Scenarios and opportunities in the sugar and ethanol industry - challenges and opportunities towards a low carbon economy in Brazil

Cenários e oportunidades do setor sucroalcooleiro - desafios e oportunidades para uma economia de baixo carbono no Brasil

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Abstract

With the future of transport embracing new models of mobility, hybridization and electrification, a reduction in fossil fuel consumption is expected. Biofuels, especially biomass-derived ethanol, play a significant role in this transition by boosting greenhouse gas emissions. Ethanol production is considered strategic by industrialized countries, coming from renewable biomass in the energy sector. Studies have explored the contribution of biofuels to
the decarbonization of the vehicle transport sector at levels from 2030 to 2050. However, the future energy matrix remains uncertain, with the potential coexistence of multiple matrices and technologies. This research evaluates Brazil's position in these scenarios, considering the challenges and risks to achieve a sustainable energy matrix in the transport sector. The methodology involves the analysis of decarbonization scenarios, methods and concepts, examining scenarios projected for the future of the light vehicle sector in the main consumer countries. In addition, the research discusses Brazil's role in biofuels and transport scenarios, with a focus on Brazilian ethanol in the global bioeconomy by 2050. The challenge of decarbonization in the transport sector is global and highlights the importance of Brazil as the second largest producer of bioethanol, after the US.

**Keywords:** Sugar and Alcohol Industry. Ethanol. Decarbonization.

**Resumo**

Com o futuro do transporte abraçando novos modelos de mobilidade, hibridização e eletrificação, espera-se uma diminuição no consumo de combustível fóssil. Os biocombustíveis, especialmente o etanol derivado da biomassa, desempenham um papel significativo nessa transição, reduzindo as emissões de gases de efeito estufa. A produção de etanol é considerada estratégica pelos países industrializados, sendo proveniente de biomassa renovável no setor de energia. Estudos têm explorado a contribuição dos biocombustíveis para a descarbonização do setor de transporte de veículos leves de 2030 a 2050. No entanto, a futura matriz energética permanece incerta, com potencial coexistência de múltiplas matrizes e tecnologias. Esta pesquisa avalia a posição do Brasil nesses cenários, considerando os desafios e riscos para alcançar uma matriz energética sustentável no setor de transportes. A metodologia envolve a análise de cenários, métodos e conceitos de descarbonização, examinando cenários projetados para o futuro do setor de veículos leves nos principais países consumidores. Além disso, a pesquisa discute o papel do Brasil em biocombustíveis e cenários de transporte, com foco no etanol brasileiro na bioeconomia global até 2050. O desafio da descarbonização no setor de transportes é global e destaca a importância do Brasil como segundo maior produtor de bioetanol, após os EUA.

**Palavras-chave:** Industria Sucroalcooleira. Etanol. Descarbonização.
Introduction

The global vehicular transportation sector has been repositioning itself (Burch; Gilchrist, 2018; Paltsev et al., 2022; Pulido-Sánchez et al., 2022; Ranta; Laihanen; Karhunen, 2021; Tamba et al., 2022) to adapt to a global need for climate decarbonization, given the predictions of global temperature rise of 1.5°C by 2030 (Allan; Arias; Berger, 2021). China (1º), the United States of America (2º), and Japan (3º) represent the three largest automotive markets for light vehicles in the world. For heavy vehicles, the ranking is China (1º), the United States of America (2º), and England (3º). In this ranking, Brazil is among the 10 largest, representing 8º place (2.7 million) for light vehicles and 4º place (115 thousand) for heavy vehicles (Anfavea, 2021).

In a process of decarbonization of the light transport sector, electric vehicles are an important alternative, because besides being more energy efficient than combustion vehicles, they have the potential to reduce greenhouse gases – GHG (Cardoso et al., 2018; He et al., 2016; Orlov; Kallbekken, 2019). The energy efficiency of electric vehicles is approximately between 60-85%, while Otto Cycle vehicles between 20-25% and Diesel Cycle engines between 40-50% (Souza, 2018), in addition, electric vehicles can provide a GHG reduction of up to 45 MtCO_2_eq (Million Tonnes of carbon dioxide equivalent) (-8.3%), when compared to the use of biofuels that provide a GHG reduction of up to 19 MtCO_2_eq (-3.6%) MtCO_2_eq (Danielis; Scorrano; Gian Soldati, 2022).

