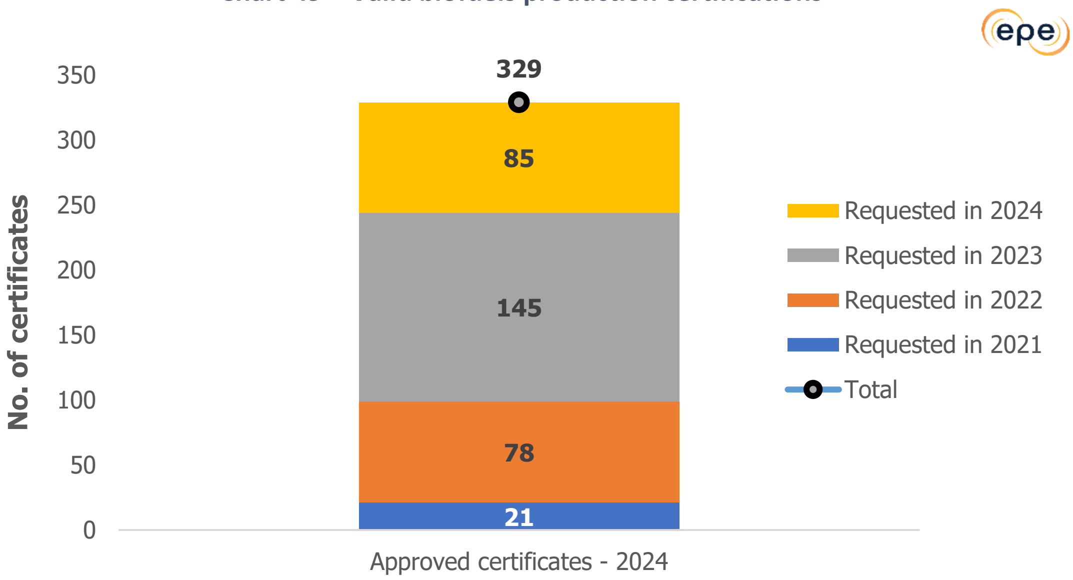
As it is still a relatively recent public policy and due to its complexity, with multiple instruments and stakeholders involved, adjustments are expected to be made along the way to minimize potential shortcomings.

In its maturity, RenovaBio can establish itself as an additional element to ensure the sustainability and predictability of Brazil's transportation matrix, as envisioned in its creation under Law No. 13,576/2017 (BRASIL, 2017).

11.1. Certifications

Between 2019 and July 2024, 290 certifications for biofuel producers were renewed, and 12 changed ownership. As shown in Chart 49, by July 2024, 329 certifications for biofuel producers were valid, 11 more than in 2023. In summary, 3 certifications were added for 1G sugarcane ethanol, 2 for 1G corn ethanol (full), 5 for biodiesel, and 1 for biomethane.

Chart 49 – Valid biofuels production certifications



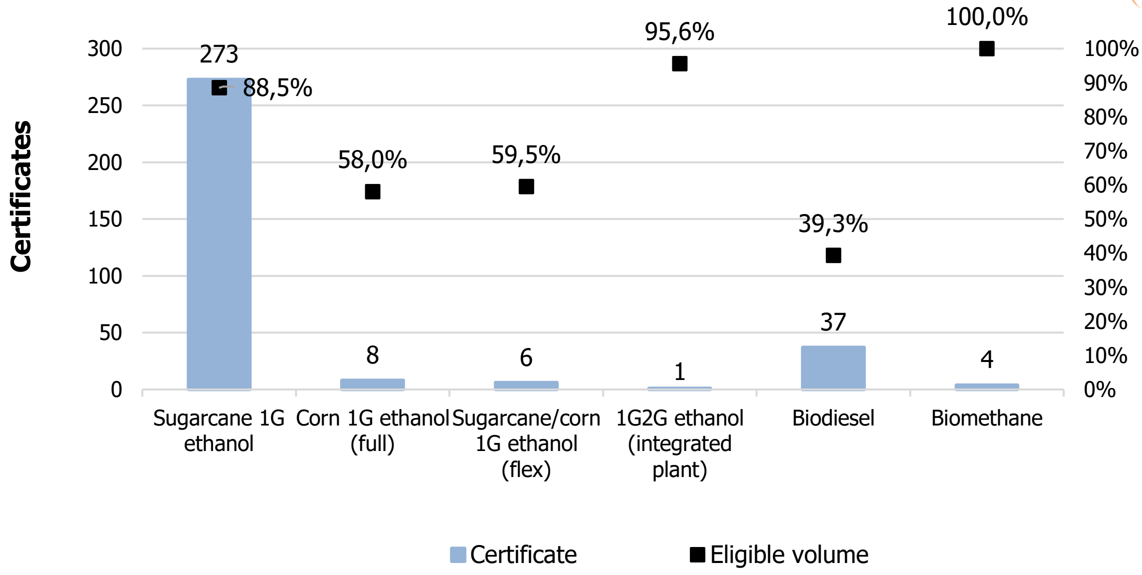
Source: ANP (2024b).

It is also noteworthy that 13 inspection firms were accredited to carry out the certification process under RenovaBio, two more than in 2023 (ANP, 2024b).

The profile of certified units by production route and eligible volume, up to July 2024, is presented in Chart 50. The eligible volume shows significant variation, mainly due to the difficulty in tracking soybean and corn crops, given the wide diversity of producers and procurement methods for these raw materials[47]. The production routes with the highest eligible volumes are 1st generation sugarcane ethanol (88.5%, a decrease of 1 percentage point compared to 2023), 1st and 2nd generation sugarcane ethanol in integrated plants (95.6%), and biomethane (100%). Ethanol from flex plants (corn and sugarcane) saw a 6.5 percentage point decrease in eligible volume, reaching 59.5%, while ethanol from full corn plants increased its eligible volume by 12 percentage points compared to the previous year, rising from 46% to 58%. The average eligible volume for biodiesel plants decreased, with 39.3% of their production deemed eligible, down from 45.6% in 2023. It is noteworthy that 1st generation sugarcane ethanol plants represent 83% of the total certified plants, while biodiesel plants account for 11%.

[47] In June 2022, ANP developed Technical Report No. 06/SBQ v.0, which establishes procedures for the implementation and verification of the grain and vegetable oil supply chain under RenovaBio. This report was supported by the technical team of the Brazil Energy Programme (BEP), a UK program aimed at promoting development and sustainability in the energy sector (ANP, 2024b).

Chart 50 – Certifications by production route and percentage of volume eligible by route

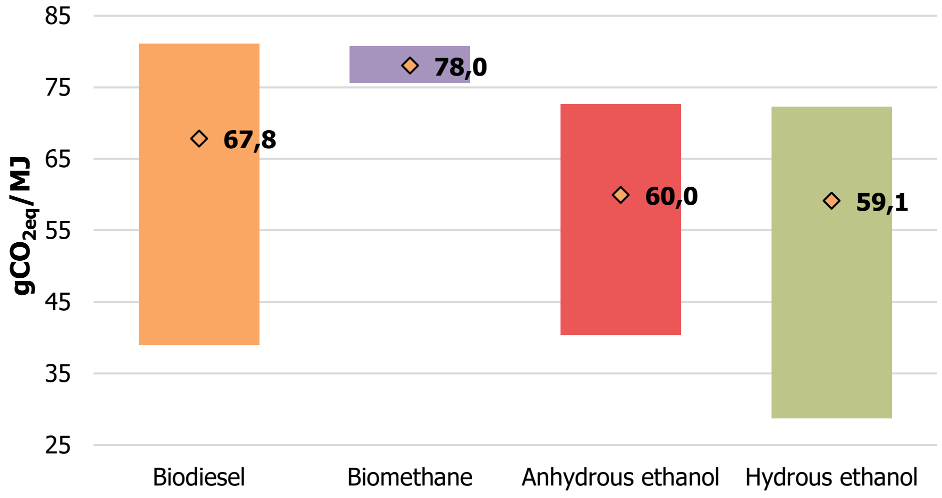


Source: (ANP, 2024b).

Considering the number of units authorized to sell biofuels by ANP up to February 2023, 288 ethanol plants out of a total of 357 (81%) have been certified, 37 out of 59 biodiesel plants (63%), and four out of six biomethane plants (67%).

Chart 51 presents the average Energy-Environmental Efficiency Score (NEEA) for certified units of each biofuel, as well as the range between the minimum and maximum values, up to July 2024. Biodiesel[48] and biomethane maintain the highest scores, except for the percentage of eligible volume for the former.

Chart 51 – Energy-environmental efficiency rating of certified units

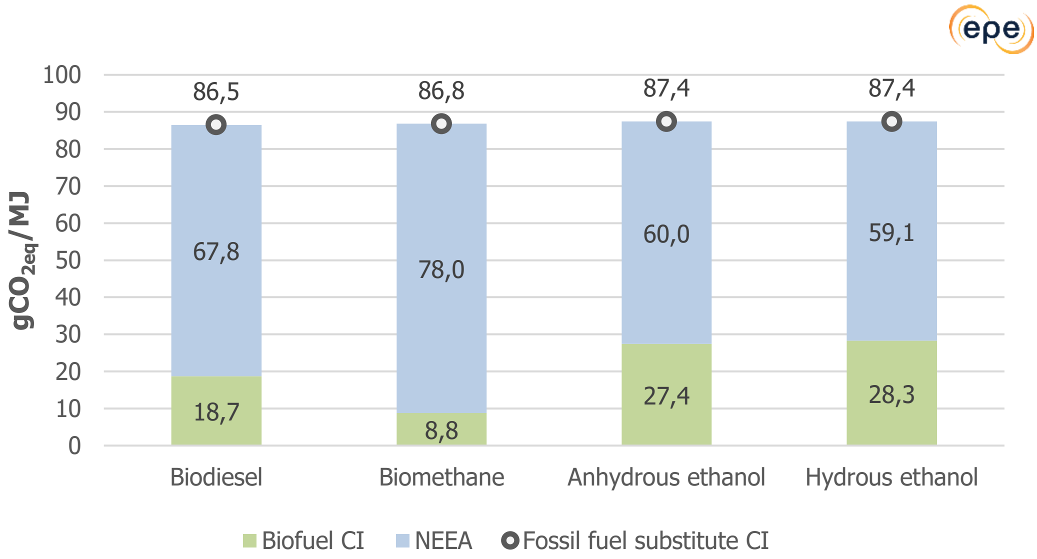


Source: EPE based on ANP (2024b).

[48] For biodiesel, a significant portion of the certified volume, to date, does not account for the agricultural stage in the certification, such as residues, which contributes to the increase in the NEEA.

By comparing the average NEEA of each biofuel with the carbon intensity (CI) of the fossil fuel it replaces, the average CI of the biofuel is determined, as shown in Chart 52. Considering the minimum and maximum NEEA indicators indicated in Chart 51, there is room for reducing the CIs of the indicated biofuels.

Chart 52 – Carbon intensity of biofuel and its fossil substitute, and NEEA

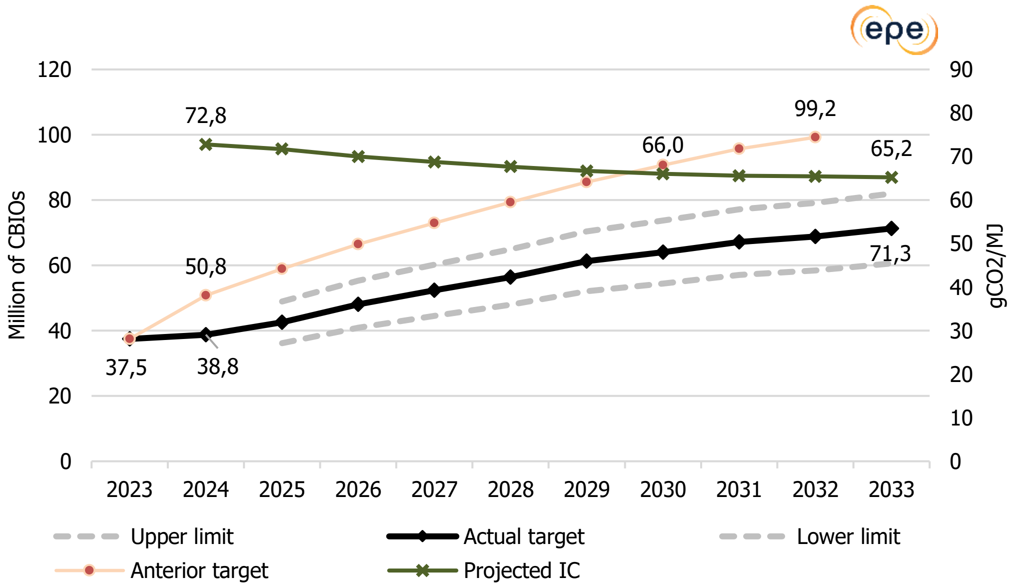


Source: EPE based on ANP (2024b).

11.2. Mandatory GHG Emission Reduction Targets

In November 2023, CNPE set the mandatory annual GHG emission reduction targets for fuel commercialization for the next decade through Resolution CNPE No. 6, adjusting the entire period based on the reassessment of fossil and renewable fuel demand projections for the decade (CNPE, 2023b). The new annual decarbonization targets, as well as the projected carbon intensity for the transportation matrix, can be observed in Chart 53.

Chart 53 – Mandatory GHG emission reduction targets and projected IC



Source: (CNPE,2023b).

Presidential Decree No. 11,141/2022 modified the deadline for proving these targets, which must now occur by March 31 of the following year (BRASIL, 2022d). Exceptionally, the proof of compliance with the 2022 individual target was required by the deadline of September 30, 2023. Decree No. 11,499/2023 reverted to the original definition, requiring compliance with the targets by December 31 of the current year starting from 2024 (BRASIL, 2023d).

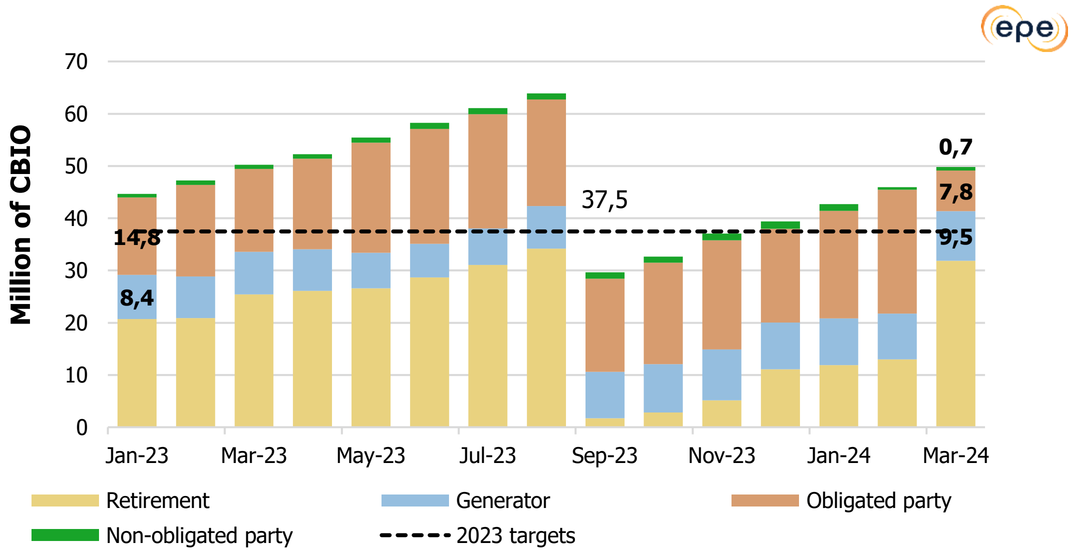
In May 2024, ANP published the mandatory individual GHG emission reduction targets for the year[49] (ANP, 2024b), applicable to distributors of fossil fuels. The three largest companies in the sector—Vibra, Raízen, and Ipiranga—account for 61% of the total. The 2023 individual mandatory targets required 37.5 million CBIOs, including 3.5 million for unmet targets from 2022, totaling 40.9 million CBIOs. However, 7.6 million CBIOs were not acquired by some distributors and were added to their 2024 targets, leading to a global target of 46.4 million CBIOs for this year. Consequently, the share of the three largest distributors in the total now stands at 51%.

