THE FUTURE OF FUELS IN THE CONTEXT OF THE ENERGY TRANSITION – A COMPARATIVE ANALYSIS APPLIED TO THE BRAZILIAN SCENARIO.

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Abstract

Given the global scenario of greater recognition of the impacts of global climate change and the importance of reducing greenhouse gas emissions to reverse this scenario, a series of energy alternatives for the total or partial replacement of traditional fuels have been researched.

This movement is corroborated by several agreements and commitments signed at a supranational level to reduce carbon emissions and other greenhouse gases and, thus, mitigate the impacts of global climate change.

These demands for new fuels have driven an energy transition movement that is reflected in energy planning at national and global levels.

The present study carries out research into these movements, evaluating the national and global adoption of new technologies in advanced fuels and carries out a comparative analysis of these proposals, evaluating their aspects from different dimensions and considering Brazilian specificities and potentialities.

In view of this new global and national scenario, in which several advanced fuels are available and competing for their adoption, the objective of this article is to carry out a comparative analysis, on the most diverse aspects, such as environmental, technical, performance, use of raw materials, production methods, legal, regulatory, among others, of the various advanced fuels that are available on the market or in development, so that it can be used as a reference in decision-making by private sector agents and public policy makers.

Introduction

Increasingly, energy alternatives have been researched and the viability of these alternatives for the total or partial replacement of traditional fuels is necessary and urgent.

In the global context, the International Energy Agency (IEA) report, "Net Zero by 2050" (IEA, 2021), defends the decarbonization of energy generation in the world within less than thirty years, which will imply restrictions on the model current exploration of oil and gas to produce fuels:

> *"No new oil and gas fields are needed on our path, and oil and natural gas reserves become increasingly concentrated in a small number of low-cost producers"* (IEA, 2021).

The search for cleaner and more accessible energy, as well as the proposal for actions against global climate change, is also present in the Sustainable Development Plan (PDS), of the United Nations (UN), and in its 2030 Agenda. Two of the 17 Sustainable Development Goals (SDGs), with a specific focus on these themes. (ONU, 2015)

In the same direction, but within the scope of Brazilian national energy planning, the need to search for alternative energy sources and advanced fuels appears in its scenarios, but with a more adapted perspective to Brazilian characteristics:

> *It is worth highlighting here that Brazil has a continental territory, with vast natural resources and very favorable climatic and soil fertility conditions that often exceed the total energy demand estimated for the next 30 years. We will move from a position of net importer of energy to another reality, of net supplier. Thus, we realize that our role now is to manage the abundance of energy resources."*
> (EPE, 2020)

In search of the best alternative in defining public policies, the Brazilian Fuel of the Future program, established by the National Energy Policy Council (CNPE), aims to propose measures to increase the use of sustainable and low-carbon intensity fuels, as well as the application of national vehicle technology, with biofuels, with a view to greater decarbonization of the Brazilian transport matrix. In this way, the Future Fuel Technical Committee (CT-CF) was created, which, among others, studies and proposes a methodology for evaluating the complete life cycle of fuels, "from the well to the wheel". (CPNE, 2021)

As a large energy public policy program to study and evaluate initiatives related to different uses of fuels, involving the way the country will treat them in the future and proposing initiatives within the scope of public policy, the Technical Committee for Fuel of the Future (CT-CF) is subdivided into six subcommittees, as shown in figure 1 below.