Despite the growing number of electric vehicles produced globally over the years, this still represents a much smaller share than observed for combustion vehicles. Countries such as Canada, Finland, France, Germany, Japan, the Netherlands, New Zealand, Norway, Poland, China, Sweden, The United Kingdom, The United States, and Spain have committed to achieving a fleet of 30% electric vehicles by 2030 (Souza, 2018). In Brazil, this participation should reach 10-18% in 2035, corresponding to at least 3.2 million units (Anfavea, 2021).

The electrification process in the world is a relevant reduction alternative for the global GHG emissions, but there are still challenges to overcome until it is finally consolidated. Even though many countries in the world have large reserves of mineral production (Lithium, Nickel, Graphite, and Manganese) - the raw material for battery production, reduced costs of batteries, technological development of car manufacturers, pressure from investors and customers more conscious about decarbonization aiming to achieve net zero in 2050, the local production of electric vehicles still requires many investments (Anfavea, 2021).

On the other hand, some countries still face difficulties in adhering to this technology,
mainly due to the need for recharging infrastructure added to the still unknown environmental impact that may be observed by the use of batteries; reduced autonomy of vehicles; high price (lack of subsidies); reduced access to electric or hybrid vehicles with autonomy over long distances; (EPE, 2020; SOUZA; CAVALET; JUNQUEIRA, 2022) need for technological development of the automobile producing industries, purchase culture, market regulation, incentive policies (ANFAVEA, 2021; BURCH; GILCHRIST, 2018).

In parallel, recent events, such as the unfolding of global goals to reduce local climate impacts as a result of increased global warming, have driven the search worldwide for the diversification of the energy matrix, in search of more socio-environmental sources, ranging from the well-known fossil fuels (gasoline, diesel, compressed natural gas - CNG, liquefied natural gas - LNG), biofuels (bioethanol, biodiesel, renewable green diesel - HVO and biogas/biomethane), to those arising from technological development and innovation such as electrified vehicles like MHEV (Mild Hybrid Electric Vehicle), HEV (Hybrid Electric Vehicle), PHEV (Plug-in Hybrid Electric Vehicle), BEV (Battery Electric Vehicle) and fuel cells (fuel cell and ethanol fuel cell) (MAL et al., 2013; NOGUEIRA et al., 2020).

In this context, the mapping of scenarios aims to support the understanding of how all variables should behave over the coming years and promote the development of strategies to reduce global climate impacts, both in the long term, such as energy efficiency policies, modal shift, and expansion of electric-powered vehicles, and in the short term, such as the increased use of biofuels (DA SILVA; DANA, 2020; ROITMAN, 2019; ROMAN; ROMAN; ROMAN, 2018; SOUZA; CAVALET; JUNQUEIRA, 2022).

All things considered, it seeks to understand through the analysis of prospective scenarios, of representative associations and private research companies, which answer the question of what will be the behavior of the decarbonization process of the vehicular transport sector in the world, especially with a cutout for Brazil, since numerous innovations, related to industrial technologies, vehicular and energy matrices have been developed. Thus, this work aims to contribute to the discussion about the process of climate decarbonization, focusing on the Brazilian transport sector (light vehicles) (DA SILVA; DANA, 2020; ROITMAN, 2019).

**Methodology**

A representative search of several databases (Science Direct, Web of Science, Scope, Google Scholar, and Google) was conducted for this critical review of literature. The main goal of the critical review is to reveal strengths, weaknesses, contradictions, controversies,
inconsistencies, and other significant issues on the existing literature on a particular topic of interest (BAUMEINSTER; LEARY, 1997; PARÉ; KITSIOU, 2017).