11.3. CBIO Stock and Retirement

By the end of the 2023 fiscal year, which concluded in March 2024, 33.1 million CBIOs were retired by obligated parties in compliance with individual targets, representing 88% of the target set by CNPE and 81% of the total individual targets assigned by ANP, including the portion not met by distributors in 2022. Non-obligated parties retired 70 CBIO units. By March 31, 2024, an additional 2.3 million CBIOs related to the 2024 individual targets, which have a deadline of December 31, 2024, were also retired.

By the end of March 2024, the available CBIOs for trading (issued + in stock) totaled 17.9 million, consisting of: 9.5 million held by primary issuers (53%), 7.8 million with obligated parties (43%), and 650,000 with non-obligated parties (4%). Chart 54 shows the CBIO stock throughout the year held by each market participant, as well as the evolution of retirements.

Chart 54 – Stock vs. Retirement of CBIOs 2023



Note: It is important to highlight that, in this Chart, it is not possible to separate the retirements related to the fiscal years 2022, 2023, and 2024 within each month, which may result in values differing from those reported by MME.

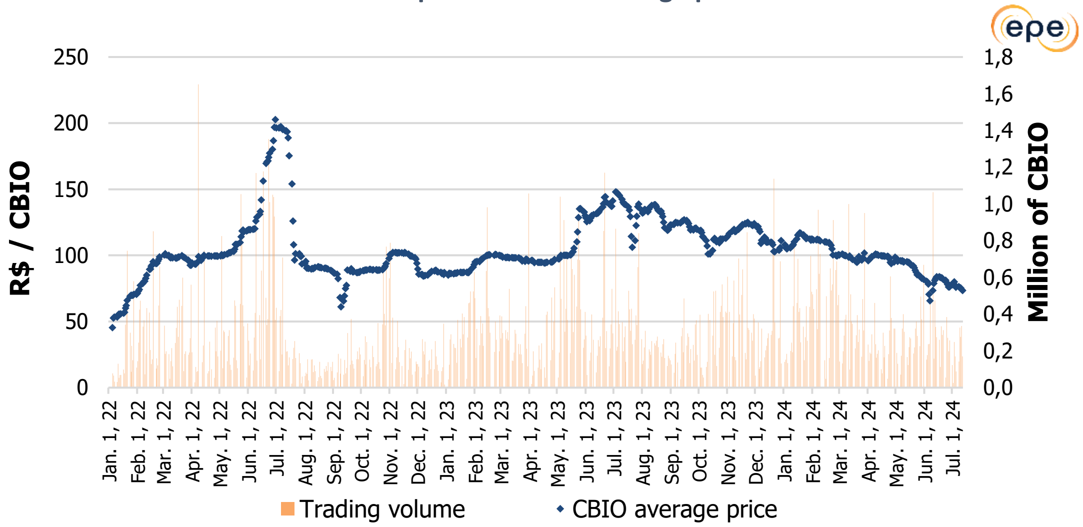
Source: EPE based on B3 (2024).

[49] According to ANP Resolution No. 791/2019, distributors who did not fully meet their targets from the previous year must face a proportional increase in their targets for the current year. As stipulated in § 2 of Article 5 of this resolution, the annual target set by CNPE for 2023 was reduced by 70 CBIOs, which were permanently removed from the market by non-obligated parties in the previous year (ANP, 2019).

11.4. CBIO Price

After experiencing significant fluctuations in 2022, the price of CBIOs showed greater stability in 2023, with a rise in June following the establishment of global and individual decarbonization targets. This was followed by a decline, ending the year at around R$ 100.00. In summary, the average annual price of CBIOs in 2023 was R$ 113.59, nearly the same as the R$ 111.63 recorded in 2022. Chart 55 presents the amount of decarbonization credits traded and their respective average prices from January 2022 to July 2024.

Chart 55 – Traded quantities and average prices of CBIOs



Source: B3 (2024).

Estimates say that biofuel producers[50] received revenue exceeding R$ 4 billion in 2023 (MME, 2023a).

11.5. Other relevant points

On March 29, 2023, ANP approved Resolution No. 921 (ANP, 2023), which amends Resolution No. 791/2019 to include provisions related to the systematic reduction of distributors' individual targets concerning the purchase of biofuels through long-term supply contracts. The main changes in the Resolution are:

- Establishment of minimum contractual terms for applying reductions, consistent across all biofuels.
- Allowance for the contract to be signed with either the biofuel producer's headquarters or a cooperative of producers.
- The volume of contracted biofuel will be multiplied by the corresponding CBIO emission factor of each production unit.
- Limitation of the reduction of the distributor's individual target to 20%, in accordance with Decree No. 9,888/2019, regardless of the number of contracts and volume.
- Annual verification of contract compliance for the purpose of target reduction.

As a result, the CBIO Platform introduced the Long-Term Contracts Module starting November 29, 2023.

These changes are expected to encourage the establishment of long-term contracts with biofuel producers who have higher NEEA scores and to increase market predictability for CBIOs.

[50] The fee charged to biofuel producers per invoice for the issuance of 1 CBIO was updated on July 13, 2024, to R$ 6.50 for the period from August 1, 2023, to December 31, 2023, up from R$ 4 in the previous period. The CBIO Platform is the tool provided by the Federal Data Processing Service (SERPRO) for IT services related to generating the information necessary for CBIO issuance.

12. Potential of low-impact land use change (“land-sparing”) techniques in biofuel production in Brazil

12.1. Introduction

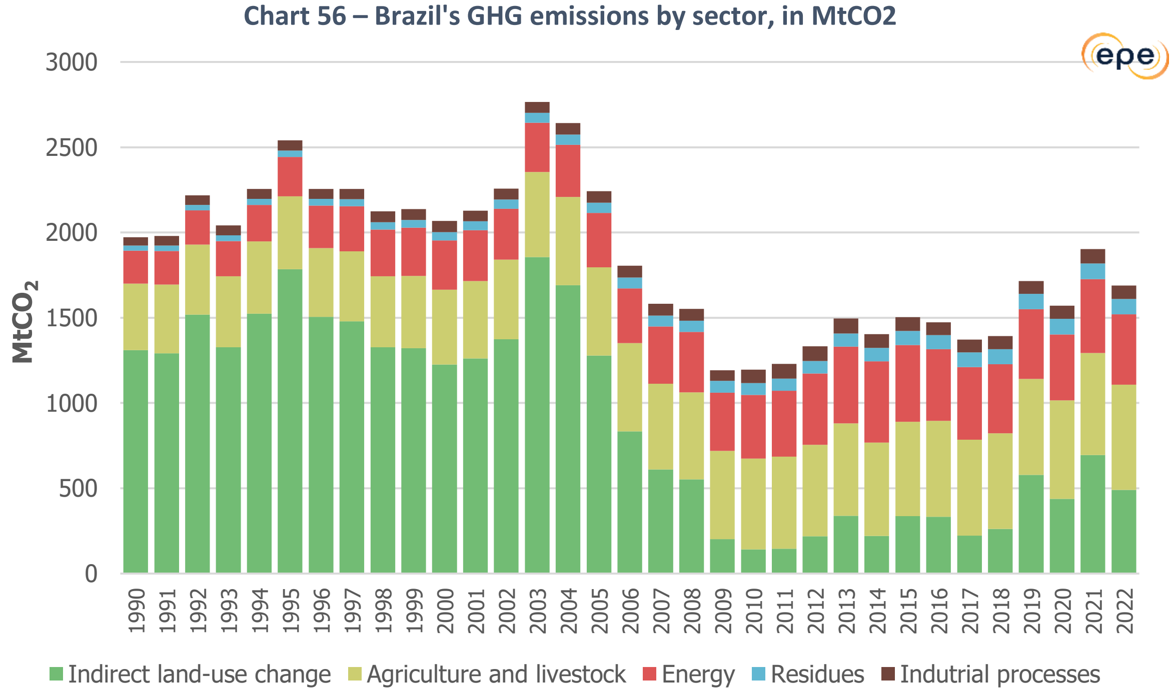
Context

With the increasing interest in transitioning to cleaner energy sources, biofuels emerge as a promising alternative to fossil fuels. However, behind this pursuit of a more renewable energy matrix, complex issues related to land use dynamics arise.

The global demand for biofuels is projected to exceed 200 billion liters within the next 4 years, up from 175 billion liters in 2023, and could more than double in scenarios aiming for net-zero emissions by 2050 (IEA, 2024; IEA, 2021), driven mainly by decarbonization targets in the transportation sector, including road, aviation, and maritime modes. Similarly, food demand is also expected to grow, though at a slower rate, estimated at over 13% by 2032, primarily due to population growth in African and Asian territories (OECD, 2023). This scenario of rapidly increasing demand for both biofuels and food in the coming years heightens uncertainties related to efficient land use.

As one of the largest producers and exporters of agricultural commodities globally, Brazil plays a crucial role in the global supply of both biofuels and food and has the capacity to ensure that this expansion is increasingly guided by sustainable practices. Over the past 40 years, Brazil's agricultural production has grown by about 600%, while the area dedicated to agriculture has increased by 100% (BOLFE et al., 2020), reflecting a successful journey of genetic improvement programs and better agricultural practices, leading to significant productivity gains. While agribusiness is highly relevant to the Brazilian economy, contributing approximately 24% to Brazil's GDP (CEPEA/ESALQ, 2024b), and holds significant potential for implementing sustainable practices and circular economy principles, GHG emissions from agriculture rank second among Brazil's top emitting sectors, behind only land use and forest changes, primarily due to deforestation and the loss of native vegetation.

Chart 56 – Brazil's GHG emissions by sector, in MtCO2



Source: SEEG, 2024.

Given this scenario, this paper aims to explore the dynamics between the rising demand for biofuels and the efficient use of land in the Brazilian context. It highlights the potential implementation of "low-impact land use change" techniques, also known as "land-sparing" techniques, which allow for the maximization of biofuel production without the need to expand new agricultural areas or compete with food production. In this regard, we will examine the benefits and the magnitude of the opportunity that arises for Brazil by integrating these techniques into biofuel production. The primary goal is to estimate a feasible additional volume of biofuels that can be achieved through the implementation of the evaluated "land-sparing" techniques, to contribute to the dissemination of information on the topic and to better guide the formulation of public policies within the country's energy planning.

Regulatory mechanisms for forest conservation in Brazil

Brazil is known for having one of the most robust legislations for forest conservation (CPI, 2017). The Forest Code of Brazil sets guidelines for the conservation of native vegetation areas, such as Permanent Preservation Areas (APPs) and Legal Reserves (RLs), which are crucial for protecting natural resources and biodiversity. Conservation requirements vary across the country's biomes. For example, in the Amazon, 80% of native vegetation must be preserved on rural properties, while in the Cerrado, the requirement is 35%. In the Atlantic Forest biome, legislation mandates the conservation of 20% of properties as legal reserves. APPs are mandatory areas for preserving soil and water quality, required along riverbanks, springs, and hilltops, among other locations.

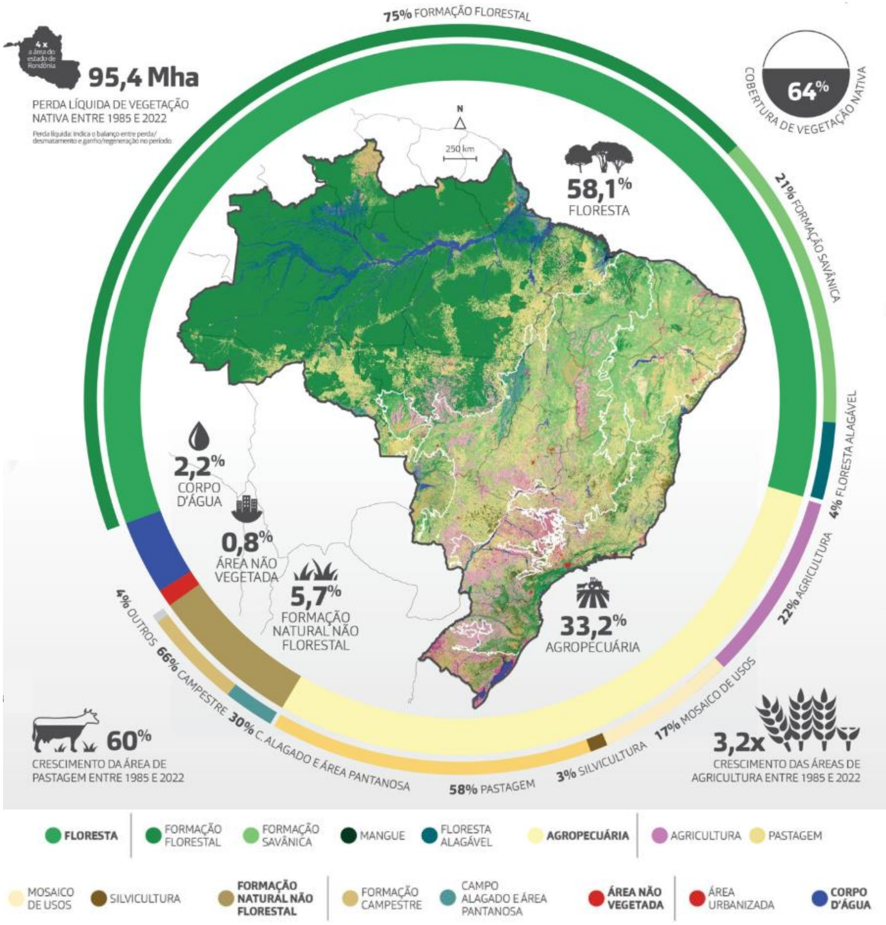
In Brazil, rural producers are required to carry out environmental regularization of their properties through the Rural Environmental Registry (Cadastro Ambiental Rural - CAR). This registry requires detailed information on the environmental characteristics and land use of each property, including the delineation of APPs RLs. To obtain the CAR, properties must comply with the Forest Code, adhering to the minimum percentages of native vegetation required for each biome. If a property does not meet legal requirements, it must develop an Environmental Regularization Plan (Plano de Regularização Ambiental - PRA), which outlines the measures to be taken to comply with environmental legislation.