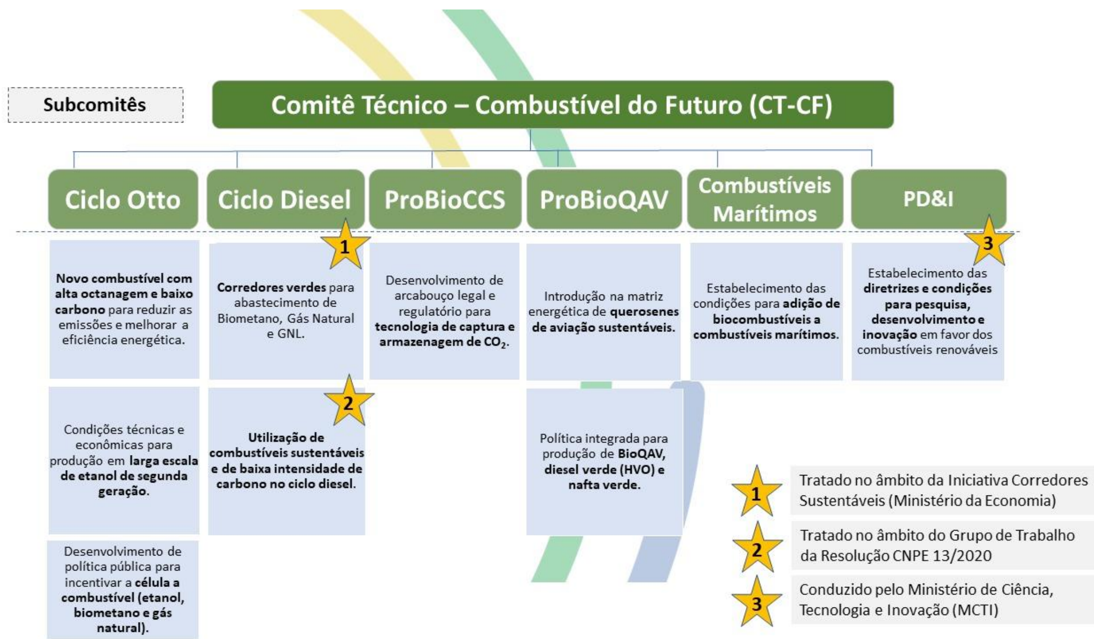

Figure 1: Organizational chart of the CT-CF and its respective Subcommittees

It is worth noting that there are already public policies implemented towards the decarbonization of Brazilian fuels and their results can now begin to be measured and evaluated.

The greatest example of this policy is the National Biofuels Policy, known as RenovaBio. Established at the end of 2017, through Law No. 13,576, it is an integral part of the national energy policy, aims to contribute to meeting the country's commitments under the Paris Agreement and promote the adequate expansion of the production and use of biofuels in the matrix national energy. (MME, 2020)

According to the Brazilian statistical yearbook for petroleum, natural gas and biofuels: 2023, published by the National Petroleum, Natural Gas and Biofuels Agency (ANP), in 2022, 31.4 million Decarbonization Credits (CBIOs) were issued by producers and certified biofuel importers. (ANP, 2023)

According to CNPE Resolution No. 6/2023, which defines RenovaBio's mandatory emission reduction targets for the 2024-2033 decade, the pace of increase in this legal obligation to acquire CBIOs will increase, reaching more than 80 million CBIOs in 2033 and consolidating the country's commitments towards the use of more sustainable fuels. (CNPE, 2023)

Year	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Estimated Carbon Intensity (gCO2/MJ)	72.77	71.70	69.97	69.74	67.67	66.68	66.02	65.56	65.44	65.22
Carbon Intensity Reduction Target (relative to 2018)	-0.8%	-2.2%	-4.6%	-6.3%	-7.7%	-9.1%	-10.0%	-10.6%	-10.8%	-11.1%
Annual Target (Million CBIOs)	38.78	42.56	48.09	52.37	56.41	61.24	64.24	67.13	68.81	71.29
Tolerance Intervals (Upper Limit)	-	48.94	55.30	60.23	64.87	70.43	73.70	77.20	79.20	81.98
Tolerance Intervals (Lower Limit)	-	36.17	40.88	44.51	47.95	52.05	54.47	57.06	58.49	60.59

Table 1: Compulsory annual greenhouse gas reduction targets, CNPE resolution no. 6/2023

It can be seen, therefore, that the study and analysis of advanced fuel alternatives proposed here, considering the global Energy Transition that is underway, is fundamental to understanding the new scenario that will present itself and what challenges will be imposed at the national level.

Study Objectives

Considering the new global and local scenario in which several advanced fuels are available and competing for their adoption, the objective of this study is to carry out a comparative analysis on the most diverse aspects, such as environmental, technical, performance, use of raw materials, production methods, regulations, etc., of the various advanced fuels that are available or under research, so that it can be used as a reference in decision-making by private sector agents and public policy makers.

As a secondary objective, this study also proposes a discussion of the various technologies related to these advanced fuels and a general description of the future scenario of these fuels and how the country can fit into this context, given its specificities.

Methods

For this study, the following techniques and approaches were adopted: review of literature related to the Energy Transition movement, publications and patents related to new advanced fuel production technologies and mapping of the main energy planning documents and commitment agreements for reducing emissions and greenhouse gases.