The descriptors "Impact Climate and Biofuel Industry" and "Sustainability and biofuel industry and industry 4.0", "ESG and Industry" were used for prior knowledge. Articles, selected by title and abstract, that mainly express a) state of the art of what climate decarbonization is about and b) decarbonization of the transport sector were considered eligible. For documents related to the projected scenarios for the decarbonization of the transport sector, the descriptors "biofuel future scenarios" were used. In addition, the following were considered as secondary filters: a) Publication period since 2021; b) Order by relevance; c) In any language; d) Review articles and e) No copyrights or citations.

Both results from quantitative and qualitative studies demonstrate projections for the global and/or national scenarios (reason 1), type of sector - transportation (reason 2), and matrix - fuels, fuel mix, and/or biofuels (reason 3), were considered eligible (inclusion criteria). Ineligible (exclusion criteria) records that had no correlation with the theme under study, a) Future scenarios, b) Fuels and c) Transport sector. The selected publications, in the qualitative and quantitative analysis were tabulated following the information: a) main author; b) journal, c) year of publication, d) scenario projection period, e) method (qualitative or quantitative), f) sample location.

Readings were conducted with the intent of selecting scientific publications that potentially held to the inclusion criteria (eligibility) that demonstrated projections for the scenarios, being these - global and/or national (Brazil). The search resulted in articles that did not present any correlation between them, returning distinct variables, which in some cases followed qualitative analysis strategies and in other cases quantitative ones. Thus, each article was evaluated independently.

**Results and Discussions**

**3.1 Behavioral Approaches to the Mapped Scenarios**

In this process of looking for decarbonizing the transportation sector, leveraging alternatives that are most closely aligned with their natural vocations and abilities has been the path of most countries (ANFAVEA, 2021; CHIARAMONTI et al., 2021; EPE, 2022; MACHADO et al., 2018; PUROHIT et al., 2018; SZKLO; PINHEIRO; CALLEGARI, 2021; WYDRA et al., 2021; ZHANG; CHEN, 2015).
3.2 Addressing the Behavior of the Mapped World Scenarios

In Europe, the decarbonization process of the transport sector is strongly supported by the target achievement plan (Renewable Energy Directive Revision - REDII) established by the government to reduce global climate impacts, which sets strict targets for the reduction of greenhouse gases. It is projected that between 2030 and 2040 there will be a scenario considered low, with a drastic reduction in total final energy consumption, with projections of a 1.2% share of total biofuels and a 0.5% share for advanced biofuels by 2030. The main scenario, with a share of total biofuels and advanced biofuels, but still a decline in total final energy consumption, remains stable until the end of the period. Lastly, a high scenario, with an upward trend for total final energy consumption, due to an overall increase in transport activities, well above the expected effect of increased efficiency in addition to the increasing contribution of advanced biofuels to total final energy consumption (CHIARAMONTI et al., 2021).

For China, biofuels are estimated to be indispensable in decarbonizing the transport sector, but will be constrained by technological progress, food security concerns, and land availability and should be driven by relevant and current policies. In addition, it is estimated to generate 0.43 Gt of CO2 emission reductions in 2050 (CM30 scenario) and will contribute 35% of the total reduction. On the other hand, it is believed that bioethanol will be more influenced by electrification than biodiesel and biofuels due to its ease of substitution with electricity (ZHANG; CHEN, 2015).

India's decarbonization process indicates that the current availability of ethanol and biodiesel in India through the first-generation biofuels route is not sufficient to meet the country's biofuels target. On the other hand, lignocellulosic agricultural residues can produce 38 and 51 billion liters of lignocellulosic ethanol/BTL in 2020 and 2030, respectively, which would be enough to meet the 20% NPB blend by 2030 (PUROHIT et al., 2018). To address the growing demand, and adverse environmental and financial impact of fossil fuels on the Indian economy, the Indian government has taken a green step towards blending 20% bioethanol in gasoline and 20% biodiesel in diesel (GUMTE; MITRA, 2020).

3.3 Approach to the Behavior of the Brazilian Mapped Scenarios

The studies related to decarbonization projection scenarios for the Brazilian transport sector are more related to the records of organizations representing the sector, namely the Empresa de Pesquisa e Energética (EPE) and the Associação Nacional dos Fabricantes de
Veículos Automotores (ANFAVEA) (2021), which conducted its research through a specialized company, the Boston Consulting Group (BCG). These records do not present a correlation in the categorization of the scenarios. One primarily evaluates the growth in the volume of fuels and the other the growth in the number of vehicles. Because of this, both are evaluated independently (EPE, 2023).