This regulatory framework for forest conservation, once fully implemented, can serve as a powerful tool for Brazil to balance increasing agricultural production with the protection of its forests (CPI, 2017).

Land use dynamics in Brazil

Currently, Brazil has 64% of its territory covered by native vegetation, with 58% consisting of forest formations and the remaining 6% of non-forest natural formations. Agriculture and livestock occupy 33% of the country's land area. Excluding pastures from this portion, less than 15% of Brazil's territory is used for agricultural production (MAPBIOMAS, 2024; SOUZA *et al.*, 2020).

Figure 5 – Land use and occupation profile in Brazil



Source: MAPBIOMAS, 2024.

Pastures in Brazil are unevenly distributed, covering an estimated area of 177 million hectares, which is approximately 20% of the national territory (BOLFE et al., 2024). It is estimated that about 60% of these pastures are in some stage of degradation.

In 2023, the area occupied by agriculture in Brazil was estimated at approximately 80 million hectares (IBGE, 2024b). About 90% of this area is dedicated to grain production (such as soybeans, corn, rice, and coffee), while 10% is used for sugarcane production. Corn, in particular, is often cultivated in the off-season, typically following soybean harvests.

Given this scenario, it is evident that Brazil's land use profile differs significantly from other countries, where fertile lands are typically allocated primarily for agriculture or other economic activities.

12.2. Objective and scope

With the objective of exploring the potential for expanding biofuel production while efficiently using land in Brazil, this study aims to evaluate several key techniques known as "land-sparing" methods. The techniques assessed are:

(a) Recovery and Use of Degraded Pastures for Agriculture.
(b) Sequential Cultivation – Expansion of Second-Crop Corn.
(c) Utilization of Available Agricultural Residues.
(d) Productivity Gains of Key Energy Crops.

For each selected technique, a brief description and evaluation of its potential were conducted, along with the quantification of the incremental volume of biofuels that could be generated from its implementation. It is important to note that the estimated potential was constrained by factors relevant to the technical, economic, and scientific realities of the sector. The goal was to estimate an incremental volume of biofuels that is likely achievable under a scenario of partial or full implementation of the evaluated techniques. Additionally, other "land-sparing" techniques and their unquantified co-benefits are mentioned in the concluding remarks for potential future enhancements of this analysis.

12.3. Evaluation of "land-sparing" techniques

This section details the selected techniques for evaluation in this paper, including the quantification of each technique’s potential to expand biofuel production without competing for food production and land use.

Recovery and use of degraded pastures for agriculture

Pastures cover about 20% of the national territory, totaling approximately 177 million hectares in 2023. Estimates show that over 60% (~110 Mha) of the pastures in Brazil have moderate to severe levels of degradation (BOLFE et al., 2024), representing stages of medium or low vegetative vigor, respectively.

A recent study by Embrapa (Brazilian Agricultural Research Corporation) (BOLFE et al., 2024) estimated that 28 Mha of degraded pastures (16% of the total pasture area) in Brazil could be suitable for agricultural conversion, representing an increase of about 35% of the area currently dedicated to agriculture in the country. This study considered various data on restricted areas, Brazil's Agricultural Risk Zoning (Zarc) (MAPA, 2023), the agricultural potential of each region, and available infrastructure for storage and transportation of agricultural production. At the same time, it excluded areas with environmental restrictions (e.g., indigenous lands and settlements) and high priority for biodiversity conservation.

Another recent study conducted by CNPEM (National Center for Energy and Materials Research) (SILVA, 2024) estimated that 36cMha of degraded pastures could be suitable for agricultural expansion. Similar to Embrapa's analysis, this study also excluded areas with environmental restrictions and high importance for biodiversity conservation, while considering the newly updated criteria in the global Agro-Ecological Zoning (AEZ) that received improvements in its spatial resolution.

The present study chose to use Embrapa's estimate of 28 million hectares (Mha) of degraded pastures suitable for agricultural conversion due to its more conservative nature and the availability of data distributed among Brazilian states. For the geoChart cut-off, the main states located in the Amazon biome will be excluded, as they are considered priority areas for forest restoration, resulting in a total of 24 Mha of degraded pastures suitable for agricultural conversion, as shown in Table 8 below. Additionally, a slope cut-off will be applied to exclude areas with inclines greater than 8%, as slopes above this level make it impractical to cultivate the main energy crops with high mechanization, such as sugarcane, corn, and soybeans. This cut-off is necessary since Embrapa's estimate does not restrict areas by biome and slope level, covering all crops, including those suitable for cultivation in rugged terrain, such as forest species and perennial crops. The slope factor used was obtained from the SGB (Geological Service of Brazil) database processed in ArcGIS software, resulting in approximately 70% of the areas, excluding the main Amazon states, having a flat (0% to 3%) or gently undulating (3% to 8%) slope (SGB, 2024). Since this data is not limited to degraded pasture areas alone and considering that, particularly in the South and Southeast regions, degraded pastures tend to occupy more rugged areas such as slopes and hills, a conservative average factor of 50% will be applied to all states. It is noted that future studies should refine this analysis considering the real average slope of degraded pastures in Brazil by region. The results are presented in Table 8.

Table 8 – Areas and production of biofuels by State

States	AL	BA	CE	ES	GO	MA	MG	MS	MT	PB	PE	PI	PR	RJ	RN	RS	SC	SE	SP	TO	Total
Degraded pasture suitable for agricultural conversion (Mha)	0.04	1.96	0.13	0.03	4.68	0.73	4.01	4.34	5.12	0.05	0.27	0.21	0.54	0.01	0.12	0.35	0.01	0.04	0.73	0.79	24.2
Slope: restriction<= 8%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	
Total selected area (Mha)	0.02	0.98	0.07	0.02	2.34	0.37	2.01	2.17	2.56	0.03	0.14	0.11	0.27	0.01	0.06	0.18	0.01	0.02	0.37	0.40	12.08
Agricultural arrangement*	1	2	1	1	3	2	3	3	3	1	1	2	3	1	1	2	2	1	1	2	
Biofuel**	E	B	E	E	B/E	B	B/E	B/E	B/E	E	E	B	B/E	E	E	B	B	E	E	B	
Biofuel production (ML)	89	131	289	67	1,111	49	952	1,031	1,216	111	601	14	128	22	267	23	1	89	1,624	53	**7,868**

**Agricultural arrangement: (1) Sugarcane / (2) Soybean / (3) Soybean and 2nd crop corn*
***Biofuel: (E) Ethanol / (B) Biodiesel*

Source: BOLFE. *et al*., 2024.

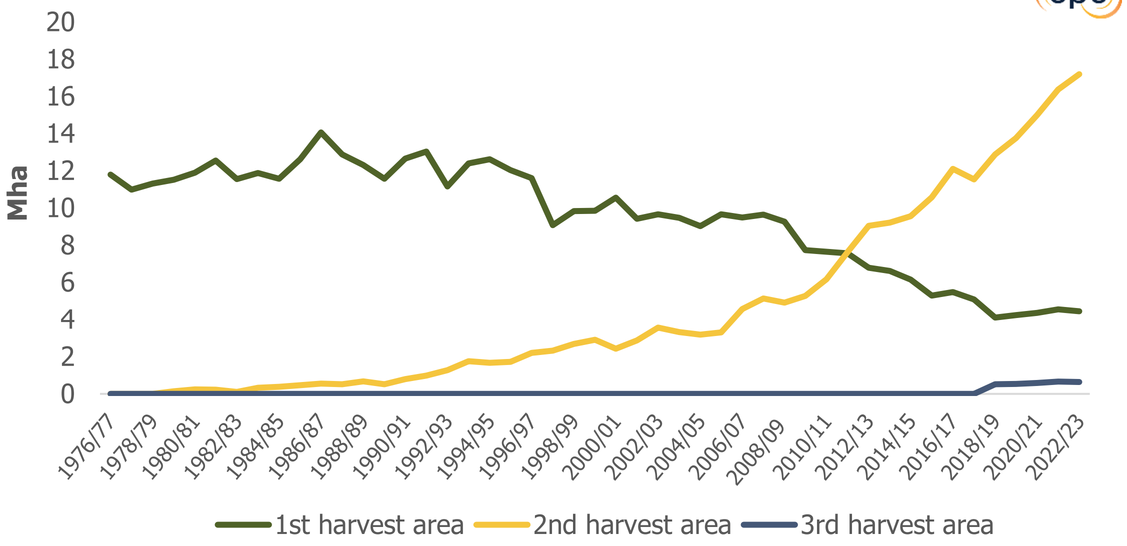
The additional production of biofuels through the recovery of degraded and potentially mechanizable pastures in Brazil was estimated at around 8 billion liters, considering the same proportion of sugarcane, soybeans, and corn currently used for biofuel production in Brazil (approximately 50%, 20%, and 15%, respectively). In a scenario where the expansion of these energy crops occurred in degraded pastures and the soybeans and corn from this additional area were entirely allocated for biofuel production, the potential could reach 32 billion liters additional. For simplicity in the analysis, only the main energy crops already established in the country (sugarcane, soybeans, and corn) and the selected agricultural arrangements by state were considered, with soybean and second-crop corn rotation only in the states of Mato Grosso, Mato Grosso do Sul, Goiás, Minas Gerais, and Paraná. The selected biofuel produced was first-generation ethanol for sugarcane and corn, and biodiesel for soybeans. It is worth noting that the additional production of these crops could also boost the generation of other biofuels, such as second-generation ethanol from agricultural residues or green diesel (HEFA route) instead of biodiesel, but this potential was not considered.

Sequential Cultivation – Expansion of Second-Crop Corn

Sequential cultivation is an agricultural practice involving the planting of two or more crops in succession within the same growing year, taking advantage of favorable climatic windows. In Brazil, this technique has gained prominence, especially in the Cerrado region, where the combination of summer soybeans followed by corn or sorghum in the fall, and in some cases, wheat or beans in a third crop, maximizes land and resource use. The benefits include increased production efficiency, reduced machinery and labor costs, and improved soil quality due to crop rotation, which helps control pests and diseases. Additionally, sequential cultivation can contribute to the economic stability of producers by generating revenue during different times of the year and reducing reliance on a single crop.

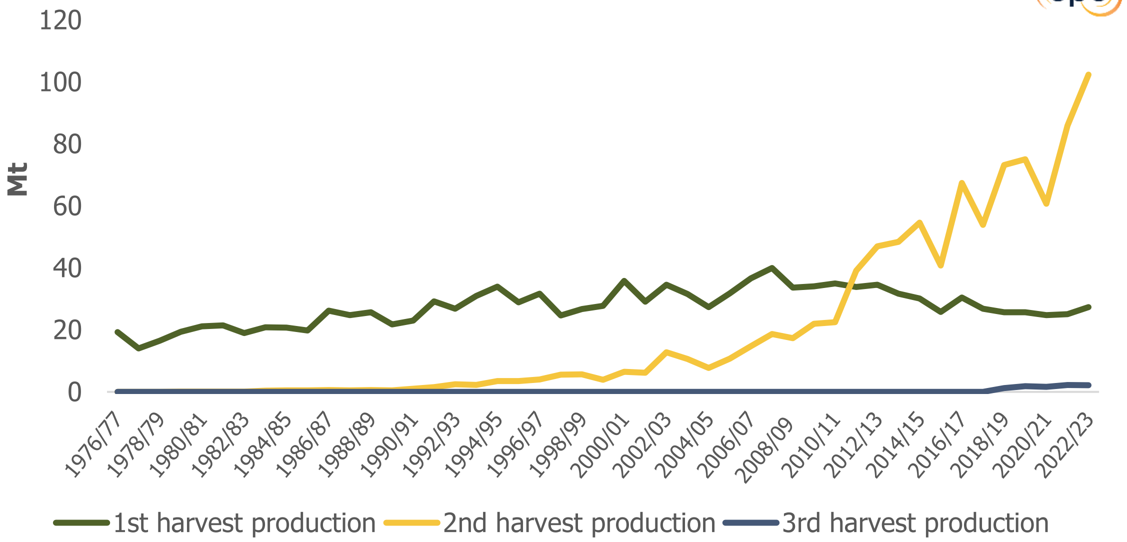
Corn is the second largest crop area in Brazil and the most widely cultivated in rotation with other crops. The corn crop that was previously planted concurrently with soybeans began to be predominantly cultivated as a second crop, especially in the Central-West region of the country, following soybean cultivation in 2011. Charts 57 and 58 below show the expansion profile of first, second, and third corn crops from 1977 to 2022. It is evident that today's corn production is mainly from the second crop, covering over 16 million hectares, compared to approximately 4 million hectares of first crop corn, with a production about 5 times higher.

Chart 57 – Corn production area



Source: EPE, 2024.

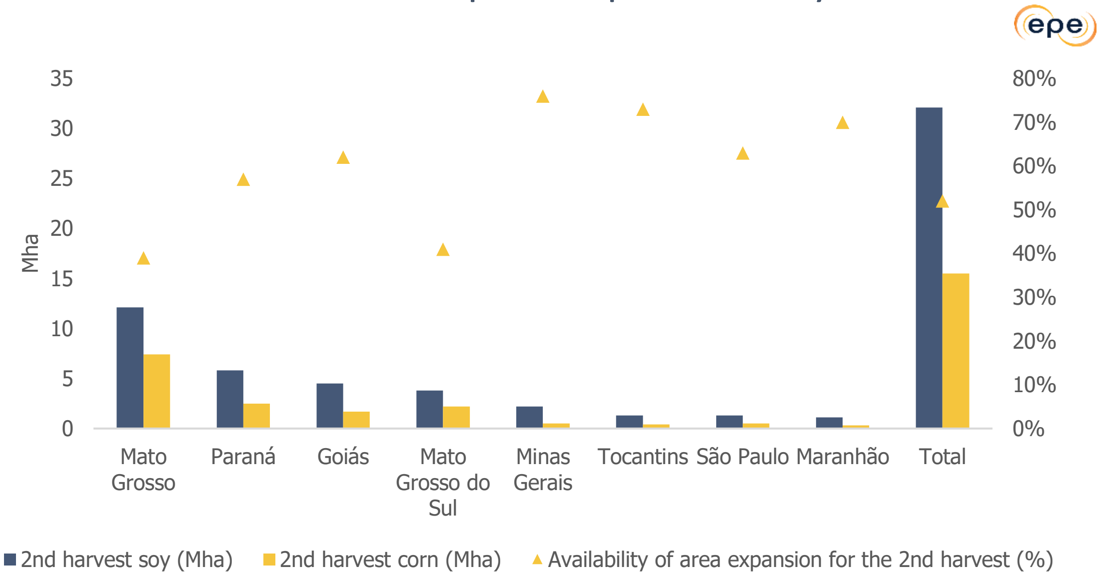
Chart 58 – Corn production



Source: EPE,2024.

The favorable climate, especially in the Central-West region of the country, allows for corn cultivation right after the soybean harvest in early autumn. However, this technique is still not viable in the soybean areas of the extreme south of the country due to cooler temperatures during the autumn and winter months. Brazil has the potential to further expand second-crop corn cultivation, considering the underutilized soybean areas during the off-season months. Chart 59 below shows the occupancy profile of soybean and second-crop corn in the 8 main grain-producing states of Brazil with favorable climatic conditions for second-crop cultivation.

