TECHNICAL NOTE

Analysis of Current Biofuels Outlook – Year 2024

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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

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Analysis of Current Biofuels Outlook

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(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)

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Presentation

The Energy Research Office presents its sixteenth edition of the Analysis of Current Biofuels Outlook, focusing on the year 2024. 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 of ethanol and its production and transport infrastructure, the Otto cycle market, the participation of bioelectricity in the national energy matrix, the biodiesel sector, biomethane, the international biofuels market, innovations and emerging perspectives for biofuels, greenhouse gas emissions avoided through the use of these renewable energy sources, and the monitoring of the National Biofuels Policy (RenovaBio).

In this edition, in addition to evaluating the main events of 2024, the document includes an article that demonstrates how increased biofuels production can occur without pressure on new land, through land-sparing techniques and the use of degraded pastures. Additionally, it highlights the Brazilian agroenergy model, which not only contributes to the renewability of the energy matrix but also allows the use of biofuels industry co-products in animal feed and promotes job creation throughout the production chain. This approach fosters the reconciliation of energy and food security, drives the energy transition, and reinforces social equity.

Finally, the publication highlights a landmark event for national public policies focused on biofuels: on October 8, 2024, President Luís Inácio Lula da Silva enacted Law No. 14,993, culminating an extensive process of studies and legislative procedures. Known as the “Fuel of the Future Law,” it establishes key guidelines for the biofuels sector, including the creation of programs for sustainable aviation fuels and renewable diesel, as well as incentives for biomethane production and sustainable mobility. Furthermore, expectations for the coming years include a gradual increase in the blend of biofuels in commercial fossil fuels and the promotion of new technologies that enable the use of biomass-derived renewable fuels.

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1. Ethanol supply

In 2024, the sugar-energy production performed well, and there was an expansion of corn ethanol production facilities, both through the capacity increase of existing plants and the commissioning of new units. Sugarcane processing amounted to 686 million tons, a reduction of 3.7% compared to 2023, while domestic corn consumption for ethanol production reached 17.3 million tons, a 30.2% increase. Sugar production totaled 44.3 million tons, a 3.1% decrease, the second highest value in the historical series, supported by sustained high price levels in the international market, with Brazil remaining the world's leading supplier of this commodity. Regarding ethanol, 29.7 billion liters were produced from sugarcane, which, when added to the 7.7 billion liters from corn-based ethanol (a 33% increase), reached a record 37.3 billion liters (5.7% higher than in 2023). The totals for hydrous and anhydrous ethanol were 24.4 and 13.0 billion liters, respectively (MAPA, 2025).

Otto cycle fuel consumption reached a historic high of 61.1 billion liters of gasoline equivalent, maintaining the continuous growth trend observed since 2021 (EPE, 2025b).

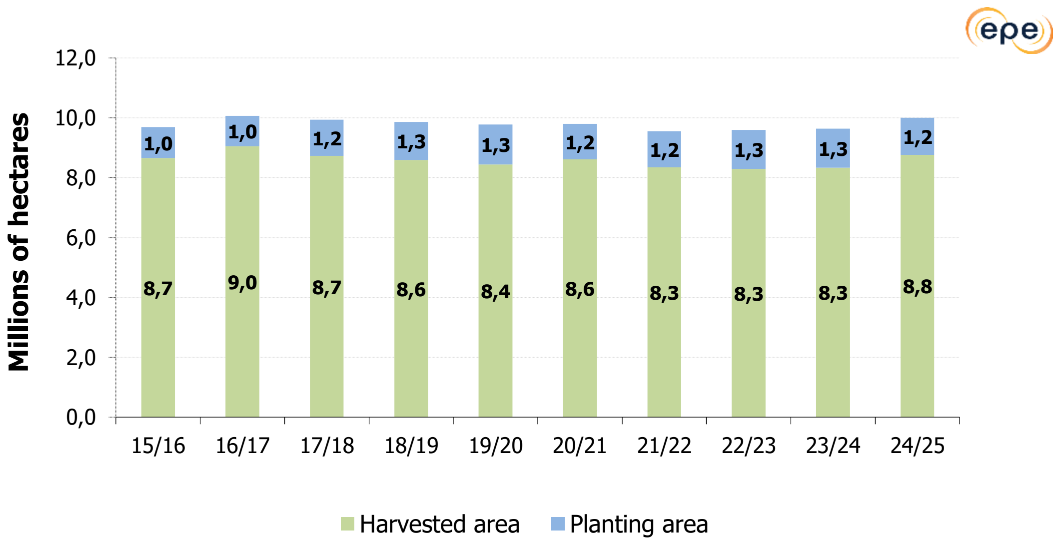
Due to unfavorable weather conditions and the wildfires recorded in 2024 during the sugarcane crop development period, prospects point to a decline in production for the 2025/26 harvest. Sugar is expected to continue benefiting from its higher profitability and existing contracts. Corn ethanol is maintaining its growth trend (CONAB, 2025a).

1.1.1. Area, Agricultural Productivity, and Sugarcane Yields

Area

The total harvested area of sugarcane in the 2024/25 harvest was 8.8 million hectares (Mha), showing an average growth of 5.3% compared to the past three years. Most regions recorded an increase in harvested areas, except for the South region (a 7.3% decline). In the period indicated in Chart 1, there is a trend of reduction in this area between the 2016/17 and 2021/22 harvests, and then stabilization up to 2023/24, generally explained by competition with temporary crops such as soybeans and corn. The planting area was 1.2 Mha, with declines in the Southeast (the main producing region) and South regions due to unfavorable weather conditions and wildfires (CONAB, 2025a, 2025b).

Chart 1 - Harvested and sugarcane planting area in the sugar-energy sector (Brazil)



Source: EPE based on (CONAB, 2025a, 2025b)

For the 2025/26 harvest, CONAB estimates that the harvested area will remain stable, totaling 8.8 million hectares (CONAB, 2025a).

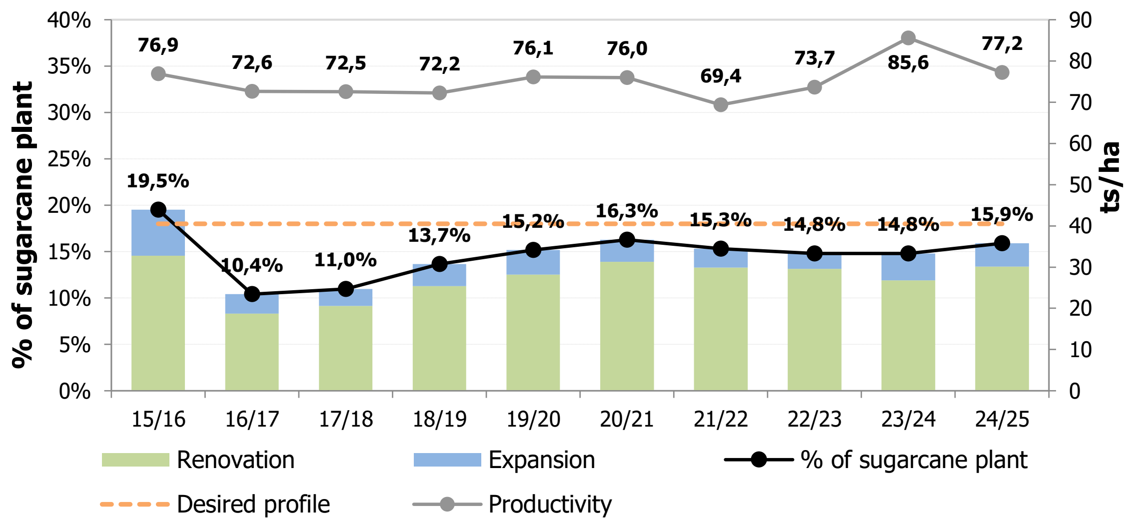
Agricultural Productivity

The average agricultural productivity of the Brazilian sugar-energy sector in the 2024/25 harvest was 77.2 tons of sugarcane per hectare (ts/ha), a 9.8% decrease compared to the previous harvest, which recorded unusually high indicators, reaching the historical maximum (85.6 ts/ha). This reduction resulted from low rainfall levels, high temperatures, and wildfires, in which fire consumed sugarcane fields during full production. The Central-South region, which accounted for 91% of total production, showed a 10.3% decrease (79.1 vs. 88.2 ts/ha), while the North-Northeast registered a -4.9% decline (61.7 vs. 64.8 ts/ha) (CONAB, 2025a).

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, 2025a, 2025c).

Chart 2 - Share of cane-plant sugarcane in the total harvested area and productivity (Brazil)



Note: The areas of expansion and renovation were estimated based on previous years.

Source: EPE based on (CONAB, 2025a, 2025c)

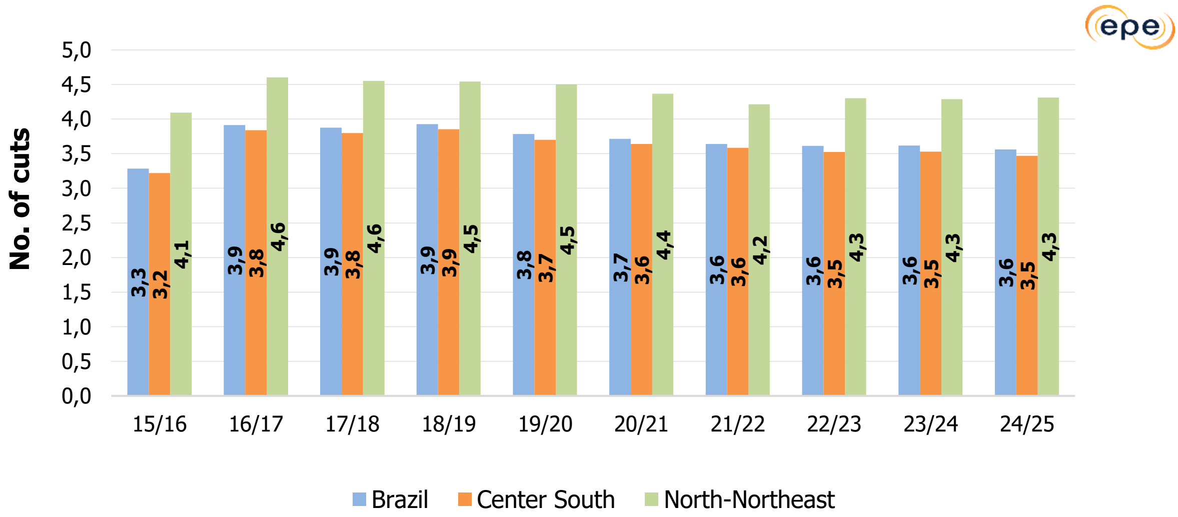
The proportion of planted cane in the total cane increased from the 2017/18 harvest, but starting in 2021/22 it showed a decline, which remained stable in the 2022/23 and 2023/24 periods. In 2024/25, its share in the total cane was 15.9%, with a slight increase compared to the previous harvest, but still below the ideal value (18%), observed only in the 2015/16 harvest.

[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 remained stable compared to the previous harvest. Chart 3 shows that this indicator was 3.3 cuts in the 2015/16 harvest and increased to 3.9 between the 2016/17 and 2018/19 harvests. From 2019/20 onward, a downward trend was observed, followed by stabilization at 3.6 since then. There is also a marked difference between the North-Northeast and Central-South regions.

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



Source: EPE based on (CONAB, 2024, 2025c).

For the 2025/26 harvest, CONAB estimates that average productivity will be 75.5 ts/ha, a 2.3% decrease compared to 2024/25 (CONAB, 2025a).

Sugarcane Yields (TRS[4]/ts)

The sugarcane yield in Brazil for the 2024/25 harvest was 140.2 kg TRS per tonne of sugarcane (kg TRS/ts), an increase of 1.9% compared to the previous harvest (137.7 kg TRS/ts[5]), following a period of decline observed between 2021/22 and 2023/24. This trend was influenced by a 1.3% increase in yield (141.0 kg TRS/ts) in the Central-South region and a 5.0% increase (132.0 kg TRS/ts) in the North/Northeast region, favored by dry weather during the harvest. Weather conditions, crop age, mineral and vegetal impurities, and the mechanization of planting and harvesting are the main factors affecting this indicator (CONAB, 2025a; DATAGRO, 2025a).

As shown in Chart 4, mechanization of harvesting in Brazil remained at 92% in the 2024/25 harvest. In the Central-South region, mechanized harvesting remained at 99%, and in the Northeast, at 27%, compared to the previous period. In the North region, this indicator has remained at 100% since 2016/17 (CONAB, 2025a). Planting mechanization in the Central-South region reached 74%, 7% higher than in the previous harvest. The lag between planting and harvesting was 25 percentage points (CTC, 2025).

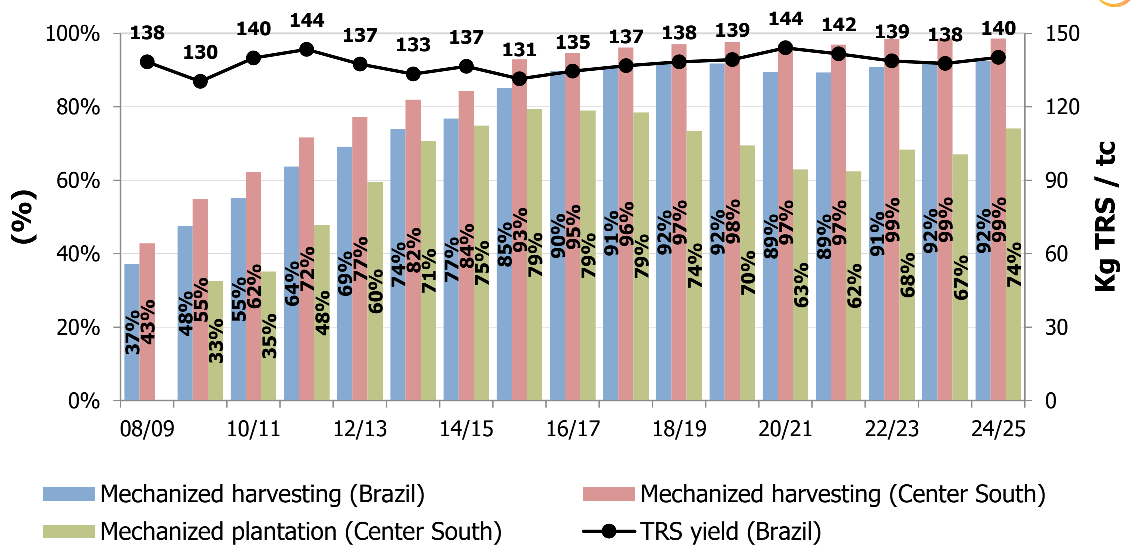
Mechanized harvesting in the Central-South region progressed rapidly, increasing from 28% in 2007/08 to over 90% of the area within just 8 years (2015/16). In recent years, yield (TRS/ts) has been at levels similar to those observed at the beginning of this process.

[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.

Chart 4 - Mechanized Harvesting and Planting vs. Sugarcane Yield



Note: Harvest data were extracted from (CONAB, 2025a), while planting data were obtained from mills associated with (CTC, 2025), which represent only a portion of the sugar-energy sector, not including suppliers.

Source: EPE based on (CONAB, 2025a), (CTC, 2025), (DATAGRO, 2025a) and (UNICA, 2013, 2014, 2017).

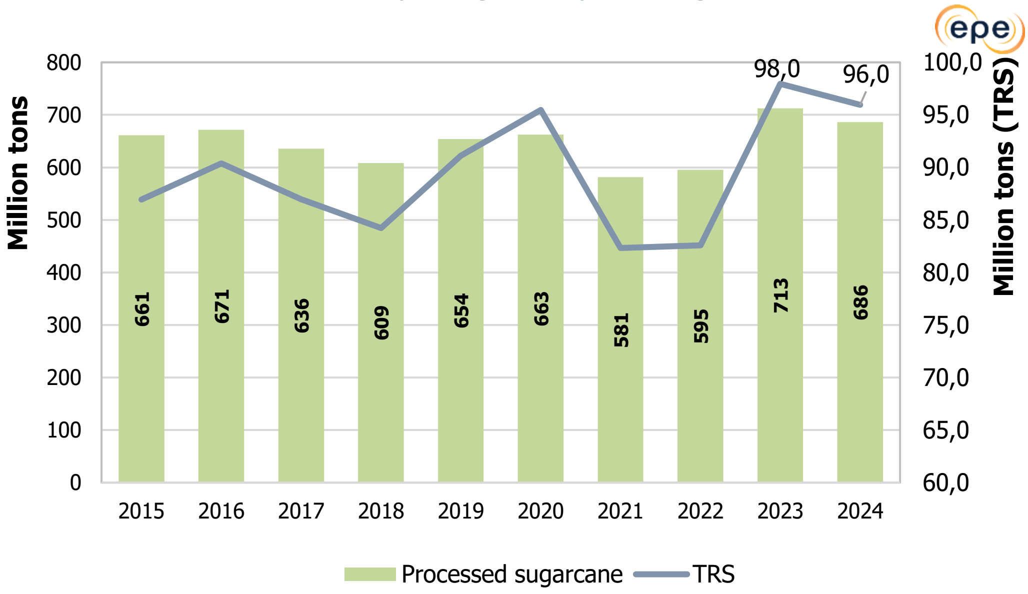
In the 2024/25 harvest, the total impurity content was 8.5% (an increase of 0.4 percentage points compared to the previous harvest). Vegetal impurities decreased from 7.9% to 7.6%, while mineral impurities remained nearly unchanged, declining slightly from 1.0% to 0.9%.

The estimated yield for the 2025/26 harvest in the Central-South region, responsible for over 90% of ethanol production, is around 138.5 kg TRS/ts, a 1.8% decrease compared to 2024/25 (141.1 kg TRS/ts) (DATAGRO, 2025b).

1.2. Sugarcane processing

The total processed sugarcane reached 686 million tons in 2024, 3.7% lower than in 2023, as shown in Chart 5. This is the second highest value in the historical series, despite the impact of dry weather and low rainfall, as well as wildfires in the main producing states (MAPA, 2025). Total recoverable sugar (TRS) reached 96 million tons, 3.7% lower than in 2023, also the second highest value in the historical series.

Chart 5 - Annual history of sugarcane processing and TRS



Source: EPE based on (MAPA, 2025).

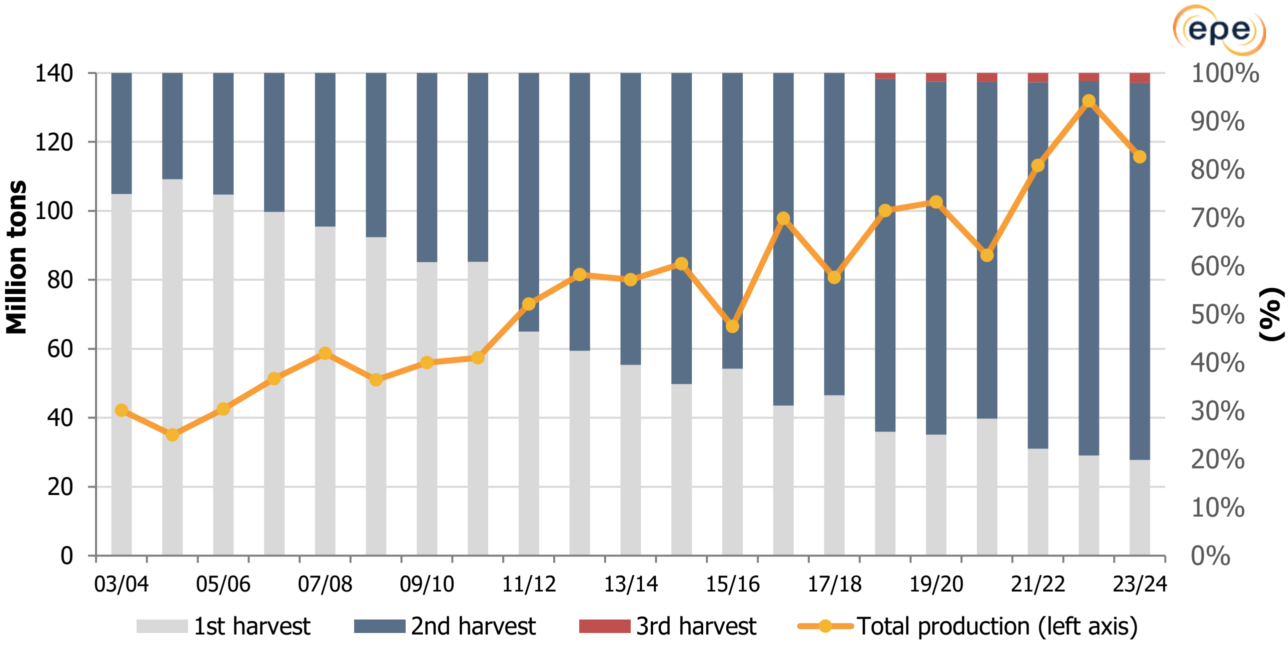
From the crop year perspective, processed sugarcane in 2024/25 (677 million tons) decreased by 5.1% compared to 2023/24 (713 million tons), also the second highest volume in the historical series, according to CONAB (CONAB, 2025d). For the 2025/26 harvest, production is estimated at 663 million tons, a 2% decrease compared to 2024/25 (CONAB, 2025a).

1.3. Corn processing

National corn production in 2024 (2023/24 harvest[6])) was 115.7 million tons, according to CONAB (CONAB, 2025e), representing a 12% decrease compared to the previous year. This result was driven by a 5.4% reduction in planted area, climatic instabilities during the first harvest, including excessive rainfall in the South in October, poorly distributed rains in the Midwest and Southeast in November, and weather variations during much of the second harvest cycle in the states of Minas Gerais, São Paulo, Mato Grosso do Sul, and Paraná, resulting in a 7.2% decline in productivity (CONAB, 2025e). Of this total, 78% was produced in the second harvest, a practice that has been expanding and supporting the growth of corn supply in the country, as shown in Chart 6.

[6] Plantings and harvest periods by crop season: 1st season, from October to December; 2nd season, from January to March; 3rd season, from April to June. Harvest periods by crop season: 1st season, from February to June; 2nd season, from May to August; 3rd season, from September to December. The state of Mato Grosso was used as a reference.

Chart 6 - Evolution of corn production and distribution by harvest

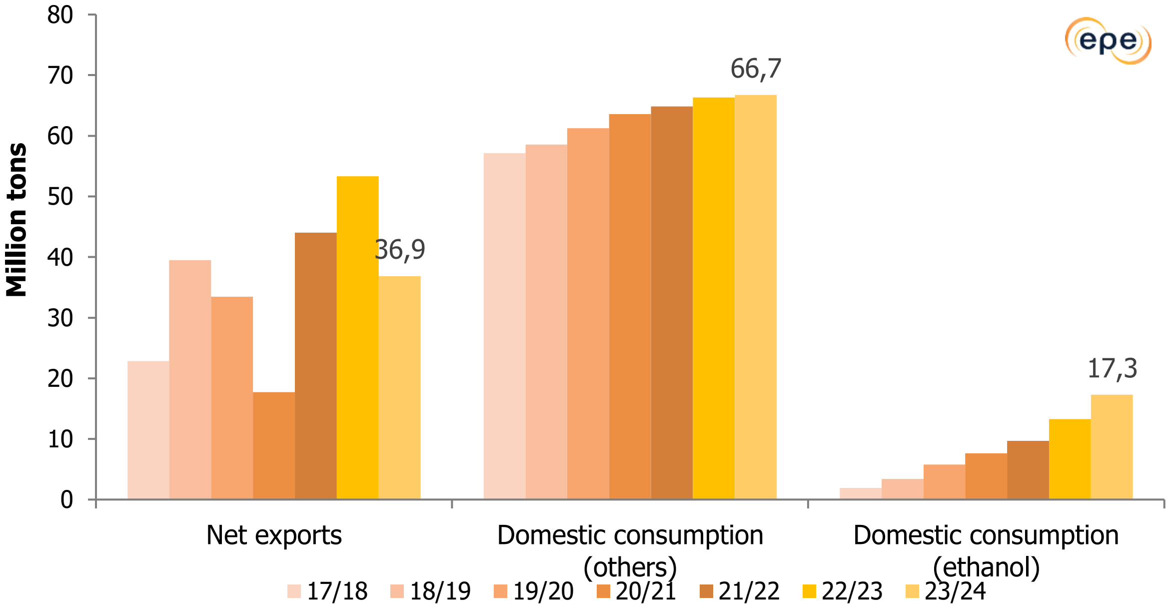


Source: EPE based on (CONAB, 2025e).

Domestic corn consumption reached 84 million tons, including the portion used for ethanol production, while net exports totaled 36.9 million tons, a 31% decrease, as shown in Chart 7.

The amount of corn processed for ethanol production quintupled over five years. From 3.4 million tons in 2019, it reached 17.3 million tons in 2024, representing 15% of production and 26% of domestic corn consumption that year (ANP, 2025a; CONAB, 2025e).

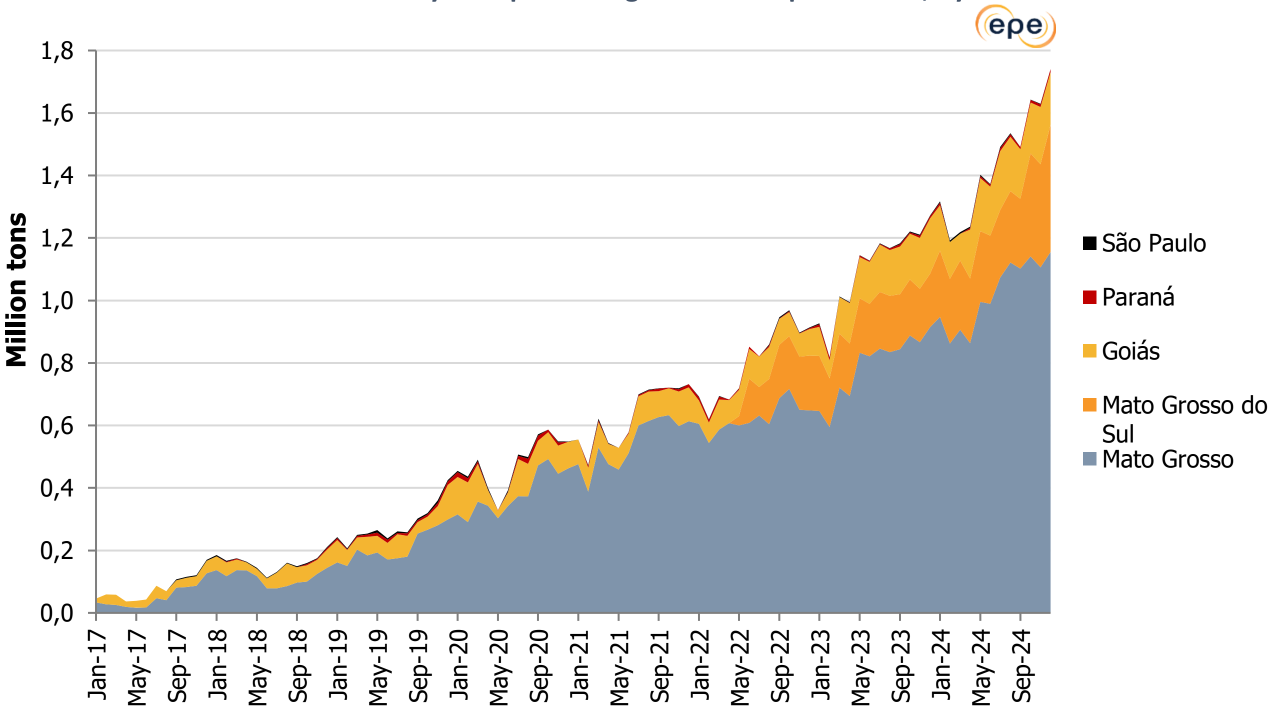
Chart 7 - Evolution of corn usage in the country



Source: EPE based on (CONAB, 2025e).

During 2024, a monthly record of 1.74 million tons of corn dedicated to ethanol production was achieved. The state of Mato Grosso remained the main contributor, accounting for 72% of the corn processed 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, 2025a).

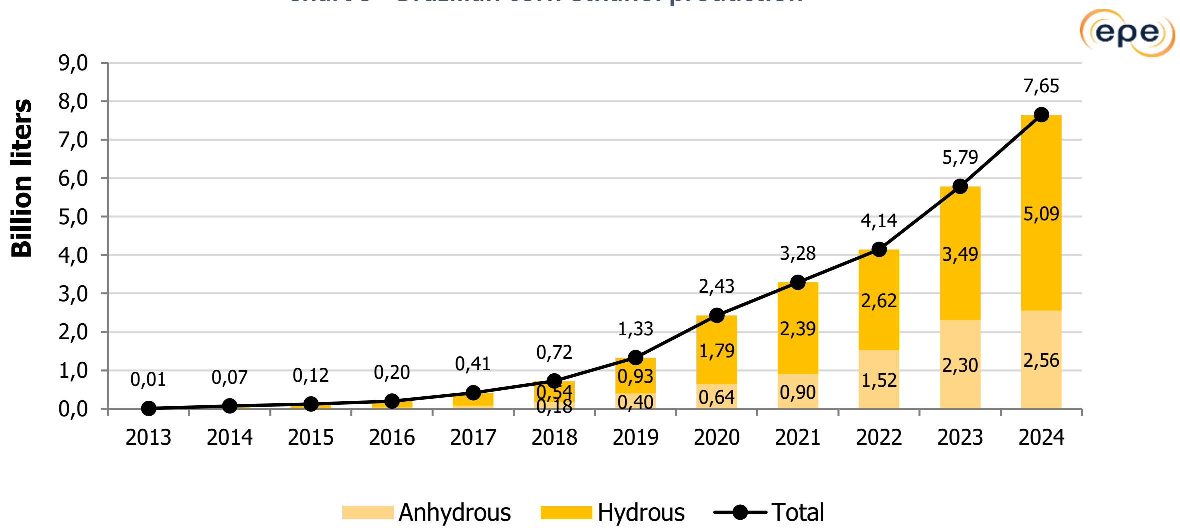
In 2024, co-products from corn ethanol production are estimated to have totaled between 3.7 and 6.3 million tons of DDGS (Dried Distillers Grains with Solubles) and 242 to 380 million liters[7] of oil. DDGS is used as a supplement in animal feed, while the oil is destined for human consumption and industrial use, including biodiesel production. Revenue from co-products varies but can account for up to 25% of the total obtained from corn processing at the plants.

1.4. Total ethanol production

Corn-based ethanol continues to show significant growth, with production reaching 7.7 billion liters in 2024, 32% higher than in 2023, as shown in Chart 9. Most of the production facilities are concentrated in the state of Mato Grosso (details in Chapter 4) (ANP, 2025a).

[7] A factor of 212-363 kg of DDG and 14-22 liters of oil per ton of corn was adopted (BENITES, 2023; DA SILVA et al., 2020; FIGUEIREDO, 2024; UNEM, 2025).

Chart 9 - Brazilian corn ethanol production

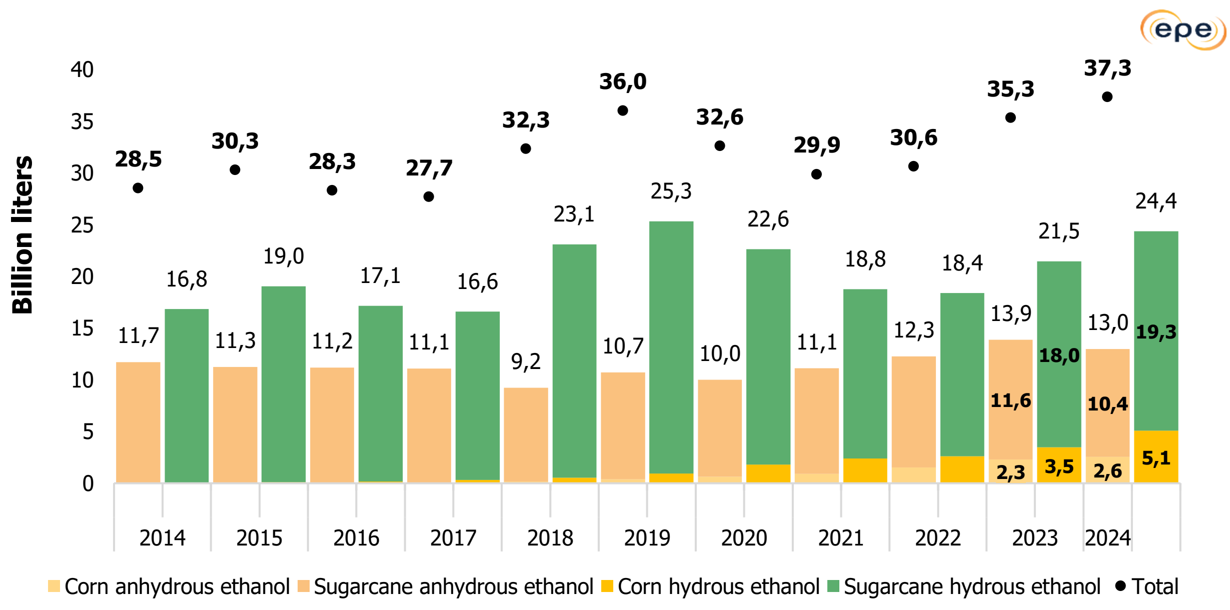


Source: EPE based on (UNICA, 2025).

From the perspective of the sugarcane harvest year, production in 2024/25 was 7.8 billion liters. Estimates for the next harvest indicate that ethanol production from corn will reach 8.7 billion liters, an increase of 11.5%. This reaffirms its potential within the portfolio of options for the biofuels sector and Brazil's energy matrix (CONAB, 2025a).

In 2024, ethanol production from sugarcane totaled 29.7 billion liters. When combined with the share from corn-based ethanol, amounted to 37.3 billion liters, divided into 24.4 billion liters of hydrous ethanol (a 13.6% increase) and 13.0 billion liters of anhydrous ethanol (a 6.4% decrease). Thus, the total volume produced was 5.7% higher than in 2023, setting a record, as illustrated in Chart 10 (MAPA, 2025).

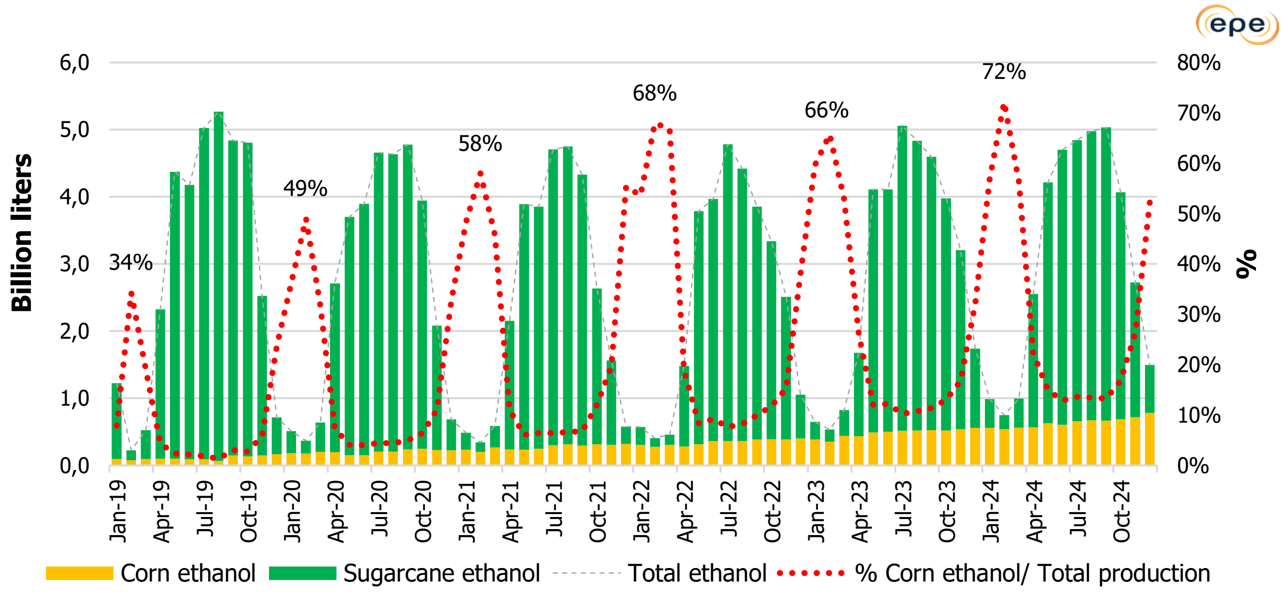
Chart 10 - Total Brazilian ethanol production (from sugarcane and corn)



Source: EPE based on (MAPA, 2025) and (UNICA, 2025).

From Chart 11, it is possible to observe the gradual increase in corn ethanol production and its importance during the sugarcane off-season in the Center-South region (December to March). Between 2019 and 2024, its share of total production increased from 34% to 72%.

Chart 11 - Monthly production sugarcane and corn ethanol



Source: EPE based on (MAPA, 2025)

In general, sugarcane mills have maintained a favorable outlook for allocating a larger share of their production mix to sugar, given their profitability in the international market. Meanwhile, corn ethanol has ensured a steady supply of this biofuel throughout the year, especially during the off-season, strengthening its competitiveness.

Ethanol production for other uses reached 1.16 billion liters, 8.5% higher than in 2023 (EPE, 2025e). Hydrous ethanol accounts for the largest share, with its main application as an antiseptic.

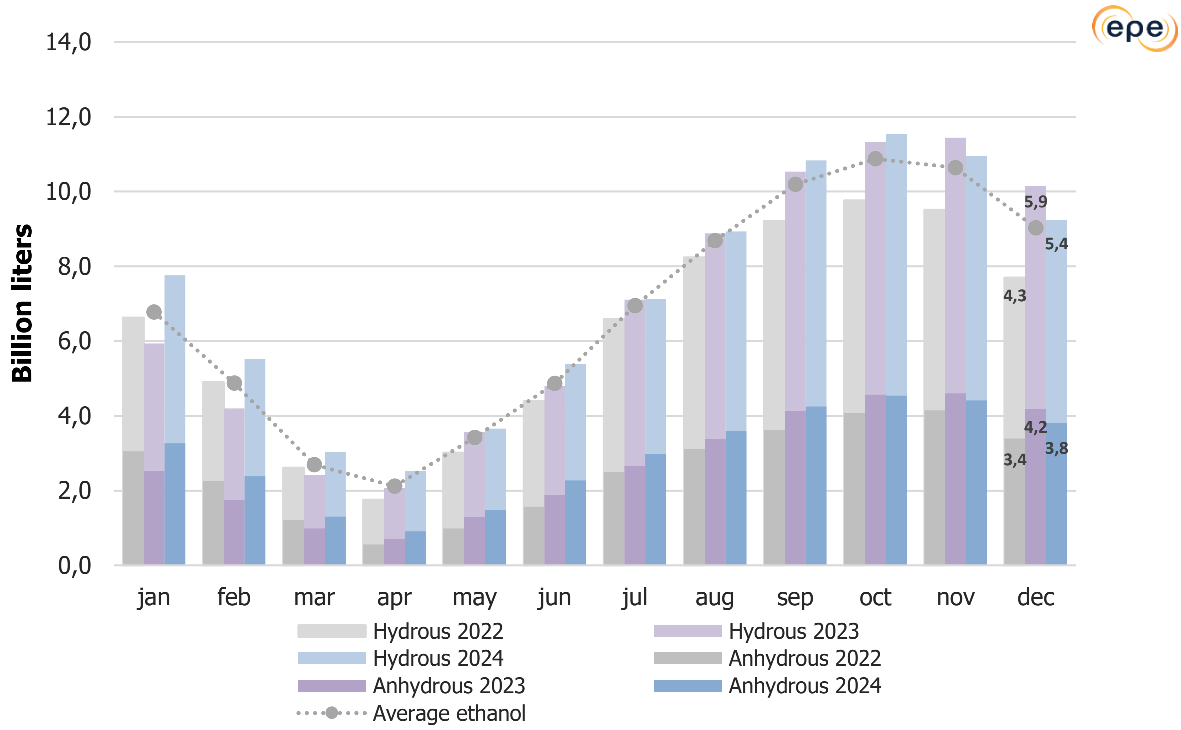
Ethanol Inventory

Chart 12 shows the historical variation in the monthly physical stock [8] of ethanol reported to MAPA. It reveals that the ending stock[9] on December 31, 2024, was 9.2 billion liters of ethanol, 8.9% lower than in 2023. Of this total, 3.8 billion liters were anhydrous ethanol, representing an 8.9% decrease compared to December 2023, while hydrous ethanol also saw an 8.9% decline in stocks (MAPA, 2025). It is worth noting that in 2024, ethanol stocks (anhydrous and hydrous) remained high from the beginning of the year, contributing to the competitiveness of hydrous ethanol relative to gasoline C throughout the year.

[8] 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.

[9] 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 stock



Source: EPE based on (MAPA, 2025).

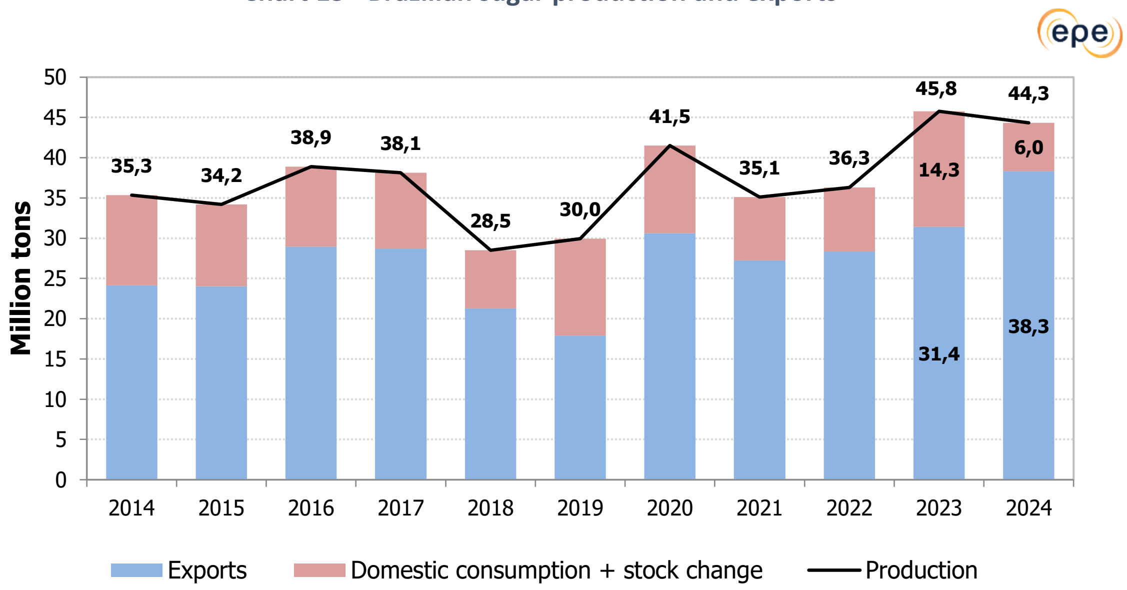
The current rules regarding the mandatory stock of anhydrous ethanol are established by ANP Resolution No. 719, dated February 22, 2018 (ANP, 2018a). According to this resolution, the mandatory minimum stock of anhydrous ethanol at production units is 25% and 4% on January 31 and March 31 of each year, respectively, 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 to ensure supply during the off-season. The available stock of anhydrous ethanol observed on March 31, 2024, at production units was 1.0 billion liters, meeting ANP requirements.

With greater ethanol availability in 2024, the total volume of the biofuel (hydrous and anhydrous) consumed was 16% higher than in 2023, with a 3.9% decrease in anhydrous ethanol due to lower demand for gasoline type C, and a 30% increase in hydrous ethanol. These points will be analyzed in detail in Section 2 of this study (EPE, 2025e; MAPA, 2025).

1.5. Sugar production

In 2024, Brazilian sugar production reached 44.3 million tons, 3.1% lower than in 2023. Due to favorable conditions in the international market, exports increased by 22.1%, totaling 38.3 million tons, the highest value in the historical series, while the "domestic consumption + change in stocks" component decreased by 8.3 million tons, as illustrated in Chart 13 (MAPA, 2025).

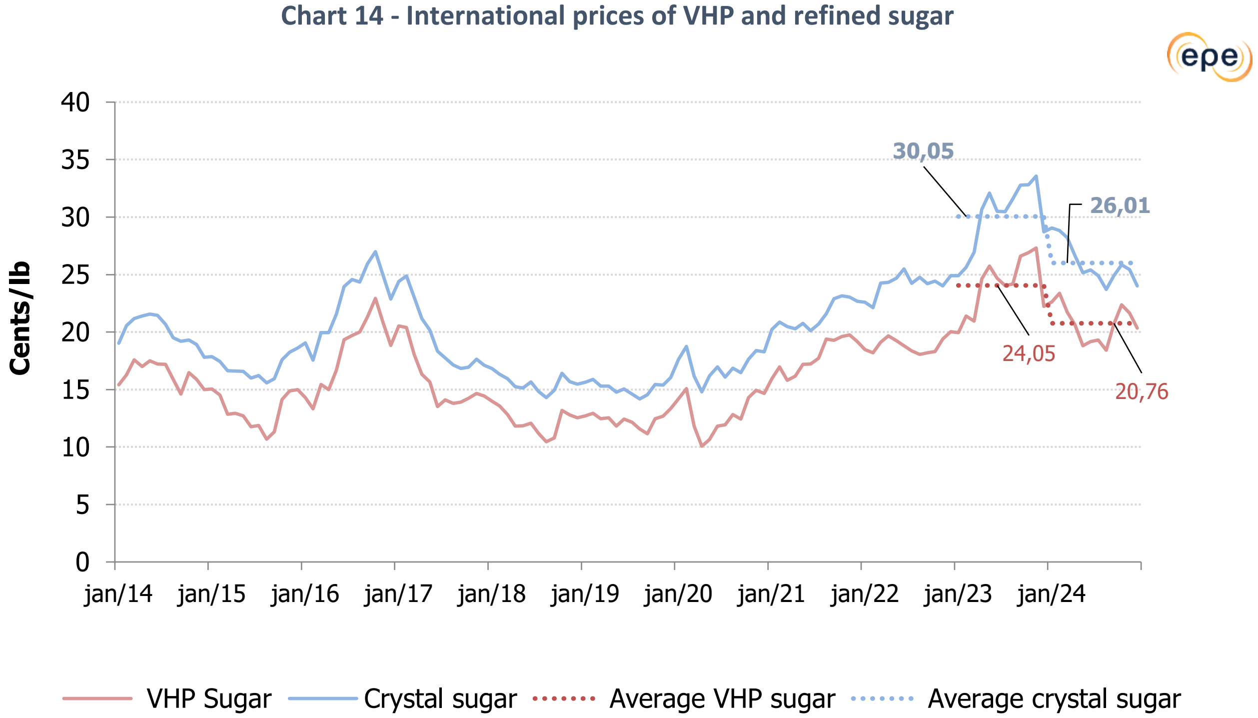
Chart 13 - Brazilian sugar production and exports



Source: EPE based on (MAPA, 2025).

Regarding the average prices of VHP and refined sugar, there was a decrease of 13.7% and 13.5%, respectively, compared to 2023, as observed in Chart 14. Despite the decline from the previous year, prices remained high when compared to other periods. Between January and December 2024, VHP and refined sugar quotations fell by 10.0% and 17.4%, respectively, showing some fluctuations during the period. The maintenance of high prices is a result of global stocks remaining at low levels (USDA, 2025).

Chart 14 - International prices of VHP and refined sugar

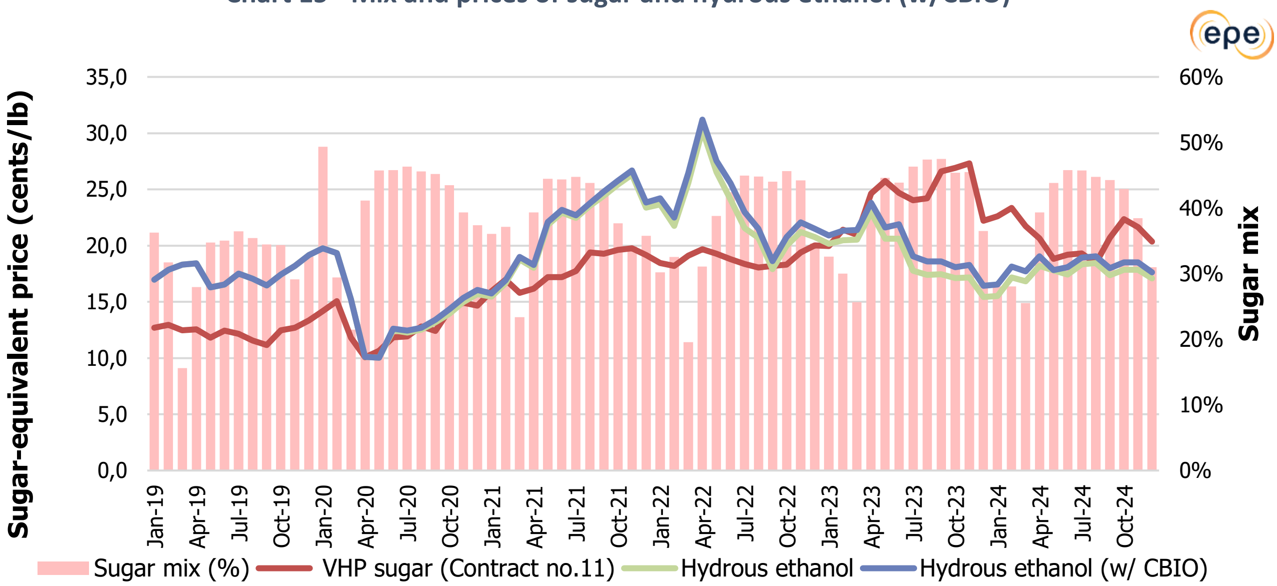


Note: VHP Sugar: Contract #11; Refined Sugar: Contract #5.

Source: EPE based on (USDA, 2025).

The global sugar supply and demand balance has shown a deficit since 2019/20 [10], with the stock-to-consumption ratio remaining above 40% in the last cycles. Since 2020, there has been a shift in the production mix towards sugar, following the rise in international sugar prices. In 2024, the price gap between the commodity and hydrous ethanol decreased. The variation in market prices for sugar and ethanol (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 1: The price of hydrous ethanol refers to the value in the domestic market (São Paulo), according to CEPEA/ESALQ, (2025)

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 2025, this value was added to the price of hydrous ethanol at the mill (São Paulo) .

Source: EPE based on (BC, 2025; CEPEA/ESALQ, 2025; EPE, 2025e; MAPA, 2025; UDOP, 2024; USDA, 2025)

The 2023/24 global season experienced a supply/demand deficit of 2 million tons of sugar, with a stock-to-consumption ratio of 44%. For the 2024/25 season, the expectation is a deficit of 5 million tons and a ratio of around 41%. Prospects for the next season (2025/26) indicate a surplus, based on production forecasts from major producers such as Brazil, Thailand, India, and the European Union (DATAGRO, 2025c).

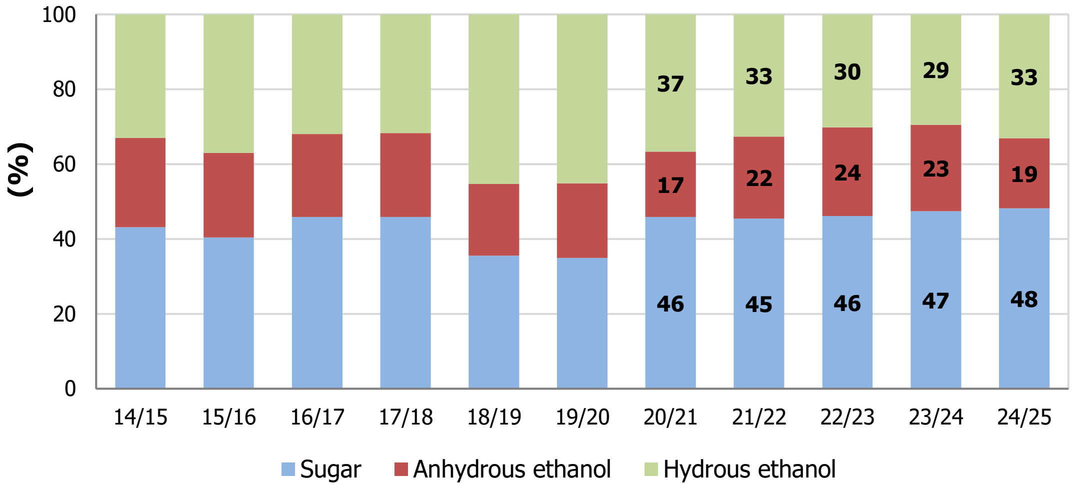
1.6. Production mix

In 2024, the percentage of TRS [11] allocated to ethanol production was 52%, 1.0 percentage point lower than in 2023, as shown in Chart 16. With the continued attractiveness of sugar in the international market, the allocation for sugar production reached 48%. It is noteworthy that Brazilian mills have consistently allocated the majority of TRS to ethanol throughout the analyzed period.

[10] Except for the 2021/22 harvest, when there was a small surplus.

[11] From the 2023/24 harvest onward, the production mix was calculated due to the unavailability of data in CONAB's Sugarcane Survey.

Chart 16 – Production mix (sugar x ethanol)



Source: EPE based on (CONAB, 2025c, 2025a; DATAGRO, 2025a).

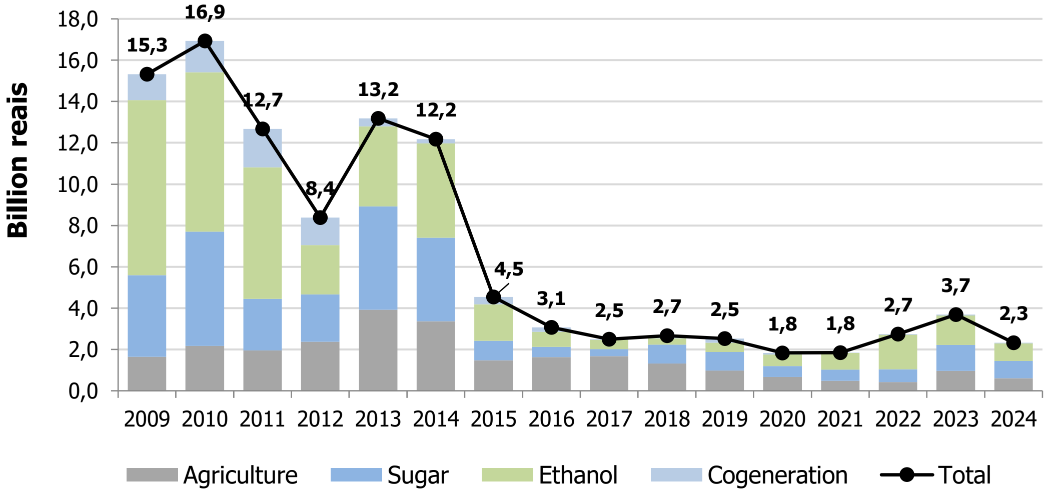
In the 2024/25 season, the TRS remuneration in the state of São Paulo was R$ 1.178/kg TRS (COSECANA, 2022), a slight decrease compared to the 2023/24 season (-2.1%).

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[12] value contracted (constant, in 2024 reais) by the ethanol and sugar sector with BNDES, including the agricultural component of sugarcane. In 2024, total investments through BNDES reached R$ 2.6 billion, 36.8% lower than in 2023. This amount represents 13.8% of the historical peak investment in the sector, in 2010, which amounted to R$ 16.9 billion.

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



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

Source: EPE based on (BNDES, 2025).

[12] Expenditures related to cogeneration will be detailed in Chapter 5.

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 was increased to R$ 3.5 billion to meet the demand of the biofuels sector for Environmental, Social, and Governance (ESG) credit by the end of 2024, with R$ 1 billion already approved for thirteen ethanol plants by early 2023 (BNDES, 2024a).

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), allowing companies to raise capital in the financial market to invest in the renewal of sugarcane plantations and their industrial facilities. Since December 2024, Ordinance No. 10 has been in force, covering investment projects in infrastructure aimed at the implementation, expansion, recovery, adaptation, or modernization of biofuel and biogas production, excluding the agricultural phase (MME, 2024). By the end of 2024, the bioenergy sector had raised R$ 17.5 billion from the offering of incentivized debentures for investors, with R$ 6.1 billion raised during 2024. In the first half of 2025, R$ 2.3 billion has already been raised by this same sector (ANBIMA DATA, 2025).

2. Otto-cycle demand

Total energy demand from light Otto cycle vehicles in 2024 reached 61.1 billion liters of gasoline equivalent (EPE, 2025e), representing an increase of 3.4% compared to the previous year.

Regarding light vehicle registrations, the second consecutive year of growth was observed, in a proportion even higher than in the 2022/2023 comparison. Similarly, motorcycle registrations also increased, marking the fourth consecutive year of successive growth.

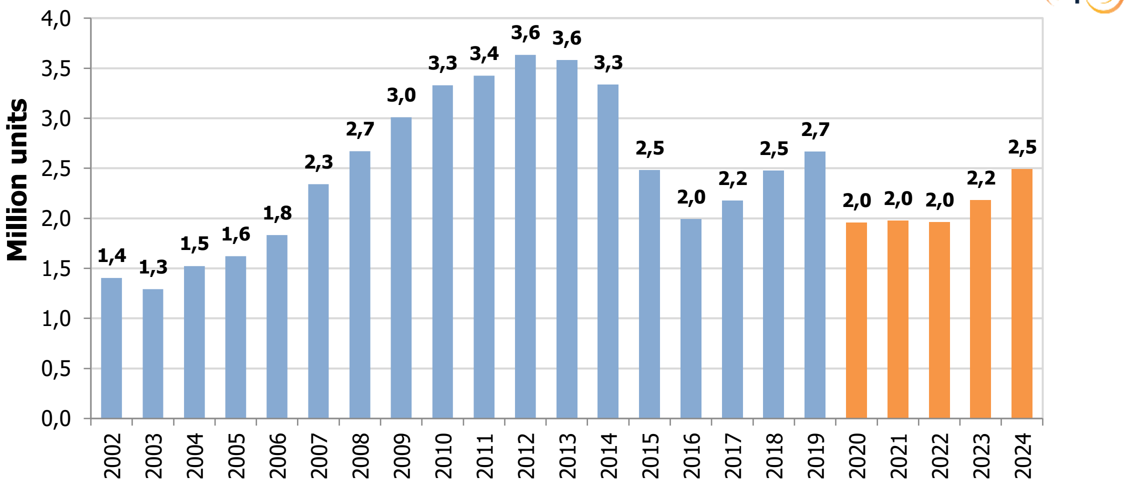
The high degree of renewability of the Brazilian transport matrix continues to be maintained. This level will be progressively reinforced by updates to the blending mandates established by the Fuel of the Future Law, which allows for an increase both in the share of biodiesel added to diesel and in the share of anhydrous ethanol incorporated into gasoline. In 2024, the transport matrix was 25.7% renewable, remaining above 20% since 2015.

Licensing and fleet of light vehicles and motorcycles

In 2024, approximately 2.5 million new light vehicles were licensed in Brazil, an increase of 14.1% compared to the previous year (ANFAVEA, 2025). This positions the country as the 6th largest light vehicle market that year, and the 2nd with the highest growth compared to 2023, behind only the Netherlands (FENABRAVE, 2025).

Chart 18 highlights the consolidation of the market recovery and the resumption of licensing levels, marking the second consecutive year of growth. During this period, two complementary factors strengthened, contributing to this increase: higher investment by automakers, largely stimulated by federal government policies such as the Mover Program; and greater availability of credit and financing for vehicle acquisition, both for rental companies and individual consumers. These factors will be analyzed in more detail throughout this chapter.

Chart 18 – Light vehicle registrations



Source: EPE based on (ANFAVEA, 2025)

Of the total light vehicle licenses, 78.3% were automobiles and 21.7% were light commercial vehicles. The latter, which include pickups, vans, and minivans, grew 17% compared to the previous year, reaching the highest proportional level in sales since 2013.

By fuel type, flex-fuel vehicles accounted for 79.1% of total licenses, remaining the majority despite a 9% decline in sales compared to 2023. Diesel-powered vehicles reached 9.7%, and gasoline-powered vehicles represented 4.1% of licenses.

Electrified vehicles (electric, hybrid, and plug-in hybrid) accounted for 7.1% of total licenses (ANFAVEA, 2025), being the category with the highest growth, with sales up 89% compared to 2023.

Regarding engine size, most licensed automobiles were equipped with engines up to 1.0 liter (53.6%[13,14]), surpassing, for the third consecutive year, vehicles with engines between 1.0 and 2.0 liters (44.4%) (ANFAVEA, 2025).

The used vehicle market[15] presents a more affordable alternative for consumers, who face average prices of R$150,000 when purchasing a new vehicle (AUTODATA, 2024b). In 2024, used vehicle sales increased by 9.2% compared to 2023, reaching 15.8 million units and accounting for 83.9% of total vehicle sales (new + used). For every new passenger car sold, 5.1 used cars were sold (FENABRAVE, 2025). For light commercial vehicles, the ratio is lower; for every 1 new vehicle sold, 3.2 used vehicles were sold.

The near-new used vehicle market (0 to 3 years old) showed significant growth, increasing by 15.2% in 2024, reaching 2.5 million units sold. In this segment, the opportunity to acquire a modern vehicle at lower prices drives the market, allowing a larger number of consumers in the country. In 2024, sales of older used vehicles[16], also increased by 8.1%, reaching 13.2 million units (FENAUTO, 2025).

In the case of electric and hybrid vehicles, this movement follows the opposite trend. The used vehicle market has proven disadvantageous, with higher depreciation levels, particularly for fully electric models. Concerns about battery lifespan and maintenance, as well as the insufficient availability of charging points, result in high inventory levels and, when sales do occur, significantly reduced prices. This trend in the used electric vehicle market can be observed on a global scale and represents a drawback of such an option (FECOMBUSTÍVEIS, 2024b).

It should be noted that the rental market has been consolidating itself as an alternative in the face of the difficulties imposed by higher vehicle acquisition prices, both for individuals and companies. Of the total, 53% are long-term rentals, mostly directed to institutions. The subscription rental modality – with contracts from one to three years – increased by 44% in 2024, indicating a transition in consumer behavior in the country, where instead of valuing ownership of the asset – in this case, the car – the preference shifts to rentals for medium and long-term periods (AUTODATA, 2024b).

In this context, car rental companies ended the year with approximately 650 thousand vehicles acquired, representing growth of about 10% compared to acquisitions in the previous year (ABLA, 2025). It should be emphasized that this total corresponds to 25% of all automobiles and light commercial vehicles licensed in Brazil in 2024. With this number, the rental sector's fleet closed the year 2024 with about 1.6 million light vehicles, representing an increase of 3% compared to the

[13] It is important to highlight that, historically - since 1993 - the IPI on vehicles with engines up to 1.0 liter has been lower. With reduced taxation, overall costs passed on to the consumer decrease, making such automobiles more financially attractive.

[14] It should be noted that, in July 2025, the federal government enacted Decree No. 12,549 (BRAZIL, 2025a), which reduces IPI rates for the most fuel-efficient cars that use clean energy and meet recyclability and safety requirements. The decree also establishes the Sustainable Car category, under which compact vehicles with high energy-environmental efficiency, manufactured in Brazil, will have zero IPI (MDIC, 2025b).

[15] This includes motorcycles and used heavy commercial vehicles.

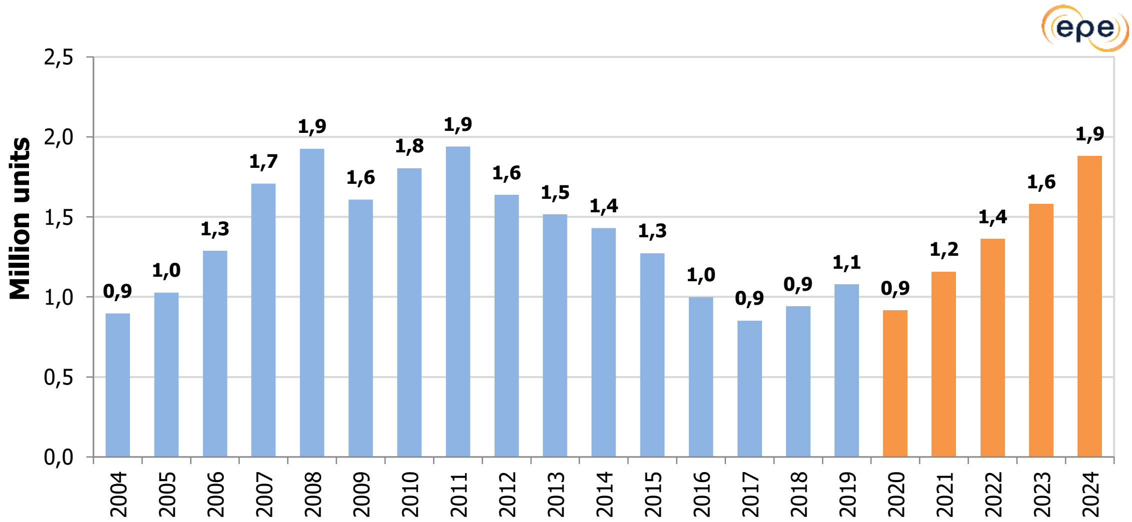
[16] Used vehicles older than three years are included, as well as motorcycles and used heavy commercial vehicles.

previous year. In the same period, the number of active rental companies in the country reached approximately 32 thousand, a 19.2% increase compared to 2023. Of these, 76% are specialized in car rentals, while the remaining 24% operate with other means of transport. It is also worth highlighting the significant growth of the electrified vehicle fleet in rental companies, which increased by 77.4% compared to 2023 (AUTODATA, 2024b).

Regarding motorcycles, in 2024, 1.9 million new units were licensed, 18.6% more than in the previous year, according to ABRACICLO (2025). As shown in Chart 19, that year marked the highest licensing level in the historical series, previously set in 2011. Since the post-Covid-19 pandemic period, licensing has been on a steady upward trend.

The expansion of transport and daily delivery services, which has been relevant in recent years, continues to be a driver of motorcycle sales. In addition, many users, faced with the costs of individual vehicles, prefer the acquisition of motorcycles, which have a lower entry price, as well as more advantageous maintenance and fuel costs.

Chart 19 – Motorcycle registrations



Source: EPE based on (ABRACICLO, 2025)

Fleet

As a result of the licensing observed in recent years, the Brazilian fleet of Otto cycle light vehicles is estimated to have reached 39.7 million units, remaining at the same level as the previous year, with flex-fuel technology representing about 85% of the total. When adding diesel cycle light commercial vehicles, the circulating fleet of automobiles and light commercial vehicles amounted to approximately 40 million units. Regarding motorcycles, the circulating fleet is estimated to have reached 17.7 million units, an increase of about 5% compared to the previous year (ABRACICLO, 2025).

In addition to automobiles, motorcycle acquisitions by rental companies also recorded significant growth, with the fleet made available by rental companies increasing by 81.4% compared to the previous year (ABLA, 2025).

Even with the growing number of new vehicle registrations in recent years, the aging process means that more than 40% of the Brazilian fleet is composed of vehicles that are more than 10 years old, whose production structure and regulatory framework were different from those currently in place. According to Sindipeças, in 2024, the average age of automobiles and light commercial vehicles was 10 years and 11 months, while for motorcycles it stood at 8 years (SINDIPEÇAS, 2025).

Vehicle licensing and fleet characterization

Electrified vehicles

The number of electrified vehicles continues to rise; in 2024, this market recorded an 89% increase in registrations (ANFAVEA, 2025). It is important to note, however, the differentiation among the types of electrified vehicles: fully electric vehicles grew by about 219%, while plug-in hybrids increased by 85% and hybrids by 32%. This disparity in sales can be partially explained by the high stock of fully electric cars in the country, which was built up in anticipation of the expected increase in IPI on imported units.[17]. However, even with the tax increase, electric vehicles accounted for almost 78% of the rise in imports, mainly Chinese models (FOLHA DE S. PAULO, 2024b).

The Southeast region remains the largest market for electrified light vehicles, accounting for 48.4% of purchases in 2024. It is followed by the South (18.5%), Center-West (14.8%), Northeast (14.7%), and North (3.6%) (ABVE, 2025a). São Paulo, Brasília (DF), and Rio de Janeiro stand out as the states and capitals with the highest sales of electrified vehicles.

As for motorcycles, electrification levels remain low. In 2024, only 0.4% of registrations were for electric motorcycles, slightly below the 0.5% observed in 2022 and 2023 (FENABRAVE, 2025).

In 2024, unlike the previous year, prices of electrified vehicles declined. Although still at high levels, the massive entry of Chinese models into the country sparked price competition, pushing domestic prices down, with dealerships offering discounts of up to 37% (FECOMBUSTÍVEIS, 2024b).

Around 40% of consumers reported considering the purchase of an electric vehicle in the future. The main factors influencing this choice were potential savings in maintenance and fueling, safety and efficiency aspects, and environmental concerns. On the other hand, the main barriers cited were the high purchase cost and limited charging infrastructure (ANFAVEA, 2024a).

Charging infrastructure, especially public stations, remains a key factor for wider adoption of electric vehicles, particularly from a territorial perspective. In 2024, there was a sharp increase in the number of charging points nationwide: from 4,300 installations in 2023 to 12,100, nearly triple the previous year's level. Of these, 1,500 are classified as fast or ultra-fast chargers (AUTODATA, 2024c). Despite growing investment in charging stations, the number remains insufficient to meet demand.

In terms of geographic distribution, almost half of the charging stations (49.6%) are located in the Southeast, mainly in São Paulo state. The North region has the fewest charging points, accounting for just 1.9% of the total. In addition, less than 20% of the 12,000 chargers in the country are classified as fast charging (ABVE, 2025b).

Several elements are fundamental to expanding the adoption of electrified vehicles. As observed in other countries leading the transition, factors such as the lack of robust charging infrastructure, the return of high prices after the removal of government subsidies, challenges related to raw materials for battery production, and the depreciation of used vehicles, among others, have dampened demand for such technologies.

[17] In 2023, it was announced that changes would be made to the tax structure for the international acquisition of electric vehicles, in response to local companies' demand for greater competitiveness of domestic products. Indeed, by the end of 2024, taxes were set at 25%, 20%, and 18% for hybrid, plug-in hybrid, and electric vehicles, respectively (AUTOESPORTE, 2025).

Economic context

The year 2024 proved to be very favorable for the automotive market, both for the automobile sector, which grew by approximately 13% compared to the previous year, and for light commercial vehicles, which grew by 17%.

The significant increases in sales, whether of new or used vehicles, in the rental segment or direct sales, can largely be explained by the rise in disposable income among the population, which has increased, among other factors, due to the decline in unemployment levels in the country, particularly in the industrial and services sectors.[18,19]. The unemployment rate closed 2024 at 6.2%, matching the levels of 2013 and marking the lowest value in the historical series, the minimum recorded since this indicator began to be measured. The minimum wage also saw a real increase, reaching R$ 1,412.00, with projected gains already established for the coming years, in accordance with the new minimum wage valorization law approved in 2023 (FOLHA DE S. PAULO, 2024a).

The SELIC rate, which is the benchmark interest rate for the Brazilian economy[20], fluctuated during 2024. It had been on an upward cycle until August, when, given the prospects of lower inflation, COPOM initiated a series of cuts that continued into early 2024. However, in September, the trend reversed, and the rate ended the year at 12.25%.

The increase in the benchmark interest rate tends to slow the growth of investments and vehicle sales. For example, the average interest rate for financing the purchase of new and used vehicles, following the SELIC trajectory, started the year on a downward trend; however, it ended 2024 returning to around 2% on vehicle credit operations (BC, 2025). Following the SELIC, the interest rate on vehicle financing closed the year at 27.51%, representing an increase of 7.8 percentage points compared to December 2023. Despite this rise, vehicle purchases through financing grew significantly.

It is important to highlight that there was a significant expansion in the availability of credit in 2024 compared to 2023. The average volume of loans granted to individuals for vehicle purchases increased by approximately 34% (BC, 2025). It should be noted that higher loan rates tend to reduce such operations over the long term.

The delinquency rate on financing specifically contracted by individuals for vehicle acquisition continued the downward trend observed since the end of the previous year, falling from 5.1% in January 2024 to 4.4% at the end of the year (BC, 2025). This trend helps sustain the expansion of available credit, as it supports market confidence in repayment, which is reflected in the Consumer Confidence Index calculated by FGV, reaching 95.6 points in November, the highest level since April 2014 (SINDIPOSTO, 2024).

The vehicle financing market grew by 20.4% compared to 2023, equivalent to 1.2 million more units financed. The increase was driven by light vehicles, which rose 19%, and even more significantly by motorcycles, which grew 25% (AGÊNCIA BRASIL, 2025a).

[18] The service sector, in addition to increasing disposable income through higher employment generation, also shows a relevant influence on light commercial vehicle sales due to the increased demand for goods delivery. The transformation in the online sales market, which increases its share each year, mainly post the COVID-19 pandemic, moves the last-mile delivery modality, which is done, predominantly, by light commercial vehicles.

[19] The level of employment in the industry increased by 2.9%, while in the service sector it rose by 3.4% (AGÊNCIA GOV, 2024).

[20] Due to this characteristic, it is the guiding rate for all interest rates in the country; that is, its movements – whether upward or downward – tend to direct changes in all Brazilian rates.

It is noteworthy that the average real income[21] increased by 4% compared to last year, reaching R$ 3,165.58 (BC, 2025). In addition, household expenditures grew by 4.8% compared to 2023, supporting the positive performance of the labor market and the increase in income and credit availability (AGÊNCIA IBGE, 2025).

Meanwhile, the auto parts market recorded a negative trade balance, which totaled US$13 billion in 2024. The deficit can be explained, in part, by the increase in domestic production, mainly of hybrid and electric vehicles, which have a higher level of technological automation and, as a result, the demand for imported parts increased. The level of exports of auto parts fell 13.3%, and exports of motor vehicles dropped 1.3%, which also impacts the greater decrease of the Brazilian trade balance (SINDIPEÇAS, 2025; ANFAVEA, 2025). On the other hand, Anfavea pointed out an increase of 8.3% in the number of jobs created in the automotive industry. In 2024, 107,000 positions were filled. This is the highest rate of job growth since 2007 (GLOBO, 2025).

The Gross Domestic Product (GDP) of the country grew 3.4%, resulting in the third consecutive year of growth since the COVID-19 pandemic (IBGE, 2025). With this, GDP per capita reached the amount of R$55,247.45 in 2024, growing about 3% compared to the previous year. In an analysis from the demand perspective, exports of goods and services in general grew 2.9%. Imports, in turn, saw a significant increase: in 2024, they rose 14.7%, largely driven by the acquisition of motor vehicles (IBGE, 2025).

The higher level of imports also impacted on the increase of Gross Fixed Capital Formation (GFCF), which ended with growth of 7.3%, largely driven by the higher level of industrial production. This, in turn, increased 3.3%, with emphasis on manufacturing industries, which include, among others, the production of the automotive industry.

Unlike in 2023, when the accumulated IPCA remained within the target set by the National Monetary Council (CMN), in 2024 inflation closed at 4.83%[22] . Analyzing the components individually, gasoline was the main driver of this increase. Throughout 2024, this fossil fuel contributed 0.91% to the cost of living, impacting the IPCA[23] by 0.48 percentage points, with an accumulated annual increase of 9.71% (AGÊNCIA BRASIL, 2025b).

[21] The average real earnings from the main job effectively received per month is an indicator collected and compiled by IBGE that measures the average real gross earnings effectively received in the reference month in the main job that employed persons perform; it is a series deflated by the IPCA and released quarterly.

[22] The target set by the CMN for 2024 was 3%, with a tolerance – upward and downward – of 1.5% (AGÊNCIA BRASIL, 2025b).

[23] It is noted that the average exchange rate in 2024 was R$ 6.10/USD (BC, 2025).

Public policies and sector investments

The National Green Mobility and Innovation Program, Mover, was sanctioned in June 2024. Part of Brazil's neoindustrialization project and the Fuel of the Future Law, the Mover Program strengthens the development environment of the country's automotive industry, establishing energy efficiency improvement targets – from 12 to 15% – measured through "well-to-wheel" carbon emissions, which considers the entire energy source cycle[24], and also establishing minimum recyclability indexes of 65% by companies. The regulation of Mover, mainly regarding the Green IPI incentive, one of the main items of the program and highly anticipated by most automakers and auto parts manufacturers, occurred in 2025 through Decree No. 12,549 (BRASIL, 2025a), which reduces the IPI rates of lighter and more efficient cars, powered by clean energy, that meet the recyclability and safety requirements.

The Mover Program also acts as a mechanism to encourage local investment, through measures such as the requirement for companies to apply a minimum of 1% of their annual revenue to Research, Development, and Innovation (R&D&I) activities, as a criterion for obtaining credits linked to the initiative in 2024, with a gradual increase of this percentage up to 1.8% in 2029 (CNN, 2024).

The Fuel of the Future Law supports the regulatory framework that stimulates the use of biofuels, directly impacting the renewable transport matrix in the country. In the case of light vehicles, the possibility of increasing the proportion of anhydrous ethanol added to gasoline — from the current 27% up to 35% tends to boost the production of flex-fuel technology vehicles. This measure contributes to consolidating national expertise in ethanol production, reinforcing Brazil's position as a global leader in this sector (GOV.BR, 2024). It is noteworthy that CNPE Resolution No. 9, of June 25, 2025, increased the anhydrous ethanol blending percentage in gasoline C to 30% as of August 1 (CNPE, 2025).

The Nova Indústria Brasil project has as its primary objective the promotion of the national industry, through six strategic missions aimed at modernizing the industrial park, strengthening autonomy and security, and promoting a sustainable ecological transition (AGÊNCIA BRASIL, 2024). Among these guidelines, Mission 5 stands out, which includes, among other aspects, the decarbonization of sectors with high transformation potential, such as the automotive industry. One of the government's targets is to increase the participation of biofuels and electric vehicles in the national transport matrix, with projections reaching 27% in 2026 and 50% in 2033. This project reinforces the regulatory environment, alongside MOVER and the Fuel of the Future Law, enhancing predictability and confidence for the productive sector, and consequently stimulating new investments in the country.

Complementing this set of regulatory initiatives, the Legal Framework for Guarantees, sanctioned in October 2023, has significant impacts on the automotive sector, particularly regarding credit provision. It allows the same asset to be used as collateral in multiple credit operations and establishes the figure of a guaranteed agent — responsible for mediating and facilitating negotiations between creditors and debtors. The framework also simplifies procedures and reduces costs associated with financing processes. One of its most significant provisions is the possibility of extrajudicial seizure of vehicles by creditors when the financed asset itself is used as collateral, contributing to a reduction in default risk. Still, facilitating direct communication between parties tends to favor renegotiations, with more frequent granting of discounts and interest rate reductions (FECOMÉRCIO, 2023).

[24] 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.

The Complementary Bill PLP68-2024, approved on December 17, 2024, by Congress, was subsequently converted into Complementary Law No. 214 on January 16, 2025. Its text maintains the inclusion of vehicles in the taxation of the so-called Selective Tax, with some known criteria serving as a basis, such as engine power, local manufacturing, and vehicle category (BRASIL, 2025b). The Green IPI, created with MOVER, is expected to serve as the foundation for this taxation (AUTODATA, 2024d).

The automotive sector remains promising, with the strengthening of recently launched and enacted public policies, such as MOVER and the Fuel of the Future. Within this political and macroeconomic environment, high volumes of investment by automakers are projected: approximately R$130 billion have been announced for the cycle through 2030 (ANFAVEA, 2024b).

The motorcycle market also benefits from the favorable purchasing environment. In 2024, companies located in the Manaus Industrial Hub (PIM) — one of the main production centers for two-wheeled vehicles in the country — invested R$641 million in expanding and modernizing their production structures (AUTODATA, 2024a).

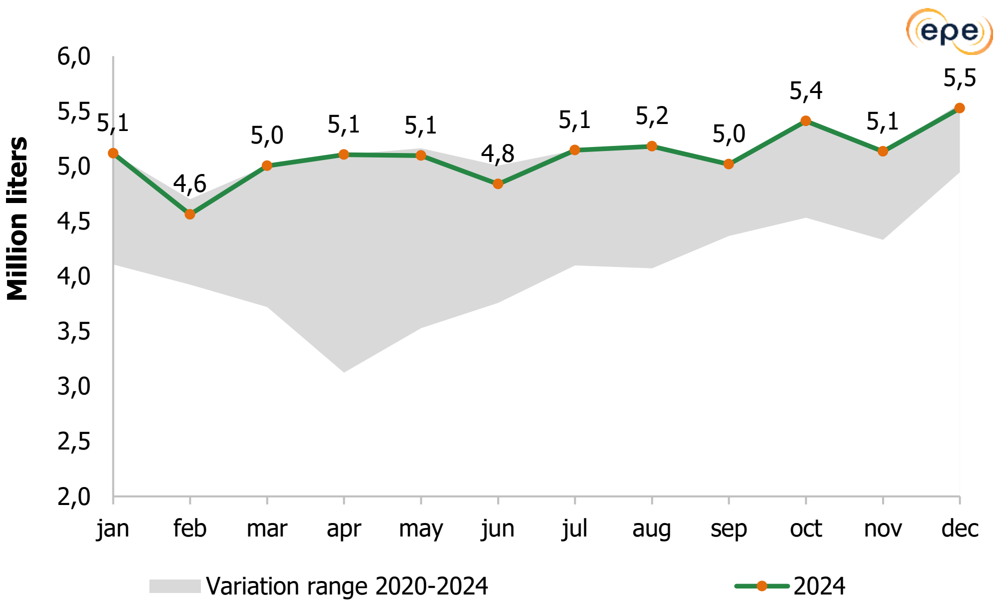
2.1. Otto-cycle fleet fuel demand

As previously mentioned, the total energy demand for light Otto cycle vehicles in 2024 was 61.1 billion liters of gasoline equivalent (EPE, 2024). This represents a 3.4% increase compared to the previous year, maintaining the growth trajectory. With the consolidation of the recovery of the light vehicle market and the sustained share of passenger cars and light commercial vehicles in the Otto cycle fleet at approximately 80%, in addition to improvements in income and employment conditions, demand for such fuels is expected to remain high.

Maintaining the trend observed since the second half of 2023, the collection of federal taxes – PIS/PASEP and Cofins – on fuels continued throughout 2024 (BRASIL, 2017b). For gasoline, the ICMS began to be collected under a single-phase system — meaning taxation is concentrated at one point in the chain, Notebly on the producer or importer. Hydrous ethanol, however, was not included in this system and therefore continued to be taxed based on the consumer weighted average price (PMPF), varying across each state. These discussions will be further detailed in the next chapter.

Gasoline A demand decreased by 4% year-on-year, while hydrous ethanol demand grew by approximately 30%, reaching the highest level in the historical series. The monthly demand trend in 2024 compared to the five-year average can be observed in the chart below.

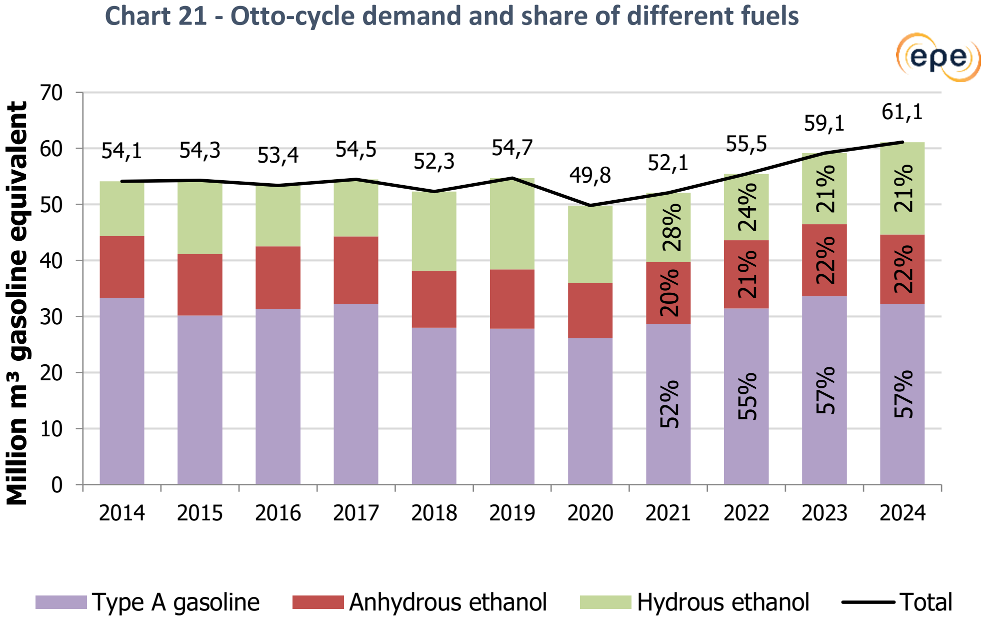
Chart 20 - Otto-cycle demand – Range of variation of the last 5 years vs. 2024



Source: EPE based on ANP (2025)

The energy share of gasoline A was approximately 53%, a decrease of 4.5 p.p. compared to 2023. Anhydrous ethanol also declined, accounting for 20%, while hydrous ethanol increased from 21% to 27% in 2024. As a result, total ethanol represented 47% of Otto cycle energy demand, 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

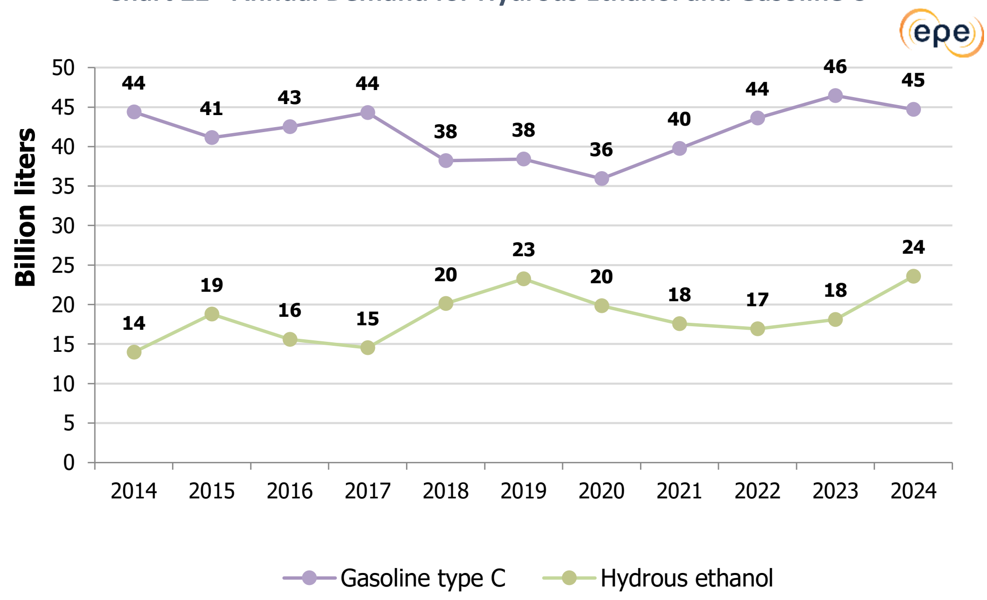


Note: The demand data excludes the portion related to CNG (Compressed Natural Gas).

Source: EPE based on EPE (2024).

The demand for hydrous ethanol in 2024 totaled 23.6 billion liters, while the consumption of gasoline type C reached 45 billion liters (EPE, 2024b), as illustrated in Chart 22.

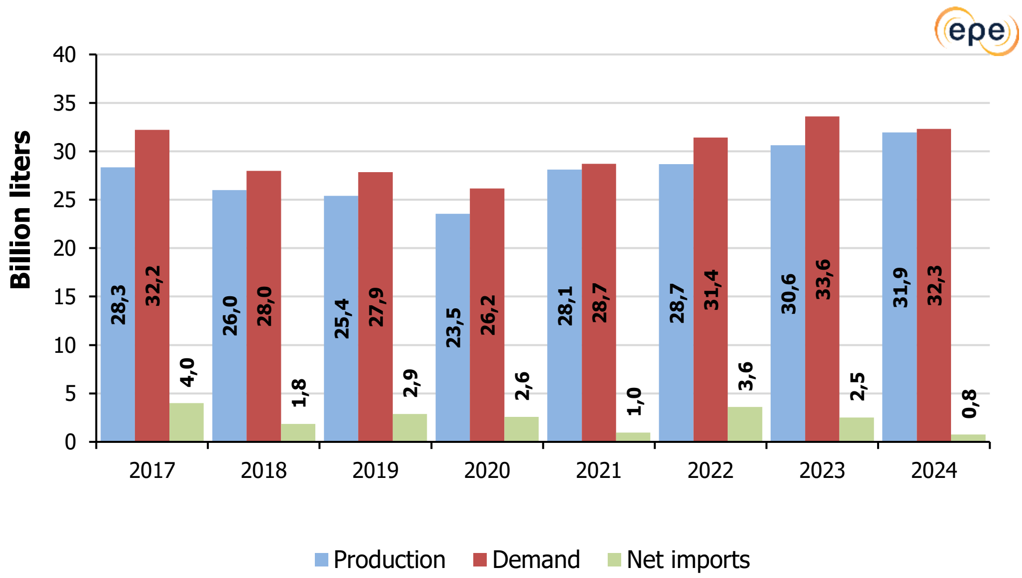
Chart 22 - Annual Demand for Hydrous Ethanol and Gasoline C



Source: EPE based on EPE (2024a).

Chart 23 shows the evolution of demand, production, and net imports of gasoline type A for the period 2016–2024.

Chart 23 - Production, demand and net imports of gasoline A



Source: EPE based on EPE (2024a).

In 2024, the national demand for gasoline type A decreased by 4.0% compared to the previous year, reaching 32.3 billion liters, while its production grew by 4.3%, totaling 31.9 billion liters. The trade balance for gasoline type A showed a net import of 0.8 billion liters, a 9.2% increase compared to the previous year. The amount of oil processed at refineries fell by 0.75% compared to 2023 levels (ANP, 2024a). Meanwhile, the demand for fossil diesel increased by 2.9%, and its production by the national refining sector grew by 3.3% (more details in Chapter 6).

3. Price and tax analysis of Otto-cycle fuels

The year 2024, continuing the trend from the previous year, maintained the recovery of economic activity. As highlighted in Chapter 2, many indicators showed the continuation of a more dynamic macroeconomic environment in the country, contributing to higher demand in the transportation sector.

For the analysis in this chapter, the reference prices are considered at constant December 2024 values, weighted by volume.

3.1. Otto cycle fuel prices

In 2024, the fuel tax burden underwent changes in the measurement of ICMS rates[25] 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 on gasoline type C throughout the national territory and remaining in place thereafter. These changes will be further explored in section 3.2.

In 2022, PIS/Pasep, COFINS, and CIDE were set to zero starting in the second half of the year, resulting in a decrease in average fuel prices. In March 2023, a Provisional Measure was enacted that partially[26], reinstated the collection of these contributions until the end of June. From the second half of 2023 onwards, the full collection of these federal taxes was resumed and remained in place throughout 2024. Consequently, the PIS and COFINS values returned to R$ 141.10/m³ and R$ 651.40/m³ for gasoline type A, respectively, and to R$ 43.19/m³ and R$ 198.62/m³ for ethanol, respectively, as established by Decree No. 9,101/2017 (BRASIL, 2017b).

Observing the price trends throughout 2024, there was a moderate increase in the average price of gasoline, rising 5.7% between January and December. Over the same period, ethanol showed a faster trajectory, with an increase of 14.6%. Consequently, the absolute price difference between gasoline type C and hydrous ethanol decreased from R$2.10/liter in December 2023 to R$2.02/liter in December 2024. When comparing the annual average prices of gasoline C and hydrous ethanol between 2023 and 2024, increases of 3.6% and a decrease of 0.3% were observed, respectively, even with the reinstatement of taxes. The combined data reveals an average ratio of 65% between the price of hydrous ethanol and fossil fuel in 2024, which favors the consumption of the biofuel, a topic that will be further explored throughout this chapter.

This year maintained a high level of sugarcane crushing and sugar production at sugar-energy mills across the country, as described in Chapter 1. Brazil reached the second highest sugar production volume in the 2024/2025 harvest, driven by favorable market conditions (MAPA, 2025). Corn ethanol production continues on a growth trajectory and, when combined with sugarcane ethanol output, resulted in a record total ethanol production in 2024.

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[25] The National Council of Fiscal Policy (Confaz) publishes, every month, the Reference Prices of Fuels, establishing the Weighted Average Price to the Final Consumer (PMPF), which serves as a benchmark for ICMS collection.

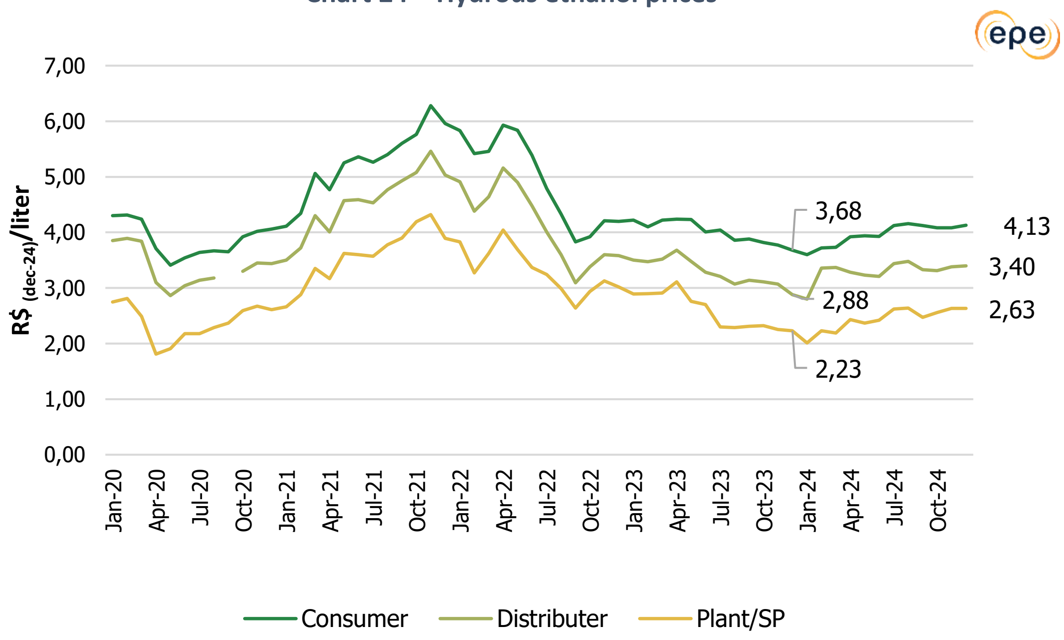
[26] Provisional Measure No. 1,163, of February 28, 2023, established new PIS and COFINS rates for the commercialization and import of gasoline and ethanol. For gasoline, PIS was set at R$ 83.84/m³ and COFINS at R$ 386.16/m³, totaling an additional R$ 0.47 per liter. For ethanol, producers and importers paid R$ 3.60/m³ for PIS and R$ 16.40/m³ for COFINS, while cooperatives paid R$ 1.64/m³ for PIS and R$ 7.53/m³ for COFINS. This provisional measure remained in effect until June 2023 (BRASIL, 2023d). The CIDE levied on gasoline has been established at R$ 0.10/liter since July 2023 (BRASIL, 2001).

Regarding domestic prices, starting in May 2023, Petrobras made changes to its commercial strategy and affirmed its commitment to maintain competitive prices aligned with both the national and international markets, although the company's pricing policy is no longer formally tied to the PPI (PETROBRAS, 2023). This change allowed Petrobras to keep prices relatively stable[27], helping to mitigate the effects of international volatility and stabilize the domestic market.

Thus, throughout 2024, the resale price of gasoline type C experienced fluctuations, ending the year with a 6.8% increase (ANP, 2025h; IBGE, 2025a).

Chart 24 presents a comparison of the average prices of hydrous ethanol for consumers (Brazil), distributors (Brazil), and mills (São Paulo), weighted by volume and deflated by the IPCA to constant December 2024 values.

Chart 24 – Hydrous ethanol prices



Source: EPE based on ANP (2025c) and CEPEA/ESALQ (2025a).

In 2024, the difference between the maximum and minimum prices of hydrous ethanol for consumers (recorded in August and January, respectively) was R$0.56 per liter. This difference was nearly identical to that observed in 2023 (R$0.54 per liter) and significantly lower than that seen in 2022 (R$2.10 per liter).

The price of hydrous ethanol in constant terms (December 2024) remained at the level observed in 2023, when the liter of the biofuel averaged around R$4.00. This stability can be explained by the continuation of high sugarcane milling levels, record ethanol production in the country, elevated stocks, and the maintenance of the tax reinstatement initiated in 2024.

Comparing month by month between 2024 and 2023, the maximum difference in resale margin occurred in January, reaching R$0.80 per liter (about 3% lower than in 2023). Notably, the average annual resale margin for hydrous ethanol in 2024 was R$0.66 per liter, 8.5% below the average observed in 2023 (R$0.72 per liter)[28]. On the other hand, the average distribution margins reached R$0.87 per liter, a reduction of 23.3% compared to 2023.

[27] An example of Petrobras' action is the case of diesel, which remained at R$ 3.53 per liter at refineries throughout 2024 (OTEMPO, 2025).

[28] In constant December 2023 values.

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 (PE/PG) and their respective variations.

Table 1 - Average annual prices of hydrous ethanol, gasoline type C and relative (EP/GP)

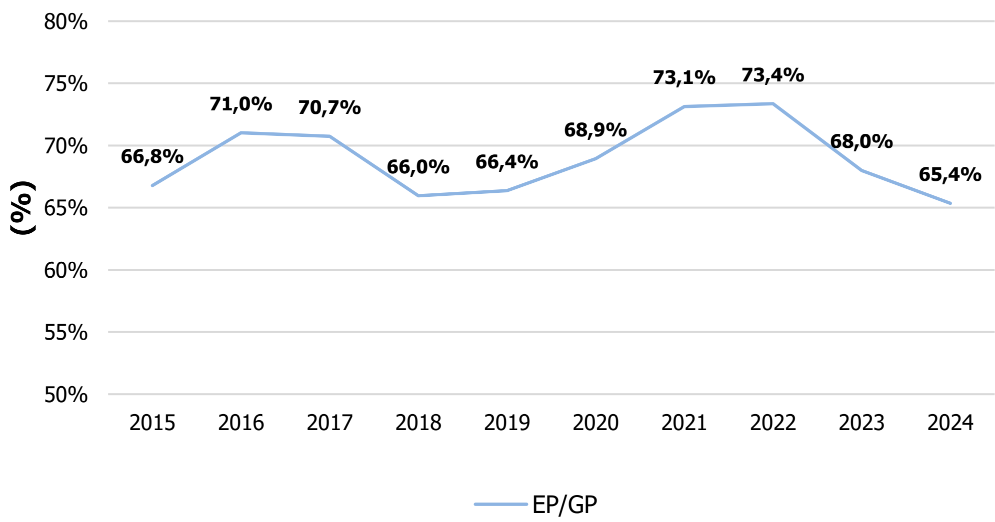
Year	Hydrous (R$dez24/l)	Var. (% p.a.)	Gasoline C (R$dez24/l)	Var. (% p.a.)	EP/GP	Var. (% p.a.)
2015	3,68	0,1	5,52	3,2	0,67	-2,8
2016	3,97	8,0	5,59	1,3	0,71	6,3
2017	3,89	-2,0	5,51	-1,4	0,71	-0,4
2018	4,09	5,0	6,21	12,7	0,66	-6,7
2019	3,95	-3,3	5,96	-4,0	0,66	0,6
2020	3,56	-10,0	5,17	5,85	0,69	3,9
2021	5,19	45,7	7,06	36,5	0,73	6,1
2022	4,92	-5,1	6,71	-4,9	0,73	0,4
2023	3,98	-19,3	5,85	-12,8	0,68	-7,5
2024	3,96	-0,3	6,06	3,6	0,65	-3,8

Note: The prices were weighted by volume and deflated by the IPCA, relative to December 2024.

Source: EPE based on (ANP, 2024a); (BC, 2025)

Throughout 2024, the price of hydrous ethanol followed the trend observed for gasoline type C, showing slightly more pronounced variations but in a manner consistent with previous years. Its average pump price was R$3.96 per liter, a decrease of 0.3% compared to 2023, while gasoline type C rose by 3.6%, reaching R$6.06 per liter. Consequently, the average relative price (EP/GP) in 2024 decreased to 0.65, below the threshold value (0.70), favoring the consumption of hydrous ethanol. Chart 25 illustrates the variation in the annual average relative price (EP/GP) since 2015.

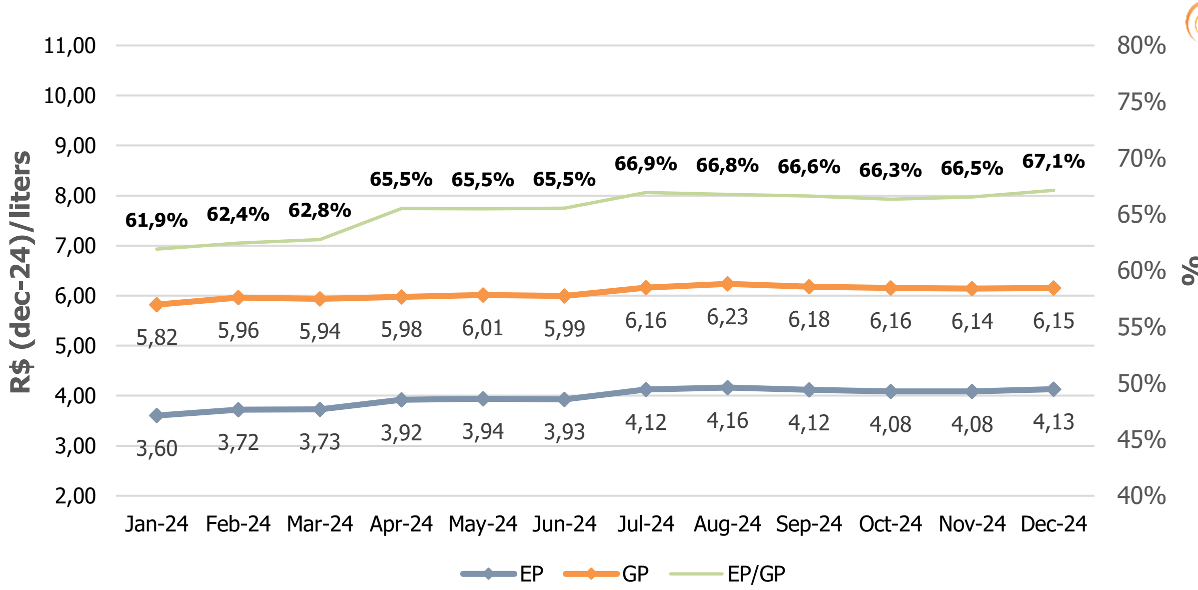
Chart 25 - Price ratio between hydrous ethanol and gasoline type C (EP/GP)



Source: EPE based on (ANP, 2024a)

The monthly analysis for 2024 indicates that, throughout the year, hydrous ethanol remained competitive, maintaining levels highly favorable for its purchase, as shown in Chart 26. This year, more states exhibited favorable PE/PG ratios for biofuel consumption compared to the previous year. In 2023, the list of states with favorable monthly PE/PG ratios included SP, GO, MT, MS, MG, and PR, which in 2024 represented, respectively, 37.6%, 17.5%, 15.2%, 11%, 9.1%, and 3.0% of total production, plus the Federal District. In 2024, this list expanded to include Acre. Although the state in the North region does not have its own ethanol production history, the favorable PE/PG ratio can be explained by the high gasoline prices at local stations, making ethanol a comparatively more advantageous option.

Chart 26 - EP, GP and monthly EP/GP ratio in 2024



Source: EPE based on (ANP, 2024a)

3.2. ICMS in Otto-cycle fuels

Complementary Law No. 192/2022 and its subsequent updates established significant changes in the collection of ICMS on fuels, such as the adoption of uniform rates – the so-called monophase taxation system[29] - and fixed values per unit of measure (liter for diesel, gasoline, and anhydrous ethanol; kilogram for LPG)[30] across the country. Starting in 2023, Confaz centralized the decisions on these rates, resulting in increases or stabilization of the amounts charged, particularly for gasoline and ethanol.

Starting in February 2024, new adjustments to ICMS rates came into effect, approved by the National Council for Fiscal Policy (Confaz) in October 2023: the ICMS on gasoline increased by R$0.10 to R$1.37 per liter, while the rate for diesel rose by R$0.06, reaching R$1.06 per liter.

Regarding ethanol, comparing 2024 values with those of May 2023[31], three states registered an increase in the tax on the biofuel: Maranhão, Ceará, and Minas Gerais, with rate increases of 10%, 5%,

[29] Single-stage taxation: the tax is applied at a single point in the fuel supply chain.

[30] 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.

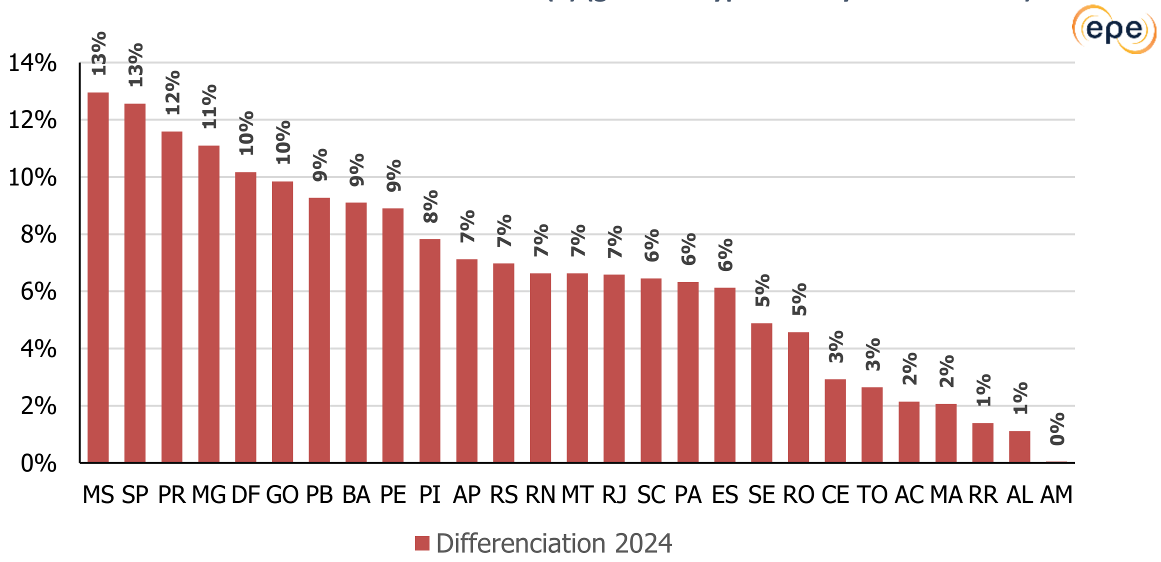
[31] May 2023 was selected due to the start of the *ad rem* rate for gasoline from June of the same year, as detailed in the previous paragraphs.

and 1.5%, respectively. Rio Grande do Norte was the only state to reduce its rate, decreasing it by 1.7% and returning to the 2022 level.

On the other hand, the increase in the average “ad rem” ICMS on gasoline type C, from R$1.22/liter in 2023 to R$1.33/liter starting in February 2024, translates into a higher estimated rate for all states and the Federal District. Although hydrous ethanol remains under the “ad valorem” regime, with the tax calculated uniformly, the average corresponding “ad rem” ICMS on the biofuel was R$0.63/liter in 2023 and R$0.75/liter in 2024.

Chart 27 presents the differentiation of the “ad rem” rates for gasoline and ethanol in effect throughout 2024.

Chart 27 - Tax Differentiation - ICMS "ad rem" (*) (gasoline type C vs. hydrous ethanol) 2024



Note: (*) "Ad rem" values for 2024 divided by the last PMPF of gasoline in May 2023 (brought to constant values of December 2024) and compared with the ICMS values of ethanol, obtained in a similar way.

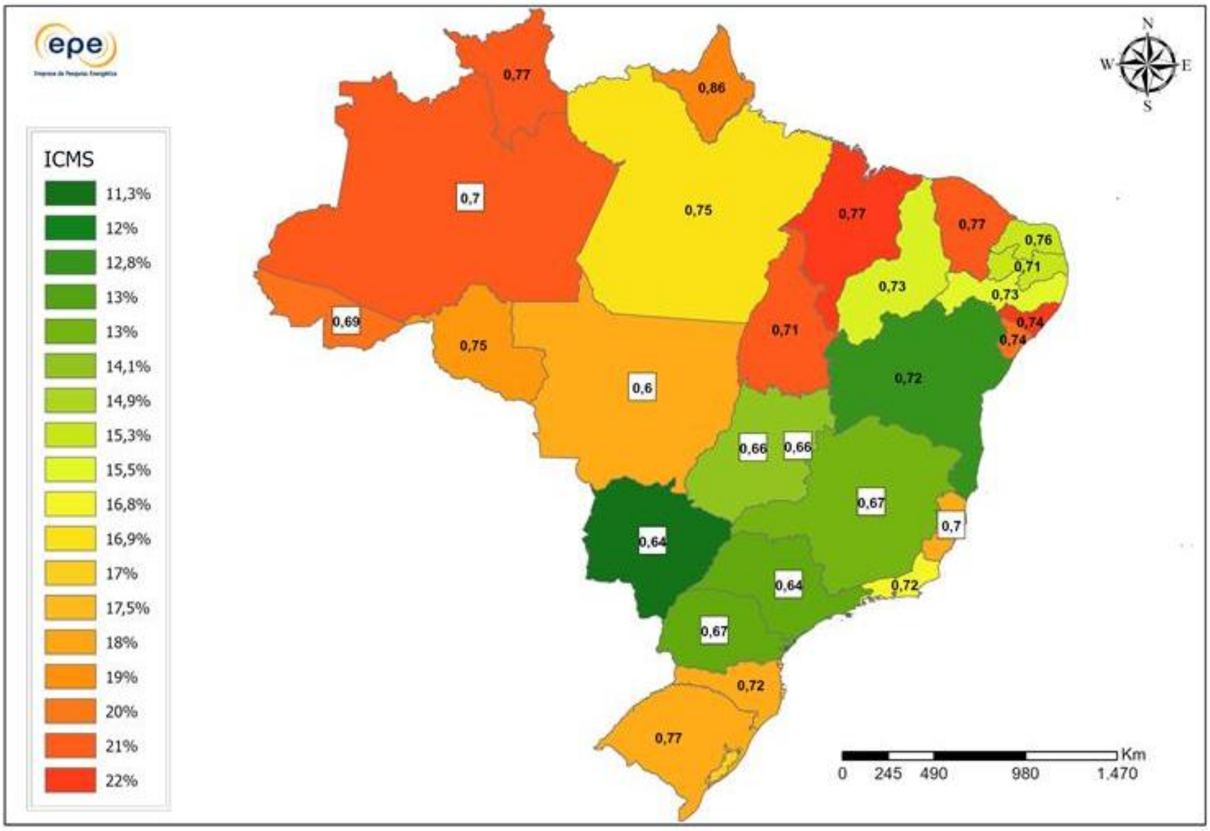
Source: (FECOMBUSTÍVEIS, 2024a) and (CONFAZ/MF, 2024a, 2024b)

From Chart 27, it’s observed that the three states with the largest tax differentiation[32] between ethanol and gasoline are São Paulo, Paraná, and Minas Gerais, with rate differentials of 13%, 12%, and 11%, respectively.

Figure 1 illustrates the relationship between ICMS taxation and the competitiveness of hydrous ethanol across Brazilian states in 2024.

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

Figure 1 - ICMS rate for ethanol and EP/GP ratio by State in 2024



Source: EPE based on (ANP, 2024a) (CONFAZ/MF, 2024a), (FECOMBUSTÍVEIS, 2024a)

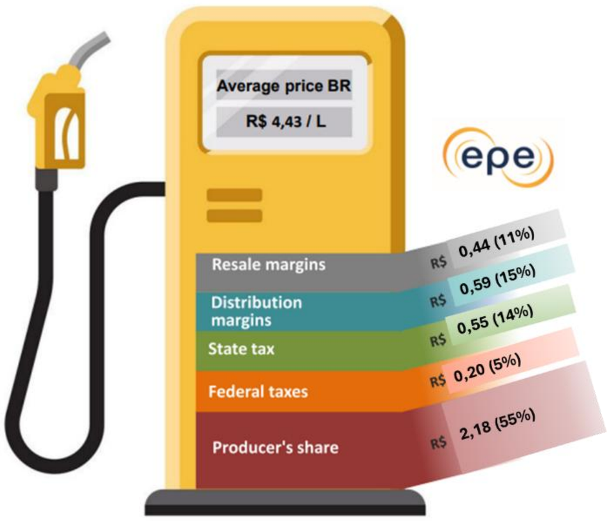
In 2024, the average PE/PG ratio for Brazil was 65%. The state of Mato Grosso recorded an annual average ratio of 59%, remaining the lowest in the country. In São Paulo, the largest producer and consumer[33], the average ratio was 64% (the ICMS rate for ethanol was the third lowest nationwide, at 12%). The least competitive states were Amapá, Ceará, and Rio Grande do Sul, where the price of hydrous ethanol reached, on average, 85.6%, 77.5%, and 77% of the price of gasoline C, respectively. In these three states, the fossil fuel price remained only slightly above that of the biofuel throughout the year. The national average price of gasoline C was R$6.06 in 2024, up from R$5.85 in 2023, while the average price of ethanol slightly declined from R$3.98 in 2023 to R$3.96 in 2024.

Special topic on hydrous ethanol prices

As highlighted in the subsections on ICMS, taxes, as well as distribution and resale margins, are key components in the formation of the retail price of hydrous ethanol. Figure 2 presents the price composition of hydrous ethanol for Brazil, based on the annual average for 2024.

[33] São Paulo accounted for 37.6% of the national production and 45.2% of the consumption of both anhydrous and hydrous ethanol in Brazil, in 2023 (MAPA, 2024).

Figure 2 - Consumer price formation of hydrous ethanol in Brazil in 2024



Source: EPE based on ANP (2025c) and CEPEA/ESALQ (2025a).

Figure 2 records the average price of hydrous ethanol for the national market at R$ 3.96 per liter. The largest portion of this price corresponds to the producer, accounting for about 55% of the final average price, or approximately R$ 2.18 per liter. Federal taxes (PIS and Cofins) and the state tax (ICMS) represented around 5% and 14% of the final price, respectively, or R$ 0.20 and R$ 0.55 per liter, on the national average. As previously shown, distribution and resale margins accounted for 15% and 11% of the final average price, or R$ 0.86 and R$ 0.44 per liter, respectively. Compared to the average price structure of regular gasoline, hydrous ethanol has lower federal and state taxes (about 19% for ethanol versus around 35% for gasoline) and higher distribution and resale margins (approximately 26% for ethanol versus about 17% for fossil fuel). Finally, the producer's share is higher for ethanol (55% versus 35% for gasoline), while gasoline C also includes an anhydrous ethanol component representing about 14% of the final price of the petroleum derivative (EPE, 2024; ANP, 2025c; PETROBRAS, 2025b; BRASIL, 2024b).

4. Production capacity and ethanol supply chain

4.1. Production capacity

In 2024, there were no new installations, reactivations, or shutdowns of sugar-energy plants. By December, 337[34] facilities were operational, including 14 sugar-producing units. The effective milling capacity was approximately 758 million tons. With 686 million tons milled, the industry's occupancy rate for the year reached 91% of this capacity (ANP, 2025a; MAPA, 2025).

Regarding corn ethanol, in 2024, there were 29 operational units (18 full and 11 flex). The total processing capacity[35] reached 20.9 million tons per year, with an ethanol production capacity of 10.6 billion liters. Six installations were implemented during the year, including four new full units and two expansions converting existing units to flex. These facilities are concentrated in the Central-West region, with 55% in Mato Grosso, 24% in Goiás, and 10% in Mato Grosso do Sul. The Northeast has two operational units: the Coruripe facility was implemented in 2024, while Balsas began operations in early 2025. Production expansion into the North and Northeast regions is expected, supported by ongoing production authorization processes at ANP (ANP, 2025a).

In addition to these feedstocks, there are three units[36] processing cereals and soybeans, and eight units processing rice and other unspecified raw materials, generally with a capacity of 10 m³/day or less, used for ethanol production. Based on the above, a total of 366 production units existed in December 2024 (ANP, 2025a, 2025b; MAPA, 2025). Chart 28 shows the flow of ethanol production units between 2005 and 2024.

Chart 28 shows the flow of ethanol production units between 2005 and 2024[37]. Regarding sugarcane mills, many began operations between 2005 and 2010; however, several halted their activities by 2017. Since then, some units have been reactivated, with only two new plants established in 2023. The nominal sugarcane milling capacity is estimated to have increased by approximately 143 million tons over the period, considering installed, deactivated, and reactivated units. The introduction of corn ethanol plants began in 2012, and since 2023, there has been a growing trend in the implementation of new units using this feedstock, predominantly of the full type, making it relevant for national capacity. More recently, projects using other cereals, such as wheat, sorghum, and soybeans, have emerged as additional options for biofuel supply, with these units being smaller in scale.

[34] This total includes flex corn ethanol plants and four units producing aguardente and/or ethanol for other uses. It does not include ethanol plants not derived from sugarcane or those that halted and resumed operations in the same year.

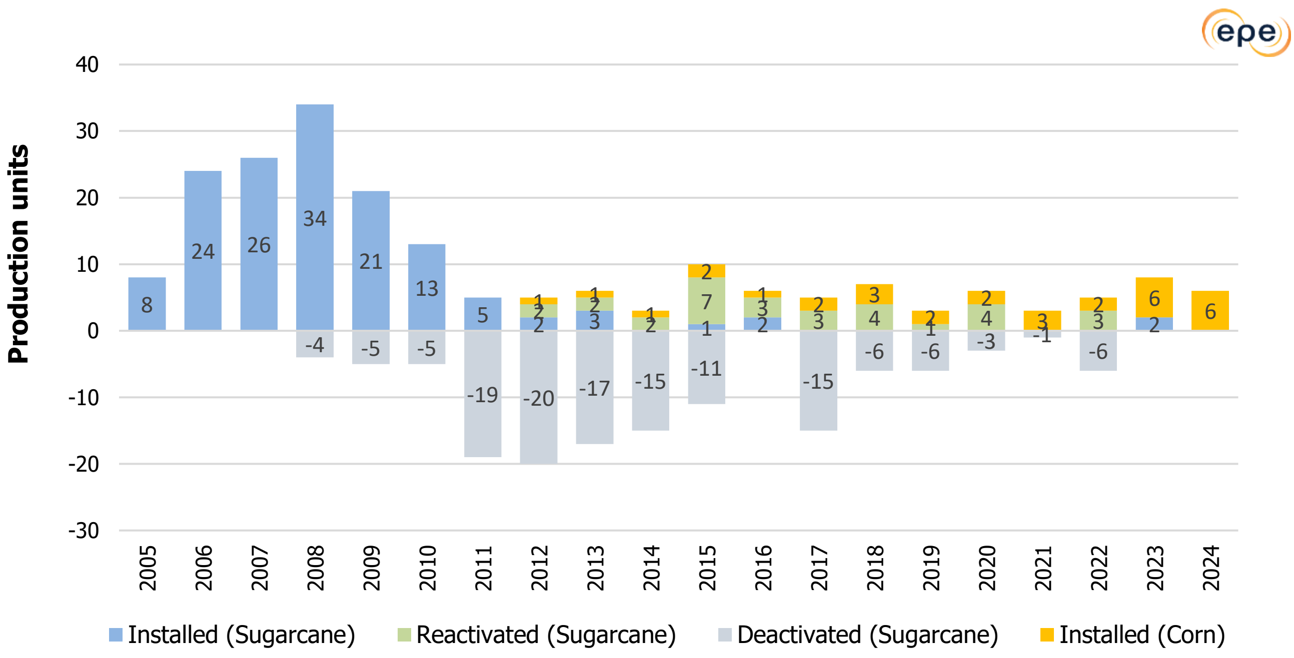
[35] This total includes flex corn ethanol plants. It should be noted that their ethanol production and corn processing capacities are accounted for together with those of full corn plants. A 155-day harvest is considered for the flex plants when only the grain is used.

[36] With an ethanol production capacity of 31.4 million liters per year.

[37] The historical series was updated using data from ANP and MAPA, company websites, and scientific articles. Ethanol fuel plants whose operating authorizations were revoked by ANP, and those with valid authorization but which published information in the media about the interruption of their activities, were classified as inactive, except for GranBio and Costa Pinto (Raízen), which may be reactivated if operations resume.

Regarding sugarcane mills, many began operations between 2005 and 2010; however, several halted their activities by 2017. Since then, some units have been reactivated, with only two new plants established in 2023. The nominal sugarcane milling capacity is estimated to have increased by approximately 143 million tons over the period, considering installed, deactivated, and reactivated units. The entry of corn ethanol plants began in 2012, and since 2023, there has been a growing trend in the implementation of new units using this feedstock, predominantly of the full type, making them relevant for national capacity. More recently, projects utilizing other cereals, such as wheat, sorghum, and soybeans, have emerged as additional options for biofuel supply, with these units being smaller in scale.

Chart 28 - Flow of sugarcane and corn ethanol plants in Brazil



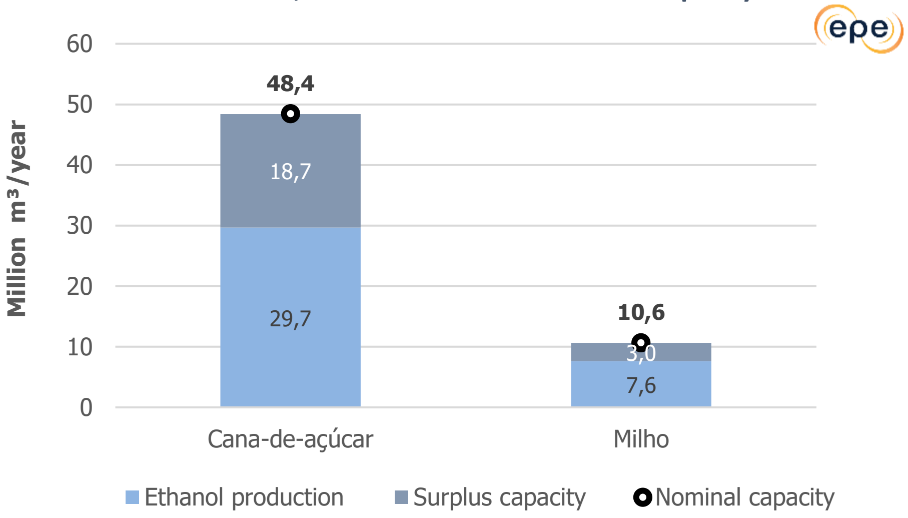
Note: Units that use soybeans and other cereals as raw material are accounted for along with corn.

Source: EPE based on (ANP, 2025a; MAPA, 2025; UNICA, 2014)).

Chart 29 presents the nominal capacity of ethanol production facilities for the year 2024, as well as the actual ethanol production (hydrous and anhydrous) and the surplus capacity for the same period[38]. Ethanol-producing units, considering both sugarcane and corn together, showed an idleness rate of 37%. It should be added that, in the case of sugarcane, part of the feedstock is also allocated to sugar production, which affects the availability for biofuel production (ANP, 2025a, 2025b; MAPA, 2025; UNICA, 2025).

[38] There are 11 ethanol production units using feedstocks other than sugarcane and corn/sorghum, responsible for approximately 1% of the nominal capacity of total ethanol production, which operated at 27% of their respective installed capacities in 2024 (ANP, 2025a, 2025b).

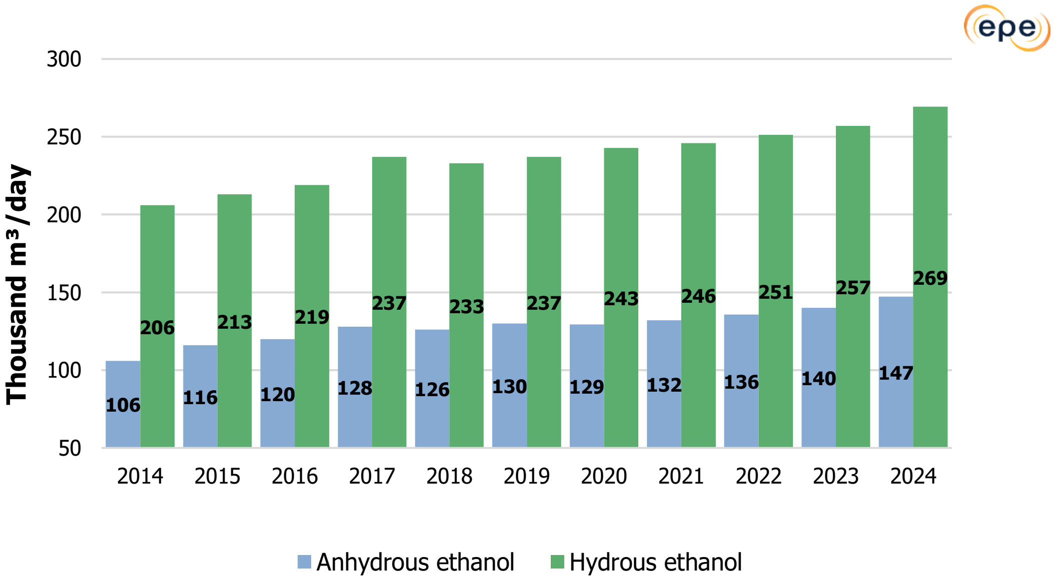
Chart 29 - Production, excess and nominal ethanol capacity in 2024



Source: EPE based on (ANP, 2025a, 2025b; MAPA, 2025; UNICA, 2025)

Additionally, there were 26 requests[39] for the construction of new plants, which will add a capacity of 13,300 m³/day for anhydrous ethanol and 15,200 m³/day for hydrous ethanol. Furthermore, 39 units had plans to expand their production capacity for these biofuels (ANP, 2025a). Chart 30 shows the evolution of installed ethanol production capacity in Brazil since 2014, highlighting an increase of 63,000 m³/day for hydrous ethanol and 41,000 m³/day for anhydrous ethanol.

Chart 30 - Evolution of the installed ethanol production capacity in Brazil



Note: The data was extracted from the daily capacities of ethanol producers authorized by ANP.

Source: EPE based on (ANP, 2025a).

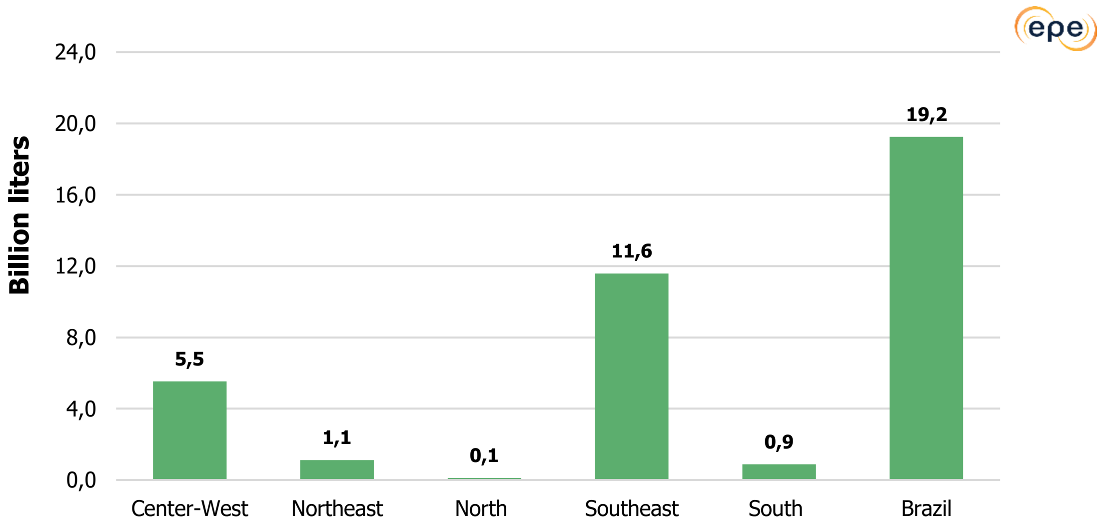
MAPA oversees the operation of units in the sugar-energy sector, including those dedicated to sugar production. ANP, in turn, monitors the units authorized to commercialize anhydrous and hydrous ethanol, even if they are not operational on a given date. The discrepancies between the reports of the two entities stem from their differing objectives.

[39] The authorizations cover sugarcane ethanol units (five, of which two already operate producing sugar, ethanol for other uses, and/or aguardente), corn/sorghum (eighteen), wheat (one), cereals (one), and sweet potato (one) (ANP, 2025a).

4.2. Storage (tankage)

In 2024, Brazil registered an ethanol storage[40] capacity of 19.2 billion liters, with the Southeast region standing out at 11.6 billion liters (60%), which reflects its alignment with the largest volumes produced and consumed in that region (ANP, 2025a). Chart 31 presents Brazil's tanking capacity by type of ethanol and by region.

Chart 31 - Brazilian ethanol storage capacity by region in 2024



Source: EPE based on (ANP, 2025a).

4.3. Pipelines

Most ethanol distribution in Brazil is carried out via road transport. However, there are alternative modes 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 both its own pipelines and the use of existing ones, with a current total length of approximately 1,100 km[41], and a maximum annual transport capacity of up to 9 billion liters of ethanol (LOGUM, 2025a).

[40] In 2024, the storage volumes reported by ANP did not distinguish between hydrous ethanol, anhydrous ethanol, and other alcohols.

[41] The initial Logum project included expansion to the port of Santos, totaling 1,400 km of pipelines. However, there is no information available regarding this expansion.

Figure 3 – Integrated logistics system for ethanol

Source: (LOGUM, 2025a)

The sections of the pipelines currently in operation are:

i. Owned pipelines: Ribeirão Preto (SP) – Paulínia (SP) (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 (SP);

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

The storage capacity of the tanks (usable volume) at the operational terminals of the system is 617 million liters. In 2024, the volume of ethanol transported reached 5.0 billion liters, 16.3% higher than in the previous year (LOGUM, 2025b).

In July 2023, Logum completed the main stage of 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 transport up to 9 billion liters of ethanol per year by 2030, with its operational system fully functional and improvements implemented (UDOP, 2023

4.4. Ports

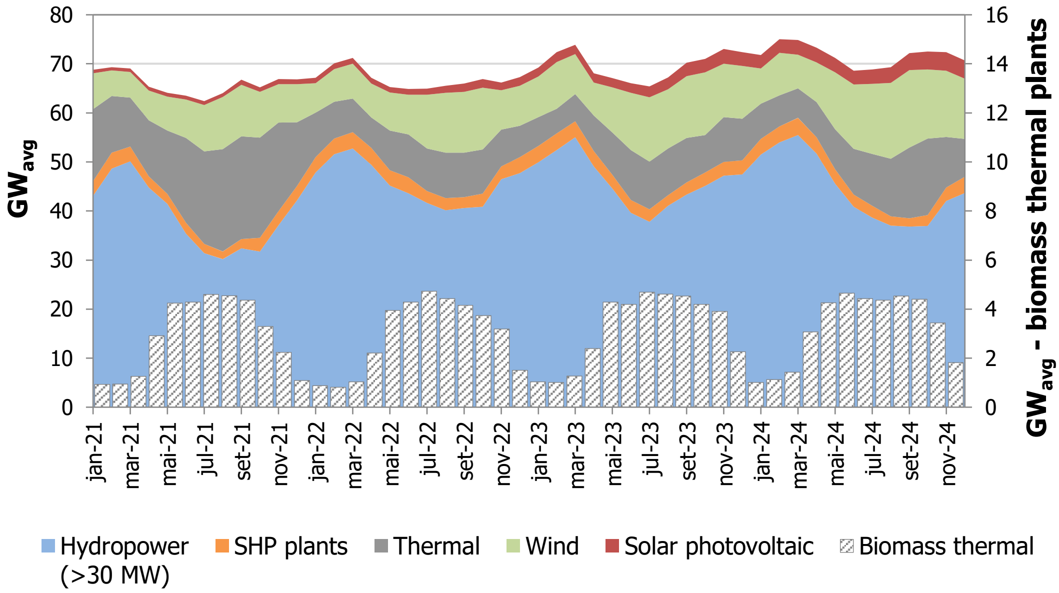
In 2024, international transactions of Brazilian ethanol occurred predominantly via maritime transport (99.7% of exports and 98.4% of imports). The Port of Santos – SP accounted for 94.7% of exported volumes, followed by Paranaguá – PR with 3.7% and Rio de Janeiro – RJ with 1.5%. The Port of São Luís – MA (59.0%) was the main entry point for imported ethanol, followed by the Port of Suape – PE (34.9%) (MDIC, 2025a).

5. Bioelectricity

Biomass thermal generation plays an key role in the national energy landscape. In 2024, the amount supplied remained stable compared to 2023. Bagasse continues to be the most used fuel for exporting energy to the National Interconnected System (SIN), accounting for 75.0%, followed by black liquor from the paper and pulp industry with 18.1%, and biogas from urban waste with 3.1%, as described in section 5.2.

In 2024, the share of energy exported from sugarcane in the national electricity matrix was 3.4%, showing a slight decrease compared to the previous year. Sugar-energy mills injected an average of 2.4 GW into the SIN, maintaining the same level as in 2023. Chart 32 presents the seasonal share of sugarcane biomass in electricity generation from 2021 to 2024, highlighting its complementarity with hydropower, as the increase in bioelectricity generation occurs during the harvest, which coincides with the dry season (CCEE, 2025).

Chart 32 – Share of sugarcane biomass in electricity generation



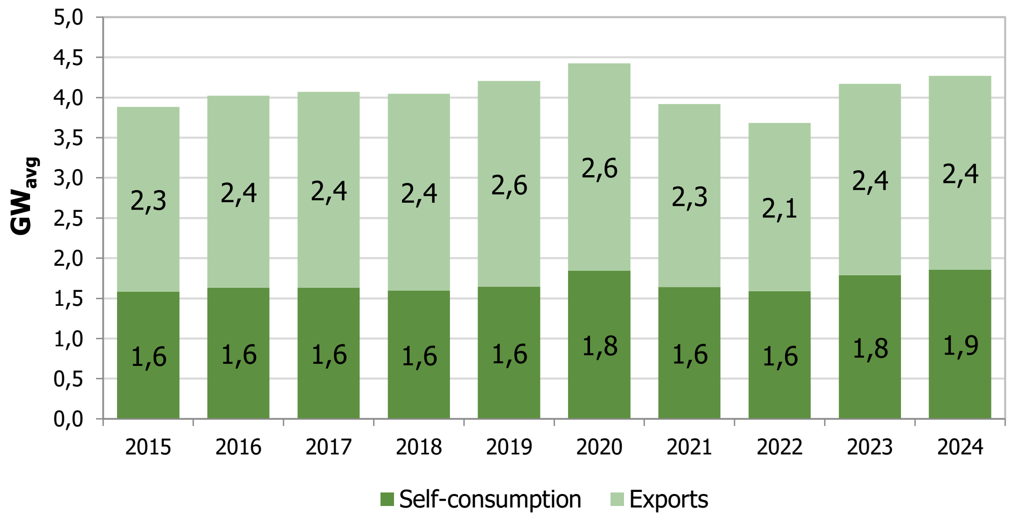
Source: EPE based on-CCEE (2024a).

5.1. Exports and power trading

In addition to energy self-sufficiency, sugarcane biomass plants are characterized by their supply of energy to the SIN[42]. According to Chart 33, electricity generation from sugarcane bagasse remained at the same level as in 2023, approaching the values observed during the 2016–2018 period, yet still slightly below the levels recorded in 2019–2020. The share allocated to self-consumption in 2024 reached the highest level of the period studied, driven by the large volume of sugarcane harvested in the 2023/2024 season, which led to increased processing at the end of the harvest for sugar production and record ethanol output.

[42] 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

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



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

Among the 337 sugarcane biomass plants operating in 2024, 266 sold electricity, seventeen more than the previous year. Of those exporting energy to the SIN, some operate exclusively in the ACL (58%) or in the ACR (4%), while the remaining (38%) sell in both contracting environments. Once again, there is a clear preference for selling the plants' energy in the ACL. As in previous years, reduced activity was observed in ACR auctions, particularly due to low distributor demand. 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, the dispatch capacity of the plants, 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 2024, sugar-energy plants held contracts amounting to 1.7 GW on average. There were small increases in biomass energy in the auctions held in 2021 and 2022. For 2024, no auctions for new energy acquisitions in the regulated market took place (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 2024, the amount of processed sugarcane decreased by 3.7%, with details provided in Chapter 1 of this publication. There was also a 1.2% increase in energy injection into the SIN, maintaining the relevance of biomass participation in the electricity matrix.

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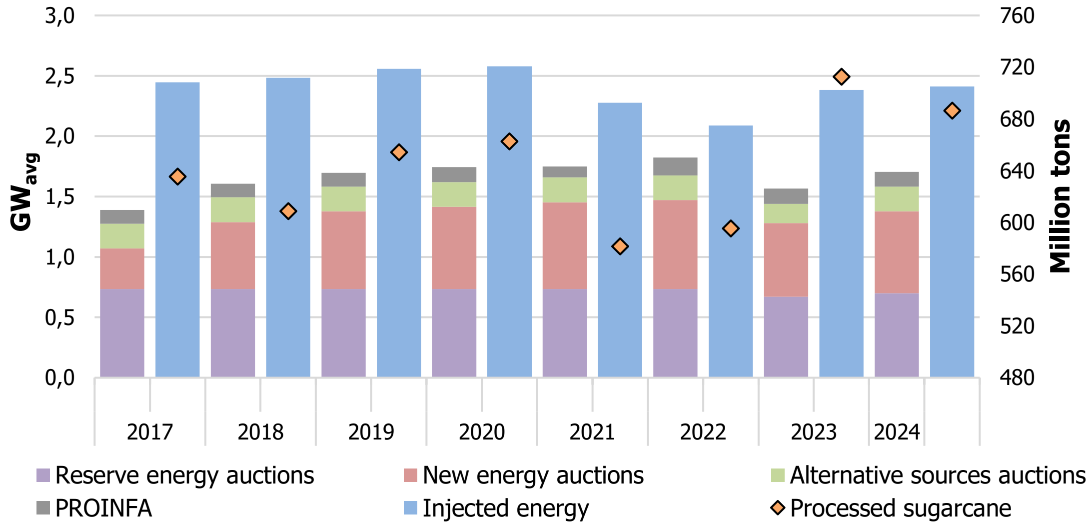
greater transparency and competition in energy commercialization. In the ACL, generation, trading, importation, exportation agents, and free consumers operate under bilateral contracts for the sale and purchase of energy, which are freely negotiated, and distributors are not permitted to acquire energy in this market. Additionally, there is the Incentive Program for Alternative Sources of Electric Energy (PROINFA), established in 2004 (CCEE, 2024a; ELETROBRÁS, 2018).

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



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

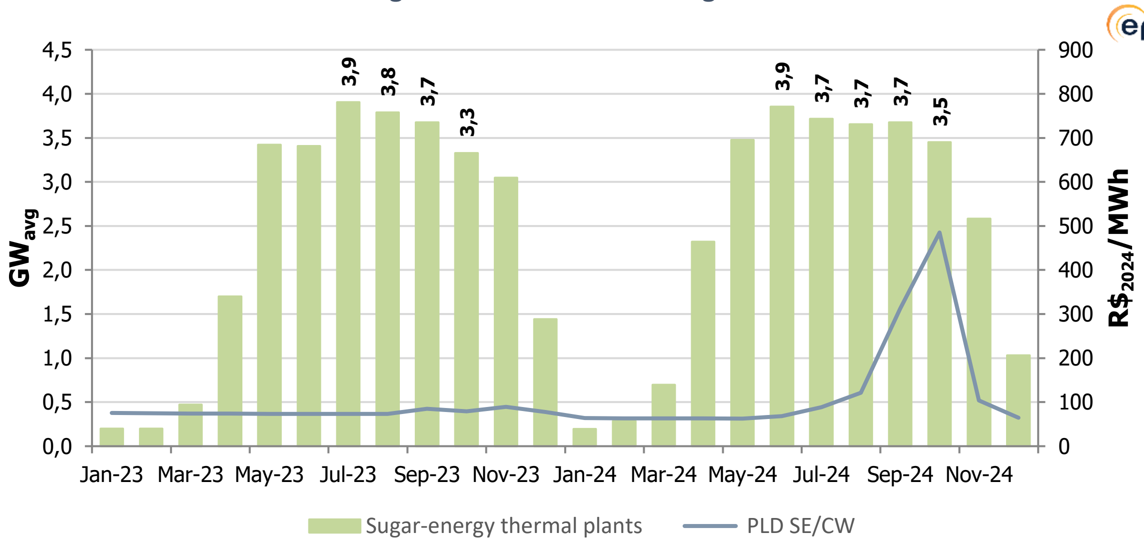
In 2024, it was possible to observe an increase in the participation of thermal power plants in meeting the load, compared to 2023 (CCEE, 2024a). Despite the increase in wind participation (16.3% of the total), the unfavorable hydrological scenario, representing about 61.8% of electricity generation, and the increase in the need for thermal dispatch during the period contributed to this result.

Chart 35 illustrates the monthly injection of energy into the SIN from sugarcane biomass thermal plants versus the PLD (Settlement Price of Differences)[43]. During the observed period, there was considerable variation in the PLD, caused by the climatic impacts that occurred throughout 2024 (such as the floods in Rio Grande do Sul that affected electricity generation and transmission, and the increase in demand due to intense and frequent heat waves) and by the increased need for dispatch from thermal plants, which have higher costs due to lower water availability impacted by reduced rainfall in key basins. The increased supply of renewable sources, such as wind and photovoltaic, was not sufficient to fully offset the reduction in hydropower supply and the increase in demand, as the intermittency of these sources requires system flexibility. At the end of 2023, ANEEL Normative Resolution No. 1.078/2023 (ANEEL, 2025) came into effect, aiming at greater transparency, more frequent updates, and more detailed dispatch and pricing systems; this resolution may have contributed to a more dynamic PLD during 2024. This movement observed in 2024 differs from that in 2023, when the PLD value did not follow the seasonality of biomass thermal generation. The values set by CCEE for the PLD in 2024 were R$716.80/MWh as the upper limit and R$61.07/MWh as the lower limit (an increase of 4.7% for the upper limit and a decrease of 11.5% for the lower limit)[44] (CCEE, 2024b).

[43] Updated weekly, this parameter aims to find the optimal balance between the present benefit of water use and the future benefit of its storage, measured in terms of the expected savings from fuel use in thermal power plants.

[44] The limit values for the PLD defined for the year 2025 were R$751.73/MWh and R$58.60/MWh, representing increases of 4.9% and decreases of 4.0%, respectively, compared to the previous year. The highest hourly PLD recorded in 2024 was R$1,470.57/MWh, which is 4.7% higher than the value registered in 2023. For 2025, the maximum hourly value for this indicator is R$1,542.23 (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).

The units had been showing a historical trend of increasing efficiency in exporting electricity per ton of cane processed, although a recent stagnation was observed. Several factors explain this trend, and the reflections of this behavior may be related to the amounts financed through BNDES funding lines. The amounts requested by the plants from this bank for bioelectricity have been low in recent years, totaling R$32.9 million in 2024, a decrease of 7.5% compared to 2023.

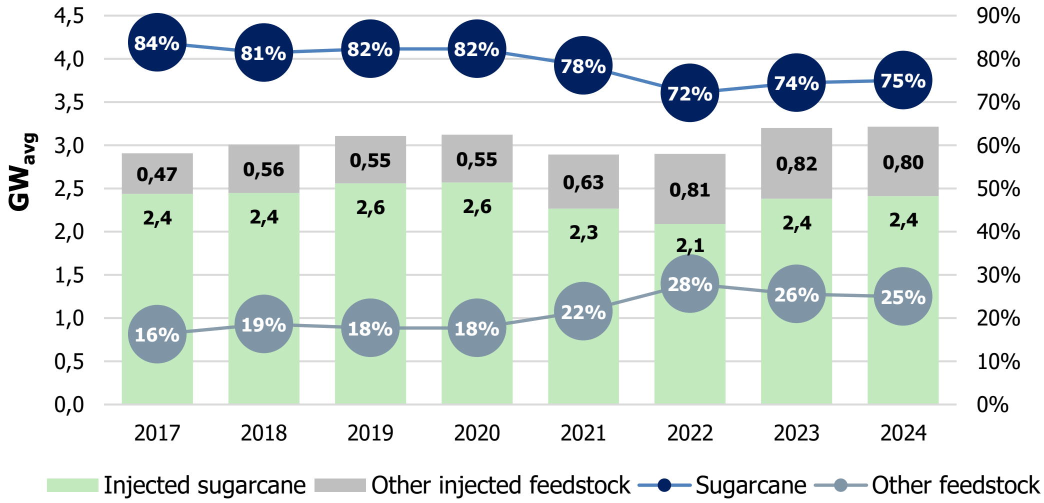
5.2. Bioelectricity from other biomasses

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 2024, in addition to the previously mentioned by-products from sugarcane, 802 MW on average were injected into the grid from projects using fuels derived from other biomass sources, whether animal or plant, showing a slight decrease of 2.2% compared to 2023.

Electricity generation from these other biomass sources (excluding sugarcane) represented 1.1% of the power matrix in 2024. Once again, black liquor accounted for the largest share (583.1 MWavg, 73%), largely driven by the growth in cellulose production over the past five years, followed by biogas (100.73 MWavg, 13.6%) and forest residues (50.2 MWavg, 6.3%). Lesser contributors include elephant grass, charcoal, rice husks, oven gas, and firewood.

In 2024, the share of these sources in the total energy exported by biomass to SIN was 25%, a decrease of 2.2% compared to the previous year. Although their contribution declined relative to 2023, approximately 3.6 GWavg have been added over the last five years, as illustrated in Chart 36.

Chart 36 – Share of other biomasses vs. sugarcane



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

Unlike sugarcane, which exhibits a well-defined seasonality and, consequently, high variation in the energy exported to the grid, generation from other biomass sources can be considered more controllable and deterministic, mainly due to the possibility of fuel storage[45]. This is an important attribute for the electricity sector, contributing to greater energy security and system reliability at a time of significant challenges and structural changes in the generation fleet.

[45] Dedicated corn ethanol plants tend to use vegetal biomass as an energy source for their ethanol production. Flex plants, which also produce sugarcane ethanol, use bagasse as their energy source (FAVA-NEVES, 2021).

6. Biodiesel

Law No. 11,097/2005 provides a broad definition of biodiesel as any fuel derived from renewable biomass for use in diesel cycle engines (BRASIL, 2005). Currently, ANP Resolution No. 920/2023 establishes the specification of the biofuel as being composed of a mixture of fatty acid esters (ANP, 2023).

In 2024, Brazil consumed 9.1 billion liters of biodiesel, a 20.9% increase compared to 2023. The mandatory biodiesel blend percentage with fossil diesel began the year at 12% by volume (B12), rose to 14% in March, and remained at this level until the end of the year (CNPE, 2023).

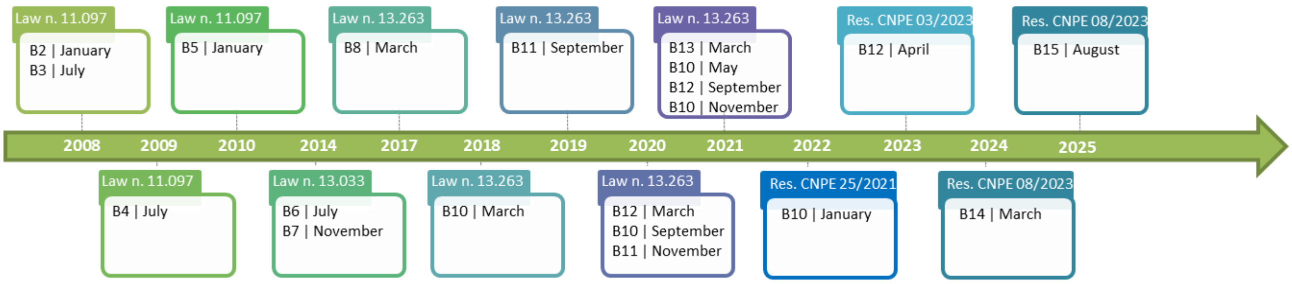
Since the inception of the National Biodiesel Production and Use Program (PNPB) in 2005, over 76.6 billion liters of this biofuel have been produced by December 2024. Comparatively, Brazil remains among the top three producers and consumers of biodiesel internationally. By December 2024, the national biodiesel sector had a total of 58 production plants, with a continued concentration in the Central-West and South regions of the country (ANP, 2025c).

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 toward higher biodiesel content. The initial value was set at 2% by volume in 2008, reaching 5% already in 2010, while the original schedule foresaw this only for 2013. In the following years, there was a gradual increase in the mandatory minimum percentages for diesel type B.

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 1, 2025. However, CNPE Resolution No. 6 of February 2025 temporarily suspended the increase to 15%, maintaining the percentage at 14%. On June 25, 2025, CNPE Resolution No. 9 set the percentage at 15% starting August 1 of that year. The evolution of mandatory biodiesel blending percentages with fossil diesel is detailed in Figure 4.

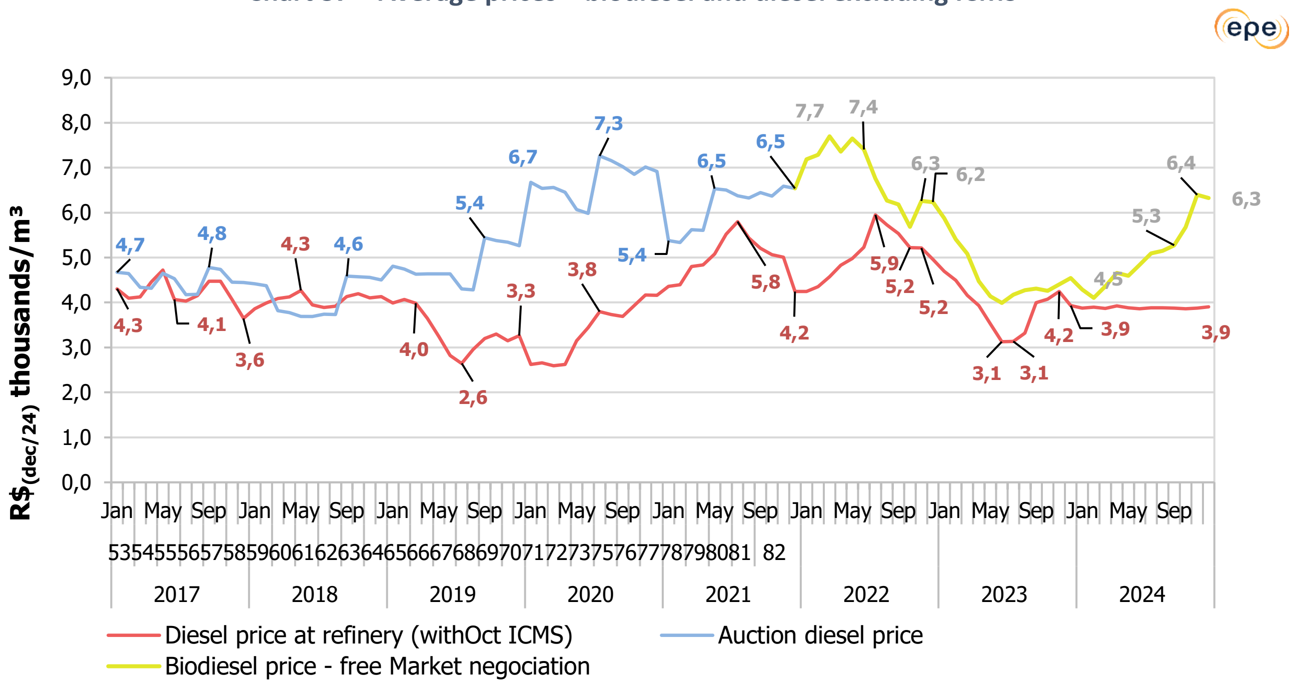
Figure 4 – Evolution of the biodiesel legal framework



Source: EPE

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, 2021a). Chart 37 presents the average prices of biodiesel and diesel type A, the latter remaining stable in 2024 in the domestic market, as well as in the international market.

Chart 37 – Average prices – biodiesel and diesel excluding ICMS



Source: EPE based on (ANP, 2024b)

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[46]. 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, 2024b). Additionally, there are initiatives to use biofuel in maritime transport by blending it with fossil fuels (BIODIESELBR, 2024c).

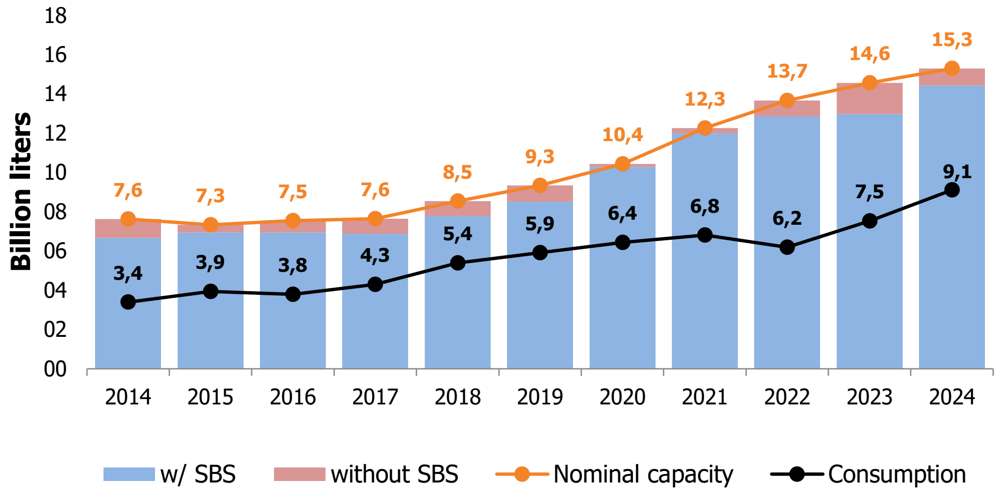
6.2. Installed capacity and regional production

According to ANP data, as of December 2024, the installed capacity was 15.3 billion liters, distributed among 58 authorized production plants, of which 55 held the Social Biofuel Seal (SBS[47]) (MDA, 2025). 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, 2025c). It is noted that in 2024, the consumption of this biofuel corresponded to 59.5% of the installed capacity in the country.

[46] 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).

[47] The SBS is a distinction granted to biodiesel-producing companies that use products from family farming in their production chain. Its purpose is to ensure income and promote social inclusion for the producing families. Biodiesel-producing companies holding the SBS benefit from access to better financing conditions with financial institutions.

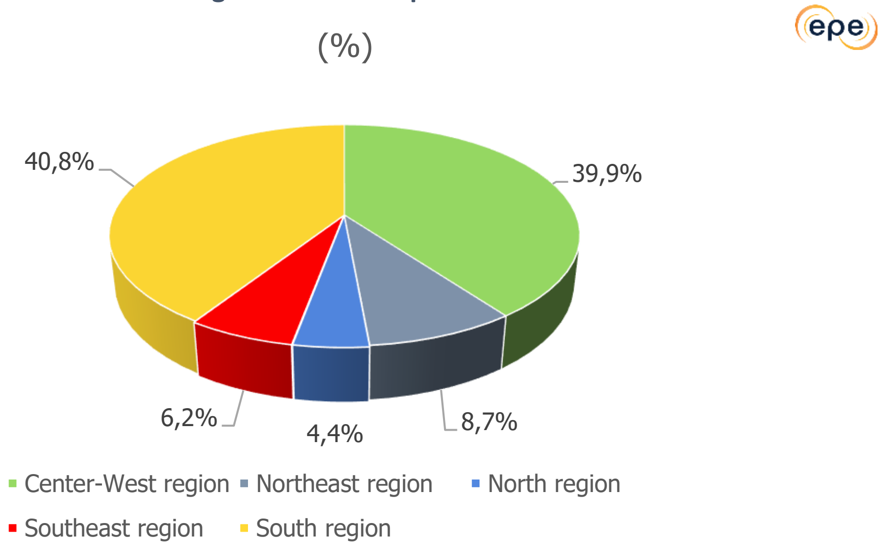
Chart 38 – Authorized nominal capacity and biodiesel consumption in 2023



Source: EPE based on (ANP, 2025c; EPE, 2024c)

The availability of major feedstocks, such as soybeans, fatty materials, and bovine tallow, in the South and Central-West 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 2024, with the highest concentration of production in the South (40.8%) and Central-West (39.9%) regions of the country.

Chart 39 – Regional biodiesel production in 2023

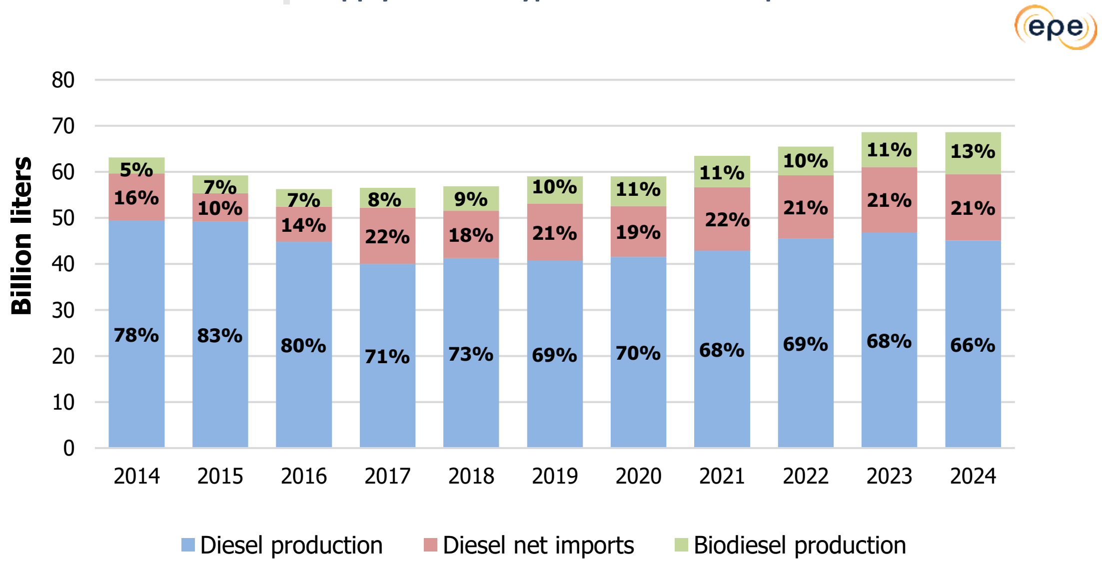


Source: EPE based on (ANP, 2025d)

The above landscape may change in the coming years due to the changes proposed by Resolution CNPE No. 03/2023 (CNPE, 2023), one of which establishes that, “as an additional criterion for maintaining the right to use the Social Biofuel Seal, each biodiesel producer must allocate a minimum percentage of the effective value destined for promotion and acquisitions within the SBS to the North, Northeast, and Semi-Arid regions: I – 10% in 2024; II – 15% in 2025; and III – 20% from 2026 onwards”. These percentages refer to the total amounts spent by each producer in the respective years.

Compared to 2023, there was a 4.0% decrease in the production of diesel type A by the national refining system and a 0.6% reduction in net imports. Furthermore, the production of biodiesel increased by 20.9% compared to the previous year, as a result of the increase in the mandatory blending percentage. 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

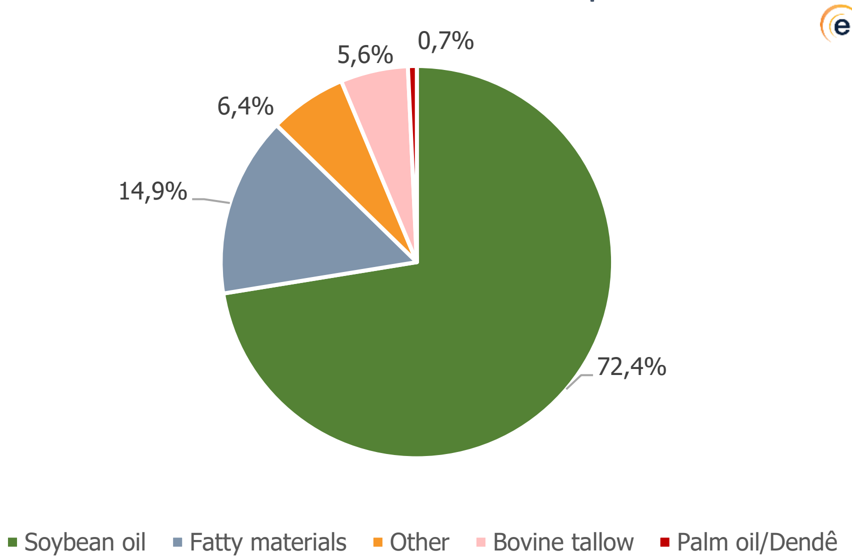


Source: EPE, based on (EPE, 2024b)

6.3. Raw materials for biodiesel

As shown in Chart 41, soybean oil was the most important feedstock for biodiesel production in 2024, totaling 7.2 billion liters (an increase of 38.5% compared to the previous year), corresponding to 72.4% of the volume produced. This was followed by “fatty materials” with a 14.9% share, while bovine tallow accounted for 5.6%. Palm oil represented 0.7%, and the category “others” summed 6.4%, including inputs such as used cooking oil, chicken fat, pork fat, corn oil, cottonseed oil, and rapeseed oil (ANP, 2025c).

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



Source: EPE based on (ANP, 2025c).

Soybean, therefore, remains the main feedstock used for biodiesel production in Brazil, with a tendency to maintain its leadership in the short and medium term. However, over the past five years, there has been a significant increase in the share of the category referred to as “Fatty Materials” in the feedstock matrix used by the sector. Currently, this category occupies the second position in terms of representativeness (ANP, 2025c; EPE, 2024c).

Information obtained from sector representative entities indicates that the classification “other fatty materials” mainly includes mixtures of soybean oil with other vegetable oils. However, a precise characterization of this fraction requires further detailing, given its significantly increasing share and the current ambiguities in its definition. Due to its growing importance, measures are needed to improve the classification and monitoring mechanisms for these feedstocks, ensuring greater transparency and accuracy in evaluating the sector’s feedstock matrix.

Considering the perspective of increasing mandatory biodiesel blending percentages in diesel, a progressive rise in demand for feedstock is expected. Although projections for soybean production are positive, there is a clear need to formulate and implement public policies that encourage diversification of the feedstock base. The inclusion of crops such as macaúba, palm oil, and other regional oilseeds is strategic to promote the socioeconomic development of different regions of the country and reduce dependence on a single feedstock.

6.3.1. Soybean harvest

Brazil’s soybean harvest was 154.4 million tons in 2024 (160.3 million in 2023), representing a 3.7% decrease compared to the previous year. Soybean oil production reached 11.3 million tons, reflecting an increase of 4.6%. Domestic processing grew by 3.0% compared to 2023 (ABIOVE, 2024).

The soybean processing capacity was 72 million tons per year, an increase of 4.8%, according to the Brazilian Association of Vegetable Oil Industries (ABIOVE, 2024). Due to 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[48]

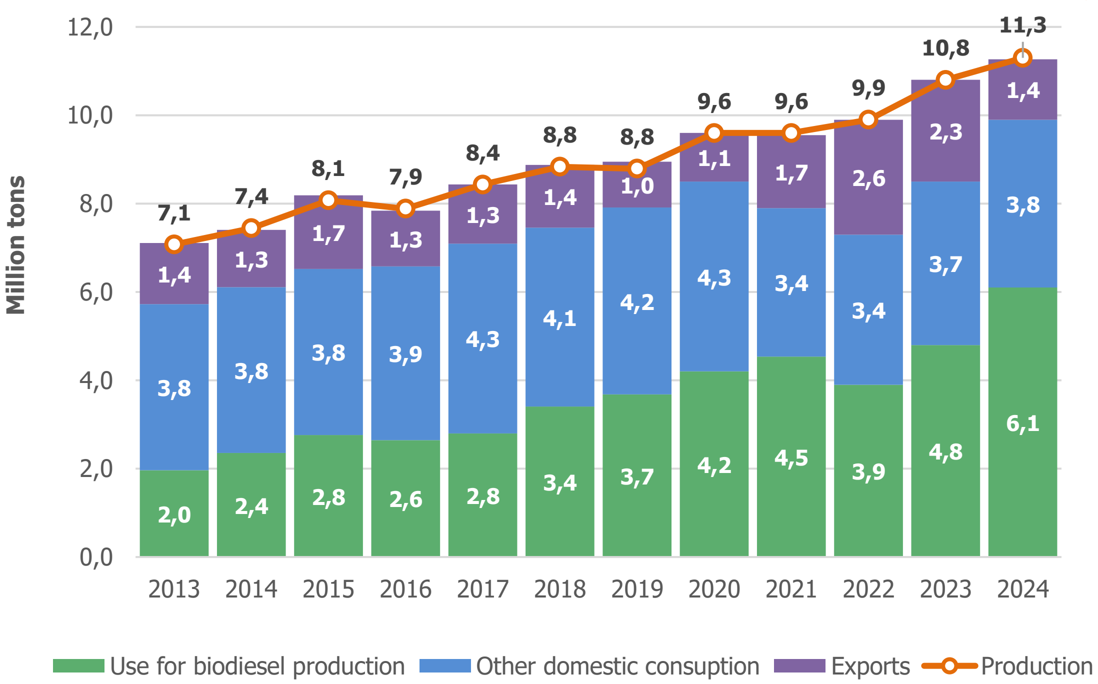
Millions tons	2023	2024	Δ % (2023-2024)
Soybean production	160,3	154,4	-3,7%
Installed soybean processing capacity	69	72,3	4,8%
Soybean grain exports	101,9	98,8	-3,0%
Processed soybeans	54,2	55,8	3,0%
Soybean meal produced	42,3	42,7	0,9%
Soybean oil produced	10,8	11,3	4,6%
Soybean oil exports	2,3	1,4	-39,1%
Soybean oil consumption for biodiesel	4,8	6,6	37,5%
Soybean oil consumption for food and other uses	3,7	3,2	-13,5%

Note: The density considered for soybean oil was 0,92 kg/l. 330 days of operation in the year were considered for the soybean processing capacity.

Source: (ABIOVE, 2024; ANP, 2025c)

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

Chart 42 – Soybean oil market



Source: EPE based on (ABIOVE, 2024)

According to ABIOVE, the mass production of soybean oil increased by 59.2% between 2013 and 2024. This growth is much lower than that intended for biodiesel production, which, in absolute terms, rose from 2.0 million to 6.1 million tons, a 205% increase over the same period. Soybean oil exports in 2024 fell by 39.1% compared to 2023, due to higher domestic use for biodiesel production (ABIOVE, 2024).

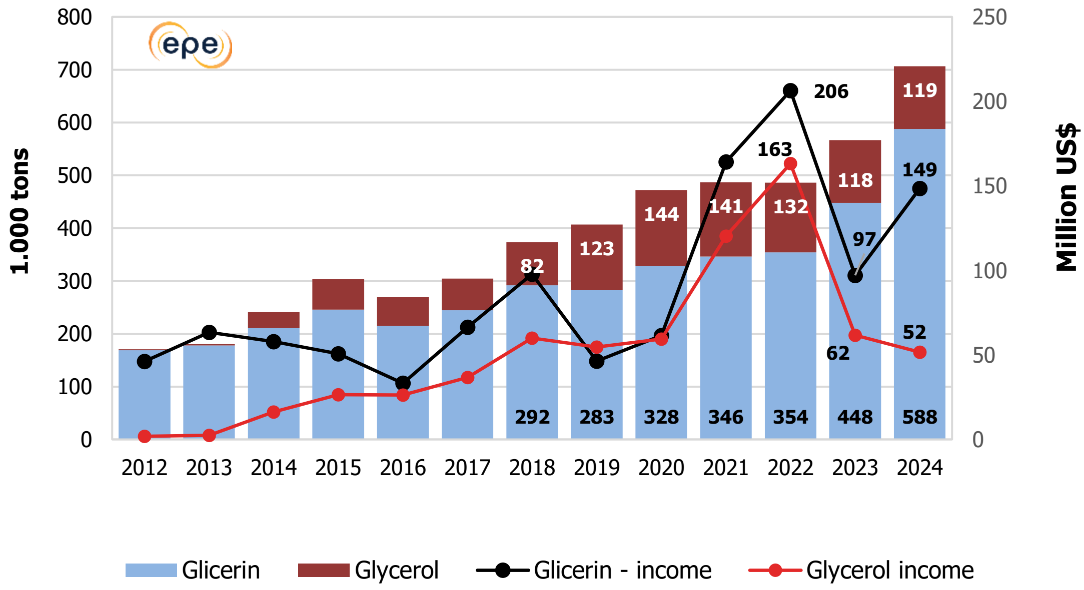
[48] The values related to domestic consumption of "soybean seeds" and other uses were not considered.

6.4. Biodiesel byproducts

Crude glycerin is a byproduct of the biodiesel production chain, representing approximately 10% by mass of the biodiesel produced. In 2024, it is estimated that 900,000 tons of crude glycerin were produced. Exports reached 598,000 tons of crude glycerin, 31% higher than in 2023. Glycerol exports totaled 119,000 tons, the same value as in 2023. Chart 43 shows the exported volumes as well as the revenue obtained from the two products: US$ 149 million for crude glycerin and US$ 52 million for glycerol.

Glycerol is a classification for refined glycerin, which commands higher 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 (ME, 2025). China remains the largest destination for exports, accounting for 87% of crude glycerin and 35% of glycerol (ME, 2025).

Chart 43 – Glycerin and glycerol exports



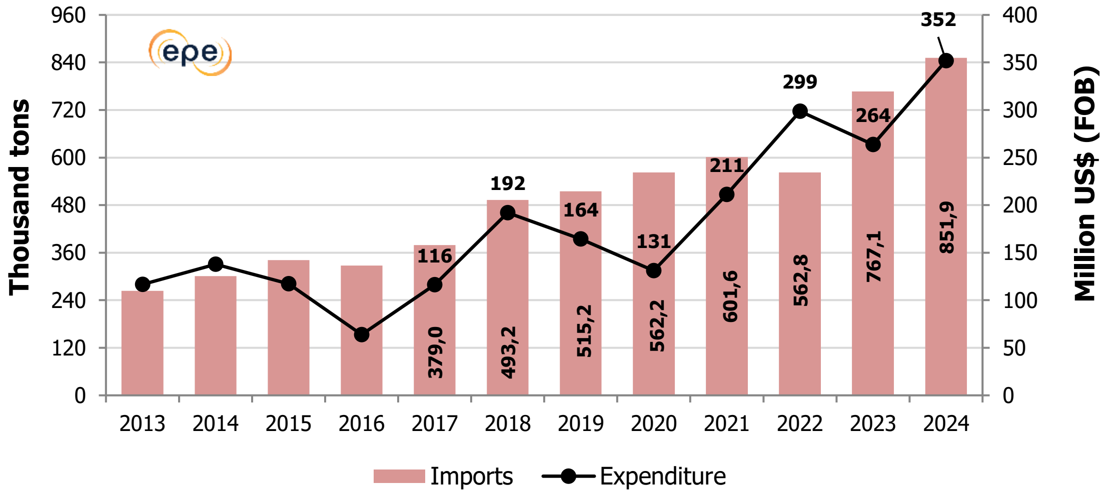
Source: (ME, 2025)

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 2024, Brazil imported 851,900 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 2024 was 11.0% higher than in 2023, with total spending amounting to US$ 352 million, 33.3% higher than in 2023 (ANP, 2025d; ME, 2025).

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, 2025d; ME, 2025).

7. Biogas and biomethane

Increasingly relevant in the national energy scenario, biogas continues to grow its share in the domestic energy supply. From 2023 to 2024, its contribution rose from 460 thousand tons of oil equivalent (toe) to 482 thousand toe, up from just 14 thousand toe in 2010 (EPE, 2025a). Positive prospects for this source gained new momentum in 2024, driven by regulatory advances and public policies, as well as signs of demand-side interest, particularly from agents seeking to decarbonize their activities. The favorable moment for the sector is particularly evident for biomethane, with a rapid increase in operating plants and several new units under construction.

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, 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 blended with this fuel in any proportion. This possibility opens a broad market for biofuels and allows its transport through pipeline networks 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 biogas produced internally in the production processes 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 the generation of credits to offset consumption, the first biogas plants appeared in 2014. By the end of 2024, there were 145 MW of installed biogas power across 545 generating units, using various raw materials – animal waste, urban waste, agroindustry, and forestry. Compared to 2023, 28 new units were added with a total capacity of 7.3 MW (ANEEL, 2025).

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 2024, according to ANEEL's Generation Information System (SIGA), biogas ended the year with 51 operating plants with registration or authorization[49], totaling 240 MW of regulated capacity. Most of this capacity, amounting to 199 MW, uses biogas from municipal solid waste as fuel (ANEEL, 2024).

7.2. Biomethane

Throughout 2024, four plants obtained ANP authorization to produce biomethane, adding 236,768 Nm³/day to the national capacity (ANP, 2025e). By the end of the year, there were ten plants authorized by the Agency[50], corresponding to a total production capacity of 656,361 Nm³/day. In the first half of 2025 (until July 31), the authorization of four new units brought the total number to fourteen, and the accumulated capacity reached 841,898 Nm³/day. Most of this capacity uses biogas derived from urban waste deposited in landfills as feedstock, as shown in Table 3.

[49] The plants registered with ANEEL for electricity generation in Brazil total 549 biogas plants covered by the compensation system and 51 not covered, with an installed capacity of 390 MW. It is worth noting that CIBiogás (CIBIOGÁS, 2024) conducts its own survey of biogas plants in the country. For the year 2024, the Center reported 1,349 electricity generation units, including plants with isolated operation. In addition to these plants and those producing biomethane, there are 178 other plants registered using biogas for thermal energy and 6 for mechanical energy.

[50] CIBiogás records (CIBIOGÁS, 2024) for 2024 indicated 54 operational biomethane plants, with 12 having ANP operation authorization, 18 in the authorization process, and 24 in non-commercial operation, producing the biofuel for self-consumption.

Table 3 - Biomethane plants with authorization to operate at ANP, RenovaBio

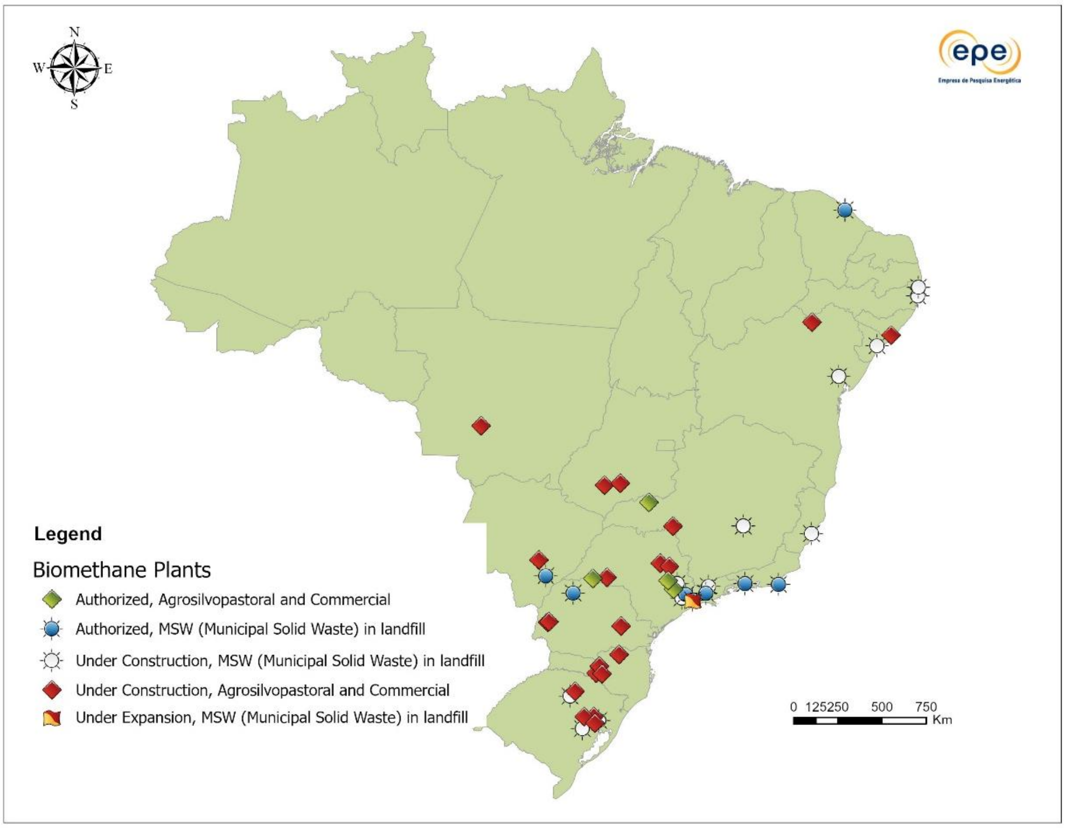
Company	City	State	Capacity [Nm³/day]	Feedstock	RenovaBio – NEEA [gCO_2eq/MJ]
COCAL ENERGIA	Narandiba	SP	27.112,8	Agroforestry and commercial	75,66
ENGEP AMBIENTAL	Jambeiro	SP	30.000	MSW in sanitary landfill	No
GÁS VERDE	Seropédica	RJ	204.000	MSW in sanitary landfill	76,73
GNR DOIS ARCOS	São Pedro da 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
RAÍZEN-GEO BIOGÁS COSTA PINTO LTDA.	PIRACICABA	SP	130.368	Agroforestry and commercial	No
ESSENCIS BIOMETANO S.A.	CAIEIRAS	SP	67.200	MSW in sanitary landfill	No
ADECOAGRO VALE DO IVINHEMA S.A.	IVINHEMA	MS	8.000	Sugar-energy and MSW in sanitary landfill	No
GEO ELÉTRICA TAMBOARA BIOENERGIA LTDA.	TAMBOARA	PR	31.200	Agroforestry and commercial	No
CRI GEO BIOGÁS S.A.	ELIAS FAUSTO	SP	23.694	Agroforestry and commercial	No
ZEG BIOGÁS AROEIRA SPE LTDA.	TUPACIGUARA	MG	16.912	Agroforestry and commercial	No
ORIZON BIOMETANO JABOATÃO DOS GUARARAPES LIMITADA	GUARARAPES	PE	108931	MSW in sanitary landfill	No
SPE CENTRAL DE TRATAMENTO INTEGRADO RESÍDUO ZERO LTDA	TRIUNFO	RS	36000	Agroforestry and commercial	No
Total (operational)			841.898		

Notes: Green marking referring to the sugar-energy plant. Status: July 2025.

Sources: (ANP, 2025e)

In July 2025, 37 plants were in the authorization process, two categorized as expansions and the remaining as new installations. If completed, these plants would add 1,413,548 Nm³/day to the national biomethane production capacity (ANP, 2025e). Figure 5 shows the biomethane production plants classified by type of authorization and feedstock.

Figure 5 - Biomethane producing plants



Source: EPE based on (ANP, 2025e)

Of the 14 plants authorized by ANP, four had valid RenovaBio certificates in July 2025, representing 42% of the production capacity. Of these certificates, one was obtained in 2021, while the other three refer to recertifications, one from 2023 and two from 2024 (ANP, 2025f).

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) of the four valid certificates is 78.35 gCO_2e/MJ. Due to production based on waste, all plants have 100% of their volume eligible for CBIO generation, a unique feature among biofuels participating in this program (ANP, 2025f). Using the average rating of 78.35 gCO_2e/MJ, it is estimated that RenovaBio could generate additional revenue of about R$ 0.25 per Nm^3 of biomethane, considering the CBIO price of R$ 88.02.[51]

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 residues of sugarcane processing and harvesting. At sugarcane mills, large-scale plants can be installed with different business models for biogas utilization, thanks to its intrinsic flexibility and the options available within the context of a mill.

Among the operating models 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.

[51] The CBIO price was assumed to be R$ 88.02, the average value recorded in 2024, and a CH_4 concentration in biomethane of 96.5%. Taxes and other producer costs were not considered.

For biomethane production, the only plant authorized by ANP in the sugar-energy sector operates connected to a dedicated pipeline, built to supply the biofuel to a region far from the integrated natural gas network. Likewise, the option of injecting biomethane into the existing grid is expected to become a reality. There is a plant awaiting operational authorization, with supply contracted to industrial units via the free market, an environment characterized by direct negotiation between producers and gas consumers. 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 is 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 gas-powered vehicles and their adaptation to the sector's operations.

7.4. Regulation and public policies

The regulatory and public policy environment related to biogas and biomethane has undergone significant advancements in recent years. The 2023 edition of this document (EPE, 2024c) revisits some of the key milestones for the sector's development, including biomethane quality resolutions established by ANP, federal measures directed at or encompassing biomethane, and state initiatives involving the role of regulatory agencies and piped gas distributors.

Between January 2024 and July 2025, the Brazilian biomethane market saw a significant increase in public calls for the acquisition of the fuel by state piped gas distributors and large institutional consumers. Notable examples include Bahiagás/Copergás (BAHIAGÁS, 2024), which received four proposals from four companies; Compagas (AEN-PR, 2023; COMPAGAS, 2024), which received fourteen proposals from ten suppliers and plans to contract up to 320,000 m³/day; and Comgás (COMGAS, 2025), whose Product 4 (biomethane) attracted sixteen proposals out of a total of twenty-two received for all products. Other relevant initiatives include the 2025 Biomethane Acquisition by SERGAS (SERGAS, 2024), the Biomethane Supply process by MSGÁS (MSGÁS, 2024), Petrobras' Public Call for Biomethane (PETROBRAS, 2025a), Gasmig's call for the Triângulo Mineiro region (GASMIG, 2025), the joint Necta/Sulgás/Compagas call (NECTA, 2025), and the BRT Metropolitan Goiânia tender (CMTC, 2025). Also noteworthy is the Public Call Notice by ES Gás (ES GÁS, 2024), originally aimed at natural gas procurement, but with an express clause allowing the acceptance of biomethane proposals, with supply scheduled to start on January 1, 2025.

At the federal level, in terms of taxation, there has been significant adoption by producers of the Special Regime of Incentives for Infrastructure Development (REIDI), which exempts them from PIS and COFINS on revenues arising from certain acquisitions related to the execution of infrastructure projects. Since the opening of incentives for biomethane production, at least 24 projects have obtained approval, reducing the amount of initial investment or investment for expansion and improvements (MME, 2022). Table 4 shows the segmentation by state of the new production capacity, highlighting the projects that have joined REIDI.

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

REIDI	Capacity [Nm³/dia]		
	Eligible	Not identified	Total
AL		60.000	60.000
BA	76.400		76.400
ES	25.000		25.000
GO	21.620		21.620
MG	108.000	10.800	118.800
MS		110.101	110.101
MT	27.600		27.600
PE	153.760		153.760
PR	36.000	56.196	92.196
RS	142.000	58.456	200.456
SC	47.440	40.160	87.600
SE		60.000	60.000
SP	279.840	153.960	433.800
Total	**917.660**	**549.673**	**1.467.333**

Source: (MME, 2025)(ANP, 2025f)

In terms of financing, the sector continues to benefit from favorable conditions. Biogas projects in the sugar-energy sector have been able to secure funding from the Climate Fund through BNDES.

Under the Fuel of the Future Law, the National Program for Decarbonization of Natural Gas Producers and Importers and Incentives for Biomethane was established, creating the Biomethane Guarantee of Origin Certificate (CGOB). This certificate provides traceability backed by the volume of biomethane produced and commercialized by the biofuel producer and is issued by an origin certifying agent accredited by ANP. The biomethane incentive program aims to promote its production and consumption, in addition to biogas, through projects related to their respective production chains. The Law also establishes that CNPE will define the annual target for GHG emission reductions in the commercialized natural gas market, which will take effect on January 1, 2026, starting at 1% and not exceeding 10%. Compliance with the GHG reduction obligation will be demonstrated through the purchase or use of biomethane and the annual registration of CGOB acquisitions.

Decree No. 12,153/2024 establishes the National Integrated Plan for Natural Gas and Biomethane Infrastructure (PNIIGB) (EPE, 2025a), aiming to promote a strategy for the development of supply, demand, and infrastructure for natural gas and biomethane in the country. The PNIIGB will cover natural gas gathering, processing, storage, and transportation facilities, as well as distribution via compressed natural gas (CNG) and liquefied natural gas (LNG), and the facilities for biomethane production and subsequent transport.

8. International biofuels market

The international biofuels landscape is of great importance for Brazil, as the country is one of the main participants in this scenario, with a large volume of production, domestic demand, and international trade.

In 2024, global ethanol fuel production reached 122 billion liters, an 8.9% increase compared to 2023 (112 billion liters). The two main market players, Brazil and the United States of America, continued to hold a high share, accounting for 81% of global biofuel production (RFA, 2025).

In the global biofuels trade, Brazil has remained prominent since 2003, the year flex-fuel vehicles were launched in the country, which encouraged sugarcane ethanol production to levels that currently place Brazil as the second-largest biofuel producer in the world (behind only the United States), while also creating conditions for it to become a major biofuel exporter. More recently, the country has also become a global power in biodiesel production, ranking among the top three producers over the last three years. Biodiesel production has been driven by PNPB policies, and virtually all biodiesel produced is destined for domestic consumption.

Brazil is the second-largest global exporter of biofuels (ethanol), exporting 1.9 billion liters in 2024—a decrease of 26.9% compared to 2023 (Chart 45). The main destinations for exported ethanol were South Korea (804.4 million liters – 41.4%), the United States (319.5 million liters – 16.5%), and the Netherlands (152.8 million liters – 7.9%) (MDIC, 2025a).

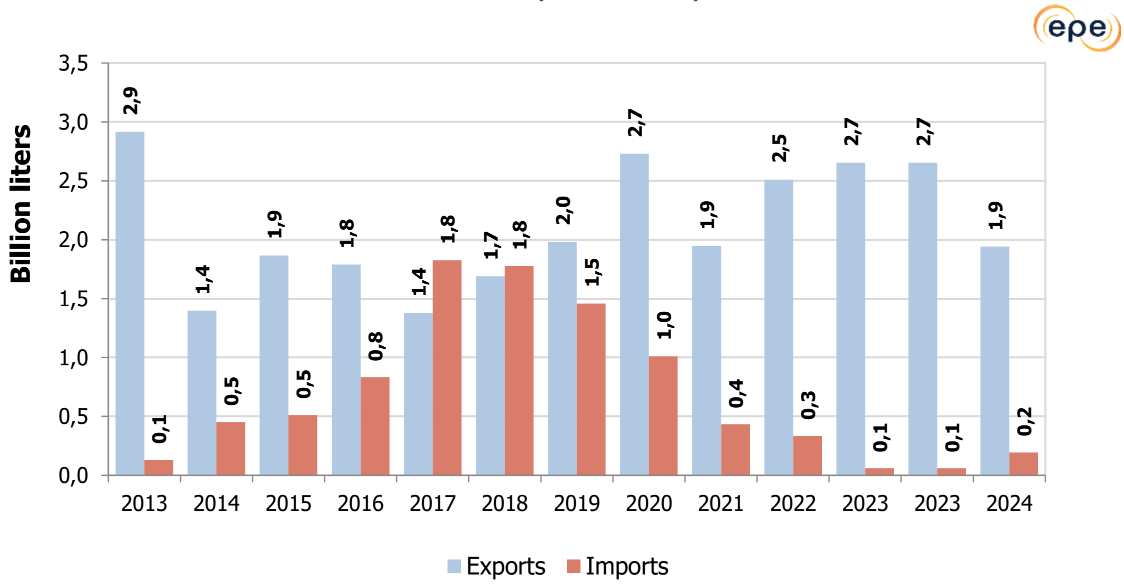
The United States was the main importer of Brazilian biofuel from 2003 to 2020, being surpassed by South Korea in the last four years. Nevertheless, the U.S. still represents a market for Brazilian ethanol due to American policies promoting the use of renewable fuels and GHG mitigation, Notebly the EISA[52], which recognizes sugarcane ethanol as an advanced biofuel and allows its domestic use to meet the corresponding portion of biofuel under the annual consumption requirement of the RFS[53].

Despite the large volume of ethanol produced domestically, Brazil also imports small, but not insignificant, volumes of ethanol. These help meet domestic demand during the months of low production, mainly in the North and Northeast regions. Historically, the United States has been its main supplier, with a share of imported volumes above 95% between 2010 and 2020. However, in the last four years, its share has decreased, while countries in the Mercosur bloc, such as Paraguay and Argentina, have grown in importance. For example, in 2024, 0.2 billion liters of ethanol were imported (227% more than in 2023), of which 56% originated from the United States, 31% from Paraguay, and 10% from Argentina (MDIC, 2025a).

[52] Energy Independence and Security Act of 2007, a law that promotes energy independence and security through various policies for energy efficiency, GHG mitigation, and the use of renewable sources, with emphasis on the Renewable Fuels Standard (RFS), which sets annual volumes of renewable fuels to be consumed in the transportation sector (USA, 2007).

[53] In addition to the U.S. national legislation, Brazilian ethanol also benefits from state-level regulations, such as California's Low Carbon Fuel Standard (LCFS), whose program favors sugar-energy mills that meet the biofuel production lifecycle requirements (COMGAS, 2025).

Chart 45 – Brazilian ethanol exports and imports – 2013 to 2024



Source: EPE based on (MDIC, 2025a).

Imported volumes are currently subject to an 18% *ad valorem* tariff. There is a long history of adjustments to the import rate (see Box I) due to various policies aimed at supporting domestic demand, particularly during periods of internal supply issues.

In addition to ethanol and biodiesel, Brazil seeks to diversify its renewable matrix with new bioenergy sources, which represent potential markets where the country could become a major global player, particularly in sustainable aviation fuel (SAF), as presented in section 9.4 (BRASIL, 2024a).

Brazilian ethanol-producing companies have been seeking new opportunities in the international market, given the demand for sustainable aviation fuel (SAF) production from ethanol in other countries. Through the International Sustainability and Carbon Certification (ISCC) [54], 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 expanding ethanol exports in the coming years (NOVACANA, 2024a).

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 made to promote the exchange of experiences on the topic and the development of the international market, as well as to discuss joint initiatives aimed at accelerating the decarbonization of the aviation sector (MRE, 2024). Japan has set one of the most ambitious targets for SAF implementation, aiming for 10% use in international flights at its airports by 2030.

[54] 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).

During the G20 meeting in September 2023 in New Delhi, the Global Biofuels Alliance (GBA) was established, comprising 32 countries and 14 international organizations. This initiative, led by India, which held the G20 presidency at the time, aims to position biofuels as a key solution for the global energy transition, contributing to the socioeconomic growth of the participating nations. The GBA seeks to advance the development and implementation of biofuels worldwide, bringing together the largest consumers and producers in this initiative. Additionally, the GBA intends to make a significant impact by accelerating the adoption of biofuels in countries with existing targets and encouraging countries without biofuel targets to establish them. Brazil presided over the G20 in 2024, when the first in-person GBA meeting took place in April, with the participation of 12 nations and 9 international organizations (GLOBAL BIOFUELS ALLIANCE, 2025).

The following section presents a brief analysis is provided of the participation of various countries and blocs in the international biofuels landscape, focusing on those of relative importance to the Brazilian market in this sector.

8.1. United States

The United States was one of the first countries to establish robust policies for energy security and sustainability, with particular attention to the promotion and use of biofuels. The main U.S. legislation in this regard is the Energy Independence and Security Act of 2007 (EISA), which establishes the Renewable Fuel Standard (RFS) – a standard of mandatory annual biofuel volumes to be consumed in blends with fossil fuel in the transportation sector. Each year, the Environmental Protection Agency (EPA) is responsible for updating the RFS volumes, adjusting them from the original values established in EISA. On June 21, 2023, the agency defined the latest change to the RFS volumes for 2023, 2024, and 2025 (EPA, 2023) [55].

Table 5 – RFS biofuel volumes[56] 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 addition to the EISA, the United States has several laws promoting renewable energy and sustainability. One of the most Notable is the Inflation Reduction Act (IRA), enacted in August 2022, aimed at reducing the federal budget deficit and, in turn, curbing inflation through a broad set of measures to lower healthcare costs, finance federal revenue, and address climate change (USA, 2022). In the latter area, the law represents the largest investment in the country's history, allocating approximately USD 400 billion in direct funding for clean energy projects. Of this total, USD 23.4 billion is directed to transportation improvements and electric vehicle projects (McKinsey & Company, 2022). Through the IRA, the United States aims to reduce carbon emissions by at least 50% by 2030, with the ambition of reaching a net-zero economy by 2050. The law also sets a target for zero-emission electricity generation by 2035.

[55] On June 13, 2025, the EPA announced a proposed revision of the RFS volumes for 2025, 2026, and 2027. In this proposal, the final volumes for 2027 are as follows: cellulosic biofuels, 5.17 billion liters; biomass-based diesel, 36 billion liters; advanced biofuels, 36 billion liters; and total renewable fuels, 93 billion liters (EPA, 2025).

[56] Renewable fuels = corn ethanol + advanced fuels. Advanced fuels = cellulosic biofuels + biomass-based diesel + other advanced fuels.

In 2024 the United States produced 61.4 billion liters of fuel ethanol (an increase of 3.8% compared to 2022) and consumed 54 billion liters the same as the previous year (EIA 2025a). The country consumes fuel ethanol mainly in the form of the E10 blend and also in the E15 blend which is approved for vehicles manufactured since 2001 and in the E85 blend which is permitted only for flex fuel vehicles (EERE 2025a).

Of the total ethanol produced annually in the United States the volume not consumed domestically is directed to the foreign market in which the country is the world's largest exporter. In 2024 U.S. ethanol exports totaled 7.2 billion liters an increase of 33.2% compared to 2023. The main destinations were Canada (36%) the United Kingdom (13%) and India (10%). Unlike previous years Brazil accounted for less than 1.0% of U.S. exports with only 0.5 million liters imported (EIA 2025b) a fact associated with the reinstatement of the 18% tariff on volumes imported by Brazil in 2024. Regarding imports the United States imported 0.4 billion liters from Brazil a decrease of 7% compared to 2022 (MDIC 2025a).

The United States uses biodiesel primarily in the B20 blend[57]. 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 2025a).

A recent and highly relevant fact for current and future trade relations between Brazil and the United States was the application of tariffs on Brazilian products by the U.S. government which came into effect on August 7 of this year. The official White House document lists several imported products while exempting others of strategic importance among which biofuels are included. As a result Brazilian fuel ethanol will not be taxed[58] (U.S. 2025). Among the justifications the White House argued that there was a trade deficit with the United States which is unfounded since Brazil has had an average deficit of six billion dollars[59] over the past five years (MDIC 2025a). The second argument referred to national sovereignty indicating a lack of knowledge of the Federal Constitution of 1988 which establishes the independence and harmony among the three branches of government[60], the Legislative the Executive and the Judiciary (BRAZIL 1988).

Finally, it should be noted that on August 13, 2025, the Brazilian government launched a support plan that provides R$30 billion in credit to be made available through a provisional measure called MP Brasil Soberano. In this way the government responds to the unilateral action of the United States by strengthening the national export financing and insurance system aiming to increase the country's international competitiveness and reduce its vulnerability to this type of imposition in the future (BRAZIL 2025c).

[57] B20 blends and lower concentrations can be used in conventional engines without modifications, provided they meet the ASTM D7467 specifications. Higher blends, up to B100, are much less used due to the lack of regulatory incentives and the requirement for specialized equipment both for storage and in the engines themselves (EERE, 2025b).

[58] It is noteworthy that, initially, there is no intention to change Brazil's ethanol import rate, whose main supplier is the United States (JOTA, 2025).

[59] FOB values are considered for expenditure (shipping and import insurance costs are disregarded).

[60] The 1988 Federal Constitution establishes in Article 2 the independence and harmony among the Union's Powers: Legislative, Executive, and Judiciary (immutable clause, see Article 60, §4, III: "No proposal for amendment tending to abolish: [...] the separation of Powers shall be subject to deliberation") (BRASIL, 1988).

8.2. European Union

The European Union has established strong legislation on energy security and sustainability with particular attention to the impact of renewable energy generation and use either by prioritizing the utilization of advanced energy sources that are not food-based or through specific criteria designed to inhibit greenhouse gas (GHG) emissions from indirect land use[61]. The bloc's main legislation is Directive 2018/2418 whose latest revision of November 2018 introduced strict measures on the use of clean energy sources to reinforce the commitment to achieving a climate-neutral society that is with net-zero GHG emissions (EC 2023) in addition to facilitating the entry of new technologies such as renewable hydrogen and electricity in different sectors.

The bloc adopted a set of climate and energy targets for 2030, 2040, and 2050, known as the European Green Deal, whose ultimate goal is to achieve a climate-neutral society by 2050, that is, with net-zero GHG emissions. For 2030, the climate objectives include at least a 55% reduction in GHG emissions compared to 1990 levels, a final energy consumption of no more than 763 Mtoe (with a maximum primary energy consumption of 992.5 Mtoe), and a renewable energy share in final consumption of at least 42.5%. For 2040, the bloc aims to reach a mitigation level of at least 90% (EC, 2025).

The most recent data from the Statistical Office of the European Union – EUROSTAT – indicate that in 2023 the European Union (27 countries) produced 15.7 billion liters of biodiesel and 4.4 million liters of ethanol domestically, while its internal consumption amounted to 18.0 billion and 6.1 million, respectively (EUROSTAT, 2025). The bloc had already achieved the renewable share and GHG mitigation targets set for 2020, partly due to the Covid-19 containment efforts, which imposed restrictions on movement.

8.3. Other countries

In 2024, China produced and consumed 4.5 billion liters of ethanol (RFA, 2025). 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, 2024a). 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.

In 2024, Indonesia remained one of the world's major biodiesel producers, with a production of 13.2 billion liters. The consumption of this biofuel in the country is driven by a blending mandate, which increased from 30% to 35% (B35) in February 2023 (USDA, 2024b) and rose to B40 in January 2025. The Indonesian government plans to increase the blend to B50 from 2026, based on the sector's performance in meeting current demand (REUTERS, 2025). The Indonesian biodiesel program is funded by taxes on palm oil exports (USDA, 2024b).

South Korea imported 290 million liters from Brazil in 2024 (MDIC, 2025a). The country uses ethanol exclusively in industry and the food sector; however, the government is studying its use as a fuel due to environmental benefits, improvements in air quality in large cities, and energy security.

[61] Indirect land-use criteria take into account GHG emissions resulting from the displacement of food crops to native areas, with destruction of the original vegetation and consequent reduction of atmospheric carbon retention.

Em 2024, India became the third-largest producer of ethanol in the world, with 6.2 billion liters (RFA, 2025). The main Indian legislation for the sector, the National Biofuels Policy of 2018, aims to reduce dependence on fossil fuels and promote sustainable development through the support of biofuels. The law establishes the Ethanol Blending Program, which encourages biofuel production from various feedstocks such as sugarcane juice, molasses, corn, and others. The law also sets blending targets, currently at E20 since March 2025. Regarding biodiesel, the country has established a B5 target for 2030 (USDA, 2024c).

9. Innovations and emerging perspectives for biofuels

Brazil has established its potential to be a key global player in sustainable energy production, particularly in biofuels. The current political and regulatory framework reinforces the country's commitment to positioning itself as a leading power in the sector, combining the availability of natural resources, technical expertise, and environmental responsibility.

The sanctioning of the Fuel of the Future Law in October 2024 established important guidelines for the biofuels sector, establishing a new regulatory framework that encourages investment and promotes the production and use of biofuels in Brazil.

Additionally, in January 2025, the Federal Government enacted Law No. 15,103/2025, which establishes the Energy Transition Acceleration Program (PATEN). This initiative aims to expand access to credit for sustainable projects, promote the modernization of the national energy infrastructure, and strengthen Brazil's commitment to sustainable development and global leadership in decarbonization (AGÊNCIA GOV, 2025). PATEN allows companies with receivables from the Union to use these assets to finance projects related to the energy transition. The program also created the Green Fund, managed by BNDES, which will serve as the main instrument for financing the planned actions. Among the areas covered, particular emphasis is given to the development of sustainable fuels and the energy recovery of solid waste (AGÊNCIA GOV, 2025).

Based on this new legal framework and the current national context, this chapter aims to identify and analyze issues related to the main emerging biofuels with potential for large-scale production in Brazil in the short and medium term, considering regulatory incentives, technological feasibility, and trends in the global energy market.

9.1. New inputs for biofuel production

Considering that the use of biofuels is an alternative to fossil fuels for decarbonizing the transport sector, it is essential to expand and diversify the raw materials used in their production, to sustain the increase in supply in the face of the growing demand expected in the coming years (GOV.BR, 2024).

In this context, the CNPE established a Working Group (WG) to explore ways to diversify raw materials and include family farmers and smallholders in biofuel production. Created in the first quarter of 2025, the WG will develop guidelines and regulatory proposals aimed at reducing dependence on specific inputs, providing greater stability and sustainability to the market, and promoting regional development, particularly in the North, Northeast, and Semi-Arid regions, where biofuel production potential is high but still underutilized (GOV.BR, 2025a, 2025b).

Public policies emerging from this work are expected to continue measures already addressed in other initiatives, such as the National Policy for Regional Development, which aims to stimulate the strengthening and economic diversification of strategic productive chains for regional development, with an emphasis on income generation and the promotion of sustainability, especially in areas with high concentrations of agricultural or mineral commodity production (BRASIL, 2025d).

In this perspective, the project studying the use of agave in the semi-arid Northeast for the production of ethanol (1G and 2G), biogas, and other products, maximizing the use of plant components, stands out. Launched in 2022, the Brazilian Agave Development Program - BRAVE involves private sector participation, academic institutions, and a research institute (REVISTA LIDE, 2024).

Planned to last five years, the project began in 2022 and is advancing simultaneously across three study fronts: biological solutions to increase agave crop productivity (BRAVE Bio), new mechanization technologies for planting and harvesting (BRAVE Mec), and processing of different species (BRAVE Ind), in addition to the construction of pilot plants to validate process scaling (BRASILAGRO, 2022).

In the oilseed-based biofuel value chain, the challenge is to move beyond soy and include other crops such as macaúba, oil palm, and babassu. Respecting their specific cultivation and utilization characteristics, this diversification addresses desirable attributes for biorefineries by stimulating the local economy and promoting regional development (GOV.BR, 2025c).

From this perspective, in early 2025, the first industrial extraction of macaúba oil for fuels took place in Brazil. The previous lab-scale technology was implemented in an agro-industrial innovation center in Montes Claros (MG), established by a private energy-sector initiative. The same technological center also hosted the planting of the first 85 macaúba seedlings for studies on its domestication, aiming to establish it as a strategic crop for decarbonization and large-scale bioenergy production, with a focus on future SAF and green diesel production (EIXOS, 2025a, 2025b).

9.2. Second-generation ethanol

Second-generation ethanol (E2G) is produced from lignocellulosic feedstocks. Currently, there are three commercially operating E2G plants in Brazil: GranBio's Bioflex-I in São Miguel dos Campos (AL), with a nominal capacity of 30 million liters per year, and two Raízen plants, one in Piracicaba (SP) with a nominal capacity of 42 million liters per year, and another in Guariba (SP) with a nominal capacity of 82 million liters per year (GRANBIO, 2025; RAÍZEN, 2024).

Bioflex-I has not produced lignocellulosic ethanol since the 2021/22 harvest, despite GranBio being authorized to export the fuel to the European Union (NOVACANA, 2024b, 2024c). In 2025, the company announced the start of expansion works for the industrial complex, renamed Exygen I, focusing mainly on installing vinasse-to-biomethane production units. GranBio indicates that its plans for E2G production remain conditional on an increase in its selling price (NOVACANA, 2025b; TEIXEIRA JUNIOR, 2025).

Raízen announced the end of commercial E2G production at its Piracicaba plant, converting it into a unit dedicated to testing and future developments (NOVACANA, 2025a). The company continues production at its Guariba plant and has two new units with the same nominal capacity of 82 million liters currently in the commissioning phase, expected to start production in 2025, located in Barra Bonita (SP) and Valparaíso (SP) (NOVACANA, 2024g). Additionally, Raízen has three more projects under construction and one new project to be initiated, as shown in Table 6. The company intends to market lignocellulosic ethanol internationally, where it already holds long-term contracts.

Table 6 – Raízen's ESG units and projects*

Related plant	City	Status	Annual capacity (millions of liters)	Operation start
Barra	Barra Bonita	Comissioning	82	2025/26
Univalem	Valparaíso	Comissioning	82	2025/26
Gasa	Andradina	Under construction	82	2025/26
Vale do Rosário	Morro Agudo	Under construction	82	2025/26
Tarumã	Tarumã	Under construction	82	2026/27
Caarapó	Caarapó	Project	-	2026/27

Source: (NOVACANA, 2024d, 2024f, 2024g; RAÍZEN, 2023a)

*Note Raízen had also indicated a project for the implementation of an E2G unit at the Santa Elisa plant, in Sertãozinho (SP). However, the company recently announced the discontinuation of operations at this unit (NOVACANA, 2025c).

Abroad, E2G projects from other companies have not been able to reach commercial production, and many plants have halted operations with no forecast for resumption.

9.3. Co-processed diesel (C type Diesel)

Co-processing is the industrial process in which renewable feedstocks, such as vegetable oils or organic residues, are integrated into the production of fossil fuels at refineries, resulting in a blended product. It occurs in already operational refining units without the need for major modifications, allowing refineries to use their established processes without significant investment in new facilities, offering advantages in terms of flexibility and scalability. Vegetable oils can be directly integrated into these units, while organic residues require additional pre-treatment steps, such as pyrolysis. The outcome is the production of fuels with renewable energy content and a lower carbon footprint, either for use as diesel (specified as C type Diesel in ANP Resolution No. 968) (ANP, 2024c) or as aviation kerosene. In the latter case, the resulting kerosene is treated as sustainable aviation fuel under the current technical framework and will therefore be discussed in the next section of this market analysis. C type Diesel is considered similar to Diesel Oil for blending purposes, and thus the addition of biodiesel to C type Diesel is mandatory for sale at fuel stations.

In commercial nomenclature, C type Diesel is referred to as Diesel RX by Petrobras, where the "X" refers to the percentage of vegetable oil used in the original blend (e.g., Diesel R5 contains 5% vegetable oil mixed with mineral diesel), showing that Diesel RX is a fuel resulting from the co-processing of a percentage of vegetable oil with mineral diesel. This co-processing occurs in the hydroprocessing (catalytic hydrogenation) or fluid catalytic cracking (FCC) stages at refineries. In the second half of 2024, Petrobras announced sales of 10 million liters of Diesel R5 per month and its first direct sale to a final consumer, Vale (AGÊNCIA PETROBRAS, 2024; MELHOR INVESTIMENTO, 2024).

In Petrobras' 2025–2029 Strategic Plan, a significant expansion of co-processing capacity is projected, with an expected increase of up to 11 times the current capacity, contingent on the advancement of applicable regulations. The target is to reach an installed production capacity of 63 thousand barrels per day of Diesel R5 through co-processing (PETROBRAS, 2024). The estimated distribution of this capacity across Petrobras' refineries is detailed in Table 7.

Table 7 - Estimated distribution of installed co-processing capacity for R5 Diesel by Petrobras refinery

Refinery	Participation (%)	Estimated capacity (mbpd)
REPAR	46%	29
RPBC	14%	8,8
REPLAN	9%	5,7
REGAP	21%	13,2
REDUC	10%	6,3

Source: (PETROBRAS, 2024)

9.4. Sustainable Aviation Fuel (SAF) and Green Diesel

Sustainable Aviation Fuels (SAF) are low-carbon fuels designed to decarbonize the aviation sector, a requirement increasingly mandated for airlines. For international flights, the United Nations' International Civil Aviation Organization (ICAO) established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The scheme sets a target for carbon-neutral growth in the aviation industry from 2020 to 2035, based on 85% of 2019 emission levels, with the ultimate goal of achieving net-zero emissions by 2050 (ICAO, 2024). Under CORSIA, SAF are defined as renewable or waste-derived fuels that comply with the sustainability criteria set by the organization (ICAO, 2023). At the national level, Brazil's Fuel of the Future Law created the National Sustainable Aviation Fuel Program (ProBioQAV), requiring airlines to gradually reduce their GHG emissions through the use of SAF on domestic flights. Beginning in 2027, airlines will be required to achieve a 1% reduction in GHG emissions, with the target increasing progressively to reach a 10% reduction by 2037.

Green diesel is a renewable fuel composed of a mixture of hydrocarbons with a chemical composition similar to that of fossil diesel, making it a fully drop-in fuel. HVO refers to green diesel produced through the hydrotreatment of oils and fats. The Future Fuel Law also established the National Green Diesel Program (PNDV) to promote research, production, and commercialization of the product. The law provides that the CNPE may establish a mandatory minimum volumetric share of the renewable fuel of up to 3% in diesel B, depending on supply, price conditions, and the international competitiveness of green diesel. The council's decision on such volumetric mandate must occur annually following the implementation of the law. ACELEN Renewables has also announced an investment of R$ 12 billion over the next 10 years to convert the Mataripe Refinery into a biorefinery, with the goal of producing 1 billion liters/year of renewable fuels (SAF and green diesel) by 2035. The project includes fostering the cultivation and development of macaúba as a feedstock and will use soybeans in the initial years of operation (ACELEN, 2024).

At the international level, sustainable aviation fuel production pathways must be certified by the American Society for Testing and Materials (ASTM), which sets the specifications for aviation fuels containing renewable content in its ASTM D7566 and ASTM D1655 standards (ASTM, 2022, 2023). In this context, renewable fractions must necessarily be blended with fossil-based fractions to obtain fuels authorized for use, with well-defined maximum blending limits. In Brazil, the same pathways are authorized by ANP through Resolution No. 856 (ANP, 2021b). Green diesel, in turn, is produced through similar pathways, authorized in Brazil under ANP Resolution No. 842 (ANP, 2021c). Table 8 summarizes these pathways. In this regard, the following feedstocks have the most promising potential for use in Brazil in the production of SAF and/or green diesel (in alphabetical order): babassu, corn, eucalyptus (forest resources), macaúba, palm, soybean, and sugarcane.

Table 8 - Technological routes certified and authorized by ANP to produce green diesel and/or aviation fuel with renewable content

Production route	Production allowed by ANP	Feedstock	Maximum Mix in Final Fuel (aviation)
HEFA	Diesel Verde (HVO) e SAF	Fats and oils	50% *
FT	Green Diesel and SAF	Agricultural and forest residues, wood, and solid waste	50%
A-FT	SAF	Agricultural and forest residues, wood, and solid waste	50%
ATJ	Green Diesel and SAF	Renewable raw materials (sugarcane, corn, or forest residues)	50%
SIP	Green Diesel and SAF	Sugars	10%
CHJ	Green Diesel and SAF	Fats and oils	50%
Co-processing with petroleum	SAF **	Fats and oils, FT hydrocarbon	5%

*Note 1: The maximum mix of the HEFA route is 10% in the case of hydrocarbons produced by the microalgae *Botryococcus braunii.*

**Note 2: The co-processing of vegetable oils and animal fats with fossil feedstock for the production of diesel is also possible, but results in a different product from Green Diesel, as specified in the section "Diesel co-processed with vegetable oils (C type Diesel)".

Source: (ANP, 2021c, 2021b)

Worldwide, SAF production has been increasing, with approximately 45 active production facilities currently in operation (ICAO, 2025). The HEFA-SPK pathway is the dominant one at present, although the ATJ-SPK pathway also already has commercial plants in operation (DOE, 2024; IATA, 2024). However, industrial and economic challenges still remain for SAF and green diesel to become competitive with fossil-based jet fuel and diesel. In Brazil, driven by CORSIA and the Future Fuel Law, some companies have been moving forward with the construction of SAF production plants, usually with associated HVO production. In addition, Vibra recently announced the start of SAF commercialization (imported) at Galeão Airport in Rio de Janeiro (VIBRA, 2025). The distributor supplied the fuel for the first flight in Brazil using sustainable aviation fuel, blended with fossil jet fuel at a 10% share. The aircraft, operated by Líder Aviação, transported workers to an offshore platform (ISTOÉ, 2025).

Petrobras has announced its intention to diversify its strategies for biofuel production, with a focus on developing dedicated plants for the manufacture of Sustainable Aviation Fuel (SAF) and HVO-type green diesel. In its 2025–2029 Strategic Plan, the company detailed projects at different stages of maturity, totaling an estimated production capacity of 44 thousand barrels per day (mbpd) of SAF and HVO. Among the projects in the implementation pipeline, the highlight is the installation of a HEFA plant at the Presidente Bernardes Refinery (RPBC) in Cubatão (SP), scheduled to start up in 2029, with a total production capacity of 15 thousand barrels per day (PETROBRAS, 2024). Among the projects under evaluation are the development of dedicated plants at the Boaventura Complex, located in Rio de Janeiro, with a planned capacity of 19 thousand barrels per day via HEFA technology, and a unit at the Paulínia Refinery (REPLAN) in São Paulo (SP), with a capacity of 10 mbpd via ATJ (Alcohol-to-Jet) technology. Other companies have also announced plans to invest in SAF production via the ATJ pathway (NOVACANA, 2024e; PETROBRAS, 2024; RAÍZEN, 2023b).

Petrobras also announced to the media its intention to begin marketing, still in 2025, aviation fuels resulting from the co-processing of 1.2% vegetable oils with fossil feedstock (CHIAPPINI, 2025).

The Riograndense Petroleum Refinery (RPR), located in Rio Grande (RS), entered a partnership in 2024 with the Danish company Topsoe to implement the technology that will enable the advancement of its full conversion project into a biorefinery. The project includes the production of SAF and HVO through the HEFA pathway and is expected to begin operations in the first half of 2028, with an estimated capacity of 15 thousand barrels per day (REFINARIA DE PETRÓLEO RIOGRANDENSE, 2024).

ACELEN Renewables announced an additional investment of R$ 12 billion over the next 10 years to convert the Mataripe Refinery into a biorefinery for the production of 1 billion liters/year of renewable fuels (SAF and green diesel) by 2035. The company's project includes promoting the cultivation and development of macaúba as a feedstock and will use soybean oil in the initial years of operation for the HEFA-SPK pathway (ACELEN, 2024).

Oil Group recently had a project approved by the National Council of Export Processing Zones (CZPE) for the installation of a modular fuel refinery in Bacabeira (MA). The company announced an investment of R$ 8 billion, to be carried out in three modular stages, with the goal of reaching a production capacity of up to 50 thousand barrels per day. The company did not disclose the feedstock to be used but indicated that it aims at the joint production of SAF; renewable, conventional, and marine diesel; and gasoline, which suggests a likely co-processing operation (CHIAPPINI, 2024).

Another announced project involves the construction of a biorefinery for the joint production of SAF and HVO from palm oil via the HEFA-SPK pathway. The unit will be located in Manaus and will have a production capacity of 500 thousand m³/year, to be shared between both fuels. The reported cost was about R$ 2.5 billion (BRASIL BIOFUELS, 2022). Although the project was initially expected to start operations in 2025, no effective mobilization has been observed so far to match this timeline.

An important aspect to highlight is the public call launched in August 2024 by BNDES and FINEP, aimed at supporting business plans focused on the production of sustainable fuels for the aviation and maritime sectors. With an estimated budget allocation of up to R$ 6 billion, the initiative sought to foster cooperation among companies and to drive the first national ventures dedicated to this value chain. This action is part of the New Industry Brazil industrial policy, which sets guidelines for the country's reindustrialization with an emphasis on innovation, energy transition, and technological development (BNDES, 2024a).

There are also some projects in Brazil aimed at producing SAF through the FT-SPK pathway, using different feedstocks for the generation of the syngas required in the process. These projects are of smaller scale and are supported by the Brazil–Germany Cooperation for Sustainable Development.

The SENAI Institute for Innovation in Renewable Energies has installed a pilot plant in Natal (RN) for the conversion of glycerin into SAF, with a production capacity of 5 liters of synthetic oil per day (G1 RN, 2023).

At the Itaipu Binacional power plant facilities in Paraná, CIBiogás inaugurated a pilot plant focused on the conversion of biogas supplemented with electrolytic hydrogen into SAF, with a production capacity of 6 kg of synthetic oil per day (CIBIOGAS, 2024).

Finally, Geo Biogás & Carbon, in partnership with Copersucar, plans to begin operating in 2025 a demonstration plant that converts sugarcane residues into aviation fuels, with the goal of advancing the technology for future scaling. This project, financed by FINEP, is expected to supply 270 thousand liters of SAF per year (MACHADO, 2024).

In addition to the announced projects, two political initiatives in Brazil in 2024 stand out for their focus on organizing and consolidating the Sustainable Aviation Fuel (SAF) market:

1) **Conexão SAF** – Launched in June 2024 by ANAC, in partnership with ANP, Conexão SAF is an informal forum that brings together representatives from the public and private sectors with the goal of identifying and developing proposals to enable the decarbonization of national aviation through the use of SAF. With more than 100 participants, the forum seeks to establish a continuous and structured space for dialogue, aimed at overcoming technical, regulatory, tax, production, and logistical challenges related to the production and consumption of SAF in the country (CONEXÃO SAF, 2024);

2) **CNPE Resolution No. 10/2024** – Published in August 2024, this resolution created a working group within the scope of CNPE to formulate guidelines and measures for the development of domestic markets for marine fuels, aviation fuels, and liquefied petroleum gas. It is expected that, as activities progress, concrete proposals will be presented for the regulation and certification of these biofuels (CNPE, 2024a).

Given the complexity of the subject, coordination through these multisectoral forums represents an important step in structuring the Brazilian sustainable fuels market, both for the aviation and maritime sectors.

9.5. Sustainable Marine Fuels

The maritime sector is responsible for approximately 3% of global greenhouse gas (GHG) emissions, which puts pressure on it to adopt low-carbon solutions. The International Maritime Organization (IMO) significantly updated its decarbonization targets for the international shipping sector in July 2023, when it adopted the IMO Revised Strategy on Greenhouse Gases (GHG). This strategy sets ambitious goals to achieve net-zero emissions in the sector by 2050, through intermediate milestones, such as reducing annual GHG emissions by 30% in 2030 and by 80% in 2040, relative to the 2008 baseline year. These targets can be achieved through further improvements in the energy efficiency of new ships and the adoption of zero- or near-zero-GHG technologies and fuels over their life cycle (DGRM, 2023).

More recently, significant amendments aimed at reducing greenhouse gas (GHG) emissions and protecting the environment in the maritime sector were discussed at the 83rd session of the IMO Marine Environment Protection Committee (MEPC 83), held from April 7 to 11, 2025. Among these, the IMO Net-Zero Framework stands out, proposing a new regulatory structure in Annex VI of the MARPOL convention, setting vessel fuel intensity targets based on their GHG emissions (GFI). Ships with a GFI above the established limits will be required to purchase Remediation Units (RUs), while those using fuels with GHG intensity below these limits may receive financial incentives. The measure will come into force on January 1, 2028, and the funds collected will be allocated to the IMO Net-Zero Fund to support innovation, research, and energy transition initiatives (IMO, 2025).

The use of biofuels to reduce GHG emissions in international maritime transport has been actively discussed in IMO negotiations. In this context, Brazil has gained prominence by demonstrating the potential of these products for decarbonization, including the possibility of achieving negative emissions by 2050 (EPE, 2024d). Some national initiatives advancing in this direction are highlighted below.

Over the past year, Petrobras has advanced its project to reconcile its focus on oil and gas with the pursuit of portfolio diversification into low-carbon businesses and announced the first shipments of the VLS B24 product, a Very Low Sulfur maritime fuel containing 24% biodiesel. Compared to 100% fossil bunker fuel, VLS B24 can reduce greenhouse gas emissions by approximately 20%, considering the full life cycle of the product and depending on the feedstock used for biodiesel production, according to the company (MARCELINO, 2024). Still available only on demand, the renewable-content bunker was blended at Transpetro's Rio Grande Terminal (RS) and used second-generation biodiesel, i.e., obtained from agro-industrial residues. In January 2025, Petrobras obtained ISCC EU RED certification for VLS B24, one of the market's most recognized certifications for the traceability and calculation of greenhouse gas emissions from sustainable feedstocks and bioproducts, consolidating a process that began with product testing at the end of 2022 (REVISTA O&G BR, 2025). Additionally, fueling operations with VLS B24 were carried out in Singapore on a Transpetro-chartered vessel and on a bulk carrier chartered by Vale (PETROBRAS, 2025a, 2025b).

In February 2025, Vibra and Svitzer began operating the first pilot project in Brazil for the use of blends of marine diesel (MD) with biodiesel in vessels at the Port of Santos (SP). After more than two years of testing, Vibra, the fuel distributor, will supply Svitzer tugboats with blends containing varying biodiesel content, starting with low percentages and gradually increasing up to 30% as the project progresses. The project is pioneering in the country and the first to offer marine diesel with ISCC EU certification (BIODIESELBR, 2025; TIMES BRASIL, 2025).

At the same time, the first fueling with HVO-type green diesel (Hydrotreated Vegetable Oil) in the Brazilian maritime sector was carried out in early 2025. Conducted in March at the Port of Açu with prior approval from ANP, the fuel was imported by Efen and used in Wilson Sons tugboats as a replacement for marine diesel. The purpose of the test is to assess efficiency, maintenance impacts, and environmental performance, as replacing marine diesel with HVO can reduce CO_2-equivalent emissions by more than 80% and does not require modifications to vessel engines (PORTOS E NAVIOS, 2025c).

In addition, Vast, responsible for the operational infrastructure of the Açu Liquid Terminal (TLA), plans to transform the site into a hub for various liquid products such as ethanol, lubricants, and light fuels. The port also hosts projects involving green hydrogen, ammonia, and synthetic fuels from CO_2 (PORTOS E NAVIOS, 2025c, 2025d). Reinforcing this positioning, Vast signed a Memorandum of Understanding (MoU) with Be8 to promote the use of low-carbon fuels, especially biodiesel (PORTOS E NAVIOS, 2025b).

Another significant MoU was signed between Brazil and Norway in February 2025 to create a sustainable maritime logistics corridor, aiming to contribute to global climate targets by reducing GHG emissions through the use of low- or zero-carbon fuels in ships operating along the route established between the two countries (PORTOS E NAVIOS, 2025a).

Finally, another important step to advance energy transition initiatives in Brazil's maritime sector was the joint public call launched by FINEP and BNDES to select business proposals focused on the development and implementation of biorefineries, with an investment of R$ 6 billion (50% from each institution) to foster the low-carbon fuels industry (GUIA MARÍTIMO, 2024). Launched in the second half of 2024, the call received 43 proposals primarily focused on aviation fuel production and 33 proposals for maritime fuels, totaling 76 submitted projects (BNDES, 2024c).

9.6. Biohydrogen

Promulgated in August 2024, Law No. 14,948 established the National Low-Carbon Hydrogen Policy, creating an important regulatory framework through programs such as the Special Incentive Regime for Low-Carbon Hydrogen Production (Rehidro) and the Low-Carbon Hydrogen Development Program (PHBC). The Ministry of Mines and Energy (MME) aims to introduce and promote hydrogen in Brazil's energy matrix and make it available for other uses, such as fertilizer production (MME, 2021). By 2030, MME has set a goal to position Brazil as the most competitive low-carbon hydrogen producer in the world, and by 2035, to consolidate low-carbon hydrogen hubs. According to its estimates, the country has the technical potential to produce 1.8 gigatons of hydrogen per year at a lower cost (MME, 2023).

Low-Carbon Hydrogen has been legally defined as hydrogen with emissions equal to or below 7 $kgCO_2eq/kgH_2$ over its life cycle, regardless of the production pathway adopted. In this context, biohydrogen stands out for typically presenting carbon intensities below this threshold and can benefit from the established regulatory incentives. Biohydrogen is defined as hydrogen produced from biomass, either through gasification of solid resources (e.g., sugarcane bagasse, wood chips, etc.), reforming of liquid or gaseous biofuels (e.g., ethanol or biomethane), or any other emerging processes (EPE, 2025b).

Bill No. 725/2022 (which is still under consideration in the Senate as of the publication date of this market analysis) establishes that, by 2032, a minimum of 5% hydrogen should be added to the gas pipeline network, rising to 10% by 2050. Within these percentages, 60% must be sustainable hydrogen by 2032 - sourced from energy such as solar, wind, biomass, biogas, and hydro. From 2050 onward, this share is expected to reach 80% (SENADO FEDERAL, 2022).

Biohydrogen stands out as an alternative to the electrolytic production route, as it relies on abundant and diverse resources available in Brazil. In recent years, a gap has been observed worldwide between the hydrogen investment announced and that actually implemented in the electrolysis segment, indicating a challenge for the sector to meet expectations initially set by markets and governments (ODENWELLER; UECKERDT, 2025). In this context, biohydrogen may represent an opportunity to expand the supply of low-carbon hydrogen through alternative technologies.

Currently, the main initiatives for hydrogen production from biomass in Brazil focus on reforming pathways, as presented below.

Biomethane and/or biogas reforming is used for biohydrogen production in some projects. In 2022, Geo Biogas & Tech, in partnership with the Federal University of Technology – Paraná (UTFPR), announced the production of hydrogen from biomethane obtained through dry catalytic reforming of biogas, a product of vinasse biodigestion (NOVACANA, 2022). Hydrogen derived from biogas reforming is also produced in pilot initiatives for SAF production via the FT-SPK pathway, presented in Section 9.4. In these cases, however, the gas is consumed directly in the process and does not constitute the final product.

Ethanol reforming for hydrogen production is highlighted in a pilot project developed at the University of São Paulo (USP) in partnership with Shell, Hytron, Raízen, and SENAI CETIQT. The reformer installed on the university campus produces 100 kilograms of hydrogen per day, which is used to fuel three urban buses and two cars (SHELL, 2025). Other Noteble initiatives in the automotive sector include partnerships between universities and automakers to carry out research projects aimed at converting ethanol into hydrogen in situ in vehicles, currently at early stages of development (ZAPAROLLI, 2023).

One of the projects selected in the Hydrogen Hubs for Industrial Decarbonization public call, whose results were released at the end of 2024, involves the potential for hydrogen production from sugarcane biomass. This Petrobras initiative envisions a low-carbon hydrogen hub, initially in the state of São Paulo, due to the large availability of biomass in the region and the fact that the company already operates four refineries in the state that could potentially consume the feedstock (EIXOS, 2025c).

In theoretical terms, the potential for biohydrogen production in Brazil is significant, given the volume of biomass available in the country. It is estimated that up to 26.7 million tons per year of hydrogen could be produced solely from the reforming of biogas generated from urban and agricultural residues by 2031 (EPE, 2023). There is also potential for solid biomass gasification routes and ethanol steam reforming, among others.

9.7. Bio-CCS / BECCS

Geological carbon capture and storage consist of a set of technologies that promotes the permanent storage of carbon dioxide (CO_2) with the objective of contributing to the mitigation of GHG emissions. Applied to biogenic carbon, that is, carbon originating from renewable biological sources, it can generate systems with negative emissions by promoting the removal of carbon from the atmosphere.

In the biofuel industry, sugar fermentation producing ethanol and the purification of biogas to biomethane are two processes that stand out for their potential to be associated with CO_2 capture. Ethanol and biomethane production generate CO_2 in high purity, offering opportunities for biogenic carbon capture at relatively lower costs when compared to streams with low CO_2 concentration, such as post-combustion gases.

The Fuel of the Future Law established the regulatory framework for this chain and designated ANP as the regulatory body, responsible for granting authorization for capture activities for storage, transport, and geological storage of carbon dioxide in Brazil.

In the law creating PATEN, another advancement was observed for the CO_2 capture and geological storage chain. The chain appears as one of the priority sectors for project financing support, along with biofuels and other mitigation solutions.

Between 2024 and early 2025, there were announcements of progress in the BioCCS project from CO_2 produced by the FS Bioenergia corn ethanol plant in Lucas do Rio Verde, Mato Grosso (MT). For example, a public hearing was held as part of the environmental licensing process of the project with the State Secretariat for the Environment of MT. The project plans the injection of 423 thousand tons per year of CO_2 at more than one thousand meters underground within the plant area, after transport of 300 meters through high-pressure pipelines. The estimated investment in July 2024 was 460 million reais (FS; GREEN AGROFLORESTAL, 2024), with financing of 170 million from FINEP being disclosed (CARDIAL, 2025).

Besides FS's project, UISA reported investing 9.3 million reais “in studies and data collection for the future implementation of the BECCS project” (UISA, 2024).

9.8. Synthetic biofuels

Also included in the final text of the Fuel of the Future Law, synthetic fuels are drop-in fuels produced through electrochemical, thermal, and/or catalytic conversion of natural feedstocks. Synthetic biofuels, in turn, are produced from biomass, either via gasification or reforming processes, as described below. Each individual step in these processes has relatively high technological maturity. However, the integration of the steps and their resulting streams still exhibits a lower level of maturity, requiring further advances to enable industrial-scale application (IEA BIOENERGY, 2025).

Gasification is a process that converts solid biomass - such as woody resources (e.g., wood chips) or agricultural and agro-industrial residues (e.g., straw, bagasse, or black liquor) - into synthesis gas, a gaseous mixture primarily composed of hydrogen and carbon monoxide (CO). This mixture can then be converted into various synthetic biofuels through operations such as Fischer-Tropsch synthesis, which produces so-called "synthetic crude," capable of being refined into synthetic biogasoline, FT diesel, biojet fuel (SAF), and maritime biofuels; methanol synthesis, generating biomethanol that can be used as a biofuel; or gas treatment for the production of high-purity hydrogen, subsequently converted into bioammonia, a potential biofuel or chemical feedstock, including for fertilizer production.

Reforming, on the other hand, is a thermochemical operation that converts liquid or gaseous feedstocks into synthesis gas. From this product, the same routes described above can be applied for synthetic fuel production. Steam reforming of fossil-derived methane is a well-established operation used in fossil syngas production and can be directly extended to the use of biomethane as feedstock. The process can also be applied to ethanol, glycerol, and other bioenergy-related molecules.

Some pilot projects have been implemented in Brazil for the development of processes for synthetic biofuel production, particularly those highlighted for the FT-SPK pathway in Section 9.4.

Additionally, biomass can serve as a carbon source for the production of synthetic electrofuels, which are generated by combining a CO_2-rich stream with an electrolytic hydrogen stream. In this context, Eletrobras and Suzano recently signed a Memorandum of Understanding to develop processes for synthetic fuel production using CO_2 generated at the paper and pulp company's production facility (SUZANO, 2024). Moreover, Petrobras announced a project to build an e-methanol plant in Pernambuco, using green hydrogen and biogenic CO_2 from ethanol plants or landfills, in partnership with European Energy (ROSA, 2024).

10. Assessment of greenhouse gas emissions avoided by bioenergy

The greenhouse gas (GHG) emissions profile in Brazil presents characteristics that differ from the global average. While in most countries the energy sector is the main 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 net GHG emissions. According to the most recent MCTI report (MCTI, 2022), 70% of the estimated emissions in 2022 were due to land use changes and agricultural activity. In the same year, the energy sector accounted for approximately 21% of emissions, an increase of 7% compared to the values recorded in 2020. Within the energy sector, the transport category was the most representative, corresponding to 52% of emissions (MCTI, 2024).

Although the energy sector is not the main contributor to national GHG emissions, efforts must also be made to drive the energy transition with a focus on ensuring sustainability, energy access, and energy security. Brazil has several comparative advantages in this process, mainly due to its abundant renewable energy resources, both for electricity generation and for the production of lower-carbon fuels. By leveraging these opportunities, the energy transition has the potential to catalyze technological and industrial development, as well as to promote job creation and income generation for the population.

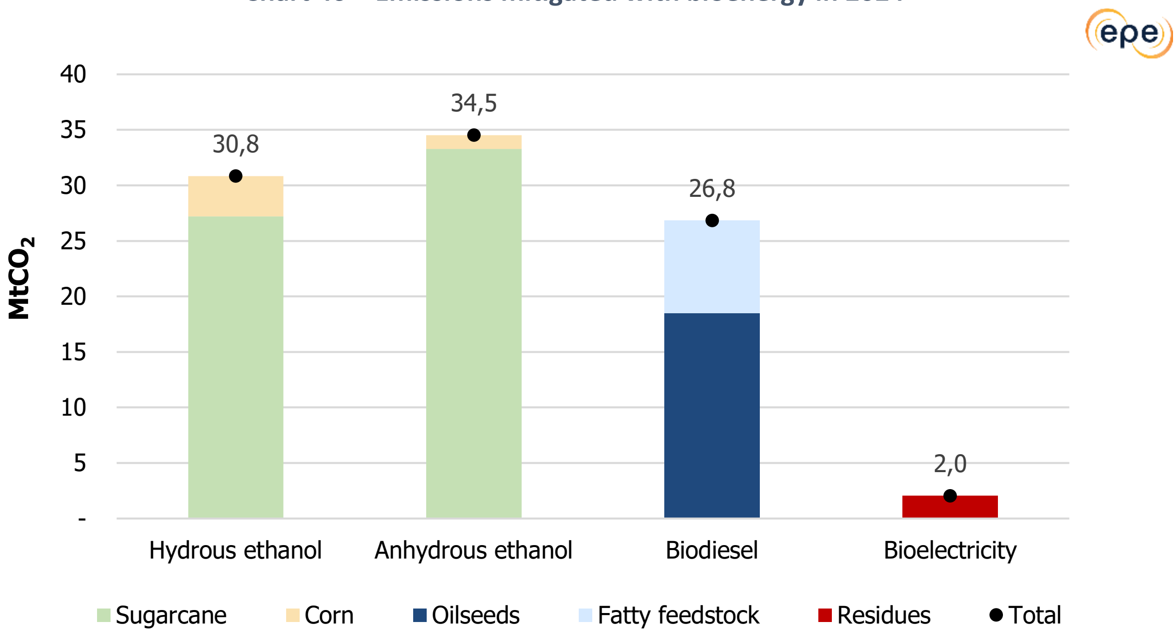
In this context, bioelectricity and biofuels already play an important role in the renewability of the national energy matrix. As discussed in previous chapters, both electricity generation at sugar-energy mills and the production of ethanol and biodiesel increased in 2024, resulting in a 10% rise in emissions avoided through bioenergy compared to the previous year.

In the electricity sector, bioelectricity accounted for 8.2% of the electricity generated in 2024, with the largest share coming from the use of sugarcane bagasse at ethanol mills. In 2024, the renewability of the Brazilian electricity matrix decreased by 1% due to a reduction in hydroelectric generation (-1%), associated with an increase in natural gas generation (+23.9%). At the same time, the increase in wind (+12.4%) and solar photovoltaic (+39.6%) generation helped maintain the high level of renewability of the Brazilian electricity matrix (EPE, 2025e). These changes resulted in an average emission factor for the National Interconnected System (SIN) of 0.0545 tCO_2/MWh, according to the Ministry of Science, Technology, and Innovation (MCTI, 2025). This factor is approximately 42% higher than the value recorded in 2023. Furthermore, electricity generated through bioelectricity in 2024 was 2.4% higher than the previous year, contributing to the avoidance of around 2 $MtCO2_2$ emissions.

Regarding liquid biofuels, there was an increase in mitigated emissions due to the 1% rise in the mandatory biodiesel blend and the record ethanol production in 2024, as reported in previous chapters. The share of biofuels led to a 25.7% renewable profile in the transport matrix (EPE, 2025e). Consequently, the emissions mitigated by using ethanol (anhydrous and hydrous from sugarcane and first-generation corn) and biodiesel, compared to their fossil equivalents (gasoline and diesel), totaled 92 $MtCO_2$ in 2024. This figure represents a 9.5% increase in mitigated emissions compared to the previous year (84 $MtCO_2$).

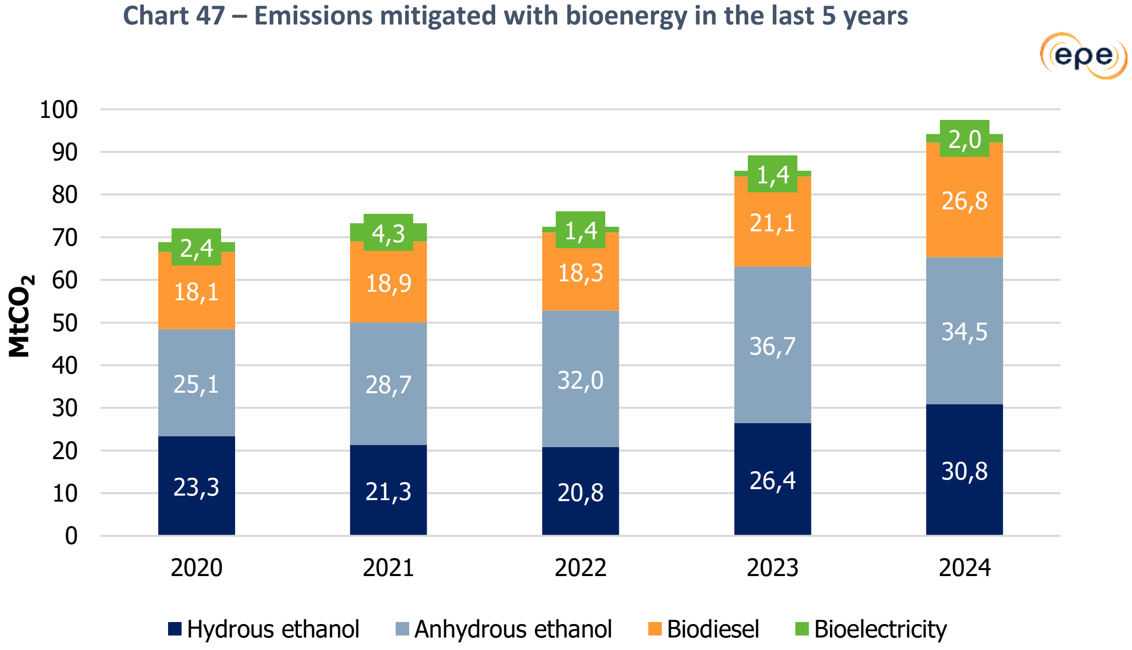
Chart 46 illustrates the mitigated emissions from the use of biofuels and sugarcane bioelectricity in 2024, while Chart 47 presents the overview for the last five years. In 2024, total mitigated emissions from bioenergy amounted to approximately 94 $MtCO_2$, the highest value in the historical series since 2006. Bioenergy is expected to gain even greater relevance with the advancement of the energy transition, particularly due to its 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 46 – Emissions mitigated with bioenergy in 2024



Source: EPE based on (EPE, 2009; IPCC, 2006; MCTI, 2025; ROSA, 2003)

Chart 47 – Emissions mitigated with bioenergy in the last 5 years



Source: EPE based on (EPE, 2009; IPCC, 2006; MCTI, 2025; ROSA, 2003)

11. National Biofuels Policy (RenovaBio)

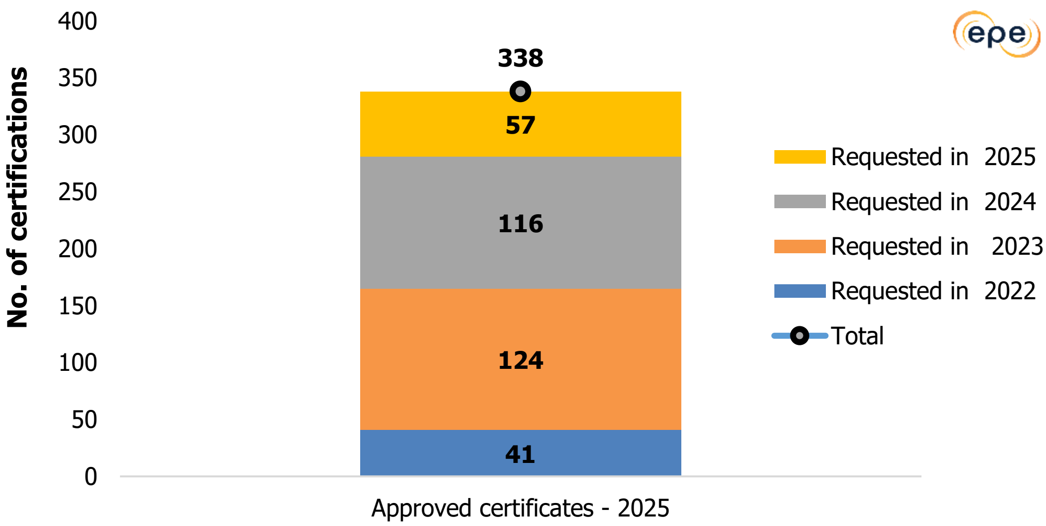
In 2024, the National Biofuels Policy (RenovaBio) completed five years of full operation. Established by Law No. 13,576, enacted on December 26, 2017 (BRASIL, 2017a), RenovaBio came into force in 2019. On April 27, 2020, the trading and registration of Decarbonization Credits (CBIO) began on the B3 – Brasil, Bolsa, Balcão trading platform, and a few weeks later, on June 15, 2020, the first CBIO transaction was executed (B3, 2025). RenovaBio established the Decarbonization Credit (CBIO) as the instrument, recorded in book-entry form, to demonstrate compliance with the individual carbon emissions reduction targets of fuel distributors.

Among the objectives of the Policy are to promote the adequate expansion of biofuel production and use within the national energy matrix and to reinforce Brazil's commitment to reducing greenhouse gas (GHG) emissions. Over these five years, RenovaBio has made a significant contribution to reducing the carbon intensity of Brazil's transport matrix and to ensuring fuel supply security.

11.1. Certifications

Between 2019 and May 2025, 253 certifications for biofuel producers were renewed, 4 changed ownership, 4 expired, 2 were annulled, and 1 changed its ethanol route from 1G sugarcane ethanol to 1G sugarcane and corn ethanol (flex). As shown in Chart 48, by May 2025, 338 certifications for biofuel producers were valid, 9 more than in 2024. In summary, 8 certifications were added for 1G sugarcane ethanol, 2 for biodiesel, and 1 certification for 1G corn ethanol (full) was cancelled/suspended (ANP, 2025h).

Chart 48 – Valid biofuels production certifications

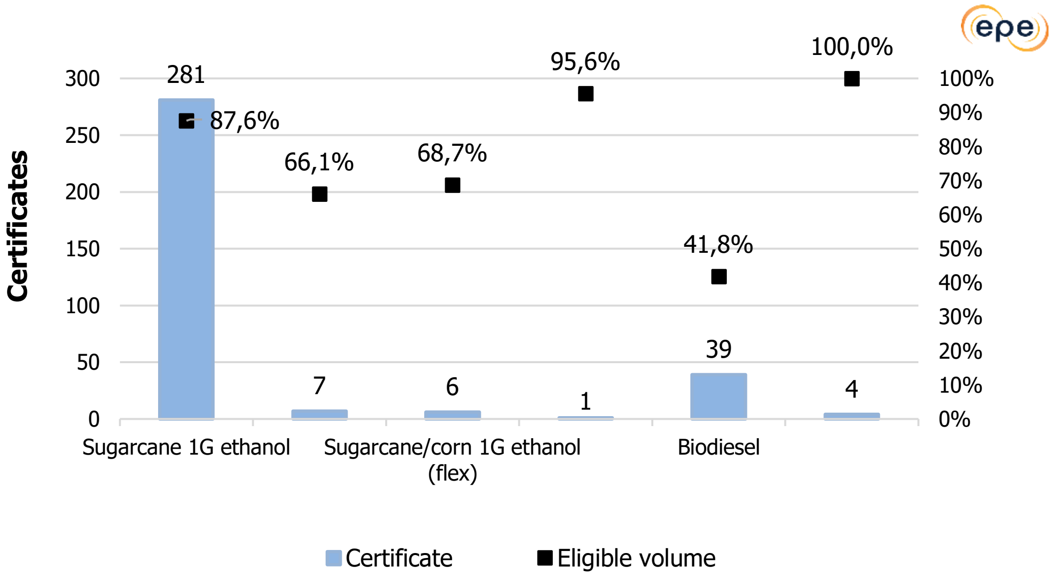


Source: (ANP, 2025g).

It is also noteworthy that 14 inspection firms are accredited to carry out the certification process under RenovaBio, one more than in 2024. One firm had its accreditation cancelled at its own request (ANP, 2025g).

The profile of certified units by production route and eligible volume, up to May 2025, is presented in Chart 49. 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 [62]. The production routes with the highest eligible volumes are 1st generation sugarcane ethanol (87.6%, a decrease of 0.9 percentage points compared to 2024), 1st and 2nd generation sugarcane ethanol in integrated plants (95.6%), and biomethane (100%). Ethanol from flex plants (corn and sugarcane) increased its eligible volume by 8.2 percentage points, reaching 68.7%, while ethanol from full corn plants remained stable compared to the previous year, despite the cancellation of one unit's certificate. The average eligible volume for biodiesel plants increased, with 41.8% of their production deemed eligible, up from 39.3% in 2024. It is noteworthy that 1st generation sugarcane ethanol plants represent 83% of the total certified plants, while biodiesel plants account for 12%.

Chart 49 – Certifications by production route and percentage of volume eligible by route



Source: (ANP, 2025g).

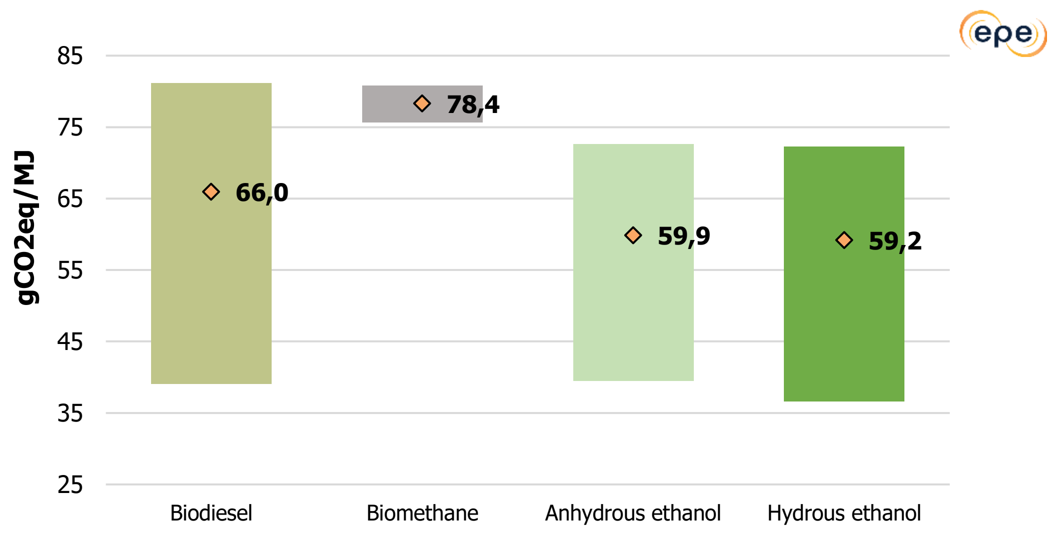
Considering the number of units authorized to commercialize biofuels by ANP up to May 2025, 295 ethanol plants out of a total of 360 (81%) have been certified, 39 out of 58 biodiesel plants (67%), and four out of 12 biomethane plants (33%). Notebly, 50% of these units were authorized to operate between 2024 and 2025, indicating a potential increase in the number of certifications since they have 100% of their production volume deemed eligible (ANP, 2025a, 2025c, 2025e).

[62] In June 2022, ANP prepared Technical Report No. 06/SBQ v.0, which establishes the procedures for implementing and verifying the chain of custody of grains and vegetable oils within the scope of RenovaBio, with the support of the technical team from the Brazil Energy Programme (BEP), a UK-based program aimed at promoting development and sustainability in the energy sector (ANP, 2025g).

It is worth highlighting that ANP Resolution No. 984, published in the Official Gazette on June 17, 2025, replacing ANP Resolution No. 758, published on November 27, 2018, reduces the minimum operational period required for a new facility to request its first Biofuel Certification process to obtain Decarbonization Credits (CBIO). Under Resolution No. 758, industrial data had to be entered into RenovaCalc based on information from the previous calendar year. The current resolution, however, allows using data from a minimum operational period of four months (ANP, 2018b, 2025h). This change will enable certifications for new facilities to be issued more quickly, as soon as all required criteria are met.

Chart 51 presents the average Energy-Environmental Efficiency Score (NEEA) of certified units for each biofuel, as well as the range between the minimum and maximum values, up to May 2025. Biodiesel[63] and biomethane maintain the highest scores, except for the low percentage of eligible volume and the higher share of residual oils in the case of biodiesel.

Chart 50 – Energy-environmental efficiency rating of certified units

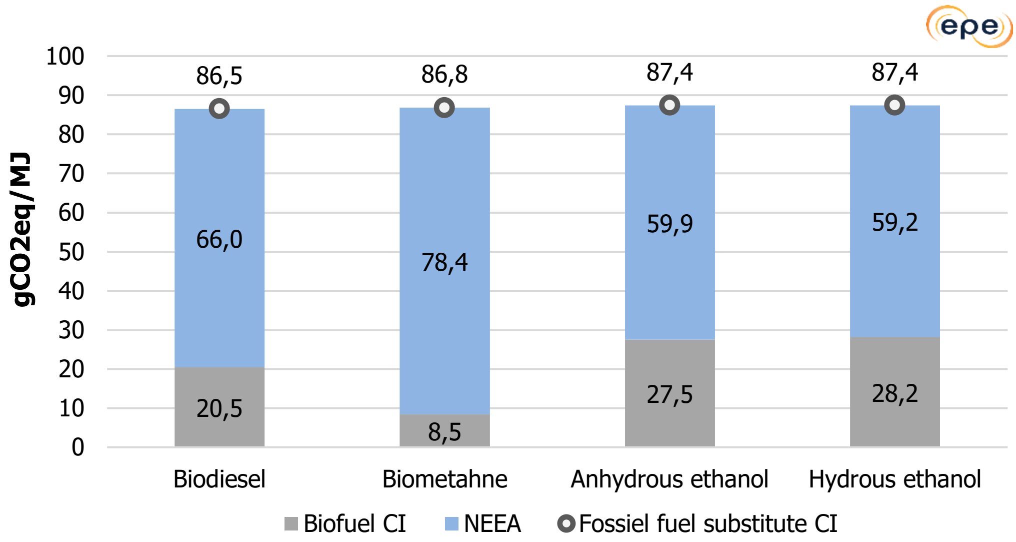


Source: EPE based on (ANP, 2025g).

By comparing the average NEEA of each biofuel with the carbon intensity (CI) of the corresponding fossil fuel, the average CI of the biofuel can be determined, as shown in Chart 52. Considering the minimum and maximum NEEA values presented in Chart 51, there is potential to further reduce the CIs of the biofuels analyzed.

[63] For biodiesel, a considerable portion of the certified volume, to date, does not take the agricultural stage into account in the certification, such as residues, which contributes to an increase in the NEEA.

Chart 51 - Carbon intensity of biofuel and its fossil substitute, and NEEA

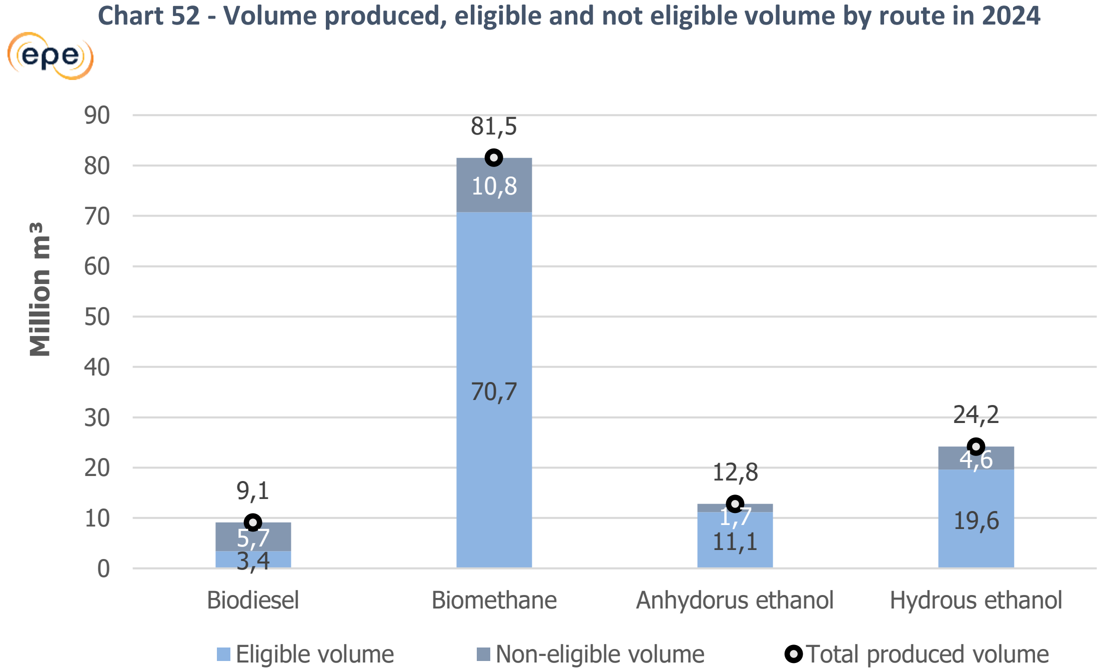


Source: EPE based on (ANP, 2025g).

11.2. Production eligible for CBIO generation via biofuel route

This section aims to assess the eligible volume for CBIO generation by biofuel production route in 2024 (Chart 53). A variation can be observed between the total volume produced and the volume eligible for credit issuance across the different routes.

Chart 52 - Volume produced, eligible and not eligible volume by route in 2024



Source: EPE based on ANP (ANP, 2025g).

In the case of biodiesel, only 37.6% of the volume produced (9.1 billion liters) was considered eligible for CBIO generation, indicating a relatively low utilization compared to other routes. The limited traceability of the grain supply chains influences this outcome, highlighting that there is still room for the biodiesel sector to increase its share in the credit market.

For biomethane, performance was significantly higher: 86.7% of the volume produced (81.5 million Nm³) was considered eligible (70.70 million Nm³), reflecting a high degree of compliance with the established criteria. This result can be partly attributed to the raw material source - organic waste - which facilitates the certification of 100% of the production within a single plant. However, the eligible volume does not correspond to 100% of the total production, as the number of biomethane-producing plants has been growing rapidly in recent years, meaning that some facilities are still uncertified.

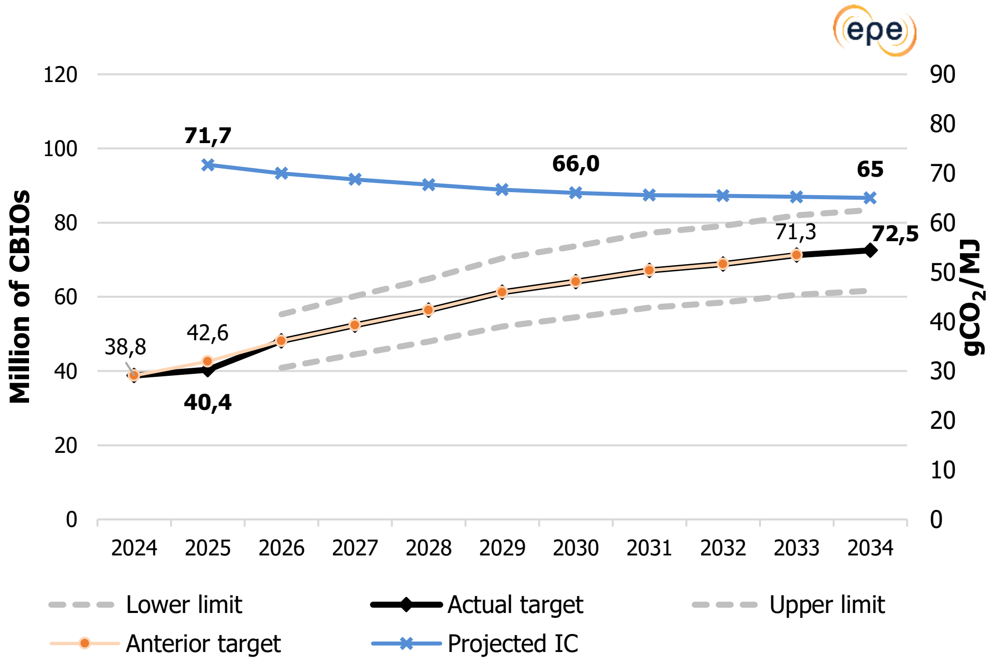
The anhydrous and hydrous ethanol routes also showed high eligibility percentages, with 87.0% and 81.0%, respectively. Considering the total ethanol production in 2024 (37.0 billion liters), 11.15 billion liters of anhydrous ethanol and 19.60 billion liters of hydrous ethanol were deemed eligible for CBIO issuance.

11.3. Mandatory GHG emission reduction targets

In December 2024, the CNPE established the mandatory annual GHG emission reduction targets based on the estimated fuel commercialization for the following decade, through CNPE Resolution No. 14, adjusting the value for 2025 and including the year 2034 (CNPE, 2024b). The deadline for compliance with these targets is December 31 of the current year (BRASIL, 2023).

The annual decarbonization targets, as well as the projected carbon intensity for the transport matrix, can be seen in Chart 53.

Chart 53 - Mandatory GHG emission reduction targets and projected IC



Source: (CNPE, 2024b)

In March 2025, ANP published the mandatory individual GHG emission reduction targets for that year[64] (ANP, 2025g), applicable to distributors that sold fossil fuels, with the three largest companies in the sector - Vibra, Raízen, and Ipiranga - accounting for 51% of the total in 2024. It is worth noting that the 2024 individual mandatory targets (38.8 million CBIOs), including the portion not met for 2023 (7.6 million), totaled 46.4 million CBIOs. However, 66 distributors did not acquire 10.5 million CBIOs, which were added to their respective 2025 targets. On the other hand, 1.5 million CBIOs were deducted from their targets due to long-term contracts with biofuel producers that expired in 2024, resulting in a global target of 49.4 million CBIOs for 2025. In this context, the share of the three largest distributors in the total drops to 44% (ANP, 2025g).

Among the distributors that did not fully meet their respective individual credit acquisition targets, 92% will be penalized for noncompliance, while the remaining 8% will not, as they retired CBIOs in quantities equal to or greater than 85% of the target and fully met the 2023 target, thus satisfying the requirement of §4 of Article 7 of Law No. 13,576 (ANP, 2025c).

According to Decree No. 12,437, published in the Official Gazette on April 17, 2025, fuel distributors in their first year of operation must demonstrate partial compliance with their individual targets on June 30, September 30, and December 31, while in the second year of operation there are two dates for verification: June 30 and December 31. Distributors, regardless of the duration of their activity, who fail to demonstrate compliance with their respective individual targets by December 31 of the current year, will, in addition to being subject to criminal liability, fines, and administrative and pecuniary sanctions, have their names forwarded to the Brazilian Institute of Environment and Renewable Natural Resources (Ibama), the Attorney General’s Office (AGU), the Federal Public Prosecutor’s Office, and other competent authorities (BRASIL, 2025).

11.4. CBIO stock and retirement

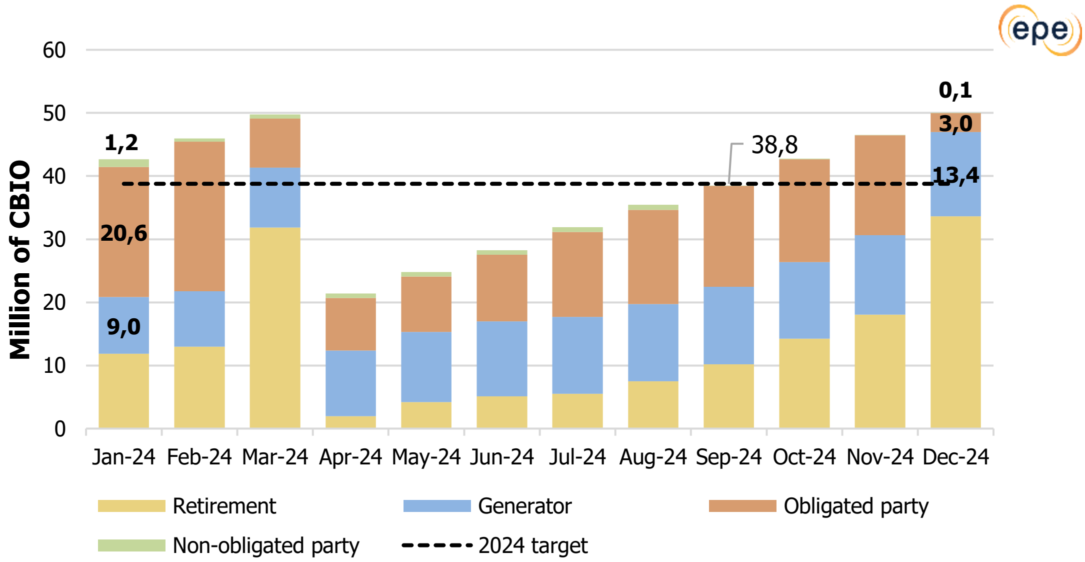
By the end of the 2024 fiscal year, which concluded in December, 35.7 million CBIOs were retired by obligated parties in compliance with individual targets, representing 92% of the target set by CNPE and 77% of the total individual targets assigned by ANP, which includes the portion not met by distributors in 2023[65]. By May 5, 2025, an additional 5.9 million CBIOs related to the 2025 individual targets, which have a deadline of December 31, 2025, were also retired (ANP, 2025c).

By the end of December 2024, the available CBIOs for trading (issued + in stock) totaled 16.41 million, consisting of: 13.37 million held by primary issuers (81.5%), 2.98 million with obligated parties (18.2%), and 53,470 with non-obligated parties (0.3%). Chart 54 shows the CBIO stock throughout the year held by each market participant, as well as the evolution of retirements.

[64] According to ANP Resolution No. 974/2024, distributors that did not demonstrate full compliance with their targets for the previous year must have a proportional increase in their respective targets for the current year (ANP, 2024d).

[65] As provided in § 2 of Article 5 of ANP Resolution No. 974/2024, the annual target established by the CNPE for 2024 was reduced by 2 CBIOs, which were permanently removed from market circulation by non-obligated parties in the previous year (ANP, 2024d).

Chart 54 – Stock vs. Retirement of CBIOs 2024



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

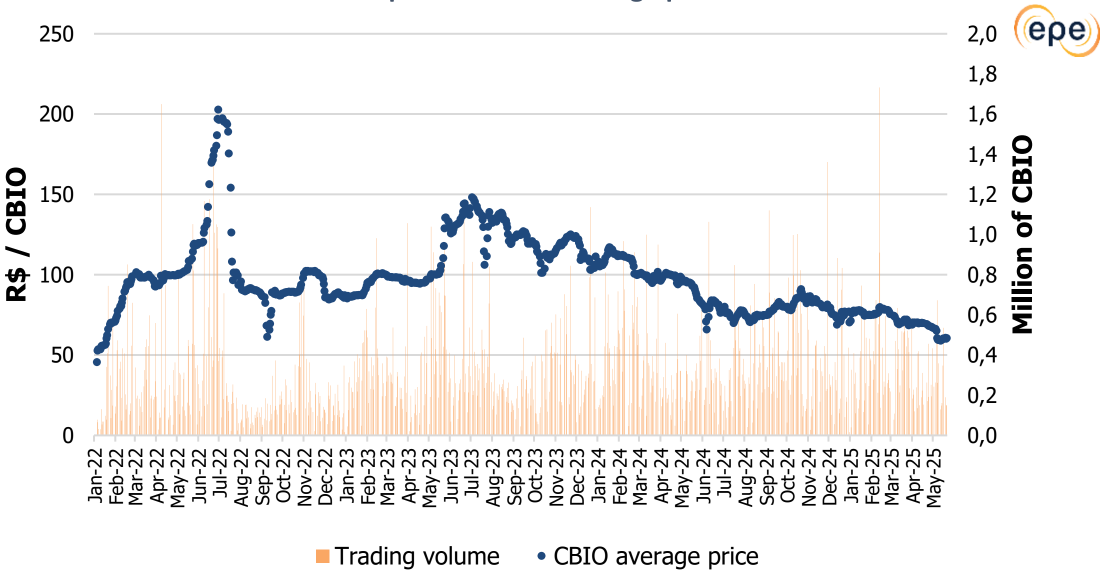
Source: EPE based on (B3, 2025).

11.5. CBIO Price

After experiencing fluctuations in 2022, the price of CBIOs showed greater stability in 2023, with an increase in June following the definition of global and individual decarbonization targets, after which it began to decline, closing the year at around R$ 100.00. The average annual price of CBIOs in 2023 was approximately R$ 110.00, the same level recorded in 2022 (B3, 2025).

In 2024, the average annual price of CBIOs was R$ 88.02 (a 21% decrease). The highest levels were recorded during the first quarter, as March 31, 2024, marked the deadline for distributors to meet their individual targets for 2023. Between May and December 2024, the CBIO price remained below R$ 100, reaching a low of R$ 65.82 in June. This decline was driven by the increased availability of carbon credits traded in the market (up to 12%) and by legal actions filed by noncompliant distributors, some of which obtained favorable rulings (B3, 2025; EIXOS, 2025d). Chart 55 presents the volume of decarbonization credits traded and their respective average prices from January 2022 to May 2025 (B3, 2025).

Chart 55 – Traded quantities and average prices of CBIO



Source: (B3, 2025).

It is estimated that biofuel producers[66] received approximately R$ 4 billion in revenue in 2024 (MME, 2024a).

11.6. Other relevant points

The CBIO Platform began operating its Long-Term Contract Module on November 29, 2023, through which 14% of distributors benefited from CBIO deductions applied to their individual targets for 2025, stemming from long-term contracts that expired in 2024. Among these distributors, Raízen, Vibra, and Ipiranga accounted for 86% of the CBIO deductions (ANP, 2025g; BRASIL, 2024b). These changes are expected to encourage the signing of such contracts with biofuel producers with higher EECAs, while also increasing market predictability for CBIOs.

On December 30, 2024, Law No. 15,082 was enacted, amending Law No. 13,576 (RenovaBio) to include independent producers of feedstock intended for biofuel production. In the case of sugarcane producers, the supply of this feedstock using the standard agricultural profile ensures them at least 60% of the revenues from CBIO trading; whereas those who provide the primary data required for the calculation of EECA using the specific agricultural profile, and who are included in the producer's certification under this profile, are entitled to at least 85% of the additional revenue from CBIO trading. For producers of other eligible biomasses included in the certification of biofuel producers, no minimum share of entitlement is established; instead, it is defined through private agreements and may be transferred in the form of a premium (tax-exempt) (BRASIL, 2024c).

[66] The amount charged to the biofuel producer per invoice for the issuance of 1 CBIO was updated on 02/21/2025 to R$ 5.73. In the previous period, from 01/01/2024 to 02/20/2025, this amount was R$ 5.49. The CBIO Platform is the tool provided by the Federal Data Processing Service (SERPRO) to deliver IT services related to the generation of the information required for CBIO issuance.

Another key point is set forth in Article 9, which establishes that non-compliance with individual targets constitutes environmental crime and subjects the distributor and its executives to the penalties provided in the relevant provisions, in addition to a fine proportional to the number of CBIOs that were not demonstrably acquired and retired. This is without prejudice to other administrative and financial sanctions provided under Law No. 9,847, as well as any applicable civil and criminal penalties (BRASIL, 2024c). According to Article 9-B, fuel and biofuel suppliers are prohibited from trading these products with distributors that fail to meet their individual targets, once their names are included on a sanctions list to be published and updated by the ANP (BRASIL, 2024c).

The purpose of this law is to ensure the continuity of the RenovaBio program, guarantee the acquisition and retirement of carbon credits by distributors, and establish penalties that prevent their operation when non-compliance with targets is identified. The MME has already filed a lawsuit with the Superior Court of Justice (STJ) to suspend injunctions favoring non-compliant distributors, aiming to reduce the judicialization of RenovaBio and address unfair competition. As of May 2025, six distributors had cases pending before the STJ, five of which also faced administrative proceedings with the ANP for failing to meet targets between 2020 and 2024, totaling 4.7 million non-retired CBIOs. Current injunctions benefited 21 distributors, covering 10.9 million CBIOs and suspending the payment of fines (EIXOS, 2025d).

12. Article - Potential for expansion of biofuel production and associated impacts

12.1. Introduction

Brazil has been a pioneer in public policies promoting the use of biofuels, with more than 90 years of experience in ethanol and 20 years in biodiesel, both of which have contributed to meeting the country's growing energy demand. What initially began as an effort to reduce external dependence evolved into a framework that also integrates social and environmental benefits (EPE, 2017, 2024c). As a result, Brazil currently has one of the most renewable transport matrices in the world, with a 25.7% share in 2024, according to the National Energy Balance (EPE, 2025e). This achievement reflects not only the legal framework built over decades of public policies but also the country's high productive capacity, favored by its edaphoclimatic conditions.

Looking ahead, Brazil's energy demand will continue to grow, with biofuels maintaining their relevance in ensuring the renewable profile of the energy matrix, consistent with the country's historical success (EPE, 2025c). Moreover, as a signatory to international decarbonization commitments (Paris Agreement, CORSIA, IMO, etc.), Brazil stands to benefit from the expansion of biofuel production, which can be further enhanced through "land-sparing" techniques. These include productivity gains, sequential cropping, the use of residual biomass, and the recovery of degraded lands.

The restoration of degraded lands holds significant potential as a practical solution to increasing biofuel output in Brazil's main agricultural crops (sugarcane, soy, and corn), applying technologies in which the country already has extensive experience, and which can deliver results in the short term. At the same time, land restoration generates local benefits for nearby communities, leading to positive socio-environmental impacts.

This article aims to demonstrate that the adoption of "land-sparing" techniques alone is sufficient to meet the increased demand for biofuel production, without placing additional pressure on new areas. It also estimates the volume of co-products associated with biofuels, in addition to the social benefits of job creation. Finally, the study highlights the key synergies between biofuel and food production, supported by various public policies and with an important role played by family farming.

12.2. Summary of Brazilian biofuels

Biofuel production in Brazil utilizes a wide range of feedstocks available nationwide, either already domesticated or in the process of domestication. The main crops used for producing these renewable energies are listed below, along with the types of biofuels currently produced in the country and those with potential for future development.

12.2.1. Raw materials for biofuels

Ethanol is produced primarily from sucrose in sugarcane and the starch in corn. Biodiesel is derived from vegetable oils and fatty materials. Among the most commonly used vegetable oils, soybean oil stands out, although oils from other crops, such as cotton, sunflower, canola, palm, corn, and peanut—are also used, in addition to residual oils. Some green diesel and SAF production routes also utilize the same feedstocks as biodiesel. It is noteworthy that for ethanol and SAF production, promising experimental initiatives are underway with agave cultivation in the semi-arid regions.

This wide array of feedstocks will support the production of Brazilian biofuels with significant relevance, as they not only diversify supply but can also integrate family farming, generating employment and income. This use, while creating economic value, can also play an important environmental role, as many of these materials were previously discarded as unusable or improperly managed.

Sugarcane

Sugarcane plays a strategic role in Brazil's agro-industrial matrix, having been cultivated since the 16th century, primarily for sugar production - a commodity with high international demand. Genetic improvement carried out by national research institutes has enabled the development of cultivars adapted to different edaphoclimatic conditions, optimizing productivity across various regions of the country. Brazil stands out as the world's largest producer of this crop.

Corn and others

Corn has gained greater relevance in recent years with the expansion of the second crop, grown in rotation with soy production. The establishment of the corn ethanol industry, particularly in Brazil's Central-West region, has absorbed a large share of the second-crop corn, while also supplying the market with important co-products such as DDGS (dried distillers grains with soluble) for animal feed and corn oil, which can be used for food purposes and biofuel production. Corn is becoming the second most important feedstock for biofuel production, contributing to ethanol, biodiesel, SAF, and even green diesel value chains.

More recently, sorghum and wheat have been introduced as feedstocks for ethanol production, particularly in the South, complementing the raw material portfolio. It is noteworthy that low-quality wheat, not suitable for human consumption, is used for this purpose.

Soy

Soybean oil is the main feedstock for diesel cycle biofuels in Brazil, historically accounting for around 70% of the total inputs used in FAME biodiesel production, as discussed in the relevant chapter of this study. Additionally, this vegetable oil is technically suitable for the synthesis of advanced fuels, such as SAF and green diesel, further increasing its relevance in the renewable energy matrix.

The diversification of biofuel feedstocks, including alternative vegetable oils and residual fats, is strategic to mitigate dependence on soybean and ensure sector resilience. It is also noteworthy that the import of oils and fats is regulated and can be activated when necessary to supply the domestic market.

Other oilseed crops

Cotton, in turn, is a well-established crop in Brazil, with cultivars adapted to various regions, including the semi-arid, producing fiber, seed oil, and meal, which can be used as animal feed. Cottonseed oil is a byproduct of the textile and food industries, with applications in cooking and pharmaceuticals. Despite its sustainability and regional potential, the crop requires specific equipment, which limits its intercropping with other crops (EMBRAPA, 2025a).

Oil palm, also known as *dendezeiro*, is a plant of African origin that shows high adaptability to Brazilian edaphoclimatic conditions and stands out as one of the oilseeds with the greatest potential for biofuel production in the country. Its notable attributes include significant carbon fixation capacity, the possibility of using its byproducts for energy purposes, and the existence of high-yield, pest and disease-resistant cultivars developed by EMBRAPA. Considering its high productivity and suitability for the recovery of degraded lands, oil palm presents favorable agronomic, technological, and territorial conditions for sustainable expansion in Brazil (EMBRAPA, 2025a).

Macaúba (*Acrocomia aculeata*), a native oil palm widely distributed across Brazil, represents a strategic alternative for diversifying the feedstock portfolio for biofuel production. Among its main agronomic attributes is its high oil yield per hectare. Its natural occurrence in forested areas across several Brazilian regions indicates broad adaptability, which favors domestication and increases its viability in different regions. Studies conducted by institutions such as Embrapa and the Federal University of Viçosa have presented preliminary results indicating the superior quality of its oil, reinforcing its suitability for energy purposes. This is a crop still in the early stages of domestication (EMBRAPA, 2025a).

Finally, **canola oil** does not have a robust production history in Brazil. Canola is gaining ground as a second-crop option, and it is likely that within the period considered up to 2035, it will be regarded as a supplementary crop to meet the country's growing vegetable oil demand.

Animal fats

Bovine tallow has historically ranked second among feedstocks used in national biodiesel production, second only to soybean oil. Over the past four years, however, it has been surpassed by "other fats and greases" - a category encompassing feedstocks not specified by producing plants - remaining as the third most used feedstock, as indicated in Chapter 6 of this study.

The international market has shown growing interest in Brazilian bovine tallow, particularly for SAF production. As an animal-origin residue, tallow exhibits high performance in reducing the carbon intensity of final fuels.

In addition to bovine tallow, other animal fats - from pig and poultry industrial production - represent promising feedstock sources for biofuel production. The diversification and integrated use of these residues can contribute to greater energy security, lower dependence on oilseed crops, and reduced environmental impact along the production chain.

12.2.2. Biofuels

Brazil is one of the world's leading producers of renewable fuels, with a broad portfolio ranging from traditional biofuels such as ethanol and biodiesel, to more recently introduced fuels like biogas and biomethane, and, soon, green diesel and Sustainable Aviation Fuel (SAF). The main elements driving the development of these energy carriers in the country are presented below.

Ethanol

Ethanol produced from sugarcane is the main biofuel in Brazil's energy matrix. It is widely used as automotive fuel in Otto cycle engines and also serves as a feedstock for the synthesis of advanced biofuels, such as SAF, through the ATJ (Alcohol-to-Jet) technological pathway.

In Brazil, several public policies have been fundamental for ethanol to reach its current market share. This process began with Decree No. 19,717/1931, which established a minimum blend of 5% ethanol in gasoline (BRASIL, 1931). In the 1970s, amid global oil crises, the government launched in 1975 the National Alcohol Program – Proálcool, through Decree No. 76,593 (BRASIL, 1975). Later, Decree No. 83,700/1979 established anhydrous ethanol as a mandatory additive to fossil fuels, while hydrous ethanol would be used in dedicated-engine vehicles (BRASIL, 1979).

The flex-fuel technology, introduced in May 2003, stimulated ethanol's return to the market. Its development, combined with Brazil's experience with Proálcool and the existing infrastructure, was crucial for the country to consolidate its position as a major ethanol producer. Using sugarcane as feedstock, national production has grown significantly, from 12.6 billion liters in 2002 to 29.7 billion liters in 2024 (MAPA, 2025).

In addition to sugarcane ethanol, Brazil is also investing in second-generation ethanol, an advanced biofuel produced from residues with a high lignocellulosic content. With six more projects and a newly inaugurated plant in 2024, the country will soon have a total of nine units, with an annual capacity of around 500 million liters.

Finally, corn ethanol in Brazil emerged due to low corn prices in the Center-West region, allowing better utilization of the industrial capacity year-round and complementing ethanol supply to meet demand during the off-season.

Diesel cycle renewable fuels

The main diesel-cycle biofuel used in Brazil is FAME biodiesel, a fuel adopted in several countries worldwide. Its production relies on various oilseeds as well as animal fats, depending on the availability and edaphoclimatic characteristics of the producing country. In Europe, for example, the most commonly used crop is rapeseed, while in the United States and Brazil, soybean is the primary oilseed for this purpose.

In Brazil, biodiesel use is anchored in the official mandatory policy established by the National Program for Production and Use of Biodiesel (PNPB), launched by the Federal Government in 2005 through Law No. 11,097. This program aims not only to produce a renewable fuel to partially replace fossil diesel but also to promote family farming in specific regions of the country, generating employment and income for small communities. In other words, besides the environmental benefits offered by biodiesel, the PNPB seeks to foster social inclusion and ensure the supply of a fuel with quality and competitive pricing.

In addition to FAME biodiesel, there is green diesel, an advanced biofuel produced through different chemical and thermochemical conversion processes using various animal and plant feedstocks to obtain a product chemically analogous to fossil diesel (drop-in). For the regulation of green diesel, ANP relies on the specifications of the European Committee for Standardization (*Comité Européen de Normalisation* – CEN) for HVO.

Biogas/Biomethane

Biogas is a gaseous biofuel primarily obtained through anaerobic biodigestion of organic waste. Its use in Brazil dates back to the 1970s (OLIVEIRA; NEGRO, 2019) and, since then, it has evolved, initially in a slow and localized manner, based on biodigester projects for communities, and later, in the early 21st century, with significant growth in production and participation in the national energy matrix. This expansion was driven both by the need to meet international mitigation commitments and by the favorable conditions of Brazil's well-developed agricultural sector, which generates large volumes of residues.

When purified, biogas can yield biomethane, a gaseous biofuel composed essentially of methane, as noted in Section 7. Meeting ANP requirements, biomethane is interchangeable with natural gas and can either replace it or be blended with it in any proportion.

Sustainable Aviation Fuel

The same advanced processes used to produce drop-in Diesel cycle biofuels from diverse organic feedstocks also allow for the production of biofuels for aviation, as noted in Section 9. This gives rise to Sustainable Aviation Fuels (SAF), offering a pathway to decarbonize the aviation sector and meet Brazil's international commitments under CORSIA. In the country, the ProBioQAV program serves as the main incentive mechanism for SAF development, establishing gradual targets for emissions reduction.

12.3. 2035 Panorama – biofuel projections

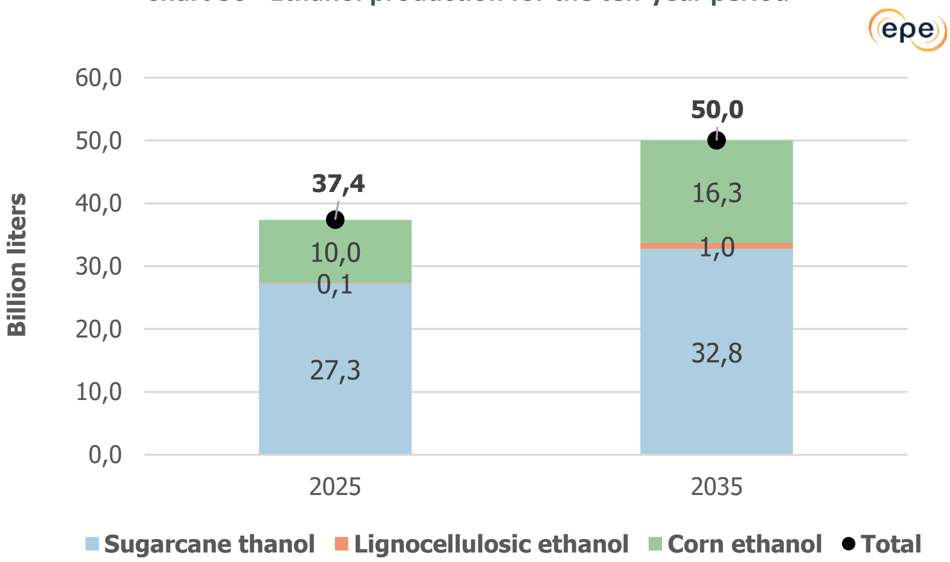
The Ten-Year Energy Expansion Plan (PDE), prepared annually by EPE, is a planning tool designed to indicate the needs and prospects for energy sector expansion, supporting the Ministry of Mines and Energy (MME) in formulating public policies that ensure accessible, high-quality energy for Brazilian society (EPE, 2025e).

For the ten-year period, the PDE estimates that Brazil will remain one of the world's leading countries in biofuels, benefiting from abundant natural resources and the development of advanced production technologies. The use of these renewable fuels also stimulates the local economy, enhances energy security, and generates employment, particularly in rural areas, as discussed in Section 12.5.

The Ten-Year Energy Expansion Plan (PDE) considers a series of assumptions for projecting ethanol supply, including: the sugarcane cycle, the evolution of productivity and production factors, as well as sugar production, second-generation ethanol, and corn ethanol production[67]. The biodiesel projection, in turn, is based on the mandatory blending percentage and diesel demand. Meanwhile, the SAF supply takes into account the biorefinery projects assessed up to 2025, including their nominal capacities and process routes, while the biomethane supply considers the units already authorized by ANP. Charts 56 and 57 present the preliminary PDE2035 projections for Brazil's biofuel supply.

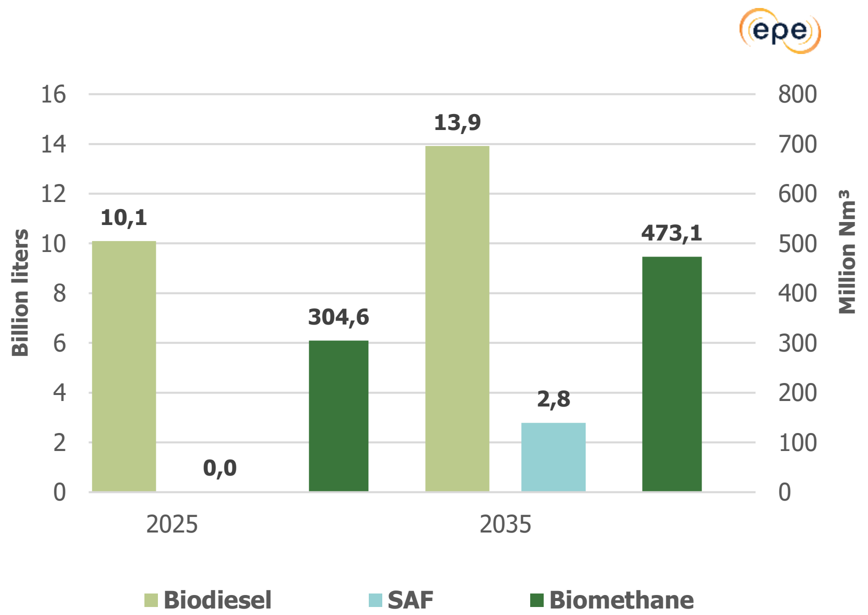
[67] Also including wheat, sorghum, soy, and other cereals.

Chart 56 - Ethanol production for the ten-year period



Source: EPE, 2025c

Chart 57 - Supply of other biofuels for the ten-year period



Source: EPE, 2025c

A significant growth is observed over the period, in the order of 20 billion liters when all biofuels are summed. This increase represents the expansion required to meet a growing demand for sustainable fuels, in line with climate commitments and energy security objectives.

The projected supply target can already be met solely through "land-sparing" techniques, thereby reducing the need to convert new areas for energy crop cultivation. The following section describes how some of these techniques can be applied to increase biofuel production.

12.4. Land-sparing techniques in the expansion of biofuels

Aiming to deepen the analysis of the linkage between biofuel production expansion and efficient land use in Brazil, this study continues previous assessments on the potential of so-called "land-sparing" techniques. The present approach seeks to quantify how much of the additional biofuel supply, projected for 2035 in preliminary PDE studies, could be met through these techniques, considering a gradual implementation that is both technically and economically feasible.

Following the previous methodology, this study incorporates more up-to-date estimates and expands the scope of the analysis, consolidating five mainland-sparing strategies with the potential to contribute to the sustainable increase of biofuel supply in the country. The focus remains on measuring the incremental volume of biofuel that each technique can provide, while respecting current agronomic, logistical, economic, and environmental constraints.

In addition to analyzing the supply of this additional biofuel by type of land-sparing technique, the study also estimated the quantity of food-related co-products generated, such as soybean meal, DDGS, corn oil, and sugar.

12.4.1. Methodology

The achievement of the additional biofuel supply in 2035 through land-sparing techniques followed a sequential logic. Initially, the volumes generated by the three most consolidated strategies, which have shown accelerated growth in recent years, were fully considered: the increase in productivity of energy crops, the expansion of second-crop corn ethanol production, and second-generation ethanol (E2G) from sugarcane residues.

Subsequently, the additional volume required to reach the projected production in 2035 was allocated to arable degraded lands, considering suitability criteria and environmental restrictions. For biodiesel, a portion was also assigned to the "other" category - including various sources of vegetable oil and animal fat with the potential to provide complementary supply by 2035. Below is a detailed description of the assumptions used for each technique considered:

(a) Productivity gains of main energy crops: Productivity gains for Brazil's main energy crops (soybean, corn, and sugarcane) are expected to continue, supported by technological advances, efficient agricultural management, and adoption of improved varieties, without yet reaching their theoretical limits. It is estimated that, by 2035, the productivity of these crops will increase on average by 5% for sugarcane and approximately 17% for soybean and corn, based on the methodology applied in the EPE's "land-sparing techniques" article (EPE, 2024e).

(b) Sequential cropping – expansion of 2nd-crop corn: Utilization of the cropping window in regions suitable for planting immediately after soybean, intensifying land use without expanding agricultural frontiers. The expansion of 2nd-crop corn was considered over the approximately 16 Mha still available after soybean cultivation, in regions with favorable climatic conditions.

(c) Utilization of available agricultural residues: Production of 2nd-generation ethanol (E2G) using agricultural residues from the sugar-energy sector, which show higher technical-economic viability over the decennial horizon. Despite the large availability of agricultural residues, logistical and agronomic constraints reduce their feasibility, except for sugarcane bagasse. Residues with lower technical-economic viability were not considered. Applying limiting factors for availability and collection (EPE, 2024e), it is estimated that approximately 30 Mton of residual biomass (sugarcane bagasse and straw) will be used for E2G production in 2035.

(d) Restoration and use of arable degraded pastures: Conversion of currently underutilized but agriculturally suitable areas for the cultivation of energy crops. Of approximately 110 Mha of degraded pastures in Brazil, 28 Mha are suitable for agricultural conversion (EMBRAPA, 2024). Applying restrictions by biome and slope for mechanization results in 12 Mha potentially cultivable with sugarcane, soy, and corn (EPE, 2024e). To meet the additional volume, approximately 7 Mha are expected to be allocated for energy crop/biofuel production by 2035.

(e) Other (Expansion of vegetable oil supply): Increase in the availability of oils and fats through additional crushing of soy, and the use of bovine tallow, macaúba, sunflower, canola, cotton, used cooking oil (UCO), and others, as a complementary and decentralized supply for biodiesel production. This diversification allows the integration of different production chains and regions, enhancing the resilience and reach of raw material supply, with potential emphasis on supporting family farming.

The results were consolidated to reflect feasible scenarios with a high probability of realization, paying particular attention to the complementarity among the strategies.

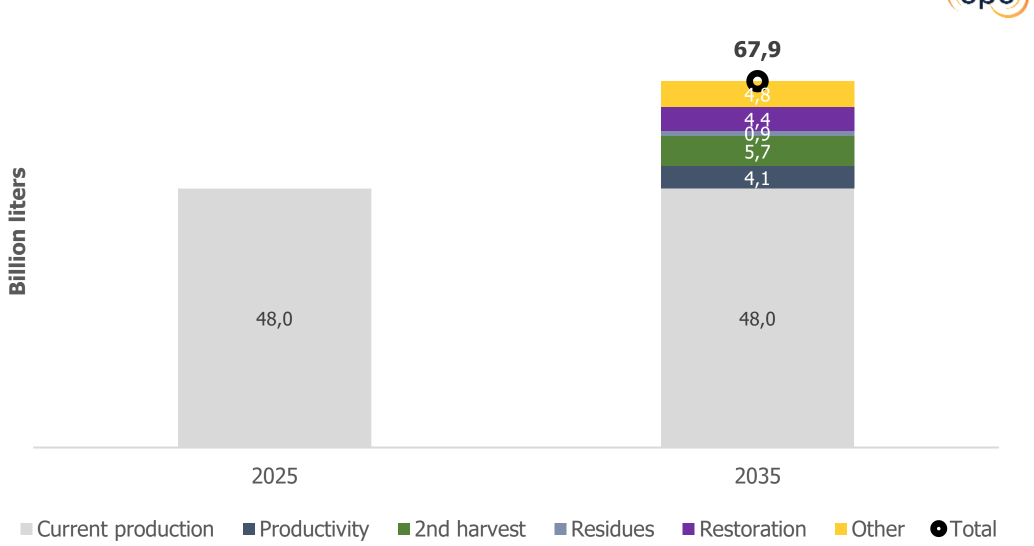
For soy, the average rates observed in the most recent year were considered: 36% of the grain processed (portion allocated to oil and meal production), 51% of the oil destined for biodiesel production, and 70% of biodiesel output supplied by soybean oil. For corn, an average of 15% of its production was assumed to be allocated to ethanol production. For sugarcane, a mean ATR mix factor of 50% for sugar and 50% for ethanol was adopted.

12.4.2. Biofuel production

The main results obtained from the application of the methodology described are presented below.

Chart 58 details the allocation of the additional biofuel volume projected for 2035 (difference compared to 2025) among the five assessed land-sparing techniques. The largest contributions come from productivity gains, sequential second-crop corn cultivation, restoration of degraded areas, and other sources of oilseed feedstocks. Although E2G has significant potential, its projected volume remains modest compared to the other land-sparing techniques over the ten-year horizon.

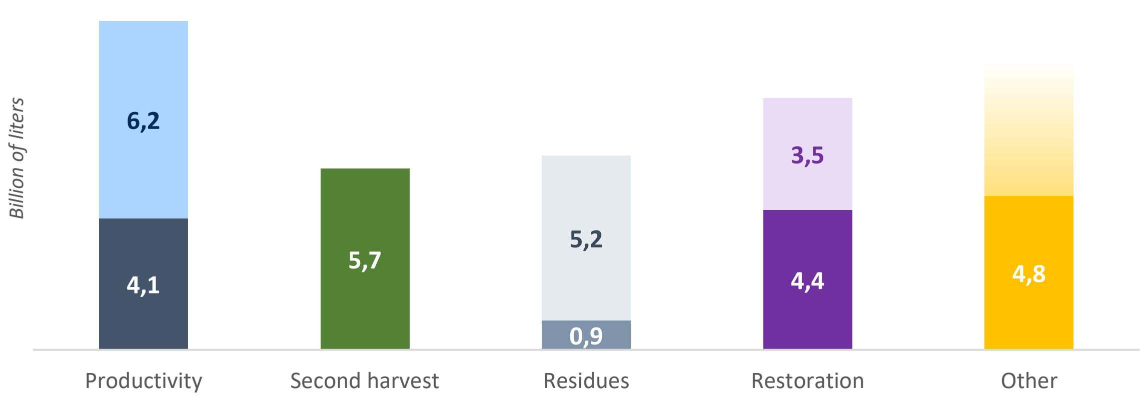
Chart 58 - Meeting the additional volume of biofuels in 2035 by land-sparing technique



Source: EPE

Chart 59 compares the volume effectively utilized by each technique in the constructed scenario with its estimated total technical potential. This analysis allows for assessing the degree of utilization of each strategy and its remaining expansion margin. For other oilseed feedstocks, no total potential was estimated, as they encompass a very diverse range of sources. As a sensitivity analysis of the effort level required to meet this volume, a 20% increase in today's soybean crushing rate would already suffice to produce approximately 4.8 billion liters of biodiesel, SAF (HEFA), and HVO. It is worth noting that the volumes potentially obtainable from adopting these various feedstocks are far higher than those projected for the other techniques shown in the chart.

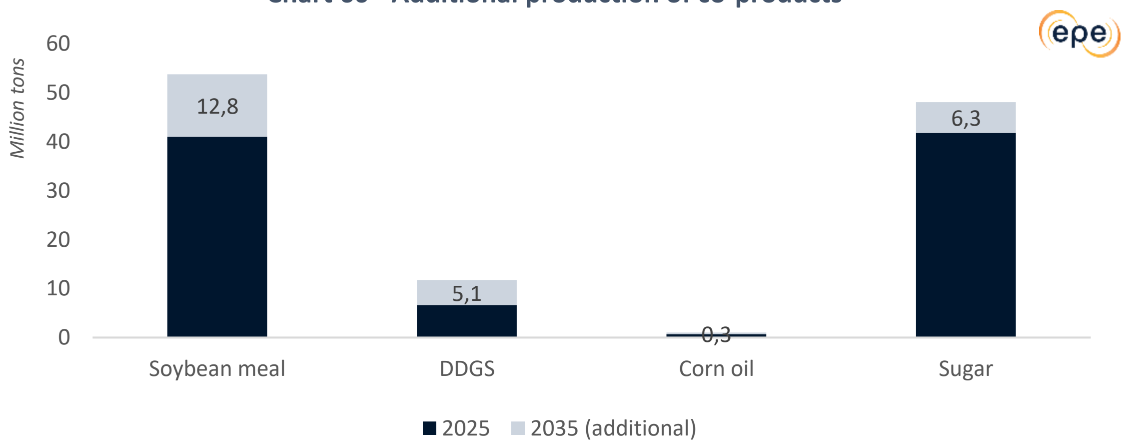
Chart 59 - Potential used (intense color) vs. total technical potential estimated by land-sparing technique (light color)



Source: EPE

Chart 60 presents the expected volumes of co-products generated from the expansion of biofuel production through 2035. The main co-products considered are those intended for animal feed, such as soybean meal and DDGS (dried distillers grains with solubles), as well as corn oil and sugar for the food sector.

Chart 60 - Additional production of co-products



Source: EPE

12.5. Job creation

This section estimates the potential for job creation associated with the adoption of three of the five agricultural production expansion techniques mentioned above.

For the sequential cropping technique (second-crop corn ethanol production), the employment generation coefficient per volume of ethanol produced was applied to the accumulated additional volume for the estimated production period. This coefficient was calculated as the ratio between the biofuel production in 2024 and the total direct jobs reported by the company Inpasa (INPASA, 2024).

Similarly, for second-generation ethanol (E2G), a comparable methodology was adopted: the employment generation coefficient per volume of biofuel produced was applied to the accumulated additional volume of second-generation ethanol for the estimated production period. This coefficient was derived from the ratio between the estimated biofuel production and the total direct jobs reported by Raízen at its Tarumã plant (RAÍZEN, 2023a).

Regarding the third technique considered - the use of degraded land - the employment generation coefficient[68] per volume of biofuel produced was applied to the accumulated production potential over the period for each of the different bio-products, namely: sugarcane ethanol, corn ethanol, and soybean biodiesel[69]. It is important to note that the result obtained may be higher than the estimate presented here, as the coefficients used refer to production on fertile land rather than degraded areas. Furthermore, this utilization first requires efforts for the recovery of these degraded areas, which will demand specialized labor and advanced agronomic restoration techniques, which are not estimated in this study.

It is important to highlight that the result obtained may be higher than the estimate presented here, as the coefficients used refer to production on fertile land rather than degraded areas. Moreover, this utilization first requires efforts to restore these degraded lands, which will demand specialized labor and advanced agronomic recovery techniques, not accounted for in this study.

Based on these parameters, it was estimated that the total number of new jobs generated could reach approximately 98,000, with a significant portion - around 87,000 jobs - associated with the productive use of degraded lands. The remaining roughly 10,000 jobs would be distributed among the other expansion vectors mentioned, as shown in Table 9.

Table 9 - Job Creation by Biofuel Production Expansion Techniques 2026-2035

	Estimated Value
2nd crop corn ethanol	7.306
Second Generation Ethanol	2.787
Degraded land – sugarcane ethanol	67.939
Degraded land – corn ethanol	723
Degraded land – biodiesel	18.708
Total	**97.463**

Source: EPE

It should be noted that most of the jobs generated would likely be concentrated in the Center-West region, due to the expansion of corn ethanol production and the high availability of degraded lands suitable for productive use in this area.

[68] Estimates were also made using the coefficient of thousands of hectares of planted area per job created. However, because these indicators overestimated job creation by more than 100% compared to estimates based on biofuel production volume, such estimates were disregarded (CEPEA/ABIOVE, 2025).

[69] For sugarcane ethanol, statistical tables from MAPA (2025) were used; for corn ethanol, CONAB (2025), MAPA (2025), and UNEM (2025); for biodiesel estimates, data from ANP (2025) for production and ABIOVE (2025) for planted area and employment were used.

Production-to-employment ratios vary depending on the level of mechanization, vertical integration, and geographic location, and biodiesel production generally generates fewer jobs per liter than sugarcane ethanol, though it may play a more relevant role in regions with family farming and diversified oilseed crops.

Notably, if only family farming were adopted in the use of degraded lands, job creation could be much higher than the estimates based on non-family agriculture. This was illustrated in the exercise presented in Section 12.6.2, where a conservative approach was chosen.

12.6. Energy and food production

12.6.1. Food insecurity

Given the concern about potential impacts of biofuel expansion on competition for land used in food production, food security has received growing attention in the global debate. However, in the Brazilian case, there is no evidence or diagnostic basis supporting a direct correlation between the growth of biofuel production and risks to food security. Previous studies - including the calculations carried out in this work - demonstrate that Brazil has sufficient land to simultaneously support food production, bioenergy, and environmental restoration, particularly when accounting for the availability of underutilized pasture areas, the vast potential for productivity intensification, and other land-saving techniques already mentioned (FAO, 2024; UN, 2025).

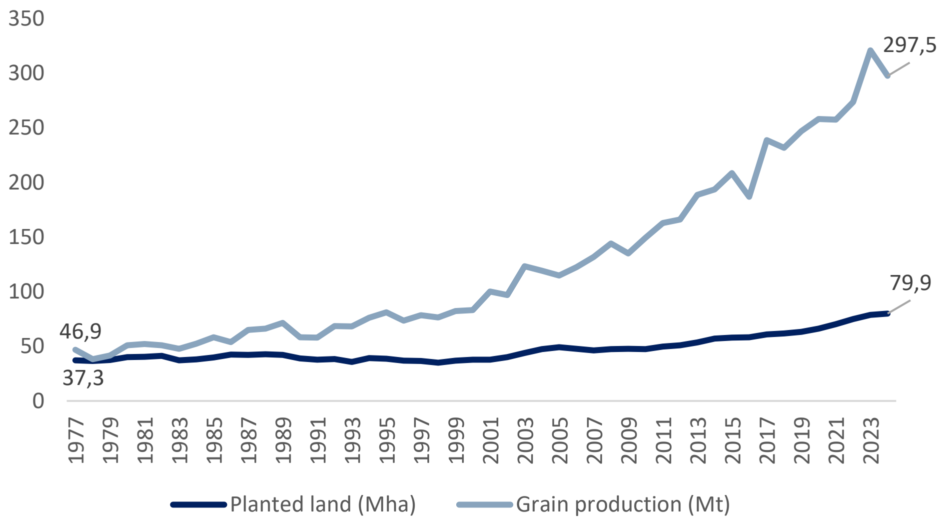
Additionally, it is important to emphasize that food security is not limited to food supply. The internationally recognized concept rests on four pillars: availability, access, utilization, and stability. In other words, agricultural production is only one dimension. Access refers to income and purchasing power; stability depends on functional logistics chains and effective public policies; and utilization relates to the nutritional quality and safety of food (FAO, 2024). Therefore, contrary to certain narratives that claim negative impacts from the coexistence of biofuel and food production, other factors have a more direct correlation with food security, such as income inequality, distribution failures, or economic and political crises.

From a broader value chain perspective, it can be inferred that biofuel production has the potential to even contribute positively to food security. The more efficient use of land through agricultural and livestock intensification, for example ILPF systems (an acronym for crop-livestock-forestry integration), promotes a reduction in greenhouse gas emissions, and in turn demands feed supplementation for animals. In this context, biofuel co-products, such as DDGS (dried distillers grains with solubles) and protein meals, become strategic inputs, fostering the intensification of livestock production, which consequently can release previously underutilized pasture areas for other uses - including food production or forest restoration - and contributing to a more efficient use of land.

It is worth mentioning that, in 2020, Brazil was able to produce food to supply around 800 million people, including the national population, through the export of grains and beef converted into grains (EMBRAPA, 2021). This data reinforces the thesis that food insecurity in Brazil must be tackled with measures that minimize obstacles other than food production.

Therefore, even though there may be concerns about possible tensions between biofuel production and food security, in the Brazilian case there is no inevitable structural conflict between these agendas. On the contrary, the planned and sustainable expansion of bioenergy can contribute with integrated solutions for land use, climate mitigation and agricultural productivity. The challenge does not lie in disputing physical space, but rather in creating productive and institutional synergies that further enhance the resilience of food and energy systems. Illustratively, Chart 61 shows the evolution of grain production and the expansion of cultivated area in Brazil over 40 years. During this period, productivity gains allowed grain production to grow by 4.2% per year and area by 1.2% per year.

Chart 61 - Evolution of grain production and planted land in Brazil



Source: EPE based on (CONAB, 2025f)

12.6.2. Public policies

The application of "land-sparing" techniques makes areas available for new crops, which can be directed to the production of food and energy. The national legal framework includes important policies to foster biofuel production, described throughout this document, such as the PNPB, RenovaBio, and the Future Fuel Law, enacted in October 2024. For food, some public policies that encourage its purchase deserve attention, such as the Food Acquisition Program (PAA), Law No. 10,696/2003, reinstated by Law No. 14,628/2023, and the National School Feeding Program (PNAE), Law No. 11,947/2009, expanded by Law No. 14,660/2023, which contributed to Brazil leaving the UN Hunger Map twice[70], according to the Pact Against Hunger[71] (BRAZIL, 2003, 2009, 2023b, 2023c)(UN, 2025).

The PAA establishes that the Federal Government purchases food produced by family farming and donates it to Popular Restaurants, Community Kitchens, Food Banks, and other entities that serve people in situations of food insecurity. The PNAE, in turn, stipulates that at least 30% of the federal resources transferred by the National Fund for Education Development (FNDE) must be invested in the direct purchase of products from family farming, a measure that stimulates the economic and sustainable development of communities. In the production sphere, the National Policy for Family Farming (PRONAF), established by Law No. 11,326/2006, provides instruments that offer subsidized credit lines.

[70] Support for food production also extends to poverty eradication initiatives. Law No. 11,346 of September 15, 2006, known as the Organic Law on Food and Nutritional Security (LOSAN), established the National Food and Nutritional Security System (SISAN), a public framework created to guarantee the Human Right to Adequate Food in Brazil (BRASIL, 2006). In addition, monitoring tools for hunger should be highlighted, such as the EBIA/PNAD, responsible for the annual assessment of food insecurity, and the Food and Nutritional Security Equipment Maps (MAPASAN), a tool to identify food security infrastructure in municipalities.

[71] Through its "SOFI 2025 Technical Analysis," SOFI – The State of Food Security and Nutrition in the World (PACTO CONTRA A FOME, 2025) (UN, 2025).

Based on these policies, through Decree No. 11,679/2023, the Federal Government created the Brazil Without Hunger Plan in 2025, a strategy that brings together the various legal frameworks mentioned here, with the objective of eradicating hunger and promoting food security in the country (UN, 2025). In addition to these initiatives, the plan also includes Bolsa Família, the valorization of the minimum wage, incentives for professional qualification, employment and entrepreneurship, as well as the expansion of school feeding programs and credit for food production by family farming (PRONAF). Another important initiative in this same direction was the launch of the Global Alliance Against Hunger and Poverty during Brazil's presidency of the G20 in 2024. With the participation of 101 member countries, as well as several foundations, institutions, and organizations, the Alliance aims to unite the efforts of its members to achieve the Sustainable Development Goals (SDGs), highlighting those focused on eradicating hunger and poverty and reducing inequalities by 2030. These policies have contributed to Brazil once again being removed from the UN Hunger Map.

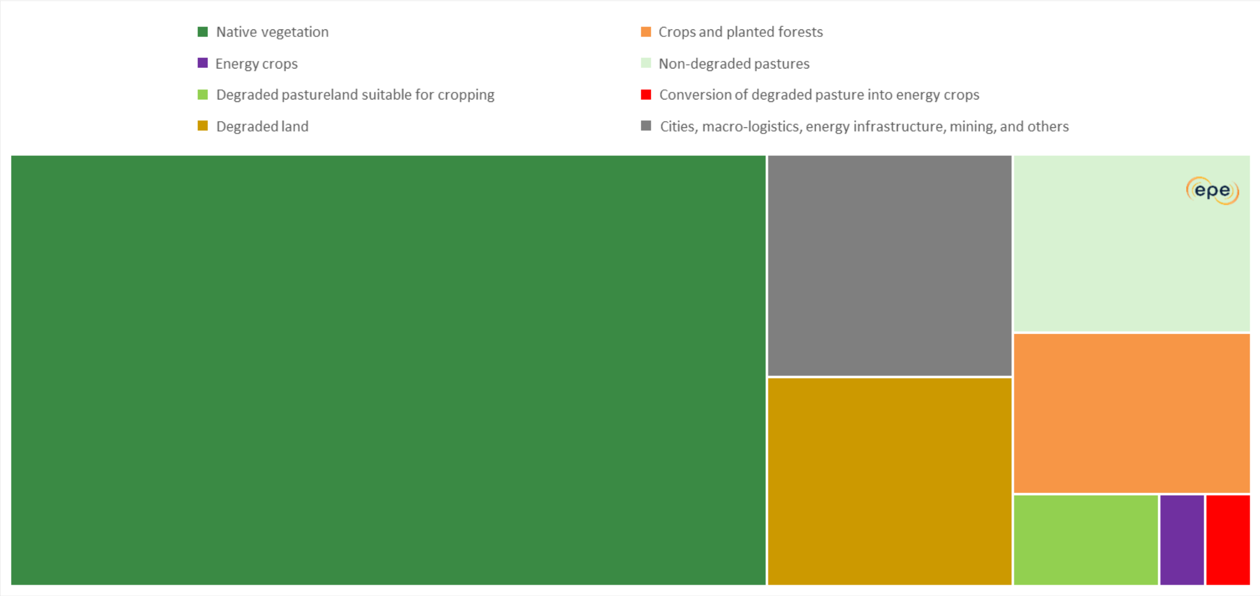
An important factor for achieving these objectives is family farming. As a powerful tool to ensure healthy and accessible food, its strengthening reduces poverty, improves nutrition, and promotes social justice. In addition, it is responsible for about 70% of the food consumed in the country (EMBRAPA, 2017). Family farming occupies an area of 80.9 Mha with more than 10 million jobs, with nearly 90% of workers having family ties to the producer (FETAESC, 2023).

In this context, it is worth mentioning the National Program for the Production and Use of Biodiesel, which has one of its pillars based on family farming, promoting social inclusion and job creation through the supply of raw materials for biodiesel production (BRASIL, 2005). For the period from 2021 to 2024, more than 60,000 families were included in this program, achieving an annual gross income per family exceeding R$ 100,000 (ABAF, 2024). With the projected growth in biodiesel demand of about 50% by 2035, reaching 13.9 billion liters, it can be roughly estimated that there is a potential proportional increase in the number of families and/or cooperatives participating in this important public policy.

It is important to note that these families, in addition to energy crops, can use the land simultaneously or in rotation for the production of other crops and activities (canola, milk and dairy products, swine and poultry). Furthermore, they have access to Technical Assistance and Rural Extension (ATER) and specific support programs, which can enhance their skills and optimize the use of the production area. This arrangement is capable of generating significant synergy between biofuel production and other food-oriented crops and can be replicated for other renewable fuels emerging in the context of the energy transition, and, therefore, is within the scope of public policy.

Brazil occupies a continuous area of 851 Mha, of which approximately 60% is still native vegetation. In addition to the contribution of the other land-sparing techniques mentioned in this document, this study indicates that, in the case of converting degraded pastures into energy crops, about 6.7 Mha would need to be converted to meet the biofuel projections indicated in the PDE 2035. Optimizing land use is vital for the preservation of biomes, and Brazil has significant potential in this regard. Data from EMBRAPA (2024) indicates that there is approximately 28 Mha of degraded land that could be used for agricultural production for food or energy purposes. In a simplified analysis, if the area required to meet PDE 2035 were deducted from this total, about 20 Mha would still be available for agricultural use. Considering a scenario in which only 10% of this degraded area (approximately 2 Mha, or about 0.3% of the national territory) is utilized by family farming and applying the general parameters of jobs per area (EMBRAPA, 2017), around 260,000 new jobs could be generated.

Chart 62 - Land occupation in Brazil



Source: EPE, based on Embrapa, MAPA, MMA, IBGE, CNA, DNIT, ANA, CNA, MPOG

12.7. Final considerations

In 2024, Brazil was recognized as a global bioenergy power and reached a historic milestone: it was removed from the Hunger Map, according to the FAO (BRASIL, 2025d). These advances highlight the importance of an integrated strategy that combines food production and renewable energy generation, with emphasis on family farming and public policies such as the Social Biofuel Seal.

The Brazilian energy matrix presented 50% renewability in 2024 (EPE, 2025e), with a significant contribution from bioenergy, composed of sources such as sugarcane biomass, firewood, charcoal, black liquor, biodiesel, and others. Integrated production avoided competition for land, expanded food and energy supply, and benefited thousands of farming families. In 2024, 1.7 million formal jobs were created, with strong social inclusion and increased income among the poorest. Small businesses and rural enterprises accounted for over 1.2 million of these positions, demonstrating that family farming is a driver of inclusion.

Agroenergy, with its high economic multipliers, generated social and economic impacts greater than those of traditional industrial sectors. Brazil presents to the world a sustainable model that reconciles food security, energy transition, and social justice. Biofuel production, in addition to contributing to the renewability of the energy matrix, can also supply part of animal feed through industry co-products, such as soybean meal and DDGS (dried distillers grains with solubles), as well as corn oil and sugar for the food sector. It is noteworthy that Brazil is the main player in the international sugar market.

Favorable edaphoclimatic conditions for national agricultural production do not reduce the need for advances in productive techniques. This article highlights land-sparing techniques which, when systematically implemented, allow for increased agricultural output without expanding the already cultivated area, simultaneously promoting sustainable use of natural resources and the recovery of degraded soils. These methods make it possible to reconcile agricultural growth with environmental conservation, reinforcing production resilience in the face of climate challenges and ensuring more efficient and sustainable agricultural development.

Public policies are essential tools for ensuring energy and food security. Throughout this article, it was possible to review several of them and demonstrate how their implementation can be reflected in the positive indicators observed recently. Regarding biofuel production, legal advancements were responsible for maintaining the high renewability of the national energy matrix. Actions undertaken to reconcile economic development with the fight against social inequalities contributed to achieving, in 2024, the lowest unemployment rate recorded since 2012, at 6.6%, in addition to reducing extreme poverty (reaching BRL 2,020) (CNN, 2025), and attaining the lowest observed Gini index, an indicator of inequality, which fell from 0.518 in 2023 to 0.506 in 2024 (CNN, 2025; IBGE, 2024). Among all these historic records, the most gratifying outcome was that Brazil once again exited the FAO's Hunger Map. The Brazilian State has followed a successful trajectory in developing a series of public policies aimed at leveraging the opportunities afforded by the country's edaphoclimatic conditions. Through these actions, by preparing fertile soil capable of fostering both food and bioenergy production, the Brazilian government reaffirms its commitment to addressing climate change, eradicating hunger, and building a just, more inclusive, and equitable world.

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