CHAPTER 5
THE FUTURE OF BIOFUELS IN BRAZIL

5.1. INTRODUCTION: RECENT CHANGE IN HABITS AND POSSIBLE IMPACTS IN TRANSPORTATION IN BRAZIL

In recent years, with the advent of the Covid-19 pandemic, have witnessed significant changes in consumer habits particularly in middle and high-income countries. This trend goes back to recent decades, when a change in the perception of vehicles ownership has been accentuated, specially within the new generation. This change needs to be better understood as it has wider implications and embraces owning a car or a house, together with the diversification of transport modes of individuals. For example, the increasing use of motorcycles, bicycles, scooters, and variations of these modes, including electric, are visible even in middle income countries such as Brazil. Probably, this change in habits is partly due to concern with the environment and climate change.

Brazil could be considered as paradise for motorcycles and their manufacturers e.g., YAMAHA, HONDA, and others. Most of these motorcycles are used in delivery services in the middle and large cities in the country, making the traffic even worse, particularly in the rush hours and noon.

Also, as a complement, mobility companies such as UBER have gained importance during the pandemic. For example, in Brazil and particularly in large cities, it is frequent the use of their services for ride-hailing, food delivery, couriers, and freight transportation.

Besides, ecommerce is another kind of service that is gaining a significant momentum, particularly during the pandemic. Also, in Brazil, with a well-established domestic aviation network, local companies such as MARISA, MERCADO LIVRE, and AMERICANAS, are now disputing this market for delivery and ecommerce.

Finally, the pandemic accelerated another important change, homeworking, in detriment of office working. This has major implications e.g., for transport and shops that depend on the commuter for their business. Brazil has been one of the countries that suffered the most with the pandemic forcing many companies to adapt to changing consumer's preferences. Another important noticeable change has been the non-presential meeting platforms in favour of video conferences, which has also resulted a substantial change in habits. It is difficult to ascertain, but one can guess that this "new normal" will have an impact on transport, and consequently on liquid fuels, particularly in light vehicles sector in Brazil. Homeworking will not go away, although it is expected that the return to the office will gradually increase.

5.2. INTRODUCTION OF ELECTRIC CARS IN BRAZIL

Electric cars are gradually entering the Brazilian market, with multinational corporations plying a key role. According to the Brazilian Association of Electric Cars (ABVE), 801 electric cars were sold in 2020 and 2,851 in 2021. This figure represents near 1.5% of light vehicles sold in 2021 (1,557,957 and 416,474 commercial light vehicles) according to the Brazilian National Federation of Vehicles (FENABRAVE). These figures do not include other vehicles such as battery-electric vehicles (BEV), hybrid electric vehicles (HEV), nor plug-in hybrid electric vehicles (PHEV).

Table 5.1 Ranking of best-selling electric cars (EV) in 2021 in Brazil. Source: Canaltech (2021).

Model	Units sold	Price R$	Price US$[1]
Nissan Leaf	439	287,300	56,330
Porsche Taycan	379	699,000	137,580
Volvo XC40	375	389,950	76,460
Mini Cooper Electric	313	239,990	47,060
Audi E-Tron	252	604,900	118,600
BMW i3	159	304,900	59,780
Fiat 500e	146	248,000	48,630
Chevrolet Bolt	132	275,100	53,940
JAC iEV	49	169,900	33,310
Renault Zoe	53	204,000	40,000

As for prices to the consumer, it is difficult to compare the retail prices of electric with combustion engine vehicles, because they use different technologies with different maturity.

1 Using average exchange rate of R$ 5.10/US$ for 2021.

If the BEV, HEV, and PHEV, are added, the total number of electric cars sold in 2021 was 34,990 representing a rise of 77% over 2020.

Table 5.2 shows the ranking models of EV according to ABVE, 10 BEV, HEV, and PHEV sold in Brazil in 2021

Table 5.2 Ranking of BEV, HEV, and PHEV vehicles sold in in Brazil in 2021. Source: ABVE (2021).

Model	Units sold
Toyota Corolla XRX Hybrid-HEV	11,027
Toyota Corolla Altis-HEV	7,921
Volvo XC60-PHEV	3,366
Volvo XC40-PHEV	3,067
Volvo XC90-PHEV	982
BMW X3 XDRIVE 30-E-PHVE	836
BMW X5 XDRIVE 45-E-PHVE	812
Toyota RAV4H-PHEV	810
BMW 330E-PHVE	579
Porsche Cayenne PHVE	554

According to ABVE the number of BEV, HEV, and PHEV vehicles sold in the first trimester of 2022 alone, has increased by 115% compared with the same period of 2021. However, the perception of consumers in Brazil is that they will need to have significant reduction in costs to increase their share of the automobile market. This cost reduction in electric vehicles may occur as the sales accelerate in China, Europe, and the USA. This electric vehicle cost reduction process will determine the speed at which electric cars will be introduced and the impact on the Brazilian market too.

Finally, the future of fuel ethanol in Brazil will certainly depend on the price of electric cars in the domestic market. This transition will take at least two decades, and in the meantime, it will be necessary to establish specific policies to protect the biofuels market given their socio-economic and political implications for the country.