Chart 59 – Profile of second-crop corn occupation in Brazil by State



Source: COLUSSI *et al.*, 2024.

It is possible to identify that second-crop corn cultivation in Brazil occupies about half of the area allocated for soybean cultivation, which represents a potential to double its volume in the future. Given this scenario, this study considered the expansion of second-crop corn cultivation on the 16.6 Mha (52%) still available following soybeans in states with suitable climatic conditions, resulting in an additional ethanol production of about 38 billion liters per year. It is worth noting that this estimate assumes all second-crop corn expansion is directed toward ethanol production, which differs from the current reality where only about 15% of corn production in Brazil is used for ethanol. Considering the same current proportion of corn processing for ethanol, the estimated additional second-crop corn production would result in approximately 6 billion liters. Associated with this production, there would also be the additional generation of the co-product DDGS (dried distiller grains with solubles) that can be used as animal feed and corn oil consumed by the food sector.

Utilization of Available Agricultural Residues

Brazil, being one of the world's leading agricultural producers, has a high availability of agricultural residues that can be converted into biofuels. However, there are certain challenges to consider when estimating this potential in a way that aligns with sector realities, such as high logistics costs for field collection and conversion technologies.

In this context, this study used the SIEnergia* tool, developed by EPE in partnership with the Itaipu Technological Park (PTI), designed to support integrated economic, energy, and environmental studies. This tool includes a specific module for agricultural by-products, which allows estimating the energy conversion potential of the main agricultural residues by imposing technical and economic constraints, such as collection and industrialization feasibility and cost. In the simulation, two technical-economic restrictive factors were applied to the total amount of the main lignocellulosic residues available for second-generation ethanol (E2G) production: (1) availability factor, which restricts the portion of residues with high collection costs (R$/t), in cases where the investment return of an E2G plant becomes unfeasible (production capacity of 82 million liters, with CAPEX of R$ 1.2 billion and OPEX of 5% per year (RAÍZEN, 2024); and (2) collection factor, which represents the portion of the residue that can be removed from the field without negatively impacting soil quality and conservation. Table 9 shows the applied factors and the estimated biofuel production.

Table 9 – Estimated production of biofuels from residual biomass

	Production *(t)*	**Biomass factor**	**Biomass** *(t)*	**Availability Factor**	**Collection factor**	**Final biomass** *(t)*	**Humidity** *(%)*	**Conversion** *(t/literE2G)*	**Production E2G** *(ML)*	**Feasibility**
Sugarcane (bagasse)	713,293,700	30%	213,988,110	10%	100%	21.398.811	50%	150	3.210	High
Sugarcane (straw)	713,293,700	16%	114,126,992	25%	40%	11.230.096	15%	255	2.864	Medium
Corn (straw)	131,085,011	187%	245,128,971	22%	40%	21.865.504	15%	255	5.576	Low
Soybean (straw)	151,963,045	134%	203,630,480	30%	30%	18.265.654	15%	255	4.658	Low

Source: EPE, 2024.

Despite the availability of other residual biomasses for biofuel production, such as forest residues (eucalyptus chips) and hulls (rice and coffee), this study focused only on lignocellulosic biomass from the main energy crops in the country. This choice was made because these resources are more abundant and already integrated into the biofuel production chain. It is also worth noting that the production of biogas and biomethane from residues with high organic matter content, such as sugarcane vinasse, was not considered, due to the possibility of competing with non-energy uses.

Additionally, except for sugarcane bagasse, which is already available at mills (10% of the total bagasse produced in Brazil was considered as excess available for E2G production), the feasibility of using straw was classified as medium or low, primarily due to the logistical and economic conditions of each crop. For example, soybean straw plays a crucial role in protecting and conserving soil to enable second-crop corn planting, while corn production is highly dispersed, with significant distances between farms and mills, making straw collection difficult. Additionally, corn straw is responsible for providing nutritional supplementation to the soil, particularly potassium.

Gain in Productivity of Key Energy Crops

The three main crops in Brazil are soybeans, corn, and sugarcane (CONAB, 2024a). Together, they cover an area of 56.8 million hectares, accounting for 6.9% of the Brazilian territory and over 70% of the area dedicated to agriculture in Brazil. These crops are also the most important for producing energy products, such as soybean oils, ethanol from sugarcane and corn, electricity from lignocellulosic residues, and biomethane from vinasse produced in the sugar-energy industry.

Soybeans currently occupy an area of 44.1 million hectares distributed throughout the country, with a production of 154.6 million tons (CONAB, 2024). From 1976 to 2023, soybean production in Brazil increased from 12.1 million to 154.6 million tons, representing a growth of about 1,200%, while the cultivated area expanded less than half that amount (approximately 530%). This is mainly a reflection of the productivity gains achieved by the sector in recent years, which increased from 1,740 kg/ha in 1976 to 3,507 kg/ha in 2023. This represents an average annual productivity increase of 2% observed during this period.

In a recent period, corn cultivation, especially in Brazil's Midwest, has undergone changes in its production profile, utilizing areas previously underused during the soybean off-season months. In 1976, corn production came exclusively from the first harvest, with an average productivity of 1,630 kg/ha. Since 2013, Brazil's corn production has been predominantly represented by the second harvest. By 2023, considering the first, second, and third corn harvests, the average productivity was 5,955 kg/ha, representing an average annual gain of approximately 6% from 1976 to 2023.

Sugarcane is the oldest commercially cultivated crop in Brazil, initially grown for sugar production and later, with the implementation of the Proálcool program in the 1970s, for ethanol fuel production. Records of sugarcane planted area date back to 1975, with 1.9 million hectares and a total production of 88.9 million tons, resulting in a productivity of 46.82 t/ha at that time. By 2023, production reached 713.1 million tons, with an average productivity of 85.58 t/ha and a planted area of 8.7 million hectares. Thus, productivity gains between 1975 and 2023 were 83%, representing an average annual gain of 1.7% observed over this period.

Although productivity gains have been relatively stable in recent harvests, the three main energy crops have not yet reached their theoretical productivity limits, which are close to those found in controlled production factor experiments. According to Conab (2017), average productivity is optimized at the point where an optimal amount of production factors is used for a given fixed area. In this context, production factors increasingly involve control and intervention with suitable varieties and cultivars for different soil and climate types, pest and disease resistance, efficient machinery, appropriate management for each crop, and other actions related to precision agriculture.

To estimate the future additional volume of biofuels that could be produced from the likely productivity gains of Brazil's three main energy crops, historical productivity increases from 1975 to 2023, and the theoretical potential found in recent literature were analyzed. Considering these factors, the average productivity increases of each crop that aligns with historical performance (referred to as "practical potential") was estimated, with 2050 set as the target year for achieving this potential, using the following formula:

$$\frac{\left(\frac{Productivity\,(2023)}{Years\,(1975-2023)} + \frac{Theoretical\,Potential}{Years\,(2025-2050)}\right)}{2} \text{ x } \textit{Years (up to 2050)}$$

The estimated practical potential for productivity increase of the three main energy crops in Brazil was:

- Soybeans: $\frac{\left(\frac{3{,}507}{48} + \frac{8{,}000}{25}\right)}{2}$ x 25 = 4,913 *kg/ha*
- Corn: $\frac{\left(\frac{5{,}955}{48} + \frac{14{,}000}{25}\right)}{2}$ x 25 = 8,551 *kg/ha*
- Sugarcane: $\frac{\left(\frac{85.6}{48} + \frac{148}{25}\right)}{2}$ x 25 = 96.3 *t/ha*

From this estimated practical potential, the additional production of each crop was calculated and converted into biofuel, as shown in Table 10.

Table 10 – Estimated productivity gain and incremental biofuel production

Productivity	1975/76	2022/23	Gain *(1975 - 2023)*	Theoretical potential[1]	Practical potential	Additional Agricultural Production (Mt)	Incremental Biofuel Production (ML)
Soybeans (kg/ha)	1,740	3,507	101%	8,000	4,913	62.0	2,355
Corn* (kg/ha)	1,630	5,955	265%	14,000	8,551	57.8	3,295
Sugarcane (t/ha)	46.8	85.6	83%	148	96.3	89.2	4,637

Source: VOGEL et al. (2021), WACLAWOVSKY et al. (2010) e LONG et al. (2017)

12.4. Results

Based on the estimated potentials for the expansion of energy crops (degraded pastures and second harvest), the availability of agricultural residues, and productivity gains, the additional amount of biofuel that can be generated was estimated in scenarios of partial or full utilization of the evaluated "land-sparing" techniques.

Table 11 – Recovery and use of degraded arable pastures

	Degraded area (Mha)	Sugarcane Ethanol (ML)	Corn Ethanol (ML)	Biodiesel (ML)	Total (ML)
Partial Scenario	12.1	3,160	3,193	1,515	7,868
Full Scenario	12.1	3,160	21,289	7,576	32,025

Note: *Partial Scenario: Reflects the current proportion of soybean and corn production allocated to biofuel production.
**Full Scenario: Considers all additional soybean and corn production being allocated to biofuel production.

Table 12 – Sequential Cropping - Expansion of Second-Crop Corn

Available area (Mha)	Available area (Mha)	Second Crop Corn Productivity (kg/ha)	Additional Corn Production (Mt)	Additional Ethanol Production* (ML)
Partial Scenario	16.6	5,954	98.8	5,672
Full Scenario	16.6	5,954	98.8	37,816

Note: *Partial Scenario: Reflects the current proportion of soybean and corn production allocated to biofuel production.
**Full Scenario: Considers all additional soybean and corn production being allocated to biofuel production.

Table 13 – Harnessing of Available Agricultural Residues

	Total biomass (Mt)	E2G Production (ML)	Feasibility
Sugarcane (bagasse)	21.4	3,210	High
Sugarcane (straw)	11.2	2,864	Medium
Corn (straw)	21.9	5,576	Low
Soybean (straw)	18.3	4,658	Low

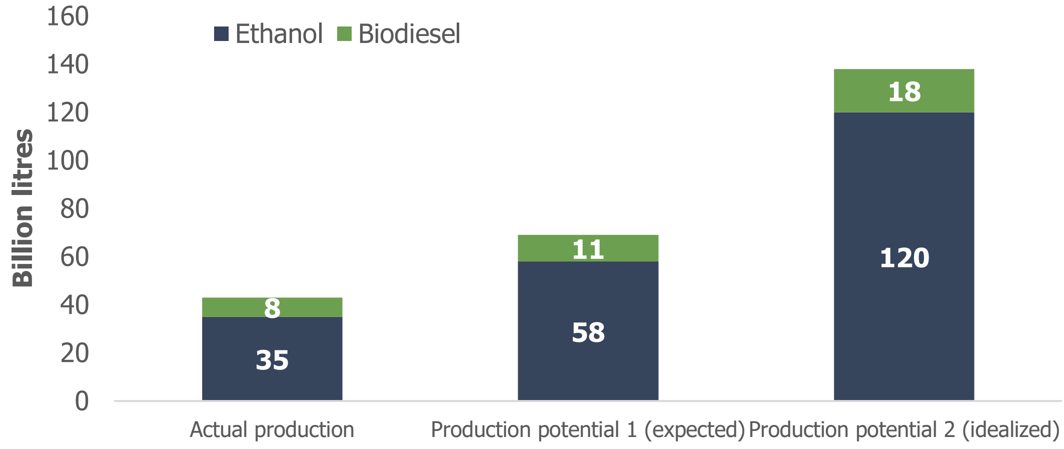
Table 14 – Productivity gains of major energy crops

	Productivity (kg/ha)	Potential productivity (kg/ha)	Planted area (Mha)	Additional Agricultural Production (Mt)	Biofuel production (ML)
Soybeans	3,507	4,913	44.1	62	2,355
Corn	5,955	8,551	22.3	57.8	3,295
Sugarcane	85.6	96.3	8.3	89.2	4,637

Note: *Soybean: biodiesel / Corn and Sugarcane: 1st generation ethanol

Based on the results, it was possible to estimate a total additional production potential of 23 to 85 billion liters of ethanol and 4 to 10 billion liters of biodiesel.

Chart 60 – Incremental biofuel production potential



Source: EPE,2024

The estimation of potential 1 (probable) represents a volume of biofuel expansion with a higher probability of being achieved, based on average indicators already practiced in the sector. This includes partial scenarios such as the recovery of degraded pastures and the cultivation of second-crop corn, as well as the inclusion of only the additional volume of second-generation ethanol produced from residues with high technical-economic viability (sugarcane bagasse). On the other hand, potential scenario 2 (aspirational) represents the total available resource in a scenario of full utilization for biofuel production, reflecting a lower probability due to the need for greater investments and overcoming technical-operational barriers.

Therefore, this study estimates that there is a concrete opportunity, with a reasonable degree of probability, for expanding biofuel production in Brazil by about 80% through the adoption of "land-sparing" techniques (potential 1 – probable). It is evident that achieving this potential will heavily depend on a robust regulatory and economic framework aimed at implementing incentive policies for the viability of these techniques, as well as the recognition of these techniques in global markets and the pursuit of efficiency by private agents.

12.5. Conclusions

This study supports the premise that, through the implementation of "land-sparing" techniques, Brazil presents a promising potential for expanding biofuel production without increasing land competition, by recovering degraded areas, using intensification and crop rotation techniques, increasing productivity, and better utilizing available agro-industrial residues.

There are co-benefits not quantified in this study that could be obtained through the expansion of biofuel production using "land-sparing" techniques, such as: additional food production, like soybean meal and corn DDGS and oil; carbon sequestration in the soil from the recovery of degraded areas; improvement in soil and water quality due to better vegetation cover; among others.

It is important to note that there are other techniques not explored in this study that could also increase biofuel production without increasing land use competition, such as: integrated crop-livestock-forest systems (ILPF), increasing soybean crushing for oil production (currently only about one-third of soybeans are processed in Brazil), utilizing biogenic CO_2 from the sugar-energy sector's plants for renewable synthetic fuel production, and utilizing other agro-industrial residues and effluents not considered in this study, among others.

For simplification purposes, this study considered only ethanol and biodiesel as biofuels. Despite this simplification, the approach allows for presenting a coherent order of magnitude for the potential volume and primary energy of biofuel expansion, even if the routes implemented in the future differ, such as vegetable oils used for producing green diesel (instead of FAME biodiesel) and SAF (HEFA route), ethanol being processed to generate other fuels like aviation bio-kerosene (AtJ route), or even its processing for renewable hydrogen production, among other possibilities.

Finally, it is crucial to pay attention to recent data on land use dynamics in Brazil. Deforestation levels, especially in the Amazon and Cerrado biomes, have remained extremely high in recent years. Although "land-sparing" techniques appear to be an alternative for more efficient land use in Brazil, they are still under-implemented due to their higher costs. Considering that biofuels can access "premium" markets with a greater willingness to pay for environmental attributes, whether related to decarbonization or other ecosystem services, once recognized and rewarded in these markets through biofuels, "land-sparing" techniques could serve as a catalyst for land recovery and deforestation reduction in Brazil, contributing to the reduction of emissions from the country's main GHG-emitting sector and aligning with the Brazilian government's efforts.