These studies, in turn, report that the decarbonization of the transportation sector may prove to be a relevant strategy for reducing climate impacts of GHG emissions, since the transportation sector corresponds to 32.5% of the total energy consumed in Brazil, leaving 32.3% from industries, 10.9% from households, 9.5% from the energy sector, 5% from agriculture and livestock, 4.8% from services, and 5.1% from non-energy (EPE, 2023).

Furthermore, Brazil's greenhouse gas emissions reached their highest level in almost two decades in 2021. There was a 12.2% increase compared to 2020, totaling 2.42 billion gross tons of CO2 equivalent. Deforestation in the Amazon and other biomes was the main cause of this increase, with emissions from land use change and forests rising by 18.5%. The destruction of Brazilian biomes resulted in 1.19 billion gross tons emitted in 2021. Additionally, nearly all sectors of the economy contributed to this increase, with agriculture (3.8%), industrial processes and product use (8.2%), and energy (12.2%) standing out. The waste sector was the only one to maintain stable emissions (IEMA, 2022).

The first initial scenario is that projected by ANFAVEA (2021, p. 38). This shows that there will be sustainment of combustion engines until 2030, particularly in volume segments, with electrification aimed at meeting specific segments, emissions requirements, and corporate customer demands. The light vehicle sector in Brazil represents 52.3% of passenger transport with a predominant fleet (89%) of flex-fuel vehicles - consuming either hydrated ethanol or a mixture of gasoline and anhydrous ethanol, but still with a significant share of gasoline-powered vehicles. In 2021, there were 85.2% flex fuel, 10.8% diesel, 3.0% gasoline, and 1.0% hybrid vehicles (19,745 units) (ANFAVEA, 2021).

This is mainly because in the past (the 2000s) Brazil had many incentives for ethanol production, such as (a) financing 90% of the resource needed for the production of a new ethanol distillery and up to 100% of the resource needed to increase the cultivated area; (b) negative interest rate conditions; (c) 3-year grace period and 12 years for loan repayment; (d) minimum prices for ethanol, more attractive compared to sugar and; (e) a government agreement with the automobile industries for the incentive to produce ethanol-powered cars (LA ROVERE, 1995), which resulted in the consolidation of the flex-fuel technology, which by presenting relevant environmental benefits, with the use of any proportions of ethanol to
gasoline (in the regulated situation at 24%), provided a new 5-fold increase in ethanol consumption in Brazil and consequently, leading the sale of flex cars to the index of 88.5% of total car sales in 2003 (LAURINI, 2017).

Another scenario considered initially is projected by the Empresa de Pesquisa Energetica - EPE (2020) for 2030, where there will not be many investments, especially in the dissemination of good agricultural practices (agricultural and varietal management, as well as renewal in the appropriate period) or technological innovations, in addition to reduced incentive policies for ethanol and modest success in RenovaBio with lower decarbonization credit prices. Resulting in the entry of 10 more new producing units increasing the nominal cane crushing capacity by about 31 million tons, a balance between reactivations and closures with an addition of 6 million tons of cane production in the installed capacity.

For MCTI and WRI Brasil (2021, p. 8), the initial scenario can be visualized in terms of the number of vehicles produced, which infers that the demand for gasoline-powered vehicles should almost double by 2050, going from approximately 3.4 million vehicles in 2018 to 5.31 million vehicles in 2050.

Considering an intermediate scenario, what Anfavea calls global convergence, Brazil will achieve in 2035, a gain in a scale of xEVs (diverse electric vehicles) similar to Europe's and will approach the electrification levels of more advanced markets. However, this will require the installation of more than 150,000 chargers and an investment of more than 14 billion by 2035 (ANFAVEA, 2021).