Another important difficulty associated with the introduction of electric vehicles in Brazil is lack of infrastructure to recharge these electric cars. Currently the country has more than 40,000 gas/petrol stations with regular ethanol (E100) and gasohol (E27.5) supply.

Although the introduction of electric cars maybe seems far into the future, electricity utility companies such as Companhia Paulista de Força e Luz (CPFL), today controlled by Chinese capital, are already installing free electric recharging stations. In 2015 the Chinese company BYD, manufacturer of electric buses, vans, trucks, and vehicles, inaugurated a new industrial plant in Brazil. Several BYD electric buses can already be seen circulating in Campinas. More recently, in 2022, the Chinese company Great Wall Motors (GWM) announced the installation of 100,000 electric vehicles factory, also in the same area. Therefore, it seems that there is already a strategy to introduce electric cars in the Brazilian market and consequently it is quite possible that this market will accelerate more rapidly than appears today.

A good example is the CPFL directly involvement in the electric car business. An important question is: where is the electricity coming from? In Brazil 85% of its electricity is generated from RE, primarily hydro power which is still the key. However more renewable electricity will be needed, and Brazilian electricity generation system needs to be properly adjusted and updated to accommodate the new demand. This will be challenging.

Naturally, more electricity will be needed, and that RE energy (mainly solar, wind, and biomass) are presently the best candidates for a rapid expansion. Wind has an important niche in Brazilian Northeast where already provides more than half of all electricity consumed. Biomass, in particular sugarcane mills, all together represents nearly 10% of all electricity consumed in the country. The share of solar is still very small but growing fast in a country with excellent sunshine potential. Solar will certainly benefit from cost reduction as it is happening around the world.

Already these three sources are providing almost 25% of Brazilian electricity. They offer the possibility of decentralized generation to enhance the security of the electricity grid. Therefore, there are good opportunities to significantly expand renewable energies, particularly for electricity generation.

5.3. PERSPECTIVES FOR FUEL ETHANOL

As a result of oil crisis in the 1970s Brazil intensified its production and use of sugarcane fuel ethanol, as discussed. During the past few decades, the country has built up a solid contribution of fuel ethanol to its liquid fuel energy matrix. However, this situation is under threat by the shift to electric light vehicle transportation technology. The introduction of electric vehicles, as indicated in Chapter 1, is growing a phenomenal speed, although unequally worldwide. China and Europe are cases in mind, but there remain serious unanswered questions as to where and how electricity will be generated. Will renewables be sufficient? Probably not and hence new alternatives need to be found.

However, as mentioned in Chapter 1, the future global energy scenarios presented by the International Energy Agency, BP, etc., forecast an important and growing contribution of modern bioenergy and advanced biofuels. Besides, difficulties related with the development of better batteries creates a situation in which liquid biofuels may still be a good solution for long distance transportation in a wide range alternative e.g., vehicles, aviation, and maritime, and the chemical sector. Table 5.3 shows different alternative fuels and their respective energy density.

Table 5.3 Different alternative fuels and their respective energy density: Sources:[2]

Transportation mode	alternative	energy density
Light vehicles	lithium-ion batteries	0.875 MJ/kg[3]
	anhydrous ethanol	30 MJ/kg
	gasohol E10	43.5 MJ/kg
Aviation	jet fuel - kerosene	35 MJ/l
	liquid hydrogen	10 MJ/l HHV 8.5 MJ/l LHV
	anhydrous ethanol	24 MJ/l
Maritime	diesel fuel	45.6 MJ/kg

Obviously, energy density is just one but important criteria in the selection of an appropriate fuel. And here biofuels may have an important niche to replace fossil fuels in long distance transportation. Also, an obvious question would be what is an ideal fuel? Could it be developed? Should it fit in the existing engines? Or should new engines be designed to fit an ideal fuel (s)?

5.3.1. THE FLEX-FUEL ENGINES IN BRAZIL

In the past two decades the most significant innovation of the automotive fuel use in Brazil was the introduction of flex-fuel engines with the ability to accept different proportions of ethanol and gasoline blends.

Flex-fuel vehicles were a positive answer to allow greater flexibility to consumers. The 1989 crisis was very disappointing for lack of planning, but the introduction of flex-fuel vehicles provided the necessary confidence on ethanol fuel. However, the flex-fuel engines were not a long-term satisfactory solution because the energy efficiency stagnated over time, creating the impression that light vehicles in Brazil were inefficient. This chronic problem, inherent to flex-fuel engines, together with a global effort to reduce GHG emissions, has created the momentum to revise policies and to consider changes to improve efficient mobility.

Consumers are not really satisfied with low performance of the flex-fuel engine. Table 5.4 illustrates fuel consumption of flex cars for E27.5 gasoline versus E100. The natural consequence is that the market for E100 is declining.