13. References

ABIOVE. (2024). *Estatísticas*. Associação Brasileira das Indústrias de Óleos Vegetais, São Paulo. Accessed in: June 2024. Available at: www.abiove.org.br/estatisticas

ABLA. (2024). *Anuário Brasileiro do Setor de Locação de Veículos 2024*. Associação Brasileira das Locadoras de Automóveis, São Paulo. Accessed in: May 2024. Available at: https://www.abla.com.br/

ABRACICLO. (2024). *Dados do Setor de Duas Rodas 2023*. Associação Brasileira dos Fabricantes de Motocicletas, Ciclomotores, Motonetas, Bicicletas e Similares, São Paulo. Accessed in: May, 2024. Available at: https://www.abraciclo.com.br/site/wp-content/uploads/2023/08/DADOS-DO-SETOR-DE-DUAS-RODAS-2023.vdef_.pdf/

ACELEN. (2024). *Acelen Renováveis*. Accessed in: April 2024. Available at: https://www.acelenrenovaveis.com.br/sobre/acelen-renovaveis/negocios/

AEN-PR. (2023). *Compagas recebe 22 propostas em chamada pública para aquisição de biometano*. Agência Estadual de Notícias, Governo do Estado do Paraná (AEN-PR). Accessed in: July 2024. Available at: https://www.aen.pr.gov.br/Noticia/Compagas-recebe-22-propostas-em-chamada-publica-para-aquisicao-de-biometano

AEN-PR. (2024). *Compagas recebe 14 propostas em chamada pública para aquisição de biometano*. Agência Estadual de Notícias, Governo do Estado do Paraná (AEN-PR). Accessed in: July 2024. Available at: https://www.aen.pr.gov.br/Noticia/Compagas-recebe-14-propostas-em-chamada-publica-para-aquisicao-de-biometano

AGÊNCIA CÂMARA DE NOTÍCIAS. (2024). *Câmara aprova projeto que cria o Programa de Aceleração da Transição Energética*. 20 de março de 2024. Accessed in: April 2024. Available at: https://www.camara.leg.br/noticias/1045598-camara-conclui-votacao-de-projeto-que-cria-o-programa-de-aceleracao-da-transicao-energetica-acompanhe/

ANEEL. (2023). *RESOLUÇÃO HOMOLOGATÓRIA Nº 3.304, DE 19 DE DEZEMBRO DE 2023*. Agência Nacional de Energia Elétrica, Brasília. Accessed in: August 2024. Available at: reh20233304ti.pdf (aneel.gov.br)

ANEEL. (2024a). *Unidades com Geração Distribuída*. Agência Nacional de Energia Elétrica, Brasília. Accessed in: March 2024. Available at: https://app.powerbi.com/view?r=eyJrIjoiY2VmMmUwN2QtYWFiOS00ZDE3LWI3NDMtZDk0NGI4MGU2NTkxIiw%20idCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9

ANEEL. (2024b). *Sistema de Informações de Geração da ANEEL - SIGA*. Agência Nacional de Energia Elétrica, Brasília. Accessed in: March 2024. Available at: https://app.powerbi.com/view?r=eyJrIjoiNjc4OGYyYjQtYWM2ZC00YjllLWJlYmEtYzdkNTQ1MTc1NjM2IiwidCI6Ij%20QwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9

ANEF. (2024). *Boletim ANEF Anual 2023*. Associação Nacional das Empresas Financeiras das Montadoras, São Paulo. Accessed in: March 2024. Available at: https://www.anef.com.br/dados-estatisticos.php/

ANFAVEA. (2023). *Dados Estatísticos para Download*. Associação Nacional dos Fabricantes de Veículos Automotores, São Paulo. Accessed in: April 2024. Available at: https://anfavea.com.br/site/edicoes-em-excel/

ANP. (2018). *Resolução ANP nº 719, de 22 de fevereiro de 2018*. Agência Nacional de Petróleo, Gás Natural e Biocombustíveis. Brasília: Diário Oficial da União. Accessed in: May 2024. Available at: https://www.in.gov.br/web/dou/-/resolucao-n-719-de-21-de-fevereiro-de-2018-4055024

ANP. (2019*). Resolução Nº 798, de 1º de agosto de 2019* Altera a Resolução ANP nº 45, de 25 de agosto de 2014, que estabelece as especificações de qualidade de biodiesel, para determinar a obrigatoriedade da aditivação do biodiesel com antioxidante e estabelecer novo limite de especificação da característica estabilidade à oxidação.. Agência Nacional do Petróleo, Gás Natural e Biocombustível. Rio de Janeiro: Diário Oficial da União. Publicado em: 02/08/2019. Accessed in: June 2024. Available at: https://www.in.gov.br/web/dou/-/resolucao-n-798-de-1-de-agosto-de-2019-208544998

ANP. (2021a). *Resolução ANP nº 842, de 14 de maio de 2021*. Estabelece a especificação do diesel verde, bem como as obrigações quanto ao controle da qualidade a serem atendidas pelos agentes econômicos que o comercializem em território nacional. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: April 2024. Available at: https://atosoficiais.com.br/anp?q=842&types=24

ANP. (2021b). *Resolução ANP nº 857, de 28 de outubro de 2021*. Dispõe sobre as regras de comercialização de biodiesel para atendimento da adição obrigatória de biodiesel ao óleo diesel comercializado com o consumidor final, estabelecido na Lei nº 13.033, de 24 de setembro de 2014. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: April 2024. Available at: https://atosoficiais.com.br/anp?q=857&types=24

ANP. (2022a). *Resolução ANP nº 906, de 18 de novembro de 2022*. Dispõe sobre as especificações do biometano oriundo de produtos e resíduos orgânicos agrossilvopastoris e comerciais destinado ao uso veicular e às instalações residenciais e comerciais a ser comercializado em todo o território nacional. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: April 2024. Available at: https://atosoficiais.com.br/anp?q=906&types=24

ANP. (2022b). *Resolução ANP nº 886, de 29 de setembro de 2022*. Estabelece a especificação e as regras para aprovação do controle da qualidade do biometano oriundo de aterros sanitários e de estações de tratamento de esgoto destinado ao uso veicular e às instalações residenciais, industriais e comerciais, a ser comercializado no território nacional. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: April 2024. Available at: https://atosoficiais.com.br/anp?q=886&types=24

ANP. (2023). *Resolução ANP nº 921, de 4 de abril de 2023*. Altera a Resolução ANP nº 791, de 12 de junho de 2019, para inclusão de previsão de redução da meta anual individual definitiva em decorrência da comprovação de aquisição de biocombustíveis por meio de contrato de fornecimento de longo prazo. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: April 2024. Available at: https://atosoficiais.com.br/anp/?q=921&types=24

ANP. (2024a). *Painel Dinâmico de Produtores de Etanol*. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: May 2024. Available at: https://app.powerbi.com/view?r=eyJrIjoiMmRhZWU2NDUtZWE2Yi00NzI5LWJjMGQtNjIwNjE0MjM0MjEzIiwidCI6IjQ0OTlmNGZmLTI0YTYtNGI0Mi1iN2VmLTEyNGFmY2FkYzkxMyJ9

ANP. (2024b). *RenovaBio*. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: May 2024. Available at: https://www.gov.br/anp/pt-br/assuntos/renovabio

ANP. (2024c). *Dados Estatísticos*. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: May 2024. Available at: https://www.gov.br/anp/pt-br/centrais-de-conteudo/dados-estatisticos

ANP. (2024d). *Informações de Mercado*. Biodiesel. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: February 2024. Available at: https://www.gov.br/anp/pt-br/centrais-de-conteudo/dados-abertos/producao-de-biocombustiveis

ANP. (2024e). *Painel Dinâmico da Logística do Monitoramento do Metanol* é uma ferramenta de análise destinada a empresas, órgãos de governo, universidades, imprensa e sociedade como um todo. E está em sintonia com a política de transparência adotada pela ANP, permitindo o conhecimento das práticas do mercado regulado com o produto que é considerado solvente nos termos da Resolução ANP nº 24/2006. Accessed in: February 2024. Available at https://www.gov.br/anp/pt-br/centrais-de-conteudo/paineis-dinamicos-da-anp/painel-dinamico-da-logistica-do-monitoramento-do-metanol

ANP. (2024f). *Painel Dinâmico de Produtores de Biodiesel*. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: March 2024. Available at: https://www.gov.br/anp/pt-br/centrais-de-conteudo/paineis-dinamicos-da-anp/paineis-e-mapa-dinamicos-de-produtores-de-combustiveis-e-derivados/painel-dinamico-de-produtores-de-biodiesel#:~:text=O%20Painel%20Din%C3%A2mico%20de%20Produtores,partir%20do%20uso%20dessa%20ferramenta

ANP. (2024g). *Preços de produtores e importadores de derivados de petróleo e biodiesel*. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: March 2024. Available at: Preços de produtores e importadores de derivados de petróleo e biodiesel — Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (www.gov.br)

ANP. (2024h). *Levantamento de Preços de Combustíveis*. Agência Nacional de Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: February 2024. Available at: https://www.gov.br/anp/pt-br/assuntos/precos-e-defesa-da-concorrencia/precos/levantamento-de-precos-de-combustiveis-ultimas-semanas-pesquisadas

ANP. (2024i). *Relatório dinâmico das instalações produtoras de biocombustíveis autorizadas pela ANP e dos processos em andamento de construção e ampliação de planta de produção de biocombustíveis*. Agência Nacional de Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Accessed in: June 2024. Available at: https://www.gov.br/anp/pt-br/assuntos/producao-e-fornecimento-de-biocombustiveis/autorizacao-para-producao-de-biocombustiveis/autorizacao-para-producao-de-biocombustiveis

ANP. (2024j). *Autorização ANP nº 208, de 12 de abril de 2024*. Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, Rio de Janeiro. Acessed in: 10 de junho de 2024. Available at: https://www.in.gov.br/en/web/dou/-/autorizacao-anp-n-208-de-12-de-abril-de-2024-553914628

APROBIO. (2022). *Projeto piloto prevê produção de combustível sustentável de aviação no RN*. Associação dos Produtores de Biocombustíveis do Brasil, São Paulo. Accessed in: June 2024. Available at https://aprobio.com.br/noticia/pprojeto-piloto-prevecirc-produccedilatildeo-de-combustiacutevel-sustentaacutevel-de-aviaccedilatildeo-no-rnp

ASTM. (2020). *ASTM D7566-20*. Especificação padrão combustível de turbina de aviação contendo hidrocarbonetos sintetizados. Accessed in: March 2024. Available at: https://www.astm.org/d7566-20.html

AUTODATA. (2024a). *Carro bioelétrico é aposta da indústria com ganho de R$7,4 trilhões*. AUTODATA, São Paulo. Accessed in: April 2024. Available at: https://www.autodata.com.br/noticias/2024/03/25/carro-bioeletrico-e-aposta-da-industria-com-ganho-de-r-7-4-trilhoes/69734/

AUTODATA. (2024b). *Proporção de eletropostos no Brasil é pior do que na Letônia*. EPBR, São Paulo. Accessed in: July 2024. Available at: https://www.autodata.com.br/noticias/2024/07/15/proporcao-de-eletropostos-no-brasil-e-pior-do-que-na-letonia/74986/

AUTODATA. (2024c). *Investimentos da indústria automotiva estão próximos dos R$100 bilhões*. AUTODATA, São Paulo. Accessed in: March 2024. Available at: https://www.autodata.com.br/noticias/2024/03/06/investimentos-da-industria-automotiva-estao-proximos-dos-r-100-bilhoes/68790/

B3. (2024). *Financiamento de veículos cresce 10% em 2023. B3, São Paulo*. Accessed in: March 2024. Available at: https://www.b3.com.br/pt_br/noticias/financiamento-de-veiculos-cresce-10-em-2023.htm/.

BC. (2024). *Sistema Gerenciador de Séries Temporais*. Banco Central do Brasil, Brasília. Accessed in: May 2024. Available at: https://www3.bcb.gov.br/sgspub/localizarseries/localizarSeries.do?method=prepararTelaLocalizarSeries.

BIODIESELBR. (2023). *Petrobras amplia testes com mistura entre biodiesel e bunker marítimo*. Accessed in: May 2024. Available at: https://www.biodieselbr.com/noticias/usinas/info/petrobras-amplia-testes-com-mistura-entre-biodiesel-e-bunker-maritimo-280623

BIODIESELBR. (2024a). *JBS recebe autorização para começar a usar B100 em caminhões* /BiodieselBR.com Accessed in: May 2024. Available at https://www.biodieselbr.com/noticias/usinas/info/jbs-recebe-autorizacao-para-comecar-a-usar-b100-em-caminhoes-130524#:~:text=JBS%20recebe%20autoriza%C3%A7%C3%A3o%20para%20come%C3%A7ar%20a%20usar%20B100%20em%20caminh%C3%B5es,-BiodieselBR.com%20%2D%2013&text=A%20JBS%20come%C3%A7ou%20a%20tirar,22%20mil%20litros%20de%20biocombust%C3%ADvel

BIODIESELBR. (2024b). *Amaggi é maior frotista de Volvo FH B100 100% a biodiesel no País*. Accessed in: May 2024. Available at: https://www.biodieselbr.com/noticias/qualidade/motor/amaggi-e-maior-frotista-de-volvo-fh-b100-100-a-biodiesel-no-pais-070524

BIODIESELBR (2024c). *ANP autoriza Petrobras a vender óleo combustível marítimo com 24% de biodiesel*. Accessed in: July 2024. Available at: https://www.biodieselbr.com/noticias/regulacao/r/anp-autoriza-petrobras-a-vender-oleo-combustivel-maritimo-com-24-de-biodiesel-110724

BOLFE et al. (2020) Bolfe, É.L.; Jorge, L.A.C.; Sanches, I.D.; Luchiari Júnior, A.; Costa, C.C.; Victoria, D.C.; Inamasu, R.Y.; Grego, C.R.; Ferreira, V.R.; Ramirez, A.R. *Precision and digital agriculture*: Adoption of technologies and perception of Brazilian farmers. Agriculture 2020, 10, 653

BOLFE et al. (2024) Bolfe, É.L.; Victoria, D.d.C.; Sano, E.E.; Bayma, G.; Massruhá, S.M.F.S.; de Oliveira, A.F. *Potential for Agricultural Expansion in Degraded Pasture Lands in Brazil Based on Geospatial Databases*. Land 2024, 13, 200

BNDES. (2024a). *Comunicação Pessoal*. Banco Nacional do Desenvolvimento Econômico e Social, Rio de Janeiro.

BNDES. (2024b). *BNDES RenovaBio*. Banco Nacional de Desenvolvimento Econômico e Social, Rio de Janeiro. Accessed in: May 2024. Available at: https://www.bndes.gov.br/wps/portal/site/home/financiamento/produto/bndes-renovabio

BRASIL. (2005). *Lei nº 11.097, de 13 de janeiro de 2005*. Dispõe sobre a introdução do biodiesel na matriz energética brasileira, e dá outras providências. Governo Federal. Brasília: Diário Oficial da união. Fonte: https://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?jornal=1&pagina=8&data=14/01/2005

BRASIL. (2016*). Lei nº 13.263, de 23 de março de 2016*. Altera a Lei nº 13.033, de 24 de setembro de 2014, para dispor sobre os percentuais de adição de biodiesel ao óleo diesel comercializado no território nacional. Governo Federal. Brasília: Diário Oficial da União. Accessed in: March 2024. Available at: https://www.in.gov.br/web/dou/-/lei-no-13-263-de-23-de-marco-de-2016-21173394

BRASIL. (2017). *Lei nº 13.576, de 23 de dezembro de 2017*. Dispõe sobre a Política Nacional de Biocombustíveis (RenovaBio) e dá outras providências. Accessed in: April 2024. Available at: https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/lei/l13576.htm

BRASIL. (2022a*). Lei Complementar nº 192, de 11 de março de 2022*. Define os combustíveis sobre os quais incidirá uma única vez o ICMS. Governo Federal, Brasília. Accessed in: June 2024. Available at: https://www.planalto.gov.br/ccivil_03/leis/lcp/lcp192.htm

BRASIL. (2022b*). Lei Complementar nº 194, de 23 de junho de 2022*. Altera a Lei nº 5.172/1966, e a Lei Complementar nº 87/1996 para considerar bens e serviços essenciais os relativos aos combustíveis, à energia elétrica, às comunicações e ao transporte coletivo. Governo Federal, Brasília. Accessed in: June 2024. Available at: https://www.in.gov.br/web/dou/-/lei-complementar-n-194-de-23-de-junho-de-2022-410028232

BRASIL. (2022c). *Medida Provisória nº 1.118, de 11 de maio de 2022*. Altera a Lei Complementar nº 192, de 11 de março de 2022. Governo Federal. Brasília. Accessed in: May 2024. Available at: https://www.in.gov.br/en/web/dou/-/medida-provisoria-n-1.118-de-17-de-maio-de-2022-401063743

BRASIL. (2022d). *Decreto nº 11.141, de 21 de julho de 2022*. Altera o Decreto nº 9.888, de 27 de junho de 2019, para dispor sobre o prazo para comprovação do atendimento à meta anual individual de redução de emissões. Governo Federal. Brasília: Diário Oficial da União. Accessed in: February 2023. Available at https://www.in.gov.br/en/web/dou/-/decreto-n-11.141-de-21-de-julho-de-2022-417054252

BRASIL. (2023a). *Medida Provisória 1.157 de 1º de janeiro de 2023*. Reduz alíquotas de contribuições incidentes sobre operações realizadas com óleo diesel, biodiesel, gás liquefeito de petróleo, álcool, querosene de aviação, gás natural veicular e gasolina. Governo Federal, Brasília. Accessed in: June 2024. Available at: https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2023/Mpv/mpv1157.htm.

BRASIL. (2023b). *Medida Provisória 1.163 de 23 de fevereiro de 2023*. Reduz alíquotas de contribuições incidentes sobre operações realizadas com gasolina, álcool, gás natural veicular e querosene de aviação. Governo Federal, Brasília. Accessed in: June 2024. Available at: https://www.planalto.gov.br/ccivil_03/_Ato2023-2026/2023/Mpv/mpv1163.htm.

BRASIL. (2023c*). Contribuição Nacionalmente Determinada (NDC) para o Acordo de Paris no âmbito da UNFCCC*. Brasília. Accessed in: June 2024. Available at: https://www.gov.br/mma/pt-br/assuntos/mudanca-do-clima/NDC

BRASIL. (2023d). *Decreto nº 11.499, de 25 de abril de 2023*. Altera o Decreto nº 9.888, de 27 de junho de 2019, para dispor sobre a alteração da composição do Comitê da Política Nacional de Biocombustíveis - Comitê RenovaBio. Governo federal. Diário Oficial da União. Accessed in: June 2023. Available at: https://www.in.gov.br/web/dou/-/decreto-n-11.499-de-25-de-abril-de-2023-479448324

BRASIL. (2024). *Diário Oficial da União – Busca*. Accessed in: June 2024. Available at: https://www.in.gov.br/consulta/.

BRASIL BIOFUELS. (2022). *BBF e Vibra, Ex-BR, vão produzir combustível para aviação com óleo de palma do Amazonas*. Brasil Biofuels, São Paulo. Accessed in: June 2024. Available at https://www.grupobbf.com.br/noticias/bbf-e-vibra-ex-br-vao-produzir-combustivel-para-aviacao-com-oleo-de-palma-no-amazonas/

BRASIL, ÍNDIA. (2020). *Memorando de Entendimento entre a República Federativa do Brasil e a República da Índia sobre Cooperação em Bioenergia.* Governo Federal. Brasília: Diário Oficial da União. Accessed in: April 2023. Available at: https://www.in.gov.br/web/dou/-/memorando-de-entendimento-entre-a-republica-federativa-do-brasil-e-a-republica-da-india-sobre-cooperacao-em-bioenergia-272979713.

BUSINESS STANDARD. (2024). *India achieves 11.6% ethanol blend with petrol in first 4 months of 2023-24*. Business Standard, Nova Delhi. Accessed in: July 2024. Available at: https://www.business-standard.com/industry/agriculture/india-achieves-11-6-ethanol-blend-with-petrol-in-first-4-months-of-2023-24-124031200972_1.htmlS

CASA CIVIL. (2021). *Aprovada a criação do Programa Combustível do Futuro*. Casa Civil, Brasília. 24 de abril de 2021, atualizado em 10 de novembro de 2022. Accessed in: May 2024. Available at https://www.gov.br/casacivil/pt-br/assuntos/noticias/2021/abril/aprovada-a-criacaodo-programa-combustivel-dofuturo#:~:text=O%20Programa%20Combust%C3%ADvel%20do%20Futuro%2C%20que%20tem%20como,um%%2020passo%20na%20lideran%C3%A7a%20da%20transi%C3%A7%C3%A3o%20

CCEE. (2024a). *InfoMercado: Dados Individuais*. Câmara de Comercialização de Energia Elétrica, São Paulo. Accessed in: March 2024. Available at: www.ccee.org.br

CCEE. (2024b). *Metodologia de Preços* - PLD. Câmara de Comercialização de Energia Elétrica, São Paulo. Accessed in: March 2024. Available at: www.ccee.org.br

CE. (2009*). Directiva 2009/28/CE do Parlamento Europeu e do Conselho de 23 de Abril de 2009*, relativa à promoção da utilização de energia proveniente de fontes renováveis que altera e subsequentemente revoga as Directivas 2001/77/CE e 2003/30/CE. Comissão Europeia. Bruxelas: Jornal Oficial da União Europeia. Accessed in: July 2024. Available at: https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:32009L0028&from=SKa

CE. (2023). *Diretiva das Energias Renováveis*. Comissão Europeia, Bruxelas. Accessed in: June 2024. Available at: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en?prefLang=pt&etrans=pta

CEPEA/ESALQ. (2024a). *Preços Agropecuários*. Etanol. Escola Superior de Agricultura Luiz de Queiroz, Centro de Estudos Avançados em Economia Aplicada, Piracicaba, SP. Accessed in: May 2024. Available at: https://www.cepea.esalq.usp.br/br/indicador/etanol.aspx

CEPEA/ESALQ. (2024b). *PIB do Agronegócio Brasileiro*. Escola Superior de Agricultura Luiz de Queiroz, Centro de Estudos Avançados em Economia Aplicada, Piracicaba, SP. Accessed in: July 2024. Available at: https://www.cepea.esalq.usp.br/br/pib-do-agronegocio-brasileiro.aspx

CIBIOGAS. (2024). *Panorama do Biogás no Brasil 2023*. Centro Internacional de Energias Renováveis – CIBiogás, Foz do Iguaçu, PR. Accessed in: June 2024. Available at: https://materiais.cibiogas.org/panorama-do-biogas-2023.

CN. (2024). *Projeto de Lei n° 2308, de 2023*. Dispõe sobre a definição legal de hidrogênio combustível e de hidrogênio verde. Congresso Nacional, Brasília. Accessed in: August 2024. Available at https://www.congressonacional.leg.br/materias/materias-bicamerais/-/ver/pl-2308-2023

CNPE. (2015). *Resolução nº 03, de 21 de setembro de 2015*. Autoriza e define diretrizes para comercialização e uso voluntário de biodiesel. Conselho Nacional de Política Energética. Brasília: Diário Oficial da União. Accessed in: May 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/2020

CNPE. (2020). *Resolução nº 14, de 9 de dezembro de 2020*. Estabelece as diretrizes para a comercialização de biodiesel em todo território nacional, e dá outras providências. Conselho Nacional de Política Energética. Brasília: Diário Oficial da União. Accessed in: May 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/2020

CNPE. (2021a). *Resolução nº 07, de 20 de abril de 2021*. Institui o Programa Combustível do Futuro, cria o Comitê Técnico Combustível do Futuro e dá outras providências. Conselho Nacional de Política Energética. Brasília: Diário Oficial da União. Accessed in: May 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/resolucoes-2021

CNPE. (2021b). *Resolução nº 25, de 22 de novembro de 2021*. Estabelece como de interesse da Política Energética Nacional a fixação do teor de mistura obrigatória do biodiesel no óleo diesel fóssil em 10% (dez por cento), para o ano de 2022. Conselho Nacional de Política Energética. Brasília: Diário Oficial da União. Accessed in: May 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/resolucoes-2021/ResCNPE252021revogada.pdf

CNPE. (2022a). *Resolução nº 12, de 21 de novembro de 2022*. Estabelece, como de interesse da Política Energética Nacional, a fixação do teor de mistura obrigatória do biodiesel no óleo diesel fóssil em 10% (dez por cento), no período de 1º de janeiro a 31 de março de 2023 e a participação, em igualdade de condições, de outras rotas tecnológicas de produção na parcela obrigatória de biodiesel no óleo diesel B, e dá outras providências. Conselho Nacional de Política Energética. Brasília: Diário Oficial da União. Accessed in: May 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/2022

CNPE. (2022b). *Resolução nº 06, de 23 de junho de 2022*. Institui o Programa Nacional do Hidrogênio. Conselho Nacional de Política Energética. Brasília: Diário Oficial da União. Accessed in: June 2024, Available at https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/2022/Res62022.pdf

CNPE. (2023a). *Resolução CNPE nº3, de 20 de março de 2023*. Altera a Resolução CNPE nº 16, de 29 de outubro de 2018, que dispõe sobre a evolução da adição obrigatória de biodiesel ao óleo diesel vendido ao consumidor final, em qualquer parte do território nacional, e dá outras providências. Conselho Nacional de Política Energética, Brasília. Accessed in: April 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/2023

CNPE. (2023b). *Resolução CNPE nº6, de 29 de novembro de 2023*. Define as metas compulsórias anuais de redução de emissões de gases causadores do efeito estufa para a comercialização de combustíveis. Conselho Nacional de Política Energética, Brasília. Accessed in: April 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/2023

COLUSSI et al. (2024). Colussi, J., N. Paulson, G. Schnitkey, C. Zulauf and J. Baltz. *Potential for Crop Expansion in Brazil Based on Pastureland and Double-Cropping*. Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, FarmDoc Daily, 14, 69, 2024

COMGÁS. *Chamada Pública n° 01/2023*. Accessed in: June 2024. Available at: https://www.comgas.com.br/chamadapublica/

CONAB. (2024a). *Levantamentos de Safra:* cana-de-açúcar. Acompanhamento da safra brasileira de cana-de-açúcar. Companhia Nacional de Abastecimento, Brasília. Accessed in: May 2024. Available at: https://www.conab.gov.br/info-agro/safras

CONAB. (2024b). *Comunicação Pessoal*. Companhia Nacional de Abastecimento, Brasília.

CONAB. (2024c). *Acompanhamento da Safra Brasileira*. Séries Históricas. Milho. Companhia Nacional de Abastecimento, Brasília. Accessed in: May 2024. Available at: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras/itemlist/category/910-Milho

CONFAZ/MF. (2024a*). Alíquotas e reduções de base de cálculo nas operações internas dos Estados e do Distrito Federal*. Ministério da Fazenda, Conselho Nacional de Política Fazendária, Brasília. Accessed in: May 2024. Available at: www.confaz.fazenda.gov.br/legislacao/aliquotas-icms-estaduais

CONFAZ/MF. (2024b). *Atos CONTEPE/PMPF*. Ministério da Fazenda, Conselho Nacional de Política Fazendária, Brasília. Accessed in: May 2024. Available at: www.confaz.fazenda.gov.br/legislacao/atos-pmpf/2023

CONSECANA. (2022). *Circulares CONSECANA*. Conselho dos Produtores de Cana-de-Açúcar, Açúcar e Etanol do Estado de São Paulo, São Paulo. Accessed in: May 2022. Available at: www.orplana.com.br

COPERGAS. (2023). *Copergás anuncia empresa vencedora da chamada pública de biometano*. Accessed in: June 2024. Available at: https://novo.copergas.com.br/comunicacao/noticias/copergas-anuncia-empresa-vencedora-da-chamada-publica-de-biometano/

CPI. (2017). Relatório Legislação Florestal e de Uso da Terra: Uma Comparação Internacional. INPUT – Iniciativa Para o Uso da Terra. CPI – Climate Policy Initiative. Accessed in: July 2024. Available at: https://www.climatepolicyinitiative.org/wp-content/uploads/2017/10/Legislacao_Florestal_e_de_Uso_da_Terra_Uma_Comparacao_Internacional_CPI.pdf

CTC. (2024*). Comunicação Pessoal*. Centro de Tecnologia Canavieira, Piracicaba, SP.

DATAGRO. (2024a). *Estimativa Balanço Oferta/Demanda*. DATAGRO Consultoria LDTA, Barueri, SP. Accessed in: April 2024. Available at: www.datagro.com

DATAGRO. (2024b). *Balanço Mundial de Açúcar*. Março-24. DATAGRO Consultoria LDTA, Barueri, SP. Accessed in: May 2024. Available at: www.datagro.com

DGRM. (2023). *Ata da 80ª Sessão do Comité de Proteção do Ambiente Marinho (MEPC 80).* Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos, Londres, Reino Unido. Accessed in: June 2024. Available at: dgrm.pt/documents/20143/46478/Nota+DGRM+-+MEPC+80_13.07.2023_PT.pdf/

DIÁRIO DO COMÉRCIO. (2023). *Taxa de importação de etanol volta a ser aplicada em todo o País*. Diário do Comércio, Belo Horizonte. Accessed in: March 2023. Available at: https://diariodocomercio.com.br/agronegocio/taxa-de-importacao-de-etanol-volta-a-ser-aplicada-em-todo-o-pais/t

EERE. (2023). *Alternative Fuels Data Center: Biodiesel Blends*. Departamento de Energia dos Estados Unidos, Escritório de Eficiência Energética e Energia Renovável, Washington DC. Accessed in: August 2023. Available at: https://afdc.energy.gov/fuels/biodiesel_blends.html.