In this case the Empresa de Pesquisa Energética – EPE (2020) projects for 2030, it is considered that there will be cost reduction actions such as the renovation of sugarcane plantations, new varieties adapted to new production environments, planting and harvesting methods, adequate cultural treatments, as well as greater efficiency in ethanol production induced by the RenovaBio instruments (Environmental Energy Efficiency Note for each primary emitter of the CNIO), in addition to a price relationship between fuels that is more favorable to ethanol, continuity of the incentive policies (differentiations in CIDE, PIS/COFINS, and ICMS) for ethanol, availability of financing lines for the sector, as well as success in RenovaBio and decarbonization credit prices that increase attractiveness. Resulting in the entry of 19 new producing units, increasing the nominal cane crushing capacity by about 67 million tons, a balance between reactivations and closures with the addition of 16 million tons of cane production in the installed capacity and the need for additional expansion of 26 million tons to process all available cane.

And for a higher scenario, ethanol gains prominence as the most relevant alternative
in the decarbonization process, made possible by favorable regulation, a flex fleet, and ample production and distribution infrastructure. In this scenario, ethanol is expected to increase by 15% in the fuel mix, reaching 61% of consumption. With electric vehicles, sales penetration is similar to the inertial scenario (ANFAVEA, 2021).

Following the same trend, the Empresa de Pesquisa Energética - EPE (2018, p. 13) projects that for 2030, the number of operational units will be greater, with higher productivity resulting from new varieties as well as the rigorous success of RenovaBio and greater intensity of ethanol incentive policies. Resulting in the entry of 25 new producing units increasing the nominal cane crushing capacity by about 85 million tons, the balance between reactivations and closures with the addition of 19 million tons of cane production in the installed capacity and the need for additional expansion of 82 million tons to process all available cane.

### 3.4 Ethanol Production in Brazil

The United States of America (1st) and Brazil (2nd) are the largest producers of Biofuels in the world, the former being primarily biodiesel and the latter sugarcane ethanol. In Brazil, the usage and production of ethanol are more economical when compared to the United States, because oil production has higher costs and the co-products of ethanol production (DDGs) are in high demand (DA SILVA; DANA, 2020). Brazil registered to have in September 2021, 290 biofuel production units, 87% of which are ethanol (MACHADO et al., 2018).

The estimate for the 2023/24 sugarcane crop indicates a 4.4% increase in production compared to the previous season. A production of 637.1 million tons is expected, with a cultivated area of 8410.3 thousand hectares and an average yield of 75751 kg/ha. The increase in the cultivated area is attributed to expansion and renewal of planting areas, positively impacting productivity. Additionally, the climatic conditions are favorable for this season, surpassing those of the previous crop (CONAB, 2023a).

Brazil produced 27.37 billion liters of ethanol from sugarcane and 3.97 billion tons from corn in the 2022/23 harvest season, representing a growth of 3.6% and 14.4% respectively compared to the previous season (CONAB, 2023a). The forecast for the 2023/24 harvest season is a production of 27.53 billion liters of ethanol from sugarcane and 33.17 billion tons from corn, which represents a 0.6% and 5.9% increase, respectively. Notably, the production of anhydrous ethanol, which is blended with gasoline, is expected to increase by 1.5% compared to the previous season, reaching a total of 11.82 billion liters. The production
of hydrated ethanol is estimated to be 15.71 billion liters, representing a 0.1% reduction compared to the previous year. In terms of corn-derived products, the production of anhydrous ethanol is projected to be 14.26 billion liters, while hydrated ethanol production is estimated to be 18.91 billion liters (CONAB, 2023b).

According to the Brazilian Energy Research Company (EPE) (2022, p. 9), the total ethanol supply projection is expected to reach 47 billion liters in 2032, representing an annual growth rate of 4.1% since 2022. This includes 36.1 billion liters from sugarcane (compared to 26.6 billion in 2021), 9.1 billion liters in 2032 from corn (compared to 3.3 billion in 2021), and 560 million liters in 2032 from lignocellulosic materials (bagasse and straw). The remaining volume is earmarked for export. As for total ethanol demand, it is projected to reach 45 billion liters in 2032, growing at an annual rate of 4.2% since 2022. This includes 33 billion liters of hydrated fuel ethanol, 10 billion liters of anhydrous fuel ethanol, and 2 billion liters for other purposes such as beverages, cosmetics, pharmaceuticals, oxygenated compounds, and chemical alcohol.