For the proposed comparative analysis, research and survey of the evolution of legal and regulatory frameworks related to both pioneering biofuels (first generation) and advanced fuels were carried out, to understand the national legal and regulatory framework.

Current and ongoing Brazilian public policy programs and the coverage of these programs for the fuels studied were also discussed, to evaluate the induction and stimulation of their application.

Thus, each advanced fuel was related and compared to a reference fossil fuel, which it is intended to partially or completely replace.

Literature review

When compared to the rest of the world, Brazil has a privileged diversity and proportion of use of renewable resources, as shown in the National Energy Balance - BEN 2022, with the total internal supply of energy from renewable sources above 44%, while we have to the world average is around 15%. (EPE, 2022; IEA, 2022)

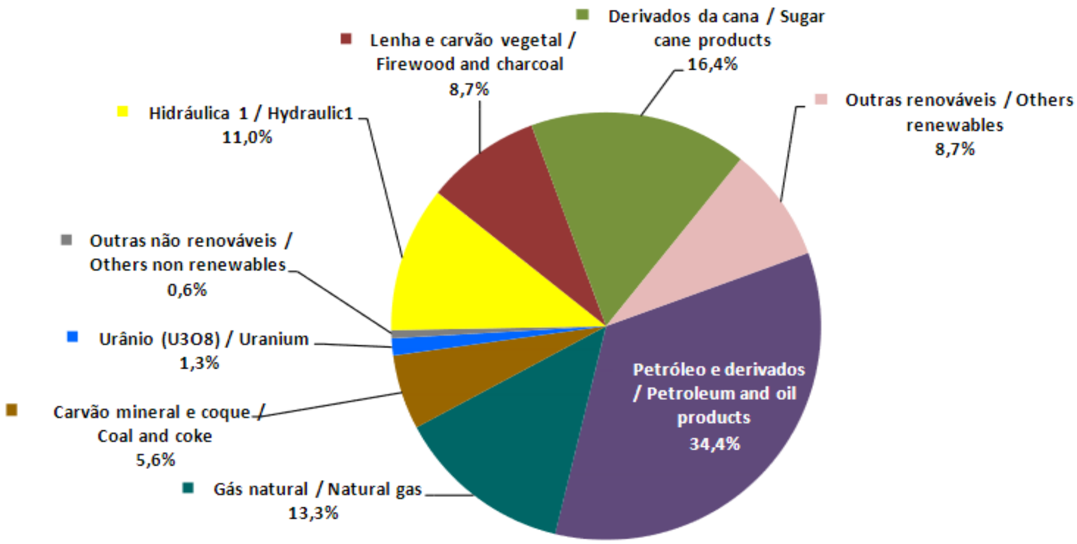

Figure 2: Domestic Energy Supply in Brazil, BEN 2022 (EPE, 2022)

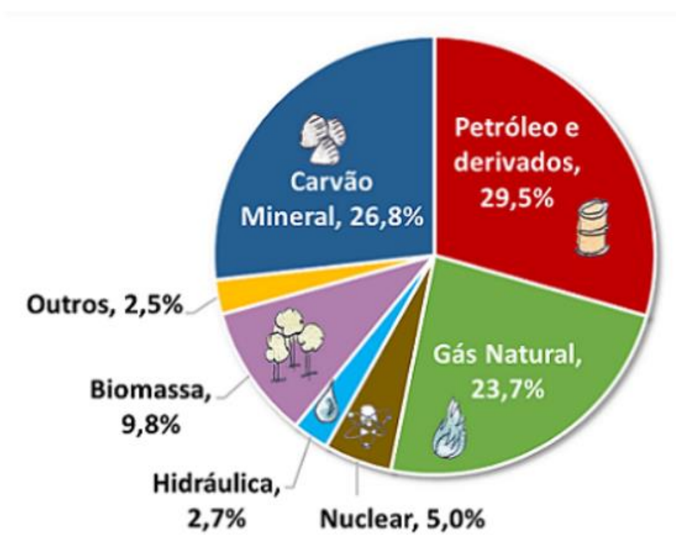

Figure 3: World Energy Supply (IEA, 2022)

When we look only at the supply of energy used in transport, this proportion decreases, due to the great role played by hydroelectric energy, and more recently, wind and solar energy in electricity generation, but it still maintains a significantly higher level than the world average, being that in 2021, the share of renewable fuels was above 22%. (EPE, 2022)

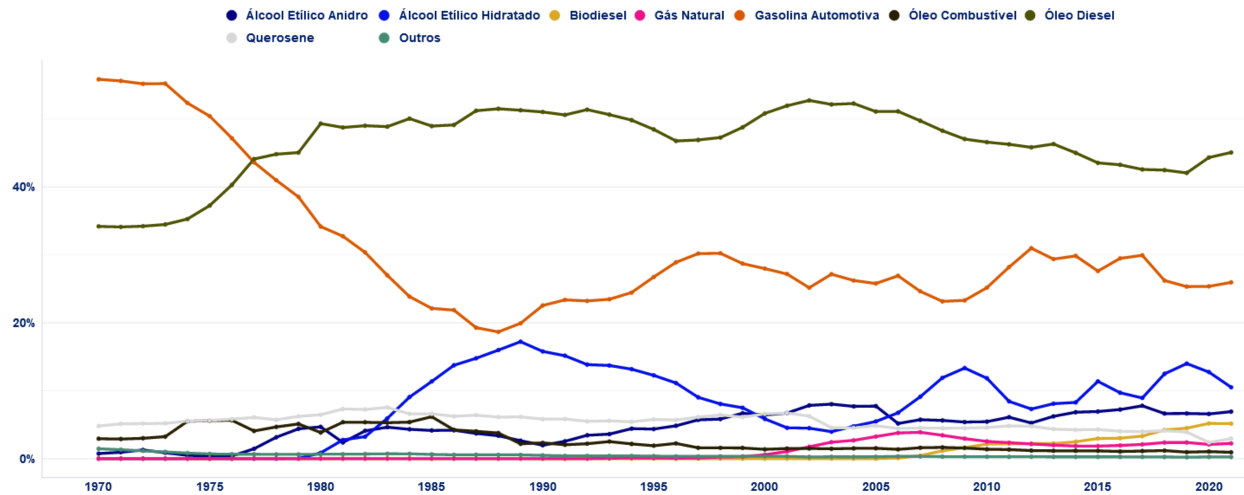

Figure 4: Historical series, BEN Interactive (EPE)

This participation is thanks to public policies that defined mandatory mandates for the use of ethanol and, more recently, biodiesel. This use can be direct, in the case of hydrated ethanol, or mixed with its fossil counterpart, in the case of anhydrous ethanol, for gasoline, and biodiesel, for diesel.

Results

The next section seeks to evaluate the various advanced fuels that are available or under research on various aspects, such as environmental, technical, performance, raw materials, production methods, regulatory, among others, to serve as a basis for a comparative analysis that allows evaluating its addition and use within the specificities of the country.

Gasoline (reference)

The evaluation of gasoline in the present study serves two purposes: to serve as a reference basis for other replacement fuels for Otto cycle engines and to evaluate its survival in a future scenario, given proposals for marginal improvements in its production and final use.

Regarding external dependence, in 2023, around 7% of gasoline A was imported. But as the country has a surplus in anhydrous ethanol, exporting around 9% of its production, and there is substitute consumption of hydrated ethanol, the impacts of this external dependence are mitigated for the Otto cycle. (ANP, 2023)

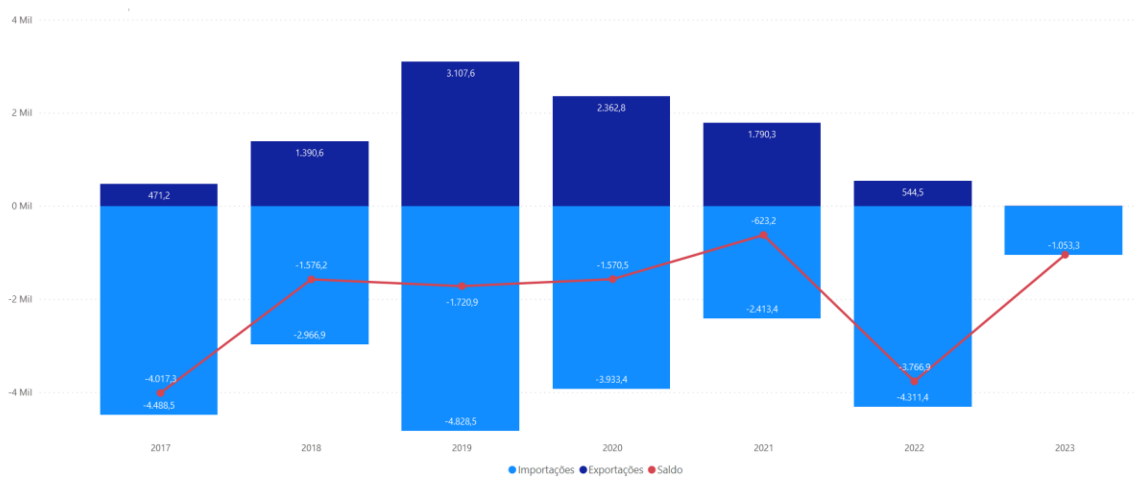

Figure 5: External Dependence on Gasoline until April/2023. Dynamic Panel of the Brazilian Liquid Fuels Market (ANP, 2023).

Regarding its reference characteristics, gasoline has its specifications given by ANP Resolution No. 807/2020, previously mentioned, and when used in its pure form, gasoline A, does not have sufficient compression resistance for use in current automotive engines, which is why it needs to be mixed with an anti-knock agent, also known as octane improver.

This increase can be promoted, to some extent, by special processes during refining, as in the case of premium gasolines, but is typically accomplished through the addition of other substances, known as boosters. Historically, following the implementation of the Proálcool program, Brazil chose Anhydrous Ethanol as its octane improver, to the detriment of old compounds based on tetraethyl lead, which is highly toxic, or other synthetic compounds, as occurs in other countries.

As of August 2020, with the publication of ANP Resolution No. 807/2020, the ANP promoted improvements in the specification and an increase in the minimum octane rating of gasoline C, which promoted marginal gains in relation to performance, consumption and, indirectly, emissions atmospheric conditions, considering the future scenario of phases L-7 and L-8 of Proconve and the Rota 2030 Program. (ANP, 2020).

Additionally, at the public policy level, the Otto Cycle subcommittee, of the Future Fuel Technical Committee (CT-CF), among others, studies the supply of high-octane, low-carbon fuels, aiming for lower emissions with greater efficiency. energy combined with the use of high compression engines.

Ethanol

As previously introduced, ethanol had an early adoption in Brazil, through the Proálcool program and, after a period of discredit in the late 90s due to the lack of product, whose production was neglected due to the recovery of sugar prices in the market international, received new vigor with the development of flex-fuel engines in the early 2000s.

As a legacy of this history, in addition to the lessons learned regarding the need for regulatory stocks to guarantee stability in prices and product availability, there was also a large industrial park installed and know-how for the production of ethanol using process residues (bagasse and straw) for energy cogeneration, used in the process itself and with surpluses sometimes sold on the free energy market.

This resulted in higher productivity and profitability when compared, for example, to North American corn ethanol production, which receives heavy subsidies. But this did not guarantee leadership in ethanol production, which was supplanted by North Americans.

It is in this context that the importance of public policy programs, such as RenovaBio, and research and production of second and third generation ethanol stands out.

Regarding external dependence, the country has historically had a surplus in this product and in 2023 around 9% of the ethanol produced in the country was exported, with around half of this export going to the Asia-Pacific region. (ANP, 2023)

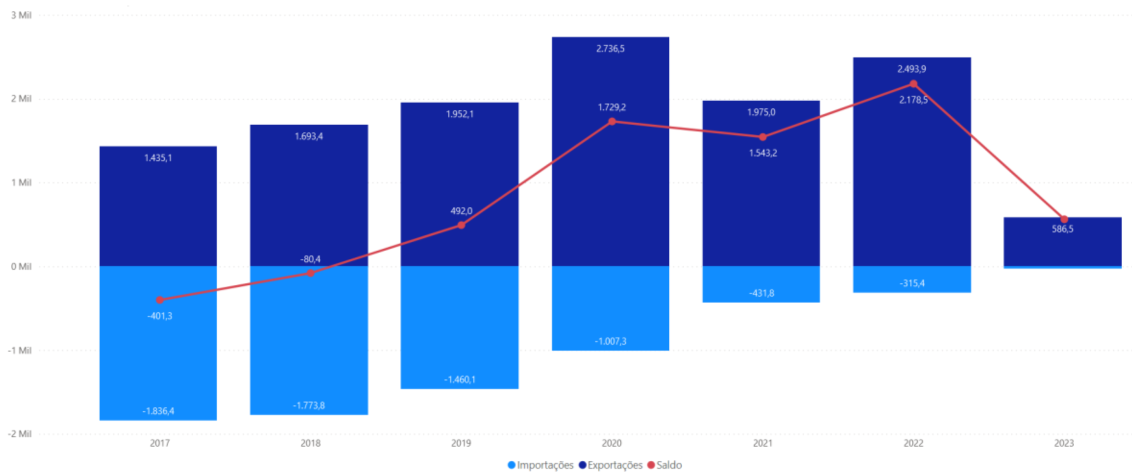

Figure 6: Ethanol surplus until April/2023. Dynamic Panel of the Brazilian Liquid Fuels Market (ANP, 2023).