EIA. (2024a). *Monthly Energy Review: Renewable Energy*. Total Energy Data. Departamento de Energia dos Estados Unidos, Agência de Informações de Energia, Washington DC. Accessed in: July 2024. Available at: www.eia.gov/totalenergy/data/monthly/index.cfm

EIA. (2024b). *Petroleum and Other Liquids*. Departamento de Energia dos Estados Unidos, Agência de Informações de Energia, Washington DC. Accessed in: July 2024. Available at: www.eia.gov/petroleum/data.php.

ELETROBRÁS. (2018). *Dados de geração e consumo das CGEE participantes do PROINFA*. Centrais Elétricas Brasileiras S.A., Rio de Janeiro. Fonte: http://eletrobras.com/pt/Paginas/Proinfa.aspx

ELETROBRAS. (2021). *Eletrobras, Cepel e Siemens Energy assinam memorando sobre hidrogênio verde*. Centrais Elétricas Brasileiras S.A., Rio de Janeirro. Accessed in: June 2022. Available at https://eletrobras.com/pt/Lists/noticias/ExibeNoticias.aspx?ID=1174

EPA. (2023). *Final Renewable Fuels Standards Rule for 2023, 2024, and 2025*. Agência de Proteção Ambiental dos Estados Unidos, Washington DC. Accessed in: May 2024. Available at: https://www.govinfo.gov/content/pkg/FR-2023-07-12/pdf/2023-13462.pdf

EPBR. (2023). *Vendas de carros elétricos crescem 76% no Brasil lideradas por híbridos.* EPBR, Brasília. Accessed in: March 2024. Available at: https://epbr.com.br/vendas-de-carros-eletricos-no-brasil-cresceram-76-lideradas-por-hibridos/.

EPE. (2020). *Combustíveis renováveis para uso em motores do ciclo diesel*. Empresa de Pesquisa Energética, Diretoria de Estudos do Petróleo, Gás e Biocombustíveis, Rio de Janeiro. Accessed in: May 2024, Available at https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/pu

EPE. (2023). *Análise de Conjuntura dos Biocombustíveis 2022*. Empresa de Pesquisa Energética, Diretoria de Estudos do Petróleo, Gás e Biocombustíveis, Rio de Janeiro. Accessed in: July 2020. Available at: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/analise-de-conjuntura-dos-biocombustiveis-2022

EPE; CIBIOGÁS. (2023). *Panorama do Biometano - Setor Sucroenergético*. Empresa de Pesquisa Energética, Diretoria de Estudos do Petróleo, Gás e Biocombustíveis, Rio de Janeiro. Accessed in: June 2024. Available at https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/panorama-do-biometano-setor-sucroenergetico

EPE. (2024). *Balanço Energético Nacional 2024: Ano-base 2023*. Empresa de Pesquisa Energética, Rio de Janeiro. Accessed in: June 2024, Available at https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2023

EPE; FBDS. (2009). *Guia de referência para encaminhamento de projetos de produção e uso de biodiesel e etanol ao mecanismo de desenvolvimento limpo* - MDL. Relatório interno. Empresa de Pesquisa Energética, Diretoria de Estudos do Petróleo, Gás e Biocombustíveis

ETHANOL PRODUCER. (2023). *Grassley introduces bill to withdraw EPA's proposed eRIN program*. Ethanol Producer Magazine, Grand Forks, US. Accessed in: May 2024. Available at: https://ethanolproducer.com/articles/20218/grassley-introduces-bill-to-withdraw-epaundefineds-proposed-erin-program

FECOMBUSTÍVEIS (2024a). *Otimismo com carro elétrico cresce no país, e setor eleva projeções de venda*. Federação Nacional do Comércio de Combustíveis e Lubrificantes, Rio de Janeiro. Accessed in: April 2024. Available at: https://www.fecombustiveis.org.br/noticia/otimismo-com-carro-eletrico-cresce-no-pais-e-setor-eleva-projecoes-de-venda/256511/

FECOMBUSTÍVEIS. (2024b). *Tributação. Federação Nacional de Comércio de Combustíveis e de Lubrificantes*, Rio de Janeiro. Accessed in: May 2024. Available at: https://www.fecombustiveis.org.br/tributacao

FENABRAVE. (2024). *Anuário FENABRAVE 2023*. Federação Nacional da Distribuição de Veículos Automotores, São Paulo. Accessed in: May 2024. Available at: https://www.fenabrave.org.br/portalv2/Conteudo/anuarios/

FENAUTO. (2024). *Comunicação pessoal*. Federação dos Revendedores de Veículos Usados, São Paulo.

FIPE. (2023). *Tabela FIPE*. Fundação Instituto de Pesquisas Econômicas. Accessed in: March 2024. Available at: https://veiculos.fipe.org.br/

GASMIG. (2023). Edital Chamada Pública GASMIG nº 05/2023. Companhia de Gás de Minas Gerais (Gasmig). Accessed in: June 2024. Available at: https://gasmig.com.br/wp-content/uploads/2023/11/Edital-5-Chamada-Gasmig-Biometano-2023.pdf

GOVERNO DO ESTADO DO CEARÁ. (2020). *Ceará deve produzir combustível sustentável para aviação*. Governo do Ceará, Fortaleza. Accessed in: March 2021, Available at https://www.ceara.gov.br/2020/02/07/seminariodiscute-producao-de-combustiveis-alternativos-para-aviacao-no-ceara/

GRANBIO. (2024). *BioFlex I: Produção de Biocombustível*. Granbio, São Paulo. Accessed in: June 2024. Available at: http://www.granbio.com.br/conteudos/bioflex-biocombustiveis/

IBGE. (2024a). *PIB cresce 2,9% em 2023 e fecha o ano em R$10,9 trilhões*. Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro. Accessed in: March 2024. Available at: https://agenciadenoticias.ibge.gov.br/agencia-sala-de-imprensa/2013-agencia-de-noticias/releases/39303-pib-cresce-2-9-em-2023-e-fecha-o-ano-em-r-10-9-trilhoes/

IBGE. (2024b). *Levantamento Sistemático da Produção Agrícola*. Instituto Brasileiro de Geografia e Estatística. Accessed in: July 2024. Available at: https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9201-levantamento-sistematico-da-producao-agricola.html

ICAO. (2024). *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*. Accessed in: July 2024. Available at: https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

IEA. (2021). *Bioenergy demand in the Net Zero Scenario, 2010-2050*, IEA, Paris. Accessed in: July 2024. Available at: https://www.iea.org/data-and-statistics/charts/bioenergy-demand-in-the-net-zero-scenario-2010-2050

IEA. (2024). *Renewables 2023*, IEA, Paris. Accessed in: July 2024. Available at: https://www.iea.org/reports/renewables-2023

IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*: volume 2, Energy. Painel Intergovernamental sobre Mudança do Clima, Genebra. Fonte: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

ISCC. (2024). *ISCC: homepage.* International Sustainability & Carbon Certification, Colônia, Alemanha. Accessed in: July 2024. Available at: https://www.iscc-system.org/

LOGUM. (2023). *O Sistema Logum*. Logum Logística S.A, Rio de Janeiro. Accessed in: May 2024. Available at: http://www.logum.com.br/php/o-sistema-logum.php

LOGUM. (2024). *Informações ANP*. Logum Logística S.A, Rio de Janeiro. Accessed in: May 2024. Available at: http://www.logum.com.br/php/informacoes-anp.php

LONG et al. (2017). Long NV, Assefa Y, Schwalbert R and Ciampitti IA (2017) *Maize Yield and Planting Date Relationship: A Synthesis-Analysis for US High-Yielding Contest-Winner and Field Research Data*. Front. Plant Sci. 8:2106

MAPA. (2023). *Projeções do Agronegócio 2022/2023 a 2032/2033*. Ministério da Agricultura, Pecuária e Abastecimento (Brasil). Accessed in: November 2023. Available at: https://www.gov.br/agricultura/pt-br/assuntos/politica-agricola/todas-publicacoes-de-politica-agricola/projecoes-do-agronegocio

MAPA. (2024). *Sustentabilidade/Agroenergia*. Ministério da Agricultura, Pecuária e Abastecimento, Brasília. Accessed in: June 2024, Available at https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/agroenergia

MAPBIOMAS. (2023). *Mapeamento Anual do Uso e Cobertura da Terra no Brasil*. Mapas de Uso e Cobertura da Terra. Accessed in: October 2023. Available at: https://brasil.mapbiomas.org/produtos/

MCKINSEY&COMPANY. (2022). *The Inflation Reduction Act: Here's what's in it*. McKinsey & Company, Nova Iorque. Accessed in: May 2024. Available at: https://www.mckinsey.com/industries/public-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it#/

MCTI. (2021). *Acordo de Paris. Ministério da Ciência, Tecnologia e Inovação, Sistema de Registro Nacional de Emissões - SIRENE*, Brasília. Accessed in: June 2024. Available at: https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/sirene/publicacoes/acordo-de-paris-e-ndc/arquivos/pdf/acordo_paris.pdf

MCTI. (2022). *Estimativas Anuais de Emissões de Gases de Efeito Estufa no Brasil - 6ª Edição. Brasília*. Accessed in: June 2024. Available at: https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/sirene/publicacoes/estimativas-anuais-de-emissoes-gee

MCTI. (2024). *Fatores de emissão de CO2 para utilizações que necessitam do fator médio de emissão do Sistema Interligado Nacional*. Ministério de Ciência, Tecnologia e Inovação, Brasília. Accessed in: June 2024. Available at: https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/sirene/dados-e-ferramentas/fatores-de-emissao

MDA. (2024). *Dispõe sobre os critérios e procedimentos relativos à concessão e manutenção do direito de uso do Selo Biocombustível Social*. Ministério do Desenvolvimento Agrário e Agricultura Familiar, Brasília. Accessed in: August 2024. Available at: https://www.in.gov.br/en/web/dou/-/portaria-mda-n-28-de-27-de-junho-de-2024-568657269

MDIC. (2023). *Imposto de importação para veículos eletrificados será retomado em janeiro de 2024*. Ministério do Desenvolvimento, Indústria, Comércio e Serviços, Brasília. Accessed in: March 2024. Available at: https://www.gov.br/mdic/pt-br/assuntos/noticias/2023/novembro/imposto-de-importacao-para-veiculos-eletrificados-sera-retomado-em-janeiro-de-2024/

ME. (2017). *Resolução nº 72, de 29 de agosto de 2017*. Altera a Lista Brasileira de Exceções à Tarifa Externa Comum do Mercosul referente aos produtos com um teor de água igual ou inferior a 1% vol (Álcool Etílico). Ministério da Economia, Secretaria Especial de Comércio Exterior e Assuntos Internacionais, Brasília. Accessed in: August 2024. Available at: http://www.camex.gov.br/resolucoes-camex-e-outros-normativos/58-resolucoes-da-camex/1916-resolucao-no-72-de-29-de-agosto-de-2017

ME. (2019). *Portaria nº 547, de 31 de agosto de 2019*. Altera o Anexo II da Resolução nº 125, de 15 de dezembro de 2016. Ministério da Economia, Secretaria Especial de Comércio Exterior e Assuntos Internacionais, Brasília. Accessed in: March 2024. Available at: http://www.camex.gov.br/resolucoes-camex-e-outros-normativos/124-portarias-secint/2316-portaria-secint-n-547-de-31-de-agosto-de-2019

ME. (2022). *Resolução GECEX Nº 317, de 22 de março DE 2022*. Altera o Anexo II da Resolução nº 125, de 15 de dezembro de 2016, da Câmara de Comércio Exterior. Ministério da Economia, Câmara de Comércio Exterior. Brasília: Diário Oficial da União. Accessed in: June 2024. Available at: https://www.in.gov.br/en/web/dou/-/resolucao-gecex-n-317-de-22-de-marco-de-2022-387969852

ME. (2024). *Estatísticas de Comércio Exterior. Ministério da Economia, Secretaria Especial de Comércio Exterior e Assuntos Internacionais*, Brasilia. Accessed in: March 2024. Available at: http://comexstat.mdic.gov.br/pt/homec

MME. (2019). *Ministro assina portaria que autoriza utilização de debêntures incentivadas pelo setor de petróleo, gás e biocombustível.* Ministério das Minas e Energia, Brasília. Accessed in: May 2020, Available at https://www.gov.br/mme/pt-br/assuntos/noticias/ministro-assina-portaria-que-autoriza-utilizacao-de-debentures-incentivadas-pelo-setor-de-petroleo-gas-e-biocombustiv-1s

MME. (2021). *Programa Nacional do Hidrogênio. Proposta de Diretrizes*. Ministério das Minas e Energia, Brasília. Accessed in: May 2024. Available at https://www.epe.gov.br/sites-pt/sala-de-imprensa/noticias/PublishingImages/Paginas/MME-apresenta-ao-CNPE-proposta-de-diretrizes-para-o-Programa-Nacional-do-Hidrogenio-PNH2/HidrognioRelatriodiretrizes.pdf

MME. (2022). *Portaria Normativa nº 37/GM/MME, de 20 de março de 2022*. Ministério das Minas e Energia, Brasília. Accessed in: March 2023. Available at https://www.gov.br/mme/pt-br/acesso-ainformacao/legislacao/portarias/2022/portaria-normativa-n-37-gm-mme-2022.pdf/view

MME. (2023a). *Melhora na modelagem do RenovaBio, com nova curva de metas anuais de descarbonização, impulsionou política para biocombustíveis*. Ministério das Minas e Energia, Brasília. Accessed in: April 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/noticias/melhora-na-modelagem-do-renovabio-com-nova-curva-de-metas-anuais-de-descarbonizacao-impulsionou-politica-para-biocombustiveis.

MME. (2023b). *Programa Nacional do Hidrogênio reforça estratégia do Brasil para liderar a transição energética*. – Ministério de Minas e Energia. Accessed in: May 2023. Available at: https://www.gov.br/mme/pt-br/assuntos/noticias/programa-nacional-do-hidrogenio-reforca-estrategia-do-brasil-para-liderar-a-transicao-energetica

MME. (2024). *Projetos Prioritários*. Ministério das Minas e Energia, Brasília. Accessed in: May 2024. Available at: https://www.gov.br/mme/pt-br/assuntos/secretarias/secretaria-executiva/projetos-prioritarios-1.

MME; MDA (2023). *Portaria Interministerial MME/MDA Nº 2, DE 3 DE AGOSTO DE 2023*. Dispõe sobre mecanismos de incremento ao fomento e aquisições provenientes da Agricultura Familiar para o Programa Nacional de Produção e Uso do Biodiesel para as Regiões Norte, Nordeste e Semiárido. Ministério das Minas e Energia; Ministério do Desenvolvimento Agrário, Brasília. Accessed in: June 2024. Available at: https://www.in.gov.br/en/web/dou/-/portaria-interministerial-mme/mda-n-2-de-3-de-agosto-de-2023-501832027

MPNG. (2022). *National Policy on Biofuels 2018*. Amendment, 2022. Ministério do Petróleo e Gás Natural da Índia, Nova Delhi. Accessed in: July 2022. Available at: https://mopng.gov.in/en/page/.

MRE. (2024*). Declaração Conjunta da Iniciativa de Parceria Brasil-Japão sobre Meio Ambiente, Clima, Desenvolvimento Sustentável e Economias Resilientes*. Ministério das Relações Exteriores, Brasília. Accessed in: June 2024. Available at: https://www.gov.br/mre/pt-br/canais_atendimento/imprensa/notas-a-imprensa/declaracao-conjunta-da-iniciativa-de-parceria-brasil-japao-sobre-meio-ambiente-clima-desenvolvimento-sustentavel-e-economias-resilientes

NOVACANA. (2022a). *Raízen investirá R$ 2 bilhões em duas novas plantas de etanol 2G*. NovaCana, Curitiba. Accessed in: June 2024. Available at https://www.novacana.com/n/industria/investimento/raizen-investira-r-2- bilhoes-duas-novas-plantas-etanol-2g-120522

NOVACANA. (2022b). *Brasil produz hidrogênio verde a partir da cana-de-açúcar em feito inédito*. NovaCana, Curitiba. Accessed in: June 2024, Available at https://www.novacana.com/noticias/brasil-hidrogenio-verde-cana-de-acucar-feito-inedito-240522

NOVACANA. (2022c). *GranBio certifica etanol celulósico para exportação à Europa*. NovaCana, Curitiba. Accessed in: June 2023. Available at: https://www.novacana.com/n/etanol/2-geracao-celulose/granbio-certifica-etanol-celulosico-exportacao-europa-260421.

NOVACANA. (2024a). *Sucroenergéticas captaram R$ 13,52 bilhões com debêntures incentivadas desde 2019*. NovaCana, Curitiba. Accessed in: June 2024. Available at: https://www.novacana.com/noticias/sucroenergeticas-captaram-r-13-52-bilhoes-debentures-incentivadas-2019-070524

NOVACANA. (2024b). *Prejuízo líquido acumulado da GranBio chega a R$ 758,86 milhões em 2023*. NovaCana, Curitiba. Accessed in: June 2024. Available at: https://www.novacana.com/noticias/prejuizo-liquido-acumulado-granbio-chega-r-758-86-milhoes-2023-02052024.

NOVACANA. (2024c). *Empresa promete investimento de R$ 2 bilhões para produzir SAF no interior de São Paulo*. 21 de março de 2024. NovaCana, Curitiba. Accessed in: June 2024. Available at: https://www.novacana.com/noticias/empresa-promete-investimento-r-2-bilhoes-produzir-saf-interior-sao-paulo-210324

NOVACANA. (2024d). *FS mira mercado internacional com certificação para combustível de aviação*. 21 de março de 2024. NovaCana, Curitiba. Accessed in: June 2024. Available at: https://www.novacana.com/noticias/fs-mira-mercado-internacional-certificacao-combustivel-aviacao-210324

NOVACANA. (2024e). *Raízen investiu mais de R$ 1 bilhão em E2G no último trimestre de 2023/24, afirma diretor*. NovaCana, Curitiba. Accessed in: June 2024. Available at: https://www.novacana.com/noticias/raizen-investiu-quase-r-3-bilhoes-e2g-ultimo-trimestre-2023-24-diretor-090424

OECD. (2023). *Agricultural Outlook 2023–2032*. Organisation for Economic Co-Operation and Development (OECD); Food and Agriculture Organization of the United Nations (FAO). OECD Publishing: Paris, France, 2023

PECEM. (2023). *Primeira molécula de Hidrogênio Verde produzida no Brasil é lançada no Ceará*. Complexo Industrial e Portuário de Pecém, São Gonçalo do Amarante. Accessed in: January 2024. Available at https://www.complexodopecem.com.br/primeira-molecula-de-hidrogenio-verde-produzida-no-brasil-elancada-no-ceara/

PETROBRAS. (2023a). *Petrobras aprova estratégia comercial de diesel e gasolina*. Petrobras S.A, Rio de Janeiro. Accessed in: March 2024. Available at: https://agencia.petrobras.com.br/w/petrobras-aprova-estrategia-comercial-de-diesel-e-gasolina#:~:text=O%20custo%20alternativo%20do%20cliente%20contempla%20as%20principais%20alternativas%20de,produ%C3%A7%C3%A3o%2C%20importa%C3%A7%C3%A3o%20e%20exporta%C3%A7%C3%A3o%20do.

PETROBRAS. (2023b). *Petrobras testa bunker com conteúdo renovável em navio da Transpetro. Petrobras S.A*, Rio de Janeiro. Accessed in: March 2024. Available at: https://agencia.petrobras.com.br/w/petrobras-testa-bunker-com-conteudo-renovavel-em-navio-da-transpetro

PETROBRAS. (2024a). *Deep Dive Petrobras 2024*. 30 de janeiro de 2024. Petrobras S.A. Accessed in: May 2024. Available at: https://api.mziq.com/mzfilemanager/v2/d/25fdf098-34f5-4608-b7fa-17d60b2de47d/50260c46-95a5-4c64-599d-b7a64ed47752?origin=1

PETROBRAS. (2024b). *Preço médio da Gasolina no Brasil*. Petrobras S.A, Rio de Janeiro. Accessed in: July 2024. Available at: https://precos.petrobras.com.br/sele%C3%A7%C3%A3o-de-estados-gasolina

RAÍZEN. (2023a). *Combustível Sustentável de Aviação (SAF): o que falta para a ideia decolar no Brasil*?. Raízen Energia S.A., São Paulo. Accessed in: June 2024. Available at: https://www.raizen.com.br/blog/saf-combustivel

RAÍZEN. (2023b). *Raízen anuncia a construção de planta de Etanol de Segunda Geração (E2G) em Tarumã*. Raízen Energia S.A., São Paulo. Accessed in: June 2024. Available at: https://raizen.com/sala-de-imprensa/raizen-anuncia-a-construcao-de-planta-de-etanol-de-segunda-geracao-e2g-em-taruma#:~:text=S%C3%A3o%20Paulo%2C%2013%20de%20novembro%20de%202023%20%E2%80%93,e%20receber%C3%A1%20investimento%20aproximado%20de%20R%EF%BC%84%201%2C2%20bilh%C3%A3o

RAÍZEN. (2024*). Raízen inaugura maior planta de etanol de segunda geração do mundo*. Raízen Energia S.A., São Paulo. Accessed in: June 2024. Available at: https://www.raizen.com.br/sala-de-imprensa/raizen-inaugura-maior-planta-de-etanol-de-segunda-geracao-do-mundo

RFA. (2024). *Ethanol Industry Outlook*. Associação de Combustíveis Renováveis, Missouri - USA. Accessed in: July 2024. Available at: https://ethanolrfa.org/resources/annual-industry-outlook.

ROSA, L. P., OLIVEIRA, L. B., COSTA, A. O., PIMENTEIRA, C. A., & MATTOS, L. B. (2003). *Geração de Energia a partir de resíduos sólidos*. Proceedings of TOLMASQUIM, M.T (Coord) Fontes Alternativas, 515.

SAF/MAPA. (2022). *Dispõe sobre os critérios e procedimentos relativos à concessão e manutenção do direito de uso do Selo Biocombustível Social*. Ministério da Agricultura, Pecuária e Abastecimento/Secretaria de Agricultura Familiar e Cooperativismo, Brasília. Accessed in: August 2024. Available at: https://www.in.gov.br/en/web/dou/-/portaria-saf/mapa-n-280-de-27-de-maio-de-2022-403689855

SEEG. (2024). *Plataforma de Dados*. Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa. Accessed in: May 2024. Available at: https://plataforma.seeg.eco.br/

SERGAS. (2024). *Chamada Pública para Aquisição de Biometano 2025*. Sergipe Gás S/A. Accessed in: July 2024. Available at: https://www.sergipegas.com.br/chamada-publica-2025/.

SF. (2022). *Projeto de Lei n° 725, de 2022*. Disciplina a inserção do hidrogênio como fonte de energia no Brasil, e estabelece parâmetros de incentivo ao uso do hidrogênio sustentável. Senado Federal, Brasília. Accessed in: May 2024, Available at https://www25.senado.leg.br/web/atividade/materias/-/materia/152413

SGB. (2024). *Mapa de Declitividade em Percentual do Relevo Brasileiro*. Serviço Geológico do Brasil. Accessed in: July 2024. Available at: https://www.sgb.gov.br/mapa-de-declividade-em-percentual-do-relevo-brasileiro

SHELL. (2023). *Pesquisa da Shell, SENAI CIMATEC e UNICAMP para produzir energia renovável a partir de Agave avança no Nordeste.* 13 de abril de 2023. Accessed in: May 2024. Available at: https://www.shell.com.br/imprensa/press-releases-2023/pesquisa-da-shell-senai-cimatec-e-unicamp-para-produzir-energia-renovavel-a-partir-de-agave-avanca-no-nordeste.html

SILVA. (2024). Silva, Eduardo do Couto. *A Multifunctional Landscape Approach for Sustainable Biomass Production*. 29 de março de 2024. Apresentação em G20 Brasil 2024.

SINDIPEÇAS. (2024). *Anuário do Sindipeças 2024*. Sindicato Nacional da Indústria de Componentes para Veículos Automotores, São Paulo. Accessed in: April 2024. Available at: https://www.sindipecas.org.br/area-atuacao/?co=s&a=desempenho-do-setor-de-autopecas/.

SOUZA et al. (2020). Souza, C.M., Jr.; Shimbo, J.Z.; Rosa, M.R.; Parente, L.L.; Alencar, A.A.; Rudorff, B.F.T.; Hasenack, H.; Matsumoto, M.; Ferreira, L.G.; Souza-Filho, P.W.M.; et al*. Reconstructing three decades of land use and land cover changes in Brazilian biomes with Landsat archive and Earth Engine*. Remote Sens. 2020, 12, 2735

SULGAS. (2023). *Chamada pública para suprimento de gás natural e biometano*. Accessed in: June 2024. Available at: https://www.sulgas.com.vc/noticias-sala/1553-chamada-publica-para-suprimento-de-gas-natural-e-biometano

TRENDSCE. (2021). *Hub de Hidrogênio Verde no Ceará promete fortalecer economia e meio ambiente*. TrendsCE, Fortaleza/CE. Accessed in: June 2024, Available at https://www.trendsce.com.br/2021/02/19/hubde-hidrogenio-verde-no-ceara-promete-fortalecer-economia-e-meio-ambiente/

UDOP. (2019). *Plantio mecanizado de cana recua*. União Nacional da Bioenergia, Araçatuba/SP. Accessed in: February 2024. Available at: https://www.udop.com.br/noticia/2019/02/26/plantio-mecanizado-de-cana-recua.html

UDOP. (2023). *Sistema de dutos de etanol da Logum inicia operação completa*. União Nacional da Bioenergia, Araçatuba/SP. Accessed in: June 2024. Available at: https://www.udop.com.br/noticia/2022/11/14/etanolduto-da-logum-ganha-musculatura-no-sudeste-do-pais.html.

UDOP. (2024). *Fórmulas e conversões utilizadas no setor sucroalcooleiro*. União Nacional da Bioenergia, Araçatuba/SP. Accessed in: May 2024. Available at:

https://www.udop.com.br/download/estatistica/setor_sucroenergetico/formulas_conversoes_utilizadas_setor.pdf

UNICA. (2013). *Coletiva de Imprensa: análise da safra 2013/14*. União da Indústria da Cana-de-Açúcar, São Paulo. Accessed in: August 2024. Available at: http://www.unica.com.br/download.php?idSecao=17&id=6288236

UNICA. (2014). *Comunicação pessoal*. União da Indústria de Cana-de-Açúcar e Bioenergia, São Paulo.

UNICA. (2017). *Comunicação pessoal*. União da Indústria de Cana-de-Açúcar e Bioenergia, São Paulo.

UNICA. (2022). *Brasil e Índia vão criar Centro de Excelência em bioenergia*. União da Indústria de Cana-de-Açúcar e Bioenergia, São Paulo. Accessed in: June 2024. Available at: https://unica.com.br/noticias/brasil-e-india-vao-criar-centro-de-excelencia-em-bioenergia/

UNICA. (2023). *Brasil e Japão dialogam sobre produção de SAF a partir do etanol*. Accessed in: May 2023. Available at: https://unica.com.br/noticias/brasil-e-japao-dialogam-sobre-producao-de-saf-a-partir-do-etanol/#:~:text=Brasil%20e%20Jap%C3%A3o%20dialogam%20sobre%20produ%C3%A7%C3%A3o%20de%20SAF%20a%20partir%20do%20etanol,-ApexBrasilInternacionalSetor&text=Na%20sequ%C3%AAncia%20da%2028%C2%AA%20Confer%C3%AAncia,discutir%20descarboniza%C3%A7%C3%A3o%20do%20setor%20a%C3%A9reo

UNICA. (2024). UNICADATA. *União da Indústria de Cana-de-Açúcar e Bioenergia*, São Paulo. Accessed in: May 2024. Available at: https://observatoriodacana.com.br/

USDA. (2023a). *Biofuels Annual: China*. Departamento de Agricultura dos Estados Unidos, Serviço de Agricultura Estrangeira, Washington DC. Accessed in: July 2024. Available at: https://fas.usda.gov/data/china-biofuels-annual-9

USDA. (2023b). *Biofuels Annual: Indonesia*. Departamento de Agricultura dos Estados Unidos, Serviço de Agricultura Estrangeira, Washington DC. Accessed in: July 2024. Available at: https://fas.usda.gov/data/indonesia-biofuels-annual-7

USDA. (2023c). *Biofuels Annual: India*. Departamento de Agricultura dos Estados Unidos, Serviço de Agricultura Estrangeira, Washington DC. Accessed in: May 2024. Available at: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_New%20Delhi_India_IN2023-0039

USDA (2024a). *Grain: World Markets and Trade*. Departamento de Agricultura dos Estados Unidos, Serviço de Agricultura Estrangeira, Washington DC. Accessed in: June 2024. Available at: https://apps.fas.usda.gov/psdonline/circulars/grain.pdf.

USDA (2024b). *Sugar and Sweeteners Yearbook Tables*. Departamento de Agricultura dos Estados Unidos, Serviço de Agricultura Estrangeira, Washington DC. Accessed in: June 2024. Available at: https://apps.fas.usda.gov/psdonline/circulars/grain.pdf

VALOR ECONÔMICO. (2024). *Setor de autopeças eleva investimento*. Valor Econômico, São Paulo. Accessed in: April 2024. Available at: https://valor.globo.com/impresso/noticia/2024/04/05/setor-de-autopecas-eleva-investimentos.ghtml

VOGEL et al. (2021). Vogel, J.T., Liu, W., Olhoft, P., Crafts-Brandner, S.J., Pennycooke, J.C. e Christiansen N. *Soybean Yield Formation Physiology – A Foundation for Precision Breeding Based Improvement*. Front. Plant Sci. 12:719706

WACLAWOVSKY et al. (2010). Waclawovsky, A.J., Sato, P.M., Lembke, C.G., Moore, P.H. e. Souza, G.M. *Sugarcane for bioenergy production: an assessment ofyield and regulation of sucrose contente.* Plant Biotechnology Journal 8, pp. 263–276