Junior et al (2019, p. 10), meanwhile, estimates that ethanol demand in Brazil is highly sensitive to macroeconomic and policy factors such as GDP and population growth, fleet composition, blending policies, fuel prices, and energy efficiency and could increase between 37.4 and 70.7 billion liters in 2030 depending on the scenario. This increase is 13% and 114% above 2018 production. This represents an expansion of the sugarcane area between 1.2 and 5 million hectares (14-58% above 2018 land use). Compared to the low demand scenario, the high demand for ethanol in 2030 drives sugarcane expansion mainly on pastures (72%) and natural vegetation mosaics (19%), however, the future ethanol demand in Brazil is not expected to substantially affect food production or native forest. This result, however, depends on compliance with sugarcane agroecological zoning (ZEA) by the ethanol sector in Brazil (DE ANDRADE JUNIOR et al., 2019).

To meet the required volume demand, ethanol production from corn and bagasse gains relevance. According to Bordonal et al. (2018, p. 15), ethanol production from sugarcane is more favorable than that from corn in terms of energy balance, because sugarcane offers 700% more energy than it consumes to be produced. Corn, on the other hand, offers only 20%. In addition, sugar cane ethanol (1st generation or 1G) is highly efficient in terms of energy balance, reduced water use, and reduced GHG emissions when compared to other feedstocks.

Many biofuel alternatives have been explored on a large scale in terms of generation and production capacities for the transportation sector, such as biodiesel, first and second-generation bioethanol, biohydrogen, bio-methane and bio-dimethyl ether (bio-DME)
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FAWZY et al., 2020). Special attention should be paid to this process of expanding the use of biofuels as a result of increased demand because other sectors of the bio-economy may be developing concurrently and therefore may act as competitors (WYDRA et al., 2021).

Ethanol originating from cellulosic feedstock, such as sugarcane bagasse and/or other feedstock that has lignocellulosic material in its composition, can be generated by the 2nd a generation or 2G process. 2G (2nd generation) ethanol has a market that will face a tradeoff, in the sense that its lignocellulosic raw materials, such as bagasse, hay, and head, are raw materials also used to generate bioelectricity. In this case, the option for transformation into ethanol will depend on the future commitments signed (auctions) and the value of the new biofuel in the domestic and foreign markets, which could be supported through additional public policies to foster research (R&D) and by the creation of new regulations that facilitate the insertion in the market of new fuels (BORDONAL et al., 2018; FAWZY et al., 2020).

Some industries such as Raízen and Grandbio are developing their production processes to use these alternatives in the production of cellulosic ethanol. This generally presents a lower carbon footprint compared to 1G ethanol (SALINA; DE ALMEIDA; BITTENCOURT, 2020), in addition to challenges of technological development of processes (pretreatment), which impact obtaining higher yields on an industrial scale, such as raw material utilization and the high cost of enzymes, which in turn can load the final cost of the process (CHANDEL et al., 2019; WYDRA et al., 2021).

Conclusion

It is premature to say which will be the predominant energy matrix worldwide. At this moment several sources are being studied, mainly due to the emerging necessity to obtain alternatives to reduce global climate impacts. However, it is possible to notice that until this process is consolidated, if this will happen or if there will be continuous technological and scientific development, it will be possible to notice an energy transition process. The research obtained, allowed the observation that in the horizon of approximately 30 years, it will still be possible to notice the predominance of biofuels, especially ethanol, as a potential energy matrix for the supply of light vehicle technologies. In this context, the role of the sugar-alcohol industry stands out, as it will be able to take advantage of this process in a relevant way, by producing and meeting this demand, generating relevant positive externalities, such as employment and income generation, local economic development, carbon credit sales, and compliance with ESG and SDG requirements, which in turn provide access to investors and
specific markets. These opportunities may drive the local government to develop research in this area of knowledge. On the other hand, it is important to emphasize that this research sits around the vehicular energy matrices, but that it can be expanded to energy matrices that supply industrial technologies as well.

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