2 https://en.wikipedia.org/wiki/Energy_density
3 https://en.wikipedia.org/wiki/Lithium-ion_battery

Table 5.4 Fuel Consumption (gasoline E27.5 and E100) and cost per km for different flex-fuel vehicles in Brazil 2021-2022. Source: SODRÉ (2022).[4]

Vehicle Model	Urban Fuel Consumption				Fuel Price		Cost per kilometer		(%) Difference E100 and E27.5
	Gasoline E27.5 (km/l)		Ethanol E100 (km/l)		Gasoline E27.5 (US$/l)	Ethanol E100 (US$/l)	Gasoline E27.5 (US$/km)	Ethanol E100 (US$/km)	
Hyundai Creta 1.6 flex 2021	12.3	0.8%	8	12.5%	1.12	0.86	0.091	0.108	+ 18.7
Hyundai Creta 1.0 turbo flex 2022	12.4		9		1.57	1.11	0.127	0.123	– 3.1
Honda City 1.5 flex 2021	11.1	4.0%	8.5	1.1%	1.12	0.86	0.101	0.101	0
Honda City 1.5 flex 2022	12.9		8.6		1.57	1.11	0.122	0.129	+ 5.7
Jeep Compass 2.0 flex 2021	8.1	33.3%	6.4	28.1%	1.12	0.86	0.138	0.134	– 2.9
Jeep Compass 2.0 flex 2021	10.8		8.2		1.57	1.11	0.145	0.135	– 6.9

Note: fuel prices for October 2021 and April 2022; price increase for gasoline E27.5 was 40.2% and for ethanol E100 was 29.1% – Exchange rates: October 2021 (1 US$ = R$ 5.65) and April 2022 (1US$ = R$ 4.60)

Light vehicles manufactured in 2022 are more efficient and less pollutant and more economic, reflecting, according to Sodré (2022), the improvements as a result of the Program for Vehicle Emission Control (PROCONVE)[5] coordinated by the Brazilian Ministry of Environment. All the participating vehicle models show an improvement in their fuel performance.

Although hydrous ethanol emits much less CO_2, consumers tend to be pragmatic and choose E27.5. The question is what will happen with E100 and flex-fuel engines in Brazil? Will simply stop producing and distribute E100? Can the existing infrastructure be used for hybrid or fuel cells technology using E100?

The 2021-2022 improvements in vehicle performance were not sufficient to offset the increase of fuel prices due to the Russian war on Ukraine despite better exchange rate in Brazil. As a result of the increase in oil prices, commodity prices (agriculture and iron ore) also went up. This phenomenon made the Brazilian Real recover much of its devaluation since the beginning of the pandemic in March 2020. Presently, the

4 SODRÉ, E. "Gasolina cara reduz vantagem de carros novos mais econômicos", in Folha de São Paulo, April 22th, 2022, Mercado, Page A12.

5 https://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/56643907

price of gasoline (E27.5) is high compared with other nations, although it is experiencing fluctuations due to a new policy of tax reduction on liquid fuels.

Table 5.5 Price of gasoline in different countries. Source: BALAGO (2022).[6]

Country	Price (R$/l)
Argentina	4.76
Mexico	5,48
United States	5.59
Chile	6.50
China	6.91
South Africa	6.95
India	6.99
Brazil	7.19
France	8.85
UK	9.93
Germany	10.05

Why ethanol prices went up following the gasoline price increase? Maybe because April prices are traditionally high due to lack of ethanol in the market. Sugarcane harvest begins in April and May in Central-South Brazil. Another explanation maybe the opportunism of ethanol producers trying to extract extra earning.

Typically, ethanol (E100) prices in gas stations are about 70% of gasoline (E27.5) prices. Consumers use a rule of thumb according which if ethanol (E100) prices are higher than 70% of gasoline E27.5 price, they prefer to use gasoline (E27.5) instead of ethanol E100.

According to the above table values, in October 2021 ethanol E100 price was 76.8% of the price of gasoline E27.5. In April 2022 ethanol price went back to 70.7% of the gasoline price.

2021 was particularly a bad year for sugarcane due to prolonged drought and the need to honour sugar exports, causing lower ethanol supply.

5.3.2. WHAT WILL HAPPEN TO E100 AND E27.5?

As mentioned in Chapter 2, Brazil has created a unique blending market for this fuel. This practice originated in the early decades of the 20th century, gained maturity

6 BALAGO, R. "Petróleo caro deve ajudar economia do Brasil em 2022, diz FMI", in Folha de São Paulo, April 20th, 2022, Mercado, A21.

during the years between WW II and the 1st oil shock in 1973. When PROALCOOL was created in 1975, the goal was immediately implemented to increase the percentage of ethanol blended in gasoline. Annexed ethanol distilleries were built alongside existing sugar mills. Later, after the 2nd oil shock of 1979 a new target was to introduce the E100 market, producing ethanol on autonomous distilleries. Also, an agreement was signed between the government, the automakers, and ethanol producers with the objective to abolish possible royalties associated with the development of E100 engine. This agreement supported by ANFAVEA was considered a turning-point on the development of fuel ethanol.

The next decade, the 1980s, was still marked by subsidies to ethanol. As it was explained before, Petrobras (the State Oil company) had an "ethanol account" which paid a higher price for ethanol than sold in petrol stations. The Brazilian Government was financing this account contributing to the country growing inflation. The first few years of 1980s was also marked by an increase on international interest rates and the Brazilian foreign debt. