TECHNICAL NOTE

Ethanol Supply Scenarios and Otto Cycle Demand from 2025 to 2034

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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 PROMOTES TRANSPARENCY AND REDUCES INFORMATION ASYMMETRY BY PRESENTING DATA AND FACTS THAT CAN CONTRIBUTE TO THE DISCUSSIONS ON BRAZIL'S ENERGY TRANSITION EFFORTS.

THIS TECHNICAL NOTE PRESENTS SUPPLY SCENARIOS FOR SUGARCANE AND CORN ETHANOL, AS WELL AS THEIR IMPLICATIONS FOR OTTO-CYCLE FUEL DEMAND AND THE NATIONAL BALANCE OF GASOLINE A. THE DOCUMENT ALSO ADDRESSES SUGARCANE-BASED BIOELECTRICITY, BIOMETHANE PRODUCTION, EMISSIONS AVOIDED THROUGH THE USE OF BIOFUELS, AND THE ALLOCATION OF ETHANOL FOR THE PRODUCTION OF SUSTAINABLE AVIATION FUELS.

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Study

Scenarios for Ethanol Supply and Otto Cycle Demand 2025–2034

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Introduction

The Energy Research Company (EPE) has released the ninth edition of the Ethanol Supply Scenarios and Otto Cycle Demand, aiming to contribute to identifying opportunities and threats to the national supply of light Otto cycle vehicles (ethanol and automotive gasoline). Considering the reference transportation demand from EPE, scenarios for the supply of sugarcane and corn ethanol[1] are presented, along with their implications for fuel demand and the national gasoline A balance until 2034. The study also includes the supply of bioelectricity from sugarcane exported to the National Interconnected System, the potential for biogas production from sugarcane residues with capacity expansion trajectories, and an evaluation of investments associated with each of the scenarios. Furthermore, it estimates the contribution of the sugar-energy sector and corn ethanol to the reduction of greenhouse gas (GHG) emissions.

This edition also presents sensitivity analyses of the impact on demand related to the increase in the anhydrous ethanol content in gasoline C and the allocation of ethanol to produce Sustainable Aviation Fuel (SAF).

1. Background

Brazil is one of the world's leading producers of biofuels, and this position is the result of several actions and public policies developed over time to encourage an increased share of biofuels in the energy matrix. Among these are the mandatory biofuel (ethanol and biodiesel) blending mandates with petroleum derivatives, tax differentiation mechanisms between renewable and fossil fuels, specific financing lines, and more recently, the National Biofuels Policy (RenovaBio) and the Future Fuels Law (BRAZIL, 2017, 2024a; EPE, 2016, 2024a).

Presiding over the G20[2] in 2024, Brazil has taken on the challenge of stimulating actions to ensure that the energy transition occurs in a fair, inclusive, and balanced manner. Throughout 2024, several technical meetings were held to address this topic. The conclusions of Brazil's G20 presidency indicate that energy needs must be met fairly, considering social inclusion and poverty eradication. At the G20 Summit, which took place in November in Rio de Janeiro, in addition to proposals related to sustainability and tackling climate change, the Global Alliance Against Hunger and Poverty was officially launched.

Given its experience in energy policies related to biofuels, Brazil could contribute to achieving the Sustainable Development Goals of the UN 2030 Agenda, which involve the production of raw materials for biofuel production and their interrelation with the promotion and development of family farming. In addition to its role in food supply and its importance as a source of rural employment generation, income increase, and quality of life improvement, family farming is one of the social protection network policies that can help in the fight against hunger eradication and food insecurity worldwide. In this way, biofuel production guided by Brazilian energy policy can, in addition to contributing to the renewability of the national energy matrix and mitigating climate change, help eradicate poverty and promote a dignified life for all (UN, 2021).

[1] The name corn ethanol also includes those from soybeans, wheat, sorghum and other cereals.

[2] Created in 1999, the G20 aims to promote international cooperation, with an agenda that includes trade, agriculture, health, climate change, among others.

Among the national biofuels, ethanol stands out, with production primarily derived from sugarcane and, in recent years, from corn, which has shown significant growth. Ethanol is marketed in the forms of hydrated and anhydrous, the latter being blended with gasoline A to form gasoline C.

Regarding sugarcane, since 2020, the impact of rising sugar prices in the international market has been observed, with the sugar-energy sector adjusting to these fluctuations to maximize revenue or minimize losses. Bioelectricity is a third asset in this segment, contributing to the increase in its revenue. The production of biogas using vinasse and filter cake has made advances.

Since 2020, CBIOs[3] have become another source of revenue for the biofuel sector for those that meet the requirements and have joined RenovaBio. Currently, most certified mills are sugarcane E1G, as corn-based mills face some challenges related to the grain supply chain (EPE, 2024a).

Ethanol production from corn has been experiencing significant growth, particularly in the Midwest region, reaching 5.8 billion liters in 2023, approximately 15% of the national production (MAPA, 2024; UNICA, 2024). This growth has been driven by the increase in corn production, which, unlike sugarcane, allows for a second annual harvest, and occasionally a third, in combination with other crops, notably soybeans. Additionally, it benefits from the generation of co-products such as corn oil, intended for human consumption, and DDGS (distiller's dried grains with solubles), for animal feed, thus adding two more revenue streams for the mills (IMEA, 2017; MILANEZ et al., 2014). Furthermore, corn offers the advantage of being storable, enabling mills to operate throughout the year.

Regarding tariff issues, from the second half of 2023, federal taxes (PIS/Pasep, COFINS, and CIDE) were fully reinstated, and the state tax (ICMS) was set at a uniform ad rem rate across the entire national territory for anhydrous ethanol and gasoline C (BRASIL, 2022a, 2022b). Otto cycle consumption (except for CNG) surpassed the historical annual maximum, reaching 59.1 billion liters of gasoline equivalent, with hydrated ethanol increasing its market share, particularly starting in August (EPE, 2024a, 2024b). The 2024/25 sugarcane harvest has shown good performance in terms of productivity and milling, although still lower than the previous period. With attractive international sugar[4] prices, this commodity has seen an increase in its share of the mix. As mentioned earlier, corn ethanol production has experienced consistent growth. Thus, the price relationship between ethanol and gasoline has remained favorable to the biofuel since the beginning of the year (CONAB, 2024a; EPE, 2024a, 2024c; MAPA, 2024; USDA, 2024). By October 2024, the consumption of hydrated ethanol was 17.9 billion liters, a 29.7% increase compared to 2023, while gasoline C consumption decreased by 4.5% (ANP, 2024a).

[3] Instrument of the National Biofuels Policy registered in book-entry form, for the purpose of proving the individual goal of the fuel distributor referred to in article 7 of Law No. 13,576/2017 (BRASIL, 2017).

[4] From January to October 2024, the national sugar production was 40.5 million tonnes, 1.7% higher than in the same period of 2023 (MAPA, 2024).

2. Assumptions of the Scenarios

This study will present three ethanol supply scenarios, with names chosen based on the growth of ethanol production from sugarcane and corn. These scenarios are: **High Growth, Medium Growth, and Low Growth**.

First, the common assumptions for these scenarios will be described, followed by the specific assumptions for each scenario.

2.1 Common Assumptions (Conditions)

Adjustments to the Base Year Factors

For the years 2023 and 2024, the area and the agricultural and industrial productivity related to sugarcane were adjusted according to the second crop survey for the 2024/25 sugarcane harvest by CONAB (2024a).

Current Installed Capacity

For units that exclusively use sugarcane, the milling and ethanol production capacity factor was set at 90%. For corn processing, this value is 95%. The biofuel plants in operation and those with expansion and construction authorizations from the ANP are based on the status as of May 2024 (ANP, 2024b).

a) Sugarcane

- The nominal installed milling capacity is approximately 870 million tons of sugarcane[5] (equivalent to 780 million tons in effective capacity), with 360[6] units in operation. The capacity for producing anhydrous and hydrated ethanol is around 49 billion liters (200 days of harvest) (ANP, 2024b; MAPA, 2024).
- Expansion[7] of ethanol production capacity from 36 operating plants, totaling 2.3 billion liters (200 days of harvest) (ANP, 2024b).
- Installation of two sugarcane ethanol production units in the medium term, one small-scale and one reactivation, all with construction authorization from the ANP. Additionally, the ANP lists two units producing aguardente and/or ethanol for other uses, and one that currently produces sugar (ANP, 2024b). All these plants have been included in the projections.

[5] The analysis considered the closure, reactivation and expansions in existing units that occurred up to the indicated period.
[6] This total includes three production companies of aguardente.
[7] It was admitted that the volume to be expanded will be available by 2028.

b) Corn and Others

- The corn processing capacity is around 20 million tons, with ethanol production capacity at 8.0 billion liters from 28 units (11 flex[8], 14 full, and three for soybeans/cereals[9]) (ANP, 2024b; MAPA, 2024; UNEM, 2023).
- Expansion of the capacity of seven plants in operation (3 full and 4 flex) by 0.86 million liters (ANP, 2024b).
- Installation of 16 new corn ethanol units, one for wheat, one for soybeans, and one for cereals (ANP, 2024b).

Yield

Industrial yield (sugarcane quality) is defined by the amount of ATR (Total Recoverable Sugars) per ton of cane and is related to its variety (whether richer in sugar or fiber), suitability to the production environment and mechanized harvesting, the age of the sugarcane field (renewal at the optimal time), plant and mineral impurities, cultural practices, and climatic factors (EPE, 2024a).

This indicator has fluctuated over past harvests (EPE, 2024a), and for the scope of this study, it is assumed that the average yield of sugarcane will be around 142 kg ATR/ton of cane.

Ethanol Export and Import

Currently, there is a global trend toward transitioning to sustainable, low-carbon-emission economies as one of the ways to mitigate the adverse effects of human actions on the climate and protect the planet's quality of life. There are alternatives to achieve these objectives, such as the use of biofuels and electrification (more widely adopted internationally), provided the electricity comes from renewable sources, with each being more suitable to the specificities of each country.

Traditionally, ethanol-importing countries are generally pursuing decarbonization through the electrification of the transport sector.

Despite the growing trend of increasing biofuel usage as a means of decarbonization, the international market is expected to maintain its current characteristics, with low volumes of biofuels traded until the end of the period. The main reasons for this scenario are: the expectation of increased energy efficiency in vehicles; the widespread pursuit of energy independence; and the imposition of barriers by major producing countries.

As a result, it is estimated that Brazilian ethanol exports will reach 2.8 billion liters by 2034. The export projection mainly considers the participation of sugarcane ethanol in meeting the goals of the U.S. Renewable Fuel Standard (RFS)[10] (EPA, 2023), with the U.S., South Korea, Japan, and the European Union remaining the primary importers of Brazilian ethanol, as described in EPE (2024a).

On the other hand, there is the potential for an increase in these exported volumes if ethanol is directed, either as a product or input, for use in sectors that are difficult to decarbonize, such as aviation, for the production of sustainable fuels via the Alcohol to Jet (AtJ) route, and maritime transport.

[8] Flex units are those that produce ethanol from sugarcane and corn. Full units use only the grain/cereal.

[9] To simplify the analyses conducted in this study, for now, ethanol production from soybeans and cereals is accounted for together with corn.

[10] According to this program, biofuels are classified according to the amount of GHG emitted in the life cycle: renewable (ethanol and biobutanol from corn), advanced (ethanol from sugarcane), biomass diesel (ester or HVO – hydrated vegetable oil) and cellulosic (ethanol and cellulosic bioethanol) (EPA, 2023).

It is estimated that ethanol imports will average around 500 million liters per year throughout the period.

Ethanol for Non-Energy Uses

In Brazil, it is projected that the demand for ethanol for non-energy uses, primarily concentrated in the production of beverages, cosmetics, pharmaceuticals, petrochemicals, and oxygenated compounds (acetic acid, ethyl acetate, and butanol), will reach 1.2 billion liters by 2034.

2.2 Specific Assumptions for Each Scenario

The scenarios developed primarily differ in terms of the economic attractiveness of ethanol production and the competitiveness of hydrated ethanol compared to gasoline C. To this end, the sector's efforts are distinguished by both the improvement of production factors (such as sugarcane productivity and yield, among others) and the expansion of capacity, as well as the intensity of government incentives. This includes efforts to expand biofuel production and contributions to meeting the goals of the 21st Conference of the Parties (COP 21) under the Paris Agreement and, more recently, at COP 29 (BRASIL, 2009, 2024b). The goal is to expand biofuel usage and contribute to the energy transition by reducing GHG emissions. In 2017, the National Biofuels Policy (RenovaBio) was approved, and in 2024, the Future Fuels Law (BRASIL, 2017, 2024).

Specifically, for RenovaBio (BRASIL, 2017), with the establishment of decarbonization targets, it is expected that the mills will be encouraged to produce more biofuels and in a more efficient manner, increasing the supply of CBIOs (Decarbonization Credits) and influencing their market price, where they will be traded. This mechanism is expected to help ensure the security necessary for investments in capacity expansions, new mills, and the adoption of new technologies. On the other hand, the Future Fuels Law (Law No. 14,993/2024), enacted by President Luís Inácio Lula da Silva on October 8, 2024, increased the percentage of anhydrous ethanol in gasoline C and, in addition to setting emission reduction targets through the use of renewable fuels, offered other possibilities for ethanol use, such as in the production of Sustainable Aviation Fuels (SAF) (BRASIL, 2024a). Thus, the aim is to create a favorable environment to increase the participation of biofuels in the national energy matrix.

Thus, each scenario will present a greater or lesser attractiveness for ethanol, which will be reflected in the variation of its production capacity, the different production factors, and technological innovations in the sector. It is assumed that the current ethanol incentive policies will remain throughout the period, such as differentiations in CIDE, PIS/COFINS, and ICMS[11] taxes on ethanol and gasoline in some states, as well as the availability of financing lines.

In all scenarios, it is assumed that the gasoline price will align with international prices, noting that, despite recent fluctuations, it is estimated to follow a stable trajectory for most of the period, with a slight reduction by the end of the decade, as indicated by the "Caderno de Preços Internacionais de Petróleo e seus Derivados" of the PDE 2034 (EPE, 2024d). The mandatory percentage of anhydrous ethanol in gasoline C was maintained at 27% throughout the period[12], the

[11] In 2023, 23 Federation Units presented tax differentiation between hydrous ethanol and gasoline C (CONFAZ/MF, 2024; EPE, 2024a).

[12] The Fuel of the Future Law established that the minimum and maximum limits of the mixture of anhydrous ethanol with gasoline sold are 22% and 35%, respectively (BRASIL, 2024).

value in effect at the time of this study's preparation. Sensitivity analyses will be conducted with 30% anhydrous ethanol content starting in 2026.

The following presents the differentiating factors between the scenarios, which were constructed based on the various factors mentioned earlier, resulting in the expansion and/or reduction of ethanol production capacity and the growth trajectories of sugar.

Ethanol Production Capacity from Sugarcane and Corn

In the early 2000s, several sugarcane production units were established due to the growing demand for ethanol from flex-fuel vehicles and sugar in the international market. In the following years, sector groups faced significant indebtedness, investments were reduced, and many units ceased operations. More recently, some mills were reactivated, and a few greenfield projects emerged (EPE, 2024a).

Regarding ethanol from corn, since 2018, several units have started operations, and existing units have expanded their capacity, leading to significant growth in production (MAPA, 2024; UNICA, 2024). The time required to establish such units is around two years, which is relatively shorter than the estimated time for sugarcane units. Furthermore, the raw material is sourced directly from grain producers, eliminating the need for the mill to own land. Unlike sugarcane, corn can have up to three harvests annually, rotating with soybeans and/or other grains and cereals. Given the rapid expansion of corn processing for ethanol, one key concern for the coming years is the availability of biomass for energy generation. The Annex provides historical data.

The sugarcane mills are adjusting their financial condition and, in recent years, have been driven by the attractiveness of sugar in the international market (CONAB, 2024a; MAPA, 2024; USDA, 2024). The investments to be made aim to expand crystallization capacity, improve sugarcane fields, co-generation, yeast production, biogas, second-generation ethanol, and carbon capture. The production of SAF (Sustainable Aviation Fuel) through the *Alcohol-to-Jet* (AtJ) route and fuels for the maritime sector are also ways to leverage their potential. It is understood that the opportunities observed for the mills already in operation will involve relatively low risks and CAPEX and may compete, in terms of investment priorities, with *greenfield* projects.

Regarding second-generation ethanol (E2G) [13], Brazil currently has commercial plants: Bioflex-I by Granbio[14] in São Miguel dos Campos, with a nominal capacity of 30 million liters/year, and Raízen's plants in Piracicaba (SP) with 42 million liters/year and in Guariba with 82 million liters/year. The company has already announced the construction of seven more projects, all with a capacity of 82 million liters, five of which are expected to be operational by 2027. The company has communicated agreements to sell 460 million liters of E2G over nine years and plans to build additional units and license the technology (GRANBIO, 2024; RAÍZEN, 2023, 2024a).

For each scenario, a variation in the ethanol production capacity was considered, based on actions from sector agents and government incentives. The graphs and tables below summarize the expansion hypotheses for ethanol production capacity, based on May 2024 data. As stated in item 2.1, for all scenarios, the entry of units with construction and expansion authorizations registered by the ANP (2024b) is included.

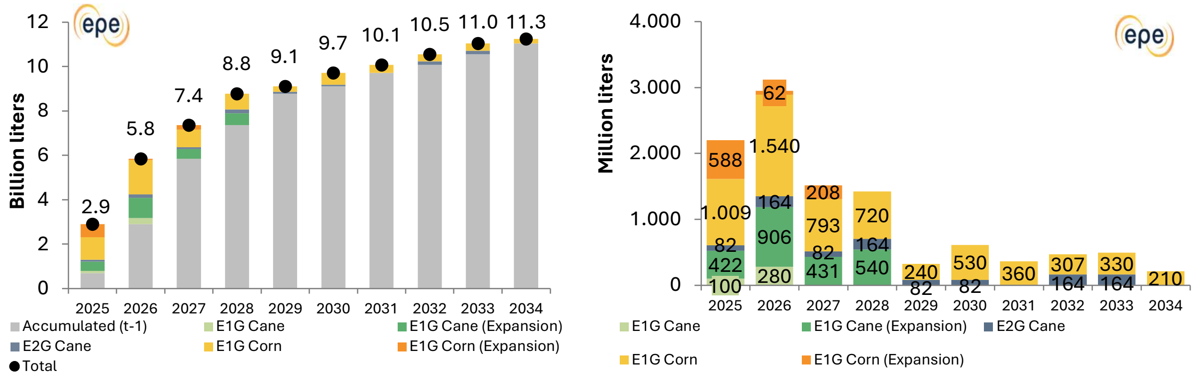
[13] There is the experimental plant of the Sugarcane Technology Center (CTC), with a capacity of 3 million liters/year.
[14] The Granbio plant has not produced lignocellulosic ethanol since the 2021/22 harvest.

Regarding the new indicative units (greenfields) from sugarcane, they were estimated only for the high scenario, with an average nominal milling capacity of 4.0 million tons of cane (Mtc) (LNBR, 2022). In the case of corn ethanol, in addition to announced projects that are not yet listed in the ANP, a locational and financial analysis was conducted for possible new investments, only for the medium and high scenarios, with Mato Grosso as the main production center (full), as well as sugarcane mills located in the main corn-producing regions and owned by financially sound groups, which could become flex mills. For second-generation ethanol (E2G), based on its valuation in the international market, the entry of units with an average specific capacity of 82 million liters is projected, according to the conditions of the different scenarios.

Medium Growth Scenario (Reference)

The medium growth scenario considers the entry of two sugarcane units and one reactivation, with construction authorized by the ANP, which increases the nominal milling capacity by 4.5 million tons (380 million liters for ethanol production). The authorized ethanol production expansions (ANP) total 2.3 billion liters. For corn, the expansions and plants authorized by the ANP result in an increase in capacity of 3.9 billion liters (ANP, 2024b), in addition to an indicative increase (new units and/or expansions) of 3.0 billion liters, with the majority being full-type plants. The processing capacity increases by 15 million tons. The increase in second-generation ethanol (E2G) production capacity will be 1.0 billion liters by 2034, from 13 producing units. The balance of sugarcane and corn ethanol[15] production units, in terms of installed production capacity, can be observed in Graph 1.

Graph 1 – Balance of Installed Ethanol Production Capacity – Medium Growth Scenario



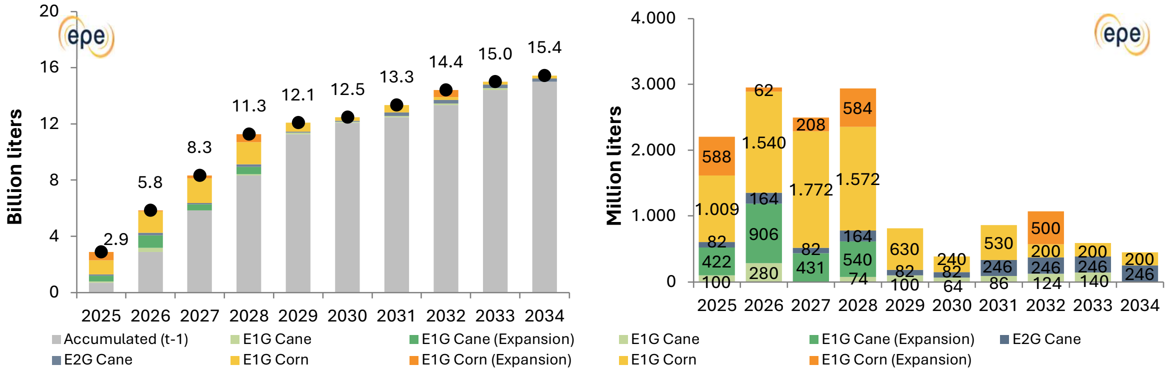
Source: EPE (Prepared by the authors)

High Growth Scenario

The high growth scenario considers the entry of sugarcane units with construction authorization from the ANP and one indicative unit, which increase the nominal milling capacity by 8.5 million tons (520 million liters of ethanol production). The balance from reactivations will be 8.7 million tons (450 million liters). The expansion (ANP) in ethanol production total 2.3 billion liters. For corn, the expansions and plants authorized by the ANP result in an increase in capacity of 3.9 billion liters (ANP, 2024b), in addition to an indicative increase (new units and/or expansions) of 4.9 billion liters, with the majority being full-type plants. The processing capacity increases by 23 million tons. Most of these units will be full-type. The increase in E2G production capacity will be 1.6 billion liters by 2034, from 20 producing units. The balance of sugarcane and corn ethanol production units, in terms of installed production capacity, is presented in the Graph 2.

[15] For all scenarios, it is considered that there will be an expansion and/or entry into operation of 0.6 billion liters referring to corn and 82 million liters of E2G in 2024.

Graph 2 – Installed ethanol production capacity balance – high growth scenario

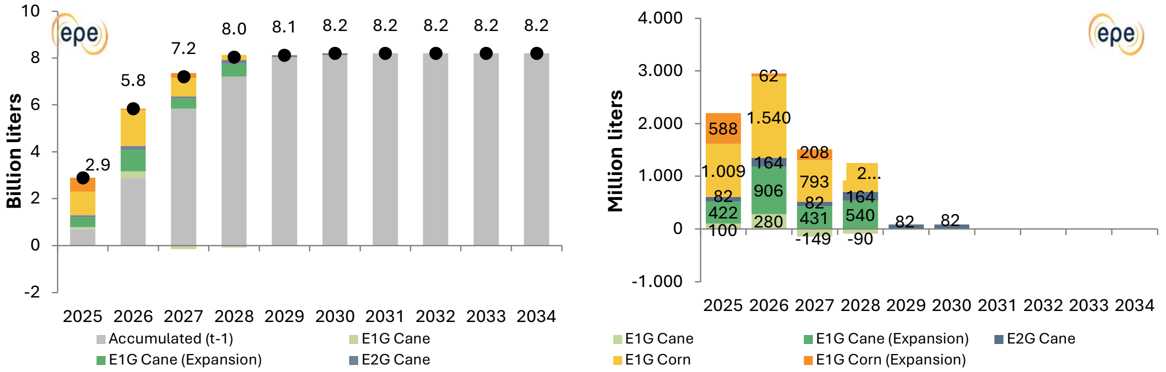


Source: EPE (Prepared by the authors)

Low growth scenario

The low growth scenario considers the entry of sugarcane units with construction authorized by ANP, which increase the nominal milling capacity by 4.5 million tons (380 million liters of ethanol production). The balance of closures will result in a decrease of 3 million tons (240 million liters of ethanol). The expansion (ANP) of ethanol production totals 2.3 billion liters. In the case of corn, the expansions and implementations authorized by ANP result in an increase in capacity of 3.9 billion liters (ANP, 2024b), in addition to an indicative (new units and/or expansions) of 0.6 billion liters, mostly of the full type. The processing capacity increases by 10 million tons. The increase in E2G production capacity will be 0.7 billion liters in 2034, from 8 producing units. The balance of sugarcane and corn ethanol production units, in terms of installed production capacity, is illustrated in the Graph 3.

Graph 3 - Installed ethanol production capacity balance[16] – low growth scenario

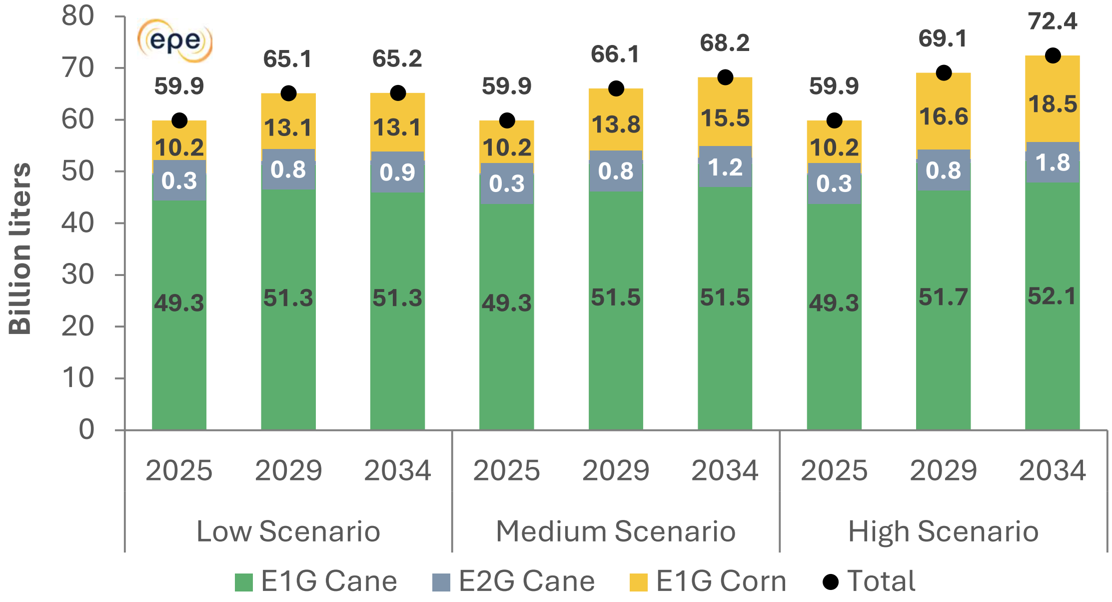


Source: EPE (Prepared by the authors)

[16] For the case of the low scenario, for simplicity, the E1G Cana denomination encompasses the units with construction authorization by the ANP together with the stoppages, projected to occur in 2027 and 2028 (graph on the right).

Graph 4 shows the nominal ethanol production capacities from sugarcane (1G and 2G) and corn, based on the previously made considerations, for the low, medium, and high growth scenarios.

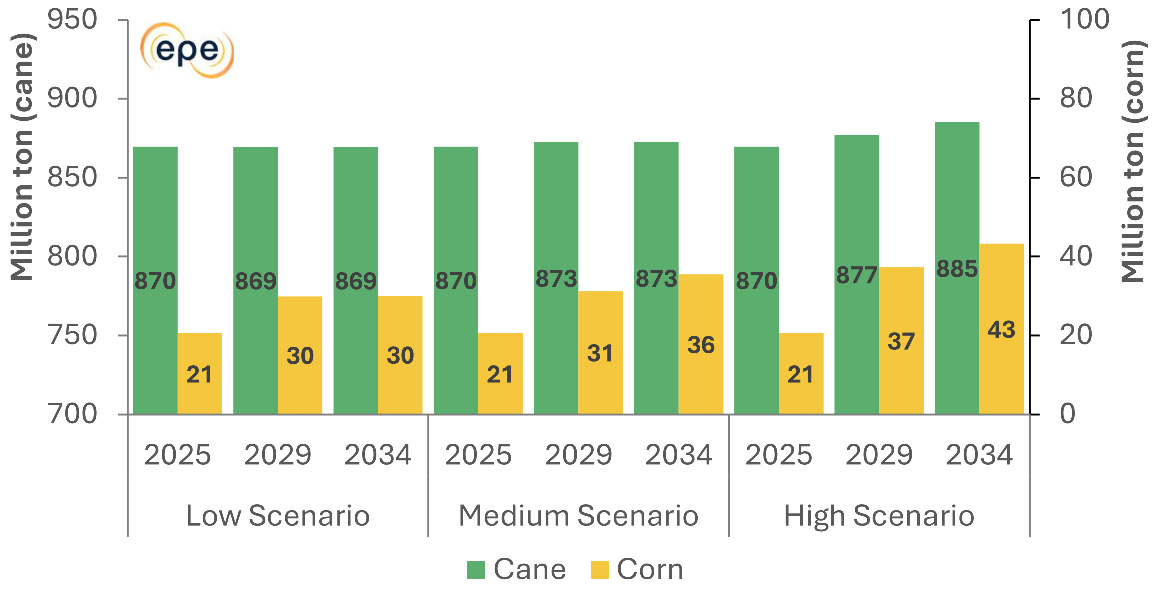
Graph 4 - Ethanol Production Capacity (Sugarcane and Corn)



Source: EPE (Prepared by the authors)

Finally, Graph 5 presents the nominal processing capacities of sugarcane and corn, based on the previously made considerations, for the low, medium, and high growth scenarios.

Graph 5 - Ethanol Production Capacity (Sugarcane and Corn)



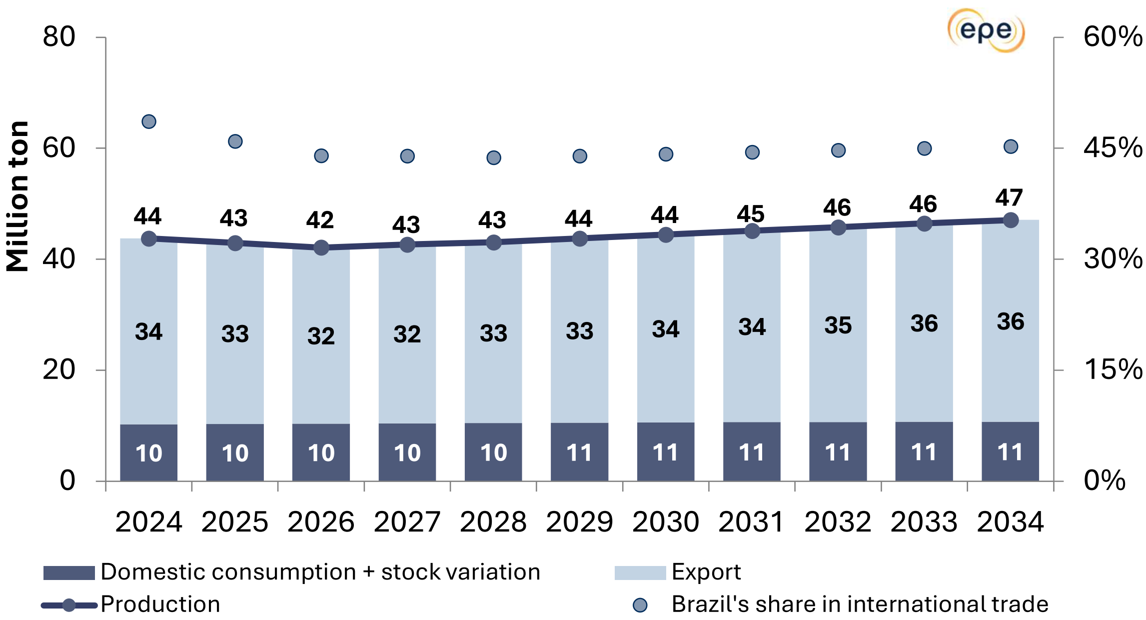
Source: EPE (Prepared by the authors)

Sugar

The projection for Brazil's sugar production consists of two components: domestic consumption and exports. Domestic consumption considers the evolution of per capita consumption in Brazil (kg/capita/year) and is related to factors such as income, population aging, and changes in dietary habits. Regarding the international market, Brazil is the leading player, responsible for more than 40% of the global market for this commodity, followed by India, Thailand, and the European Union (FAO, 2012, 2023; ISO, 2023).

For the medium and low growth scenarios, it was assumed that per capita domestic consumption of sugar will remain around 48 kg/capita/year throughout the period (FAO, 2012, 2023; ISO, 2023, MAPA, 2024). The export projection for the commodity was estimated based on the assumption that Brazil's share in the global trade flow will remain high, at 45% in 2034 (FAO, 2023). As a result, the projected growth rate for sugar production from 2024 to 2034 is 0.7% per year, reaching 47.1 million tons in 2034, as shown in Graph 6 below.

Graph 6 - Production of sugar (reference scenario)



Source: EPE (Prepared by the authors)

For the high growth scenario, the estimated sugar production reaches 50.1 million tons by 2034, with Brazil's share in the global trade flow reaching 48%.

3. Results – Supply Expansion Studies

The results of the projections for harvested area, productivity, processed cane and corn, total ATR produced, ethanol supply (cane and corn), bioelectricity, biogas, GHG emissions reduction, and investments for each scenario are presented below.

Climate conditions have a significant influence on cane productivity, and consequently, on processed cane and total recoverable sugars (ATR). Outliers can be observed in the historical productivity data (Graph 8) for the 2021/22 and 2023/24 harvests, which resulted from extreme weather conditions, unfavorable and favorable, respectively. CONAB's (2024a) expectation for the 2024/25 harvest productivity is lower than the previous period.

Processed Cane Area

Based on assumptions of installed capacity and the establishment of new units, projections for the processed cane area show the growth rates indicated in Table 1 and in Source: EPE (projections) and CONAB (2024a, 2024b) (historical)

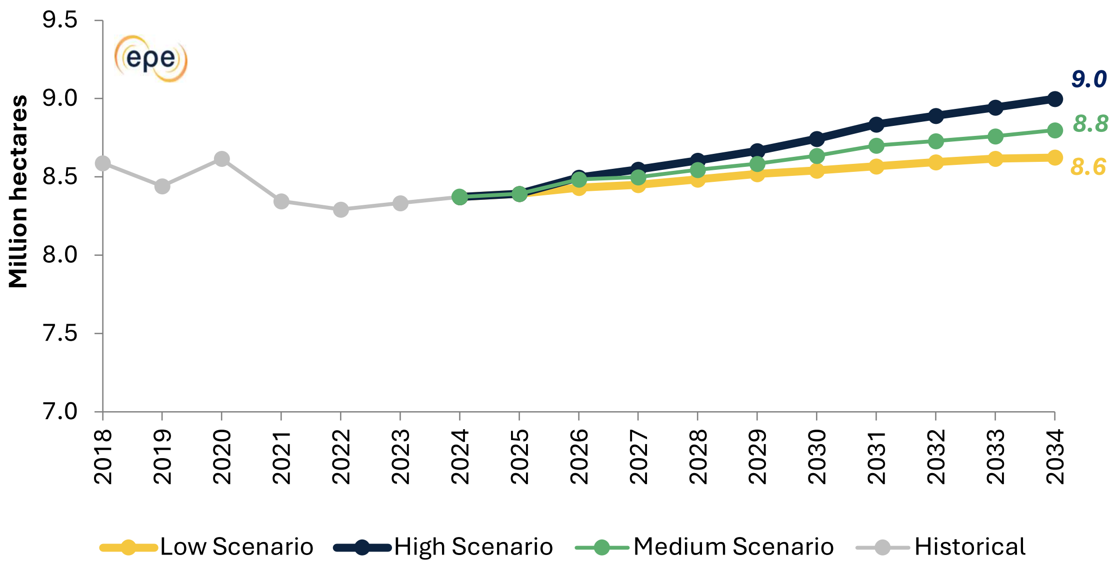
Graph 7.

Table 1 - Growth Rate and Variation in Processed Cane Area

	2024 - 2029		2024 – 2034	
Scenarios	**Rate (%)**	**Variation (Mha)**	**Rate (%)**	**Variation (Mha)**
Low Growth	0.3	0.1	0.3	0.3
Medium Growth	0.5	0.2	0.5	0.4
High Growth	0.7	0.3	0.7	0.6

Source: EPE (projections) and CONAB (2024a, 2024b) (historical)

Graph 7 - Processed Cane Area



Source: EPE (projections) and CONAB (2024a, 2024b) (historical)

Sugar Cane Productivity

For the projection, according to the qualitative assumptions described for each scenario, the variations in productivity obtained are presented in Table 2 and in Source: EPE (projections) and CONAB (2024a, 2024b) (historical)

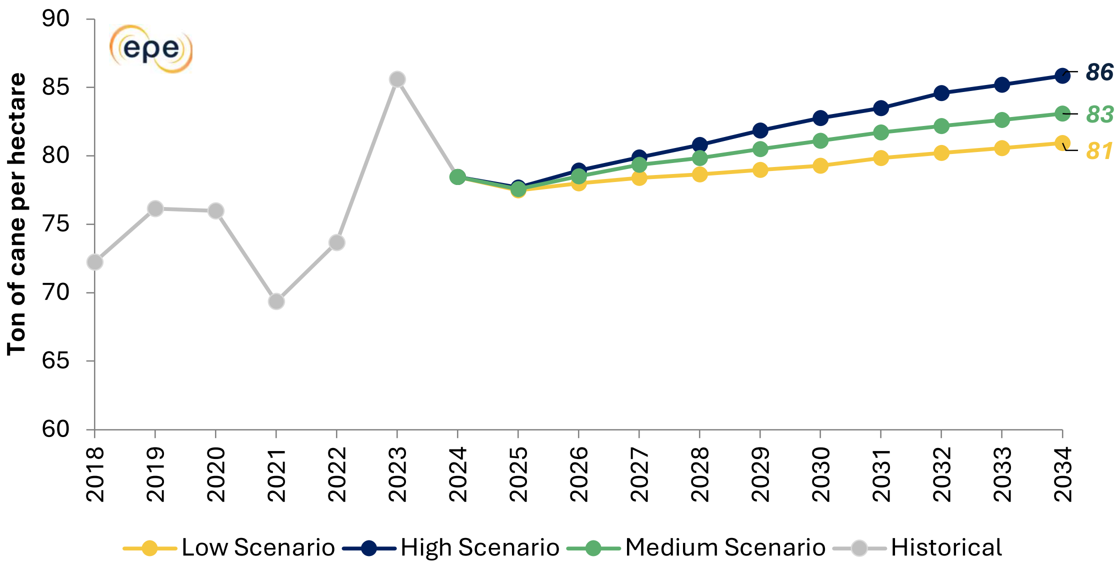
Graph 8 below:

Table 2 - Growth Rate and Productivity Variation

	2024 - 2029		2024 – 2034	
Scenarios	**Rate (%)**	**Variation (ton/ha)**	**Rate (%)**	**Variation (ton/ha)**
Low Growth	0.1	0.5	0.3	2.5
Medium Growth	0.5	2.0	0.6	4.6
High Growth	0.9	3.4	0.9	7.4

Source: EPE (projections) and CONAB (2024a, 2024b) (historical)

Graph 8 - Sugarcane Productivity



Source: EPE (projections) and CONAB (2024a, 2024b) (historical)

Processed Cane

Based on the estimates of area and productivity, the projection of processed cane for the study horizon is obtained. The projections for each scenario are presented in Table 3 and in Source: EPE (projections) and MAPA (2024) (historical)

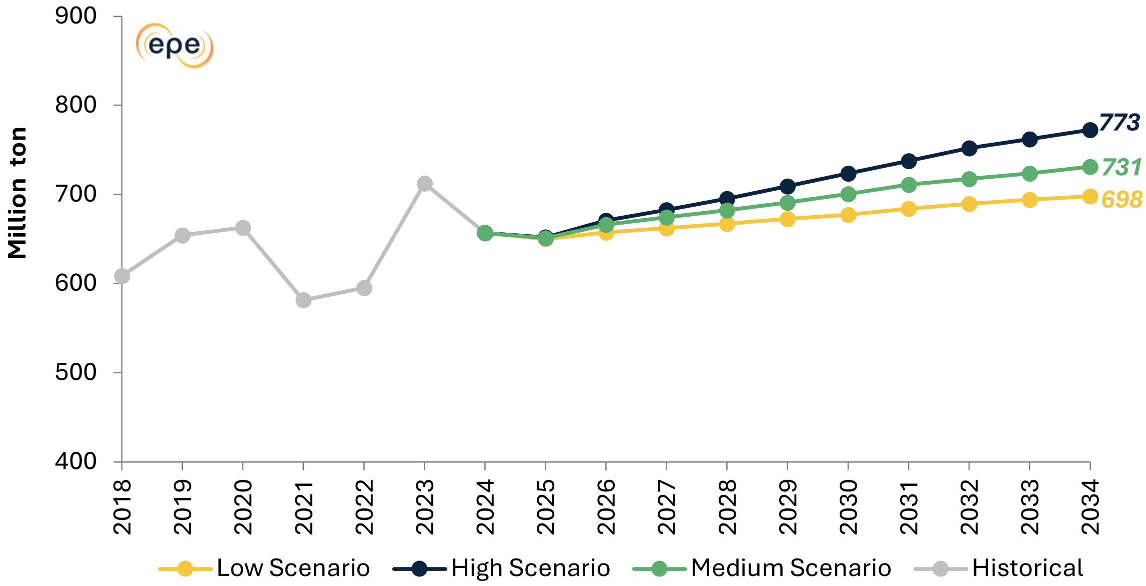
Graph 9.

Table 3 - Growth Rate and Variation of Processed Cane

	2024 - 2029		2024 – 2034	
Scenarios	**Rate (%)**	**Variation (Mton)**	**Rate (%)**	**Variation (Mton)**
Low Growth	0.5	16	0.6	41
Medium Growth	1.0	34	1.1	74
High Growth	1.6	53	1.6	116

Source: EPE (projections) and MAPA (2024) (historical)

Graph 9 - Processed Cane



Source: EPE (projections) and MAPA (2024) (historical)

In 2034, it is estimated that 384 million tons of sugarcane will be allocated to ethanol in the medium scenario (53%), 351 million in the low scenario (50%), and 403 million in the high scenario (52% - higher sugar production).

Total ATR

As a result of the composition of area, productivity, and yield, the total ATR produced will vary for each scenario, according to the assumptions for each of these production factors. Table 4 and

Source: EPE (projections) and CONAB (2024a, 2024b), MAPA (2024) (historical)

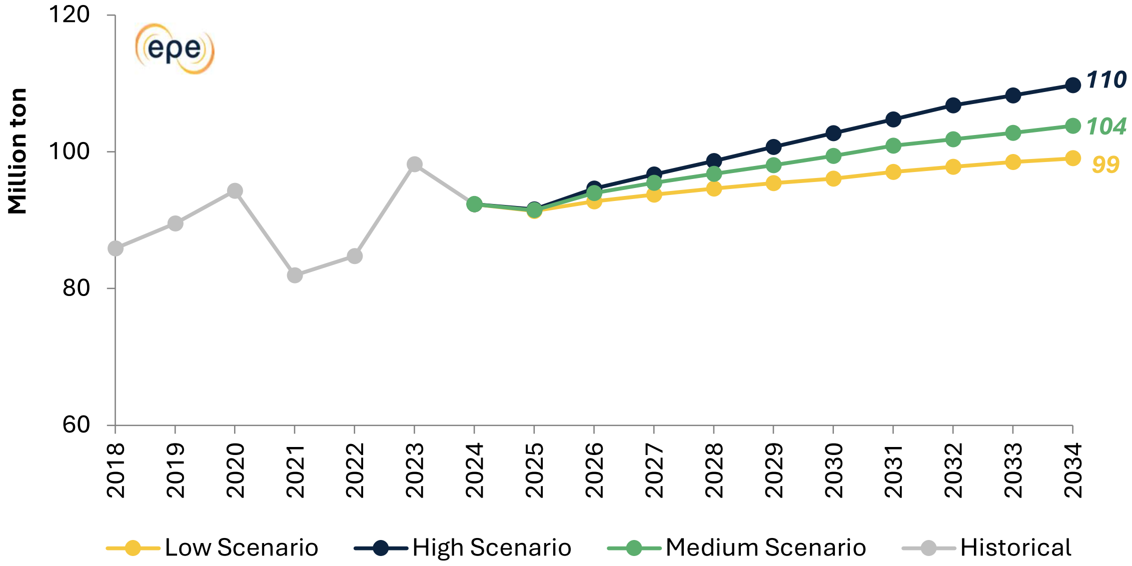
Graph 10 below present the growth rate and variation of total ATR between 2024 and 2034.

Table 4 - Growth Rate and Variation of ATR

	2024 - 2029		2024 – 2034	
Scenarios	**Rate (%)**	**Variation (Mt)**	**Rate (%)**	**Variation (Mt)**
Low Growth	0.7	3.1	0.7	6.7
Medium Growth	1.2	5.7	1.2	11.5
High Growth	1.7	8.4	1.7	17.4

Source: EPE (projections) and CONAB (2024a, 2024b), MAPA (2024) (historical)

Graph 10 - Total Recoverable Sugars (ATR) Quantity



Source: EPE (projections) and CONAB (2024a, 2024b), MAPA (2024) (historical)

Corn Processing

The projection of corn processing[17][18] for ethanol production is summarized in Table 5 and in Source: EPE (projections) and ANP (2024c), CONAB (2024a), MAPA (2024) (historical)

Graph 11 below.

Table 5 - Growth Rate and Variation of Corn Processing for Ethanol Production

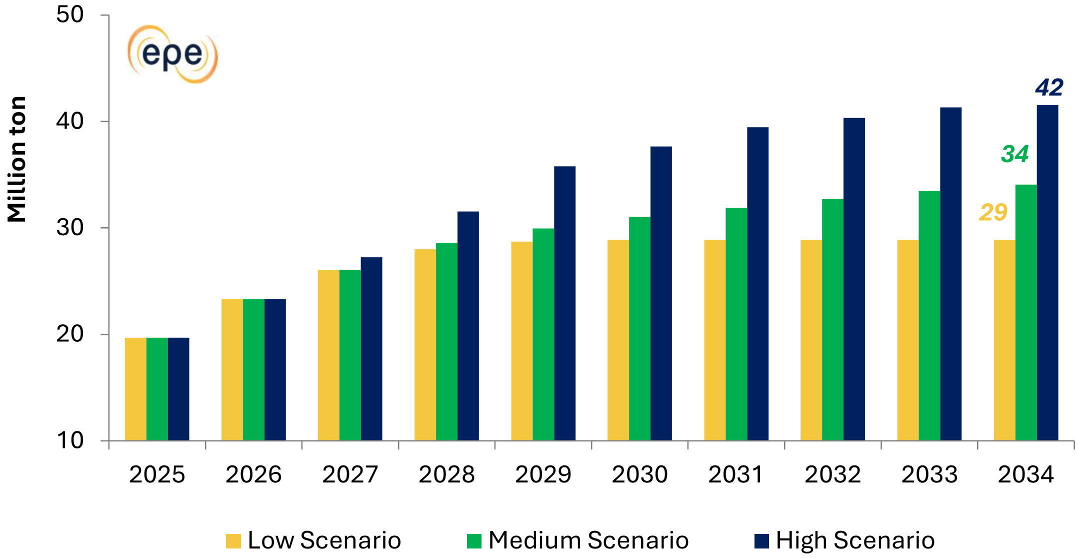
	2024 – 2029		2024 – 2034	
Scenarios	**Rate (%)**	**Variation (Mton)**	**Rate (%)**	**Variation (Mton)**
Low Growth	10.6	11.4	5.2	11.5
Medium Growth	11.5	12.6	7.0	16.7
High Growth	15.6	18.4	9.2	24.4

Source: EPE (projections) and ANP (2024c), CONAB (2024a), MAPA (2024) (historical)

[17] The processing of corn for ethanol production is estimated based on 420 liters of ethanol/ton of corn and a utilization factor of 95%.