Regarding their reference characteristics, anhydrous ethanol and hydrated ethanol have their specifications given by ANP Resolution No. 907/2020, which also establishes quality controls over these products and their marketing rules.

Diesel (reference)

In the same way as with gasoline, the objective of analyzing traditional fossil diesel oil is to establish reference elements for comparison with its more modern complements and substitutes, Biodiesel and Green Diesel.

Due to the fact that Brazil has adopted a development model strongly based on road transport, diesel, as it is the fuel for commercial fleets of cargo and passenger transport vehicles, has high relevance in public policy planning and in the costs of most national economic sectors.

In addition to this, historically the country has always had a strong external dependence for the supply of this product, and in 2023 more than 24% of this product was imported, much of it from Russia and the United States. (ANP, 2023)

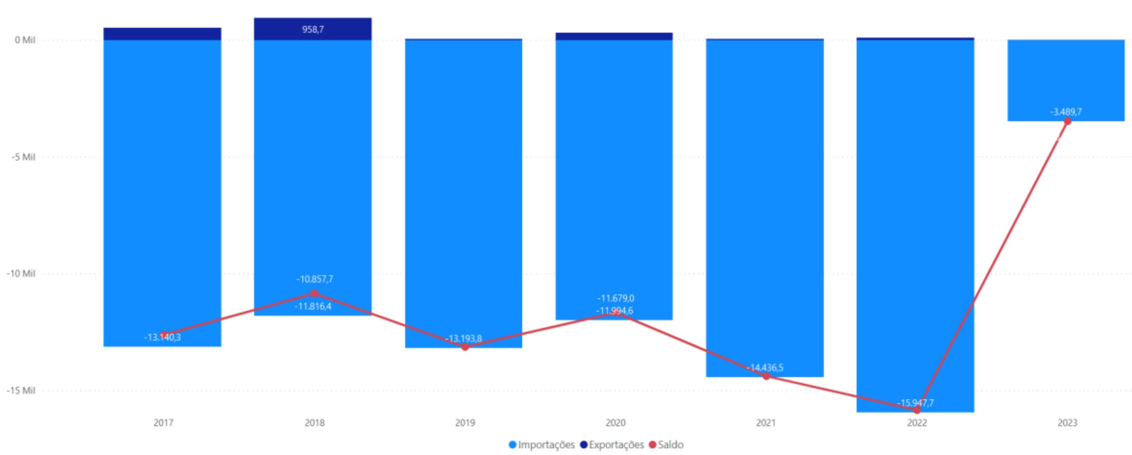

Figure 7: External Dependence on Diesel until April/2023. Dynamic Panel of the Brazilian Liquid Fuels Market (ANP, 2023).

Regarding its reference characteristics, Diesel A oil has its specifications given by ANP Resolution No. 968/2024, which also establishes its quality controls.

Biodiesel

As previously introduced, biodiesel is a biofuel, for use in diesel cycle engines, which is derived from renewable sources such as vegetable oils and animal fats.

As defined by Law No. 9,478/1997, the Petroleum Law, in its wording given by Law No. 11,097/2005, the biodiesel is defined as “biofuel derived from renewable biomass for use in internal combustion engines with compression ignition or, as per regulation, to generate another type of energy, which can partially or completely replace fossil fuels”.

In its regulation, the ANP adopted a narrower definition, according to which biodiesel is a renewable fuel obtained from a chemical process called transesterification. Through this process, triglycerides present in oils and animal fat react with a primary alcohol, methanol or ethanol, generating two products: ester and glycerin. The first can only be sold as biodiesel, after going through purification processes to adapt to the quality specification, while the second is a by-product, but with relative economic value. (ANP, 2020)

Its specification has been constantly improved over the years and, recently, the ANP updated its regulations defining stricter technical criteria for specification, handling and transportation, in order to guarantee the quality of this product throughout the entire production and distribution chain. Thus, in April 2023, ANP Resolution No. 920/2023 was approved, which establishes the new biodiesel specification and the obligations regarding quality control to be met by economic agents that sell the product in the national territory.