[18] In 2034, for the indicated corn processing, the total DDGS varies from 11.0 to 15.9 million tons between the low and high scenarios (factor of 380 kg DDGS/ton corn, according to VIEIRA (2022) *apud* WYMAN (1996)). For corn oil, the value is between 0.5 and 0.8 million tons (factor of 18 kg/ton corn, according to IMEA (2017)).

Graph 11 – Corn Processing for Ethanol Production



Source: EPE (Prepared by the authors)

Total Ethanol Supply

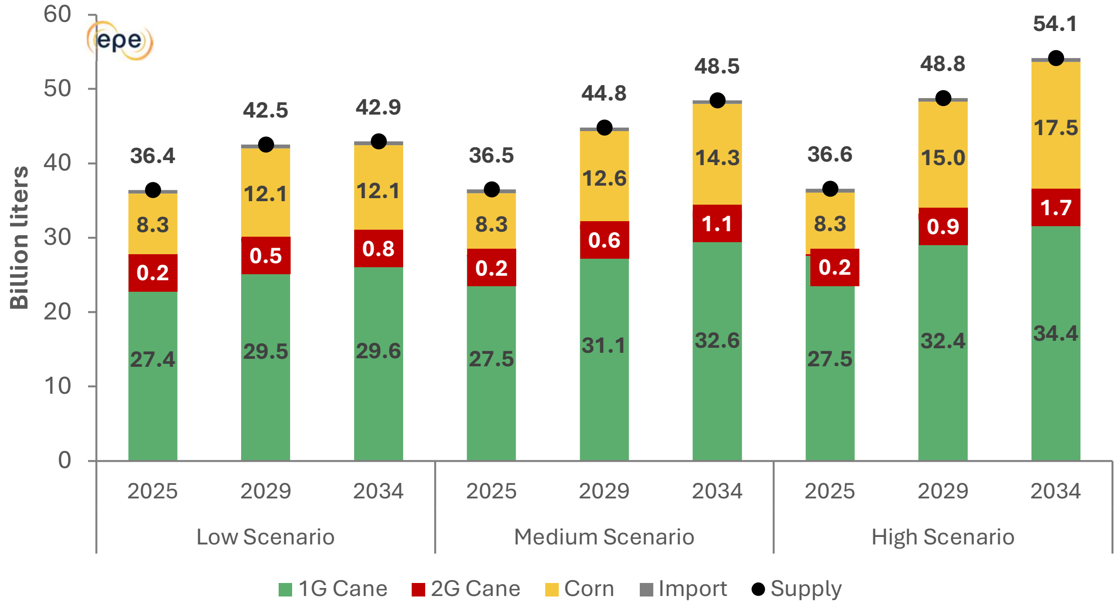
Finally, from the produced ATR, the portion allocated to sugar (as presented in Item 0) is deducted, and the ethanol production from corn and second-generation cane is included, resulting in the national ethanol production. By adding imported ethanol, the total ethanol supply is obtained. Table 6 and Source: EPE (projections) and CONAB (2024a, 2024b), MAPA (2024), ME (2024) (historical) Graph 12 present the growth rates and variations in the total ethanol supply.

Table 6 - Growth Rate and Variation in Total Ethanol Supply

	2024 – 2029		2024 – 2034	
Scenarios	Rate (%)	Variation (Bi litros)	Rate (%)	Variation (Bi litros)
Low Growth	3.7	7.1	1.9	7.5
Medium Growth	4.8	9.4	3.2	13.1
High Growth	6.6	13.4	4.3	18.7

Source: EPE (projections) and CONAB (2024a, 2024b), MAPA (2024), ME (2024) (historical)

Graph 12 - Total ethanol supply by feedstock



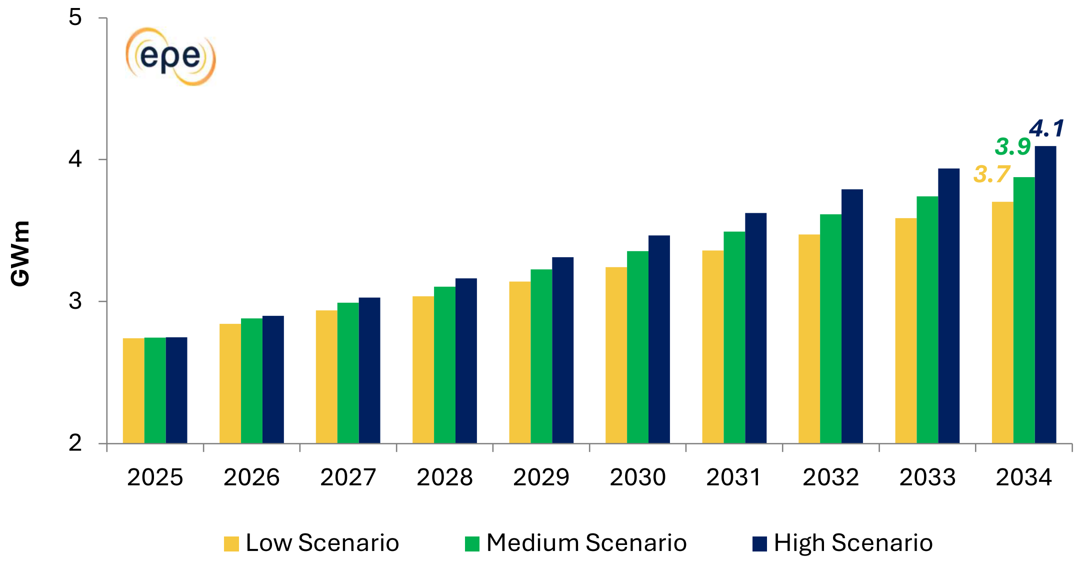
Source: EPE (Prepared by the authors)

Bioelectricity

Based on the projection of sugarcane biomass supply, the study made two estimates of the bioelectricity supply to the grid: (1) the bioelectricity export curve based on the historical behavior of the sector[19] and (2) the technical potential calculation, based on data from the energy auction-winning plants (CCEE, 2024).

Based on the historical behavior of the sugar-energy sector, the amount injected into the National Interconnected System (SIN) in 2034 is 4.1 GWm, 3.9 GWm, and 3.7 GWm, respectively, for the high, medium, and low growth scenarios, as shown in Graph 13 below.

Graph 13 - Projection of Bioelectricity from History (Conversion Curve)

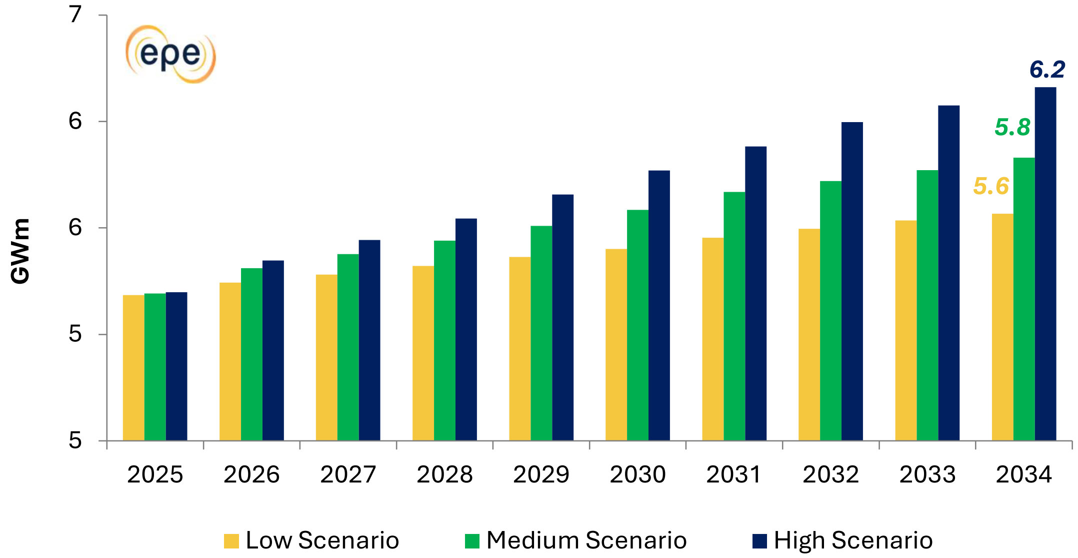


Source: EPE (Prepared by the authors)

The projections of the technical potential presented in Graph 14 illustrate that the total amount of bioelectricity from sugarcane injected into the grid in 2034 could vary from 5.6 GWm to 6.2 GWm, representing the low and high growth scenarios, respectively.

[19] This methodology accounts for the entire national sugar-energy park, including all sugarcane processed in the country and all energy exported by the sector. The export factors used were 69.86 kWh/tc for the technical potential and a variation from 36.01 kWh/tc to 46.46 kWh/tc, between 2024 and 2034 respectively, for the bioelectricity export curve based on historical behavior.

Graph 14 - Projection of bioelectricity from technical potential



Source: EPE (Prepared by the authors)

Biomethane from sugarcane biomass

The cultivation of sugarcane and its processing for ethanol and sugar production generates a large amount of organic waste in the form of vinasse, filter cake, and leaves and tops, the utilization of which optimizes the energy content of sugarcane. The fermentation of these residues results in biogas[20], which is primarily composed of methane (CH4, 55 – 70% v/v) and carbon dioxide (CO2, 30 – 45% v/v). Vinasse biogas is characterized by a relatively high presence of hydrogen sulfide (H2S, 200 – 4000 ppm/v), an impurity with potentially harmful effects on equipment.

The cleaning of contaminants and upgrading of biogas result in biomethane, a standardized biofuel considered interchangeable with natural gas if it meets the ANP[21] regulatory requirements. It can be used in combustion engines adapted or originally designed to run on gas in trucks and agricultural machinery, marketed as compressed or liquefied gas (CNG/LNG), or injected into natural gas networks.

This study initially presents the potential for biomethane production. The estimates consider that all vinasse[22] and filter cake will be directed toward biogas production, based on the availability of residues derived from the ethanol production scenarios presented.

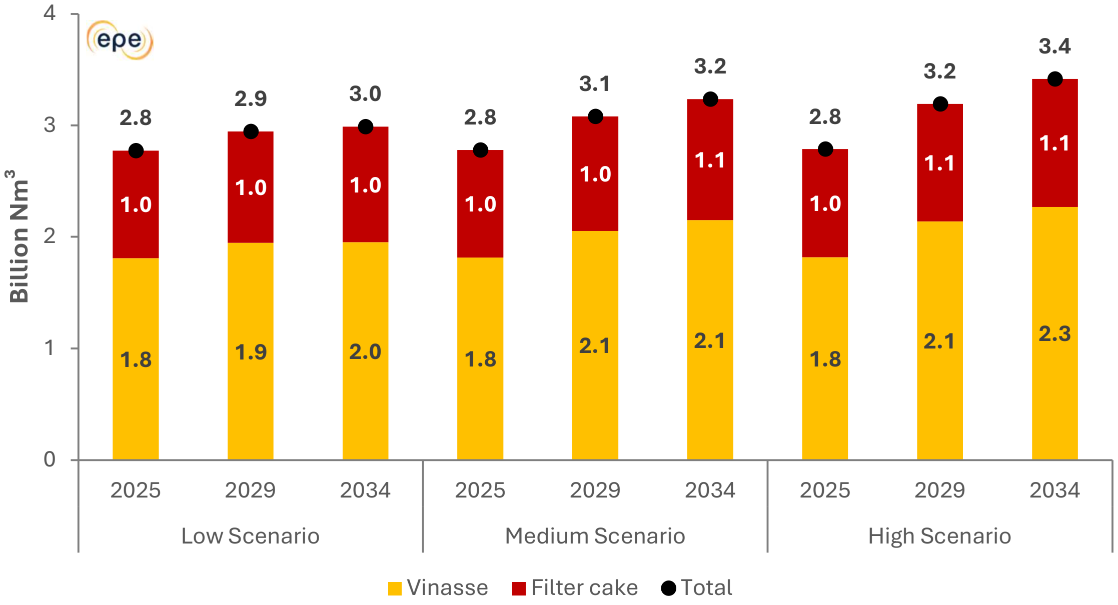
Under these assumptions, the potential volume of biomethane is estimated to range from 3.4 billion Nm^3 to 3.0 billion Nm^3 per year for the high and low scenarios, respectively, as illustrated in Graph 15.

[20] Parameters: 1 t filter cake = 90-120 Nm^3 biogas; 1 m^3 vinasse = 12-25 Nm^3 biogas and 1 t straw and tips = 240 Nm^3 biogas (ABIOGÁS, 2017).

[21] The minimum permitted concentration of CH4 is 90%. For the sugar-energy sector, ANP Resolution No. 906/2022 is applicable, valid for biomethane from agrosilvopastoral and commercial organic products and waste (ANP, 2022).

[22] Only residual vinasse from the production of first-generation ethanol from sugarcane is adopted.

Graph 15 - Potential for Biogas Production



Source: EPE (Prepared by the authors)

If there is economic viability for harvesting the leaves and tops of the sugar-energy sector, using a fraction of 20% of the total, the biogas potential would range from 6.2 billion Nm³ to 5.4 billion Nm³ per year, for the high and low scenarios, respectively.

It is also possible to observe the potential of plants that belong to the most economically efficient group in the sector[23] (ITAUBBA, 2019; NOVACANA, 2020), which could expedite investments in biomethane production, utilizing residues from sugar-energy plants, such as vinasse and filter cake. In this case, the potential in 2034 ranges from 1.4 billion Nm³ to 1.6 billion Nm³, as shown in Table 7.

Table 7 - Biomethane potential of the most efficient plants [billion Nm³]

Scenarios	2025	2029	2034
Low Growth	1.3	1.4	1.4
Medium Growth	1.3	1.5	1.5
High Growth	1.3	1.5	1.6

Source: EPE (Prepared by the authors)

Conditions for the expansion of sugarcane-based biomethane

In recent years, there has been the successful implementation and announcement of a series of biogas and biomethane production projects from sugarcane residues. The diversity of plants investing in biomethane, not limited to one or a few economic groups, indicates the maturity of this technology—suggesting the possibility of dissemination to new units.

[23] Financial institutions have been reporting a significant improvement in the economic situation of companies in the sugar-energy sector. To carry out a more conservative analysis that reflects the capacity to make new investments, it was decided to maintain the proportion of mills in this group, as observed in previous studies.

The viability of biomethane production businesses benefits from the advancement of public policies. By establishing it as the biofuel with the lowest carbon intensity in RenovaBio, the additional revenue from certified sales is significant. Moreover, the inclusion of biomethane in the REIDI[24] framework allows for a reduction in investment costs for project installations (EPE, 2023).

The Fuel of the Future Law (Law No. 14.993/2024) created the National Decarbonization Program for Natural Gas Producers and Importers and Incentives for Biomethane. The initiative aims to stimulate research, production, commercialization, and use of biomethane and biogas in Brazil's energy matrix. The legal text stipulates that the CNPE will set annual targets for reducing greenhouse gas emissions by the natural gas sector, to be met by producers and importers of natural gas. The program will begin in January 2026 with a pre-established target of 1%, which cannot exceed the limit of 10%.

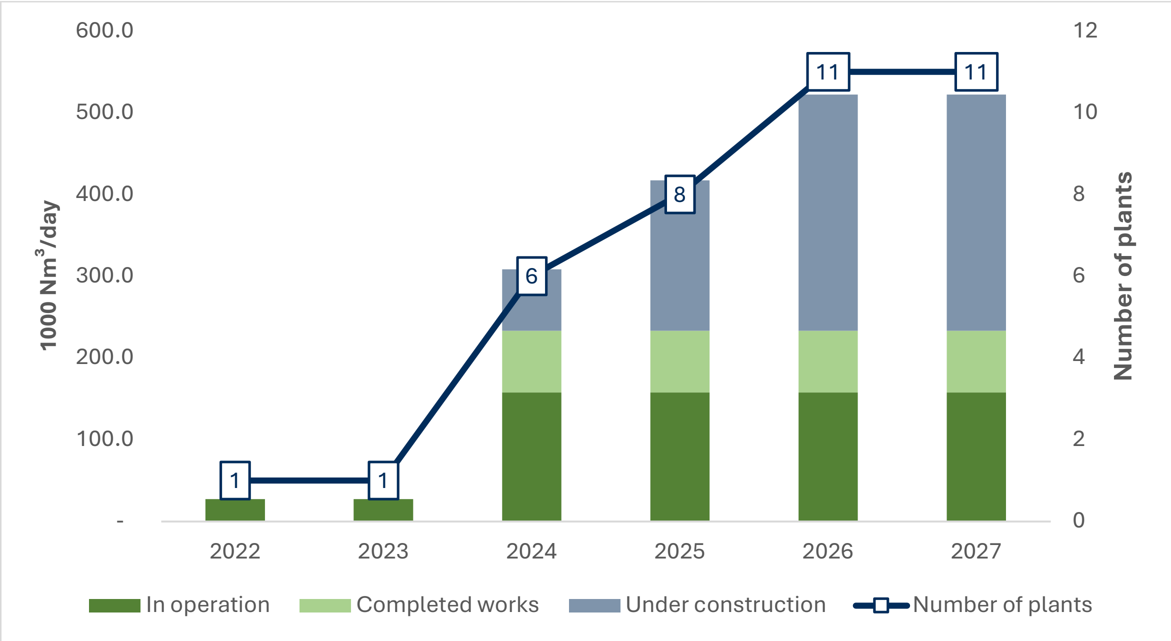
With technological maturity and growing public policy support, a favorable environment is identified for the expansion of biomethane in sugarcane mills in the coming years.

Scenarios for the installation of biomethane production units in sugar-energy plants

For the construction of biomethane plant scenarios, data from the ANP[25] is used as a reference, which records plants authorized to operate and those in the authorization process.

As of early November 2024, there were 8 units in operation, 2 of which were from the sugar-energy sector. Additionally, 31 installations were in the authorization process, and cross-referencing with other information indicates that 9 of them would be from sugarcane[26], as depicted in Graph 16.

Graph 16. Evolution of biomethane installations in the sugar-energy sector registered with ANP



Source: EPE from ANP (2024b)

[24] The Special Incentive Regime for Infrastructure Development suspends the requirement of PIS/PASEP and Cofins on the sale or import of goods and services intended for the works.
[25] According to CIBiogás (2024), there are a number of biomethane production units in "non-commercial" operation, without ANP authorization. These units are not considered in the study.
[26] The ANP records do not inform the raw material of the mills in the authorization process.

With the ANP registration including mills with construction completion expected by the end of 2026, it was assumed for all scenarios that the plants installed by this year will be exclusively those already identified in this database.

Based on recent developments in the sector, three scenarios for implementing projects in sugarcane mills for the 2027-2034 period are proposed, as shown in Table 8.

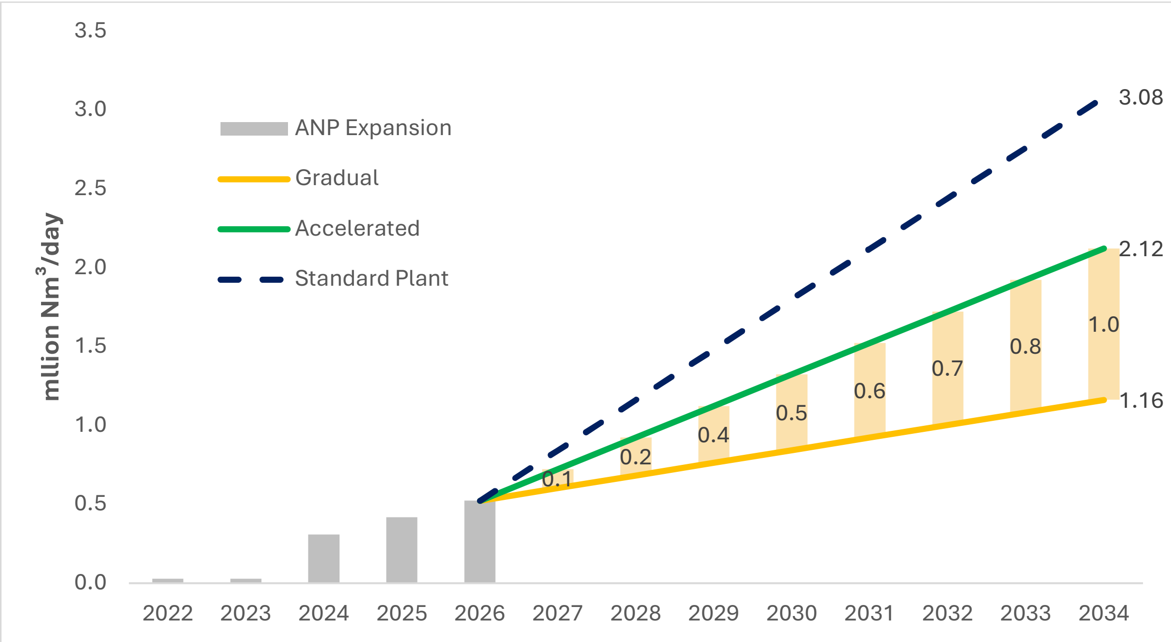
Table 8 - Detailing of scenarios for the entry of biomethane plants

Cenário	Justificativa
Cadenced expansion: 2 new plants per year	Investments impeded by possible barriers, such as: • supply chain constraints; • option for other projects in the plants; • timid demand; • caution of producers, waiting for advanced solutions for the use of biogas, access to infrastructure or wide availability of gas equipment.
Accelerated expansion: 5 new plants per year	Sequence at the pace of new projects observed in 2024, including plants with completed works and/or expected completion by the end of the year, based on ANP records.
Towards the standard plant: 8 new plants per year	Investment in biomethane becoming an inevitable decision in all plants, in a virtuous cycle driven by public policies. Conditions: • successful experiences being disseminated; • advancement in the learning curve with cost reduction and increased productivity; • maintenance of the incentives in force; • implementation of the annual targets of the Fuel of the Future Act.

Source: EPE (Prepared by the authors)

As an estimate of the scale of the new plants, an average value of 40,000 Nm³ of biomethane per day was adopted, close to the average capacity of the plants in the authorization process at ANP. The consolidated result of the scenarios is presented in Graph 17.

Graph 17. Scenarios of installed biomethane capacity in the sugar-energy sector



Source: EPE (Prepared by the authors)

In the gradual expansion scenario, the number of biomethane plants in the sugar-energy sector reaches 27 by 2034, while the accelerated expansion scenario leads to 51. In the scenario where biomethane is viewed as a new product within the portfolio of standard sugarcane mills in the country, the number would reach 75 units by the end of the period. Installed capacity ranges from 1.2 to 3.1 million Nm^3 per day within the study horizon.

Biomethane production by the sugar-energy sector will be a key driver for the significant expansion of this biofuel in Brazil, in combination with biomethane derived from other feedstocks. The contribution of sugarcane mills to the targets that will be established by the CNPE under the Future Fuel program will be the subject of a specific study to be published by EPE.

Avoided Greenhouse Gas Emissions

To estimate the greenhouse gas emissions avoided using sugarcane and corn ethanol (both hydrous and anhydrous), as well as sugarcane-based bioelectricity, as substitutes for fossil fuels, parameters established by the IPCC (2006), RenovaBio (ANP, 2024c), and MCTI (2021) were applied. For sugarcane ethanol, avoided emissions were estimated at 2.56 $kgCO_2eq$/liter for anhydrous ethanol and 1.12 $kgCO_2eq$/liter for hydrous ethanol.

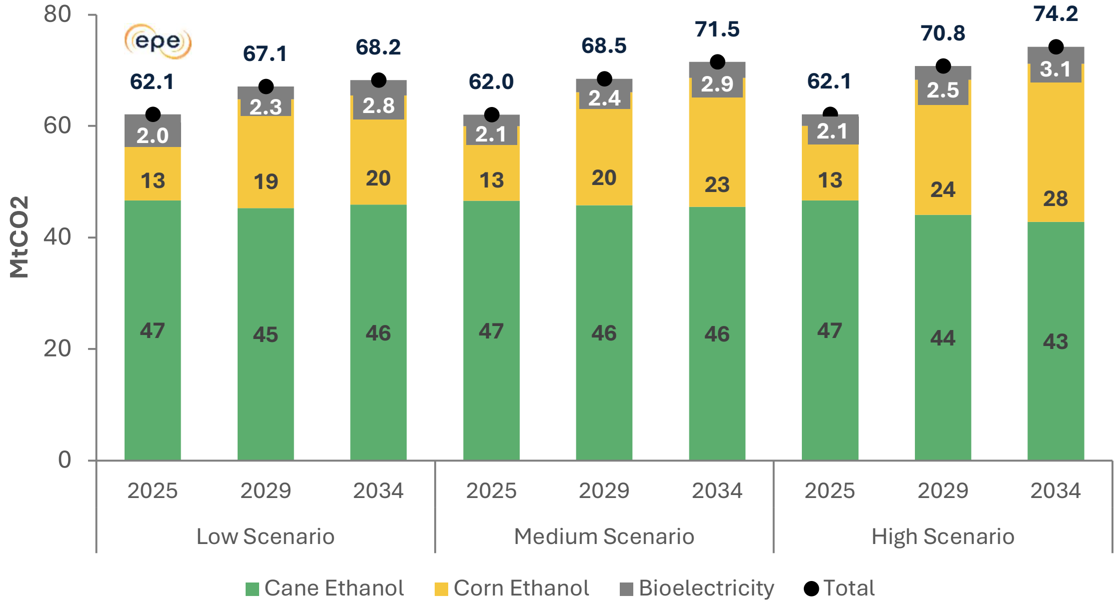
In the case of corn ethanol, data available from RenovaBio served as the basis for calculating the substitution of gasoline A (anhydrous) and gasoline C (hydrous). The avoided emissions factors for this biofuel were 2.33 $kgCO_2eq$/liter (anhydrous) and 1.20 $kgCO_2eq$/liter (hydrous).

For bioelectricity, it is assumed that its generation replaces electricity produced by the National Interconnected System (SIN), whose emission factor varies according to the annual composition of Brazil's electricity matrix. A significant reduction in this factor was observed in 2023, reaching 0.0385 tCO_2/MWh—approximately one-third of the value recorded in 2021, a year marked by severe hydrological stress, when the factor reached 0.1264 tCO_2/MWh.

Adopting the most conservative approach for bioelectricity[27] (Graph 13) and considering the fuel demand for ethanol from both sugarcane and corn, up to 74.1 $MtCO_2$ could be avoided under the high scenario, and 68.2 $MtCO_2$ under the low scenario, as illustrated in Graph 18.

[27] For the projections of emissions avoided with bioelectricity, the factor used corresponds to the annual average of the last ten years.

Graph 18 - Avoided GHG Emissions from Ethanol and Bioelectricity Use



Source: EPE (Prepared by the authors) based on IPCC (2006) and MCTI (2021)

Investments

For the assessment of the required (indicative) investments, mixed first-generation greenfield sugar-energy units were considered, with an optimized technological profile and an average nominal processing capacity of 4 million tonnes. These units are implemented only under the high-growth scenario. The average CAPEX for this type of facility is estimated at BRL 605.8 per tonne of cane (IBGE, 2024; LNBR, 2022; FGV, 2024). For the expansion of existing units, a specific investment value of BRL 271.7 per tonne of cane was adopted (NOVACANA, 2024; FGV, 2024).

The investment estimate for new lignocellulosic ethanol plants was based on the values of recently announced projects in Brazil, estimated at BRL 14.60 per liter (RAÍZEN, 2024b, 2024c).

For corn ethanol, the estimated CAPEX for the implementation of a flex plant is BRL 1.29 per liter, while for a full plant, the value is BRL 2.55 per liter (IBGE, 2024; LNBR, 2022).

Based on these values, an estimate of the required investments in new facilities was made for the scenarios considered, as shown in Table 9.

Table 9 – Estimated investment for new projects and expansions

CAPEX (R$ bilhões)	Low	Medium	High
E1G Cane	5.4	5.4	9.5
E2G Cane	9.6	14.4	24.0
Corn	11.1	17.0	24.9
Total	26.1	36.8	58.4

Source: EPE based on LNBR (2022); FGV (2024), IBGE (2024); NOVACANA (2024) and RAÍZEN (2024b, 2024c)

For further details, refer to the publication “Nota Técnica de Investimentos e Custos Operacionais e de Manutenção no Setor de Biocombustíveis” (EPE, 2024e).

4. Results – Fuel Demand

This section presents the projected evolution of total liquid fuel demand for the light-duty vehicle fleet (passenger cars and light commercial vehicles) running on Otto-cycle engines, across the three ethanol supply scenarios developed. A 27% blend of anhydrous ethanol in gasoline C is assumed throughout the period. A sensitivity analysis considering an increase in the blend ratio to 30%, starting in 2026, will also be presented in Section 5.

Total fuel demand is projected using an accounting model developed by EPE (2010), which considers, in addition to the macroeconomic scenario (EPE, 2024d), various factors such as light vehicle licensing, the introduction of new vehicle technologies (e.g., hybrids and electric vehicles), domestic ethanol supply, domestic gasoline prices, and consumer preference between gasoline and ethanol when refueling flex-fuel vehicles. Further details can be found in “Nota Técnica de Demanda de Energia dos Veículos Leves” (EPE, 2024f).

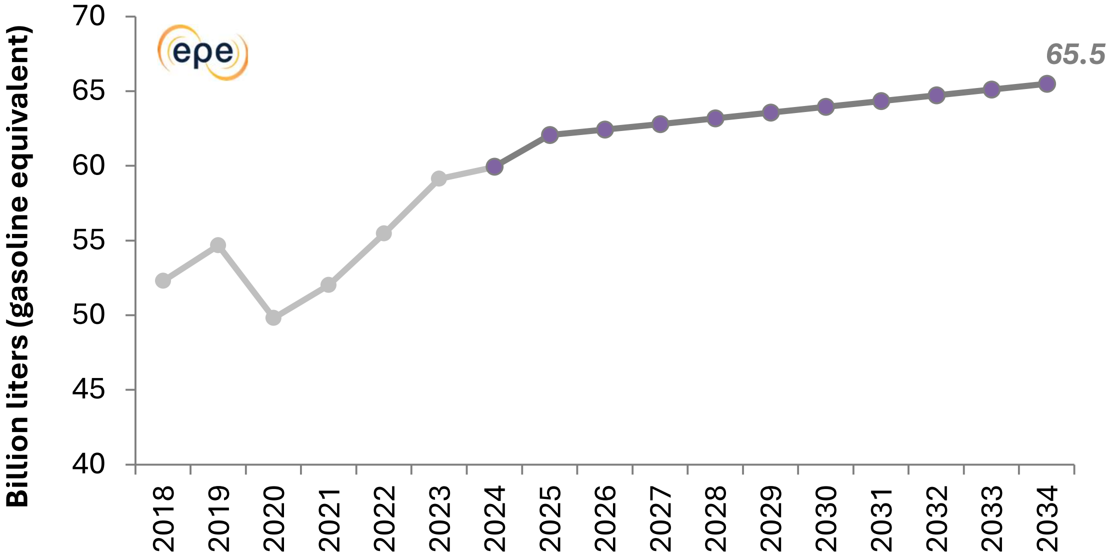
The projected licensing trajectory leads to an increase in the national Otto-cycle vehicle fleet, which grows at an average annual rate of 2.1% from 2024 to 2034, reaching 45.4 million units by 2034. By the end of this period, internal combustion flex-fuel vehicles will account for 82% of the fleet; gasoline-only vehicles, 6.6%; electrified vehicles, 11.2%; and ethanol-dedicated vehicles will represent a residual share.

For the period from 2024 to 2034, the estimated growth rate of fuel demand for the total Otto-cycle light vehicle fleet (excluding CNG[28]) is 0.9% per year, reaching 65.5 billion liters of gasoline equivalent, as shown in Graph 19.

Fuel consumption by Otto-cycle vehicles has shown sustained growth since July 2022. This may be associated with an 11.2% increase in light vehicle licensing and a 16.1% increase in motorcycle licensing in 2023 compared to the previous year. This growth, in turn, reflects a more favorable economic environment, linked, for example, to higher per capita GDP and improved credit conditions. However, it is not yet possible to fully assess the underlying causes. For more information, see EPE (2024f).

[28] It is estimated that the demand for CNG will evolve from 2.7 billion to 3.8 billion liters of gasoline equivalent between 2024 and 2034.

Graph 19 – Otto cycle demand (without GNV)



Source: EPE (Prepared by the authors)

Fuel ethanol

Fuel ethanol demand is derived from the total ethanol supply, subtracting the volumes allocated for exports and other uses, as presented in the Common Assumptions section (2.1). From the remaining volume, the demand from dedicated fleets running on gasoline C and hydrous ethanol was estimated, as well as the share of flex-fuel vehicle demand that will be met by hydrous ethanol and by gasoline C (composed of gasoline A and anhydrous ethanol).

Table 10 and Source: EPE (projections) and EPE (2024b) (historical)

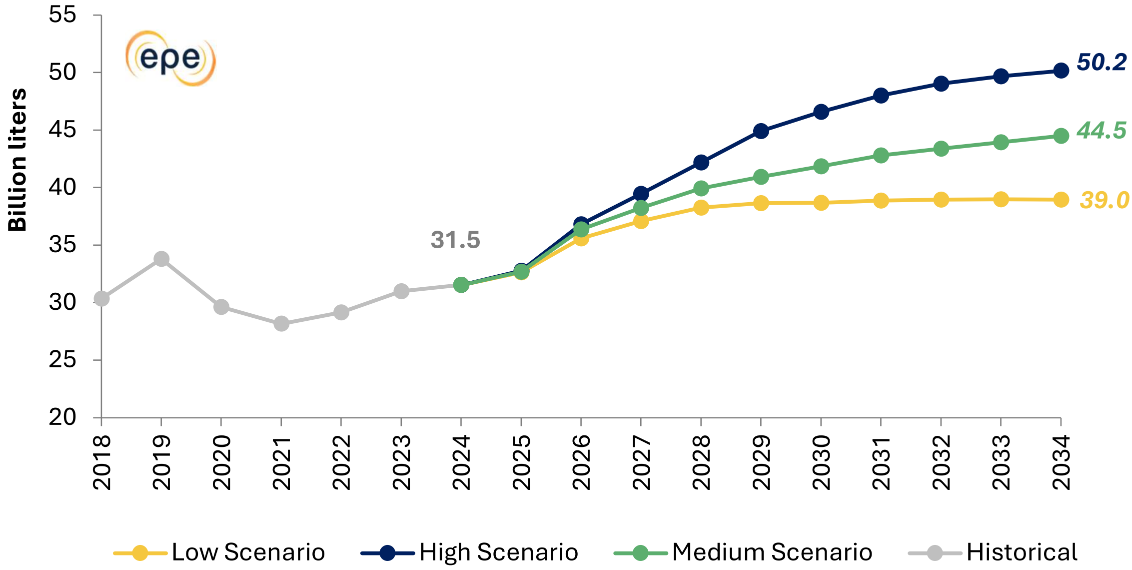
Graph 20 present the growth rates and variations in fuel ethanol demand between 2024 and 2034.

Table 10 – Growth rate and variation (in billion liters) of fuel ethanol demand

	2023 - 2029		2023 – 2034	
Scenarios	**Rate (%)**	**Variation (Bi liters)**	**Rate (%)**	**Variation (Bi liters)**
Low Scenario	4.1	7.1	2.1	7.4
Medium Scenario	5.4	9.4	3.5	13.0
High Scenario	7.3	13.4	4.8	18.6

Source: EPE (projections) and EPE (2024b) (historical)

Graph 20 – Fuel ethanol demand



Source: EPE (projections) and EPE (2024b) (historical)

Gasolina A

Gasoline A, when blended with anhydrous ethanol (forming gasoline C), serves both dedicated fleets and a portion of the flex-fuel fleet. It is estimated that, in 2034, the volume of fossil gasoline will reach 30.9 billion liters under the medium growth scenario — a level similar to that observed in 2022. A Table 11 and Source: EPE (projections) and EPE (2024b) (historical)

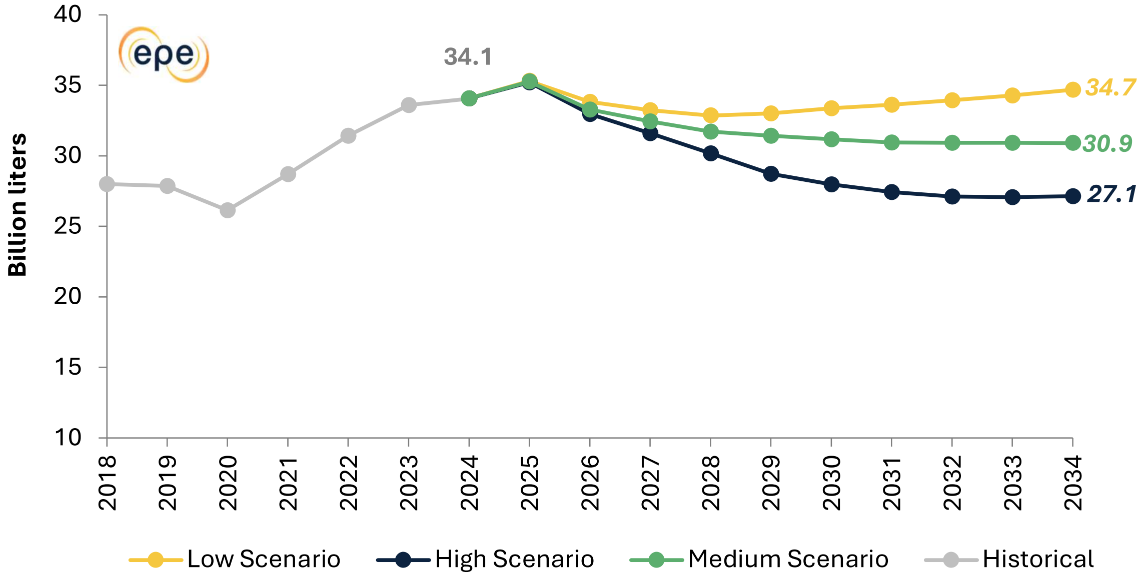
Graph 21 present the growth rates and changes in gasoline A demand between 2024 and the years 2029 and 2034.

Table 11 - Growth Rate and Variation in Gasoline A Demand

	2023 - 2029		2023 – 2034	
Scenarios	Growth Rate (%)	Volume Change (Bn liters)	Growth Rate (%)	Volume Change (Bn liters)
Low Scenario	-0.6	-1.1	0.2	0.6
Medium Scenario	-1.6	-2.7	-1.0	-3.2
High Scenario	-3.4	-5.4	-2.3	-6.9

Source: EPE (projections) and EPE (2024b) (historical)

Graph 21 - Gasoline A Demand

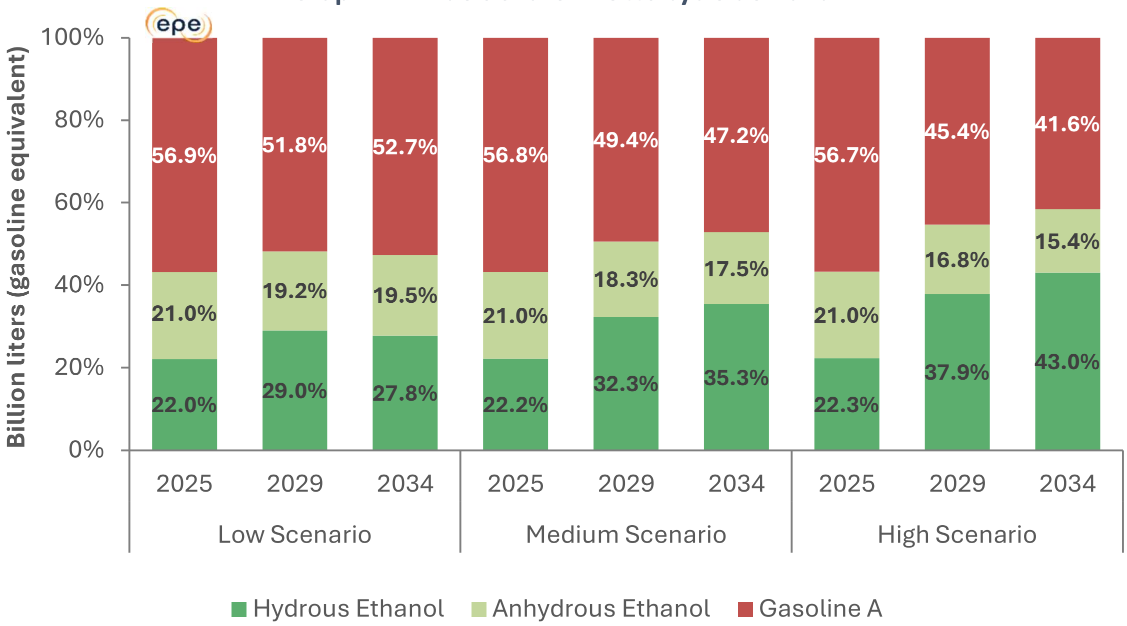


Source: EPE (projections) and EPE (2024b) (historical)

Fuel Share in the Otto Cycle

The share of hydrous ethanol, anhydrous ethanol, and gasoline A in the Otto cycle for each scenario is shown in Graph 22. The share of biofuels reaches 47%, 53%, and 58% in 2034 under the low, medium, and high growth scenarios, respectively.

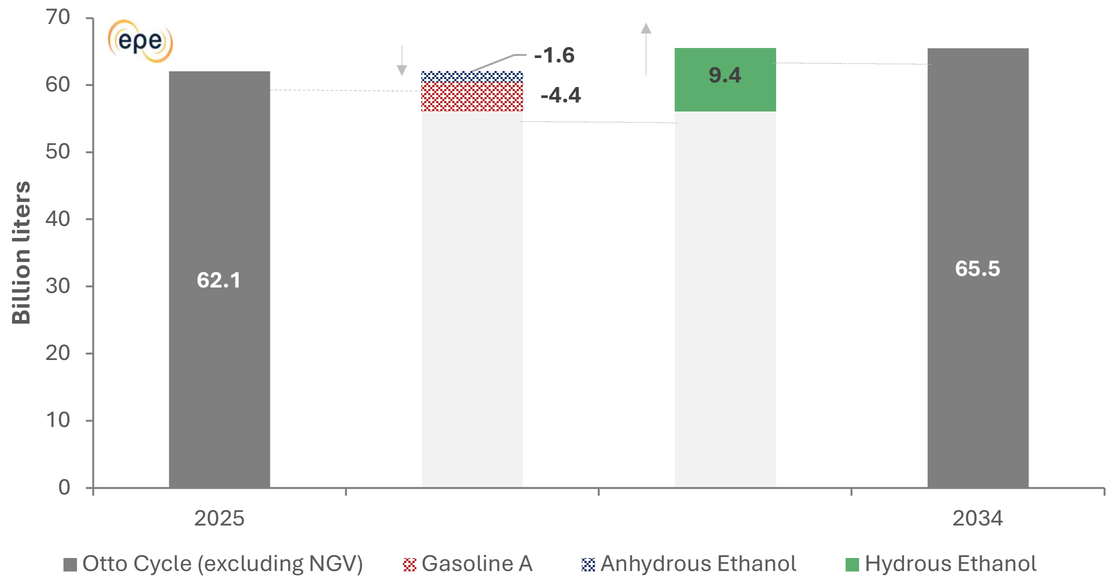
Graph 22 – Fuels share in Otto cycle demand



Source: EPE (Prepared by the authors)

O Graph 23 shows the evolution of Otto-cycle fuel demand by fuel type between 2025 and 2034 under the medium growth scenario, in which gasoline C decreases by 4.4 billion liters, while hydrous ethanol demand increases by approximately 9 billion liters.

Graph 23 - Evolution of Otto cycle demand segmented by fuel

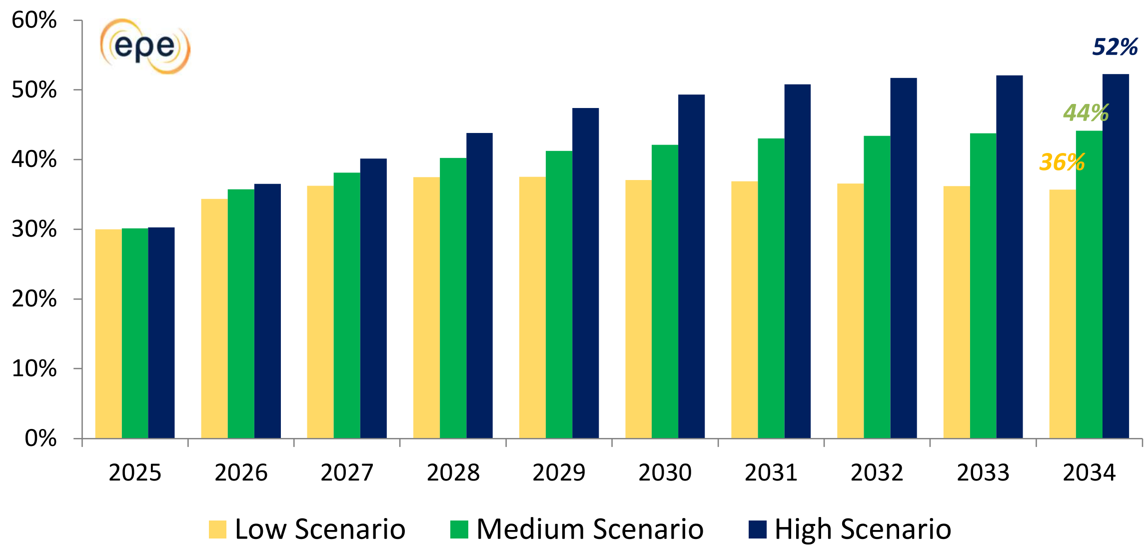


Source: EPE (Prepared by the authors)

Hydrous Ethanol Market Share in Flex-Fuel Vehicles

Based on the availability of hydrous fuel ethanol, the trajectory of its share in flex-fuel vehicle demand is analyzed. No Graph 24, shows that this availability leads to an increase in the market share of hydrous ethanol within the flex-fuel fleet. In 2034, this share reaches 36% under the low ethanol supply growth scenario. For the medium and high growth scenarios, it reaches 44% and 52%, respectively.

Graph 24 - Hydrous Ethanol Market Share in Flex-Fuel Vehicles (by Volume)



Source: EPE (Prepared by the authors)

National Balance of Gasoline A

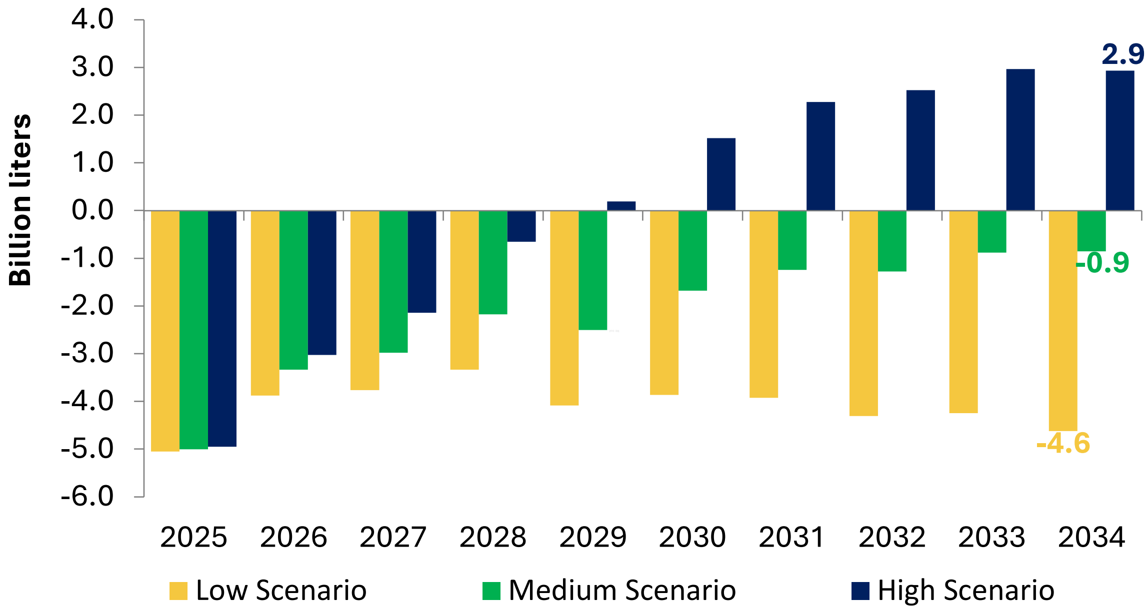
The assessment of the gasoline A balance over the study horizon considered the production projection from PDE 2034 (EPE, 2024d), the average volume between 2016 and 2022, as well as the ethanol supply scenarios presented throughout this study.

Since gasoline and naphtha fractions are derived from similar petroleum cuts, gasoline supply is primarily determined by the analysis of demand, prices, and logistical flows of these derivatives. However, other elements also influence this market flow, such as the opportunity cost of ethanol and sugar, and crop conditions. Therefore, even with several indicators pointing to domestic gasoline production, it may be affected by the aforementioned factors, potentially resulting in lower import volumes.

To estimate the impact on the national supply for light-duty vehicles, a sensitivity analysis was carried out, considering the gasoline A production projected in PDE 2034—which reaches 30.1 billion liters in 2034 (EPE, 2024d)—and the average volume between 2016 and 2022, 26.3 billion liters, a period when fossil gasoline production by refineries was lower (EPE, 2024b).

As shown in Graph 25, this exercise revealed that imports will be required throughout the entire study horizon under the low and medium scenarios, reaching 4.6 billion and 0.9 billion liters in 2034, respectively. Under the high scenario, imports are only necessary until 2028.

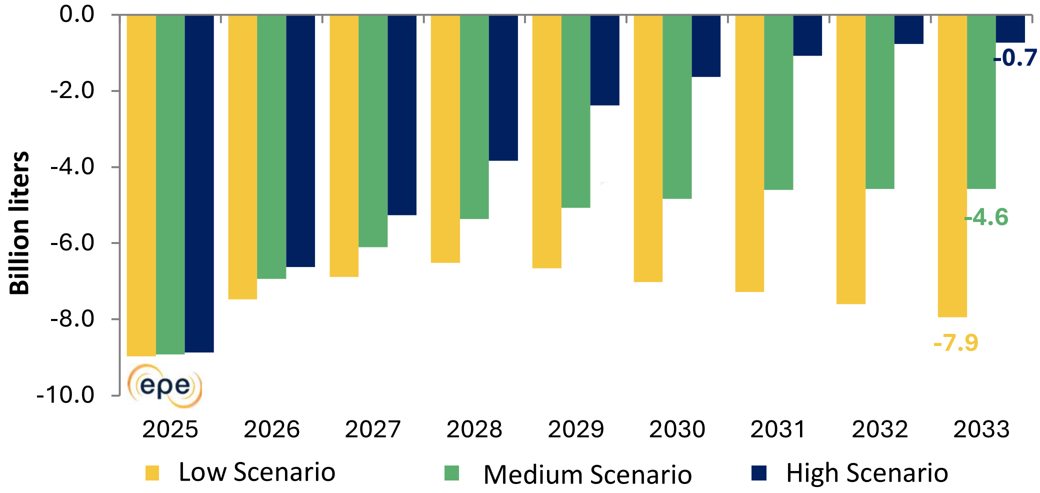
Graph 25 - National Balance of Gasoline A – PDE 2034 Production



Source: EPE (Prepared by the authors)

The second sensitivity analysis, aimed at assessing the impacts on the national gasoline balance under a lower supply scenario—production of 26.3 billion liters, the average between 2016 and 2022—indicates that imports will be required across all scenarios. According to Graph 26 import volumes would reach 7.8, 4.6, and 0.7 billion liters under the low, medium, and high scenarios, respectively.

Graph 26 - National Balance of Gasoline A – Average Production Volumes from 2016 to 2022



Source: EPE (Prepared by the authors)

5. Sensitivity Analyses

This section presents sensitivity analyses regarding the impact on Otto-cycle fuel demand, considering the allocation of ethanol to increase the anhydrous blend in gasoline C from 27% to 30% starting in 2026, and to produce SAF through the ATJ route in 2027—possibilities introduced by the Future Fuel Law (BRASIL, 2024a). Additionally, an assessment is made on the greater allocation of TRS for sugar production, driven by the valorization of this commodity and Brazil's strengthening position in the international market.

For the medium growth scenario, these sensitivities will first be presented separately, analyzing the effect of each one, and are referred to as E30, ATJ, and High Sugar. Subsequently, a combined analysis will be presented (i.e., a scenario in which the sugarcane production factors are maintained, while the allocation of TRS is adjusted to favor increased sugar production—see Item 0—alongside the adoption of a 30% anhydrous ethanol blend in gasoline C starting in 2026 and the allocation of ethanol for SAF production in 2027). For the low and high growth scenarios, the sensitivities will be presented only in grouped form. These will be referred to as Low Scenario (E30, ATJ, High Sugar), Medium Scenario (E30, ATJ, High Sugar), and High Scenario (E30, ATJ, High Sugar). It is worth noting that the high growth scenario already assumes increased sugar production, as previously described.

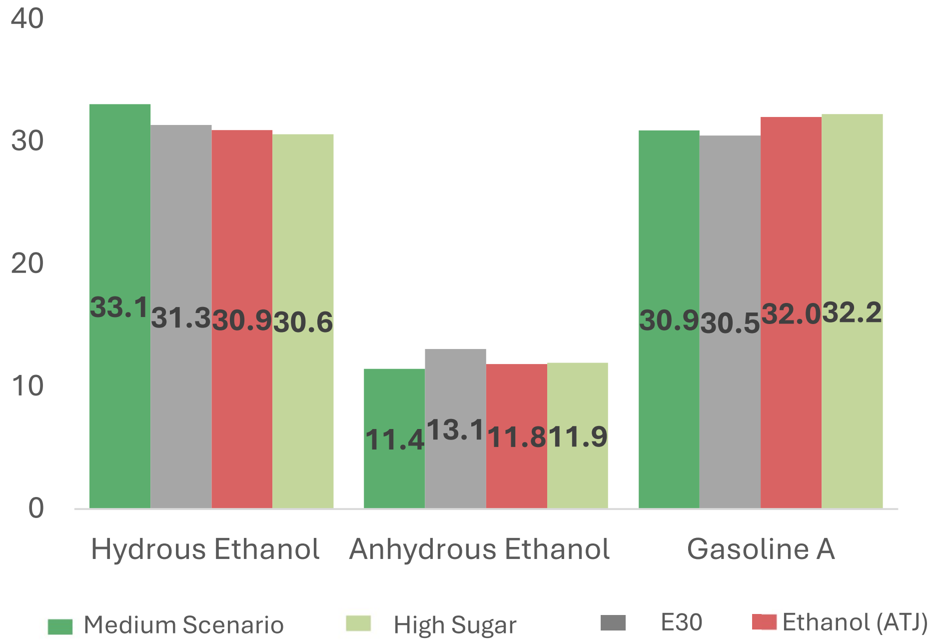
The volumetric SAF demand to meet the goals established by CORSIA and ProBioQAV will depend on the carbon intensity of each technology pathway and feedstock used. In this regard, EPE (2024g)[29] evaluated relevant criteria to produce this fuel in Brazil and proposed a potential combination of technological routes and feedstocks to meet emissions reduction targets. Along this path, AtJ production from 1G and 2G sugarcane ethanol and 1G corn ethanol would represent around 780 million liters, or 26% of total SAF production in 2034. This volume corresponds to a demand of approximately 1.7 billion liters of ethanol, assuming an average conversion yield of 0.46 liters of SAF per liter of ethanol, according to ICS (2024).

For the medium growth scenario, the impact on the demand for hydrous ethanol, anhydrous ethanol, and gasoline A—due to increased sugar production, a 30% anhydrous blend, and ethanol allocation for SAF via the AtJ route—can be observed in Graph 27. Additionally, the absolute and percentage changes in fuel demand for each sensitivity are shown in Source: EPE (Prepared by the authors)

Table 12.

[29] For more information, it is suggested to consult the study Sustainable aviation fuels in Brazil (EPE, 2024g).

Graph 27 – Isolated impact of sensitivities on the demand for hydrous ethanol, anhydrous ethanol, and gasoline A in 2034



Source: EPE (Prepared by the authors)

Table 12 - Variation of sensitivities on the demand for hydrous ethanol, anhydrous ethanol, and gasoline A in 2034

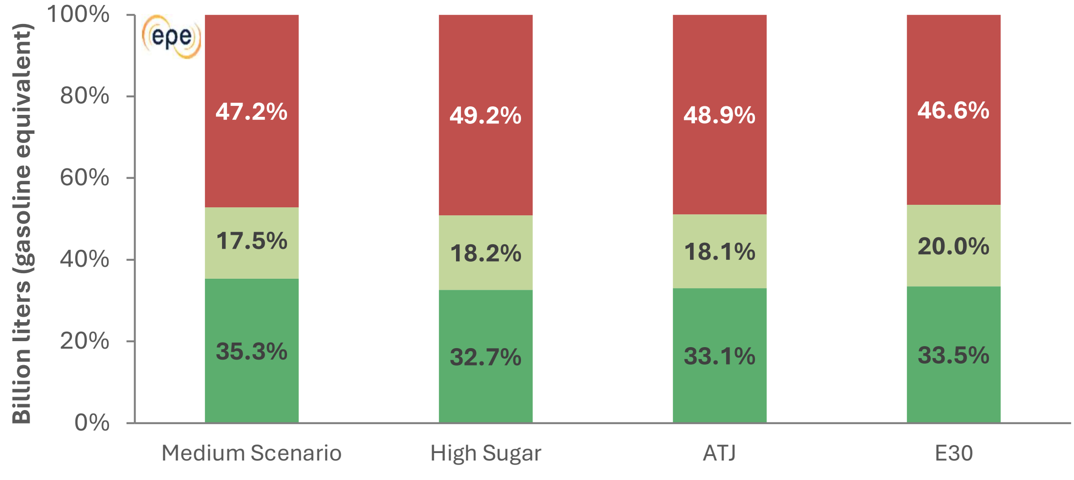
	Hydrous Ethanol	Etanol Anidro	Gasoline A
Scenarios		**Variation (billion liters/%)**	
E30	-1.7 (-5.2%)	1.6 (14.3%)	-0.4 (-1.4%)
ATJ	-2.1 (-6.4%)	0.4 (3.5%)	1.1 (3.5%)
High Sugar	-2.5 (-7.4%)	0.5 (4.3%)	1.3 (4.3%)

Note: The variation and rates are in relation to the average growth scenario.

Source: EPE (Prepared by the authors)

The composition of Otto cycle fuel demand, based on the analyzed sensitivities for the medium growth scenario, in isolation, is presented in Graph 28.

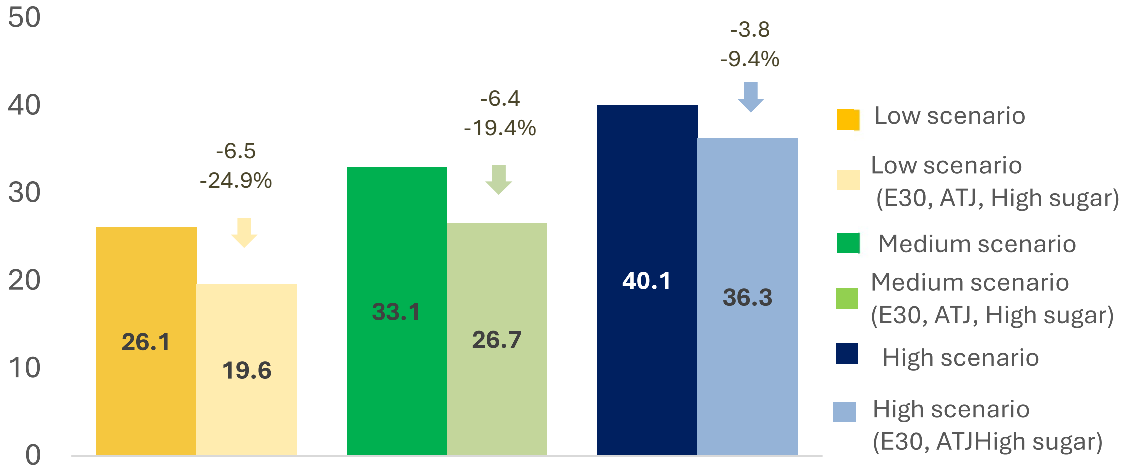
Graph 28 – Otto cycle composition for the sensitivities of the medium growth scenario in 2034.



Source: EPE (Prepared by the authors)

The following are the joint sensitivity analyses for the low, medium, and high growth scenarios, which will be referred to as low (E30, ATJ, High Sugar), medium (E30, ATJ, High Sugar), and high (E30, ATJ, High Sugar), according to the details described previously. Graphs 29, 30 and 31 present the results for hydrated ethanol, anhydrous ethanol, and gasoline A, respectively.

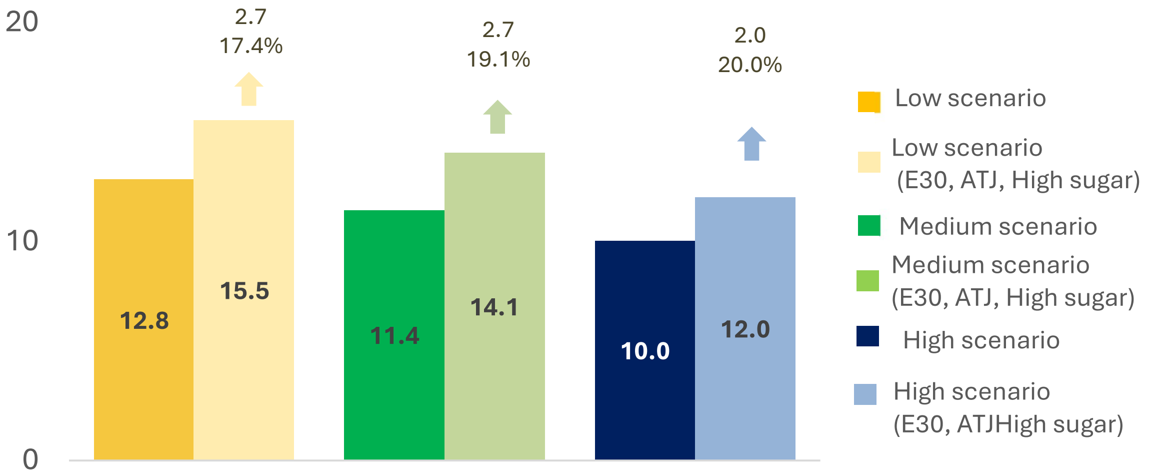
Graph 29 – Impacts on hydrated ethanol demand for each scenario in 2034



Note: The low, medium, and high scenarios correspond to those described above.

Source: EPE (Prepared by the authors)

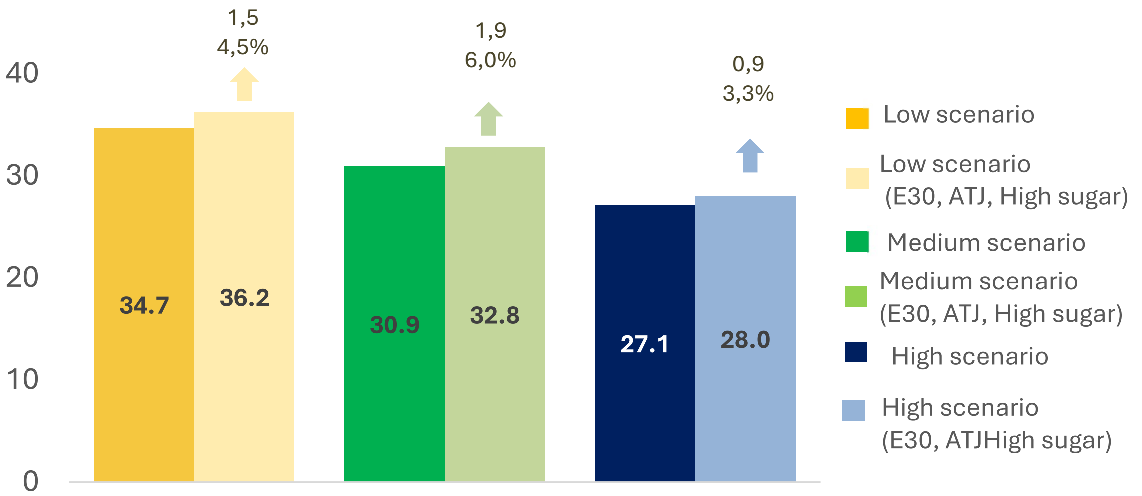
Graph 30 – Impacts on anhydrous ethanol demand for each scenario in 2034



Note: The low, medium, and high scenarios correspond to those described above.

Source: EPE (Prepared by the authors)

Graph 31 – Impacts on gasoline A demand for each scenario in 2034

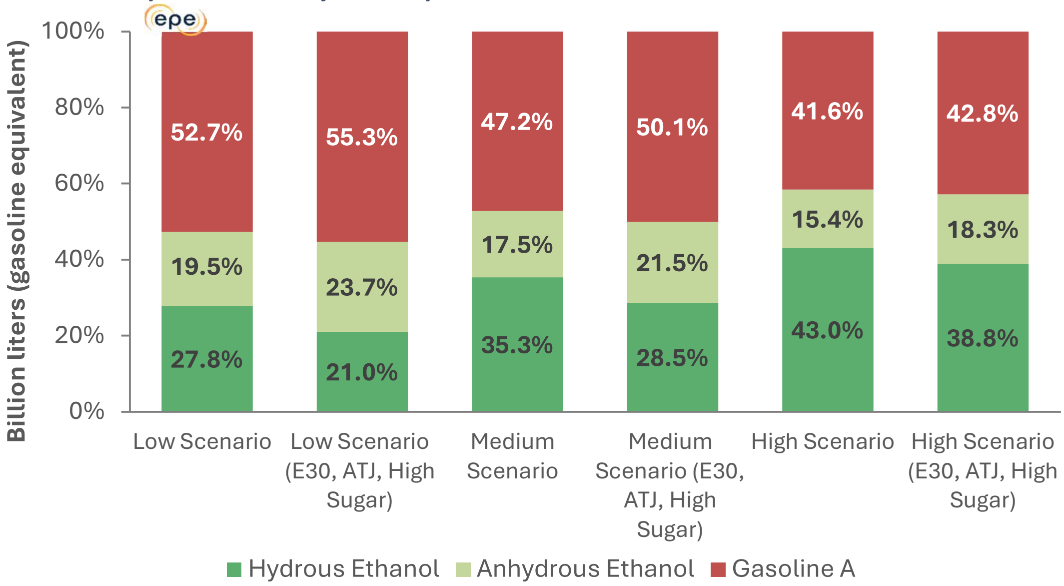


Note: The low, medium, and high scenarios correspond to those described above.

Source: EPE (Prepared by the authors)

The composition of Otto cycle fuel demand for the analyzed scenarios and their sensitivities is presented in Graph 32.

Graph 32 – Otto cycle composition for the scenario sensitivities in 2034



Source: EPE (Prepared by the authors)

BOX 1 - Ethanol supply stabilization

This box aims to present an analysis of ethanol supply and Otto cycle fuel demand, considering a scenario less favorable to the biofuels sector, in terms of public policies and company actions. Additionally, international oil prices are assumed to remain at moderate levels. Thus, despite RenovaBio and the Future Fuels Law, the economic attractiveness of the ethanol sector would not be sufficient to drive significant investments.

Regarding new units, only those with estimated entry into operation by 2026 were considered, based on construction authorization requests filed with ANP (as of May 2024) (ANP, 2024b). For sugarcane, under this criterion, two new mills will come online (one of small capacity), and one will be reactivated (380 million liters), along with expansions totaling 1.3 billion liters. The net closure of mills is also considered in unfavorable financial situations, resulting in a processing capacity loss equivalent to 6 million tons of cane (520 million liters of ethanol). For corn, sixteen new plants and expansions are expected, adding a nominal production capacity of 2.8 billion liters of ethanol.

This analysis uses the same estimates for yield, national sugar production (as a reference), exports, and ethanol for other uses. The nominal installed capacity is projected to be 866 Mtc for sugarcane and 25 Mton for corn by 2034. The sugarcane processing area is 8.5 million hectares, and the agricultural productivity is projected at 74.7 tc/ha in the same year. As a result, approximately 639 million tons of sugarcane are expected to be crushed by the end of the period. Ethanol supply by feedstock is shown in Table 13.

Table 13 - Ethanol supply by feedstock in 2034 (billion liters)

Cane 1G	Cane 2G	Corn	Import	Total Supply
24.3	0.6	10.6	0.5	36.0

Source: EPE (Prepared by the authors).

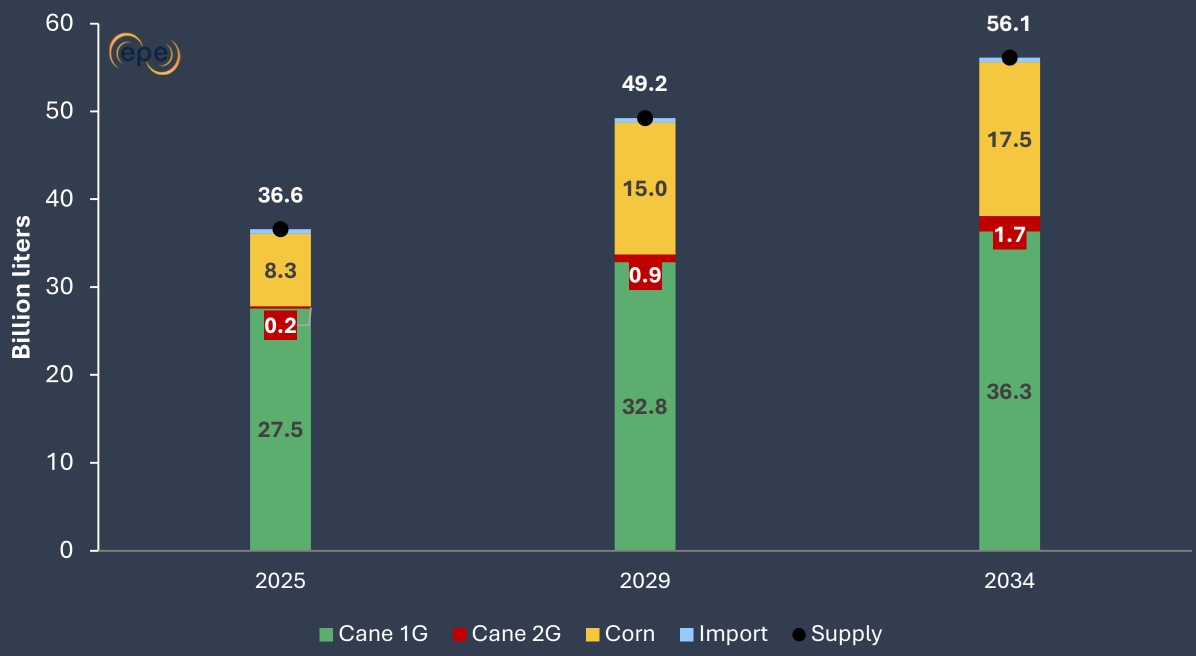
Considering the objective of ensuring national energy supply, this analysis was based on the reference Otto cycle fuel demand. In this scenario, it was found that the volumes of gasoline A and anhydrous ethanol would reach 39.3 billion liters (an increase of 8.4 billion liters) and 14.5 billion liters (an increase of 3.1 billion liters), respectively. This growth results from the lower volume of hydrated ethanol made available by producers for the fuel market—approximately 17.5 billion liters, which is 15.6 billion liters below the reference scenario.

Finally, when analyzing the national gasoline A balance, based on its projected production according to PDE 2034 (EPE, 2024d), it becomes necessary to import 9.3 billion liters in 2034, corresponding to 24% of fossil fuel demand. If the analysis is based on the average production between 2016 and 2022, the import requirement would increase to 13.0 billion liters (33%). It is worth noting that the historical maximum import volume of this fossil fuel was 4.9 billion liters in 2020 (EPE, 2024b), indicating that a subsequent evaluation of the national fuel logistics infrastructure capacity would be required.

BOX 2 - High Ethanol Scenario vs. Reference Sugar Production

It aims to present an analysis of ethanol supply and Otto cycle fuel demand, considering the sugarcane (1G and 2G) and corn production factors indicated in the high growth scenario, while assuming the reference sugar production level (used in the low and high scenarios), making the scenario even more favorable to the biofuels sector. Sugar production reaches 47.1 million tons in 2034, as previously described, maintaining Brazil's leadership in the international trade of this commodity. Graph 33 presents ethanol supply by feedstock.

Graph 33 – Ethanol supply by feedstock



Source: EPE (Prepared by the authors).

The ethanol supply reaches 56.1 billion liters, which is 2 billion liters higher than the volume projected in the high growth scenario (54.1 billion liters). Based on the reference Otto cycle demand from this PDE, the volumes of gasoline A and anhydrous ethanol would reach 25.8 billion liters and 9.6 billion liters, respectively. The volume of hydrated ethanol would be 42.6 billion liters. Accordingly, the Otto cycle fuel mix would be composed of 45.7% hydrated ethanol, 14.7% anhydrous ethanol, and 39.6% gasoline A.

The analysis of the national gasoline A balance, assuming production levels projected in the PDE 2034 (EPE, 2024), indicates that no imports would be necessary. If the analysis is based on the average production from 2016 to 2022 (26.3 billion liters), imports would be limited to less than 500 thousand liters, and only from 2032 onward.

6. Conclusion

This study presented the ethanol supply scenarios considered for the 2025–2034 period and their respective impacts on Otto cycle demand and the national gasoline A balance.

The developed scenarios indicate variations in ethanol fuel supply, considering industry actions aimed at cost reduction (such as sugarcane field renewal and proper agronomic practices) and ethanol incentive policies (such as tax and contribution differentiations, availability of financing lines for the sector, among others). These scenarios reflect different assumptions regarding the economic attractiveness of investments in the sugar-energy sector and corn ethanol production.

Sugarcane mills are adjusting their financial conditions and benefiting from the attractiveness of sugar in the international market and internal opportunities, such as improvements in sugarcane fields, biogas production, E2G, among others mentioned in this study, as well as external factors that support their development. Meanwhile, corn ethanol production units have shown consistent growth, beginning operations in a short period, with the possibility of more than one harvest per year, usually rotating with soybeans. As a result of these projections, ethanol supply could reach values ranging from 42.9 billion to 54.1 billion liters. It is worth highlighting that the share of corn ethanol is expected to represent between 29% and 32% of total supply by the end of the period, demonstrating its relevance in the national energy matrix.

Based on the estimated Otto cycle demand and corresponding fuel production, a sensitivity analysis was conducted considering the gasoline A production from PDE 2034 and the average value between 2016 and 2022, of 26.3 billion liters. In the first case, imports would be required throughout the study horizon for the low and medium scenarios, reaching 4.6 billion and 0.9 billion liters in 2034, respectively. For the high scenario, imports would occur until 2028. For the 26.3 billion liters production case, no imports would be necessary throughout the entire period across all three scenarios considered.

The study highlights that the contribution of sugarcane biomass to the national energy landscape could become even more substantial. In the most conservative assessment, bioelectricity could inject up to 4.1 GWm into the grid by 2034 under the high growth scenario, and 3.7 GWm under the low growth scenario. Additionally, the use of sugarcane residual biomass (vinasse and filter cake) for biogas production in the form of biomethane, within the same horizon, could result in the generation of 3.4 billion Nm^3 and 3.0 billion Nm^3 for the respective scenarios.

Considering a more conservative estimate—focusing on more efficient and financially sound groups — potential volumes would reach 1.4 billion Nm^3 and 1.6 billion Nm^3, respectively. The study also presented scenarios for the entry of biomethane production units, which could range from 27 to 75 facilities, depending on the level of investment in this sector.

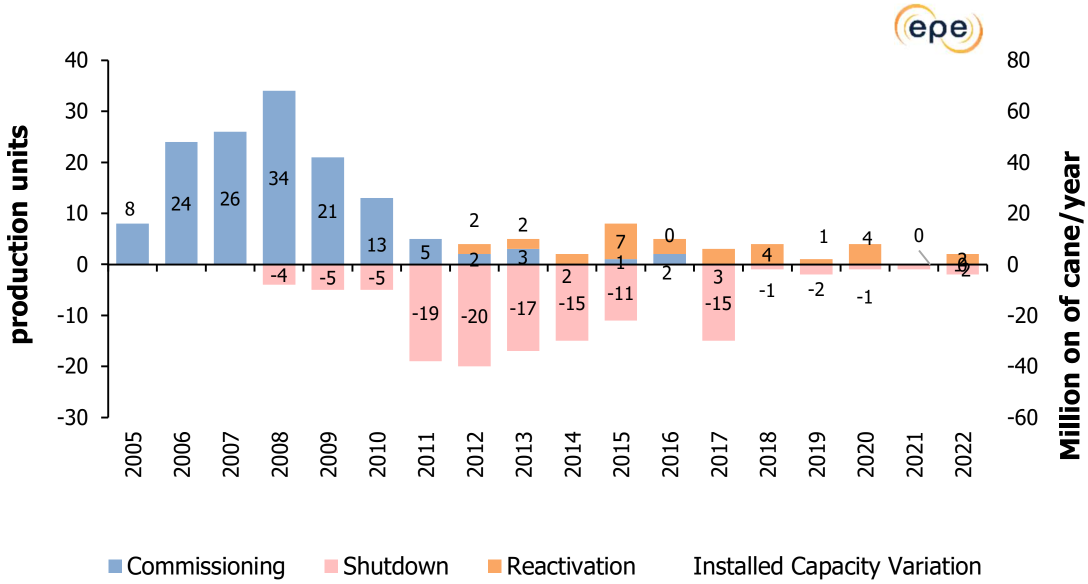
The GHG emissions avoided using sugarcane-based products are highly relevant within the national context. Considering ethanol demand for fuel purposes and the contribution of bioelectricity, under the most conservative analysis, avoided emissions could range from 74.1 $MtCO_2$ to 68.2 $MtCO_2$ in 2034, for the high and low growth scenarios, respectively.

The study also pointed out the effects of increasing the share of anhydrous ethanol in gasoline C to 30%, the allocation of ethanol to SAF production via the AtJ pathway, and the increased diversion of ATR for sugar production.

This study proves to be relevant in supporting the implementation of public policies aimed at supplying the Otto-cycle vehicle market and fulfilling Brazil’s international commitments under the Paris Agreement, as well as national policies such as RenovaBio and Fuel of the Future. It plays a crucial role in the country’s medium- and long-term energy planning. Additionally, as emphasized by the conclusions of Brazil's G20 presidency, energy needs must be met equitably, considering social inclusion and poverty reduction — objectives to which biofuels can significantly contribute.

Annex

Graph A1 – Flow of sugarcane mills in Brazil



Fonte: EPE from EPE (2024a); MAPA (2024), UNICA (2014a, 2014b)

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