Another regulatory framework that promoted changes in relation to biodiesel is ANP Resolution No. 857/2021, which ended the public auction format and defined a new, freer commercialization model from the beginning of 2022.

This change was motivated by CNPE Resolution No. 14/2020, which also brought the possibility of opening the market for the import of biodiesel, previously prohibited. However, the regulatory process to authorize this operation is still ongoing, according to information in its Regulatory Agenda for the 2022-2023 biennium. (ANP, 2022)

Another innovative device focused on social sustainability that was initially introduced in 2004, through Decree nº 5,297/2004, and later amended by Decrees nº 10,527/2020 and 10,708/2021, was the “Social Biofuel Seal”.

The Social Biofuel Seal is a certification that gives its holder the character of promoter of productive inclusion of family farmers and allows the biodiesel producer to have access to PIS/Pasep and COFINS rates with different reduction coefficients for biodiesel, which vary according to the material raw material acquired and region of acquisition. (MAPA, 2023)

To obtain this certification, the producer must purchase a minimum percentage of raw materials from family farmers, ensuring minimum prices, training and technical assistance for family farming.

Green Diesel and Coprocessed Diesel

Like biodiesel, green diesel is a renewable fuel produced from the processing of vegetable oils, animal fats and even waste from the food industry, such as frying oil.

According to ANP Resolution No. 842/2021, green diesel is a biofuel composed of paraffinic hydrocarbons, intended for Diesel cycle engines, produced by one of the five routes indicated in the body of this resolution or through another process, as long as it is approved by the Agency, and produced from raw materials exclusively derived from renewable biomass.

Unlike biodiesel, green diesel is a drop-in fuel, that is, because it has a chemical composition exactly the same as diesel oil of fossil origin, green diesel can be added to diesel in any proportion and even be replaced in full form.

However, due to its legal and regulatory framework differing from that of biodiesel, it cannot be included in the mandatory blending mandate, which currently stands at 14%. Therefore, its adoption should occur more slowly and gradually, as its production costs approach those of biodiesel.

It is important to highlight that both fuels, biodiesel and green diesel, compete for the same raw materials. However, because it is chemically the same, and not just compatible, as is the case with biodiesel, it makes the future adoption of green diesel more promising, depending mainly on the reduction of its costs, as the production technology becomes more mature and its volume implies economies of scale.

Results

The results obtained in the research carried out and in the comparative analysis were analyzed to measure the extent to which each technological and productive route for each fuel studied contributes to achieving the goals and objectives established both in international agreements and in public actions and policies that have focusing on the Energy Transition towards cleaner and more sustainable fuels.

This analysis was carried out through comparisons in tables and graphs in which the characteristics specific to each technology were included, here defined as study dimensions, as summarized in the comparison matrix presented in Tables 2 and 3:

Fuel	Raw Materials	Production Method	Relevant performance aspects	Support Legal & Regulatory	Incentive Programs and Public Policies	Infrastructure for production	Brazil's External Dependence	Drop-in	*"Selo Social"*
Gasoline (reference)	Fossil	Refinement	Needs octane enhancers	RANP* 807/2020	No	Traditional	Slightly deficient	-	No
1st generation ethanol	Ethanol, Corn	Fermentation and Distillation	Chosen as an octane enhancer in Brazil (anhydrous) and substitute for C gasoline (hydrous)	RANP 907/2022	Mixing Mandate + RenovaBio + *Combustível do Futuro*	Traditional	Slightly surplus	For flex-fuel vehicles only	No
2nd generation ethanol	Cellulosic biomass (Sugarcane bagasse, corn husks and others)	Enzymatic, Fermentation and Distillation	Molecule identical to that of 1st generation Ethanol	No specific treatment (RANP 907/2022, by analogy)	Mixing Mandate + RenovaBio + *Combustível do Futuro*	Needs new production plants (growing)	Not representative, but compatible with the 1st generation ethanol market	For flex-fuel vehicles only	No
3rd generation ethanol	Microalgae	Cultivation, Fermentation and Distillation	Molecule identical to that of 1st generation Ethanol	No specific treatment (RANP 907/2022, by analogy)	Mixing Mandate + RenovaBio + *Combustível do Futuro*	Needs new production plants (experimental)	-	For flex-fuel vehicles only	No
Diesel (reference)	Fossil	Refinement	Need lubricity improvers	RANP 50/2013	No	Traditional	Heavily deficient	-	No
Biodiesel	Soybeans, animal fat, palm, peanuts, cotton, frying oil and waste	Transesterification	Product "compatible" with Fossil Diesel Assists in increasing the lubricity of Diesel BX	RANP 45/2014	Mixing Mandate + RenovaBio + *Combustível do Futuro*	National production park already installed	Compatible with the Diesel market (NOTE: Import trade still under study)	No	Yes
Diesel Verde (Green Diesel)	Same as Biodiesel	Hydrotreatment, among other routes	Molecules identical to fossil diesel	RANP 842/2021	Mixing Mandate + RenovaBio + *Combustível do Futuro*	Needs new production plants	Compatible with the Diesel market and with the possibility of reducing external dependence	Yes	No, but it could be adapted for that purpose.
Co-processed diesel	Same as Biodiesel	Hydrotreatment	Molecules identical to fossil diesel	No	No	Can be processed in adapted refining units	Compatible with the Diesel market and with the possibility of reducing external dependence	Yes	No, but it could be adapted for that purpose.
Aviation kerosene (reference)	Fossil	Refinement	Strict controls on quality and certification for use in aircraft	RANP 778/2019	No	Traditional	Slightly deficient	-	No
Aviation biokerosene (SAF)	Same as Biodiesel	Hydrotreatment	Molecules identical to fossil kerosene	RANP 778/2019	RenovaBio + *Combustível do Futuro*	It can be processed in adapted refining units and produced in conjunction with Green Diesel	Not representative, but compatible with the Aviation kerosene market	Yes	No

*RANP: *Resolução ANP* (ANP Resolution)

Table 2: Comparative analysis of the Otto and Diesel Cycles and Aviation.

Fuel	Raw Materials	Production Method	Relevant performance aspects	Support Legal & Regulatory	Incentive Programs and Public Policies	Infrastructure for production	External Dependence	Drop-in	Social Seal
NG, LNG and CNG (reference)	Fossil	UPGN	Must be liquefied (LNG) or compressed (CNG) for use in transportation	RANP 16/2008 (GN), PANP 118/2000 (LNG) and RANP 41/2007 (CNG)	No	Network industry for NG and Traditional for LNG and CNG	Heavily deficient	-	No
Biomethane	Biogas from the decomposition of organic matter	Biogas Purification and Specification	Molecules identical to NG	RANP 685/2017	RenovaBio + *Combustível do Futuro*	New production plants in operation and construction (growing)	Not representative	Yes	No
Grey Hydrogen (reference)	Fossil	Petrochemical industry	General use by the industry with input	-	No	Traditional	Traditional (small)	-	No
Blue Hydrogen	Natural gas	NG Reform	Carrier of energy, fuel, use by the industry as input and as raw material for synthetic fuels	No	*PNH2**	Can be transported along with NG (with limitations)	Market in the making	Yes	No
Green Hydrogen	Water	Electrolysis from renewable sources	Carrier of energy, fuel, use by the industry as input and as raw material for synthetic fuels	No	*PNH2*	Can be transported along with NG (with limitations)	Market in the making	Yes	No

*PNH2: *Programa Nacional do Hidrogênio* (National Hydrogen Program)

Table 3: Comparative analysis of Natural Gas and Hydrogen.

Conclusions

From the results obtained and the comparisons made, it was possible to identify points of improvement, weaknesses and opportunities for Brazil in the use of the advanced fuels presented.

From this analysis, we can notice a slowness in establishing legal and regulatory frameworks for the most recent advanced fuels, especially hydrogen.

Despite the country's successful experience and pioneering spirit in establishing a robust and stable legal and regulatory framework in relation to biofuels, there is still a long way to go to establish the same level of maturity for the aviation sectors and the nascent low-carbon hydrogen market.

For aviation, it is noted that the traditional establishment of volumetric mandates traditionally used for biofuels would not be in line with the global design of general mandates for carbon emission reductions in the airline sector.

On the other hand, it is noted that public policy programs under development, such as PNH2, or being implemented, such as Fuel of the Future, in addition to being aligned with a domestic and global environmental agenda, have advanced to fill this gap.

Finally, the study shows that, depending on the history and specific characteristics of Brazil, the future of fuels indicates a diversity of solutions and actors throughout the Energy Transition movement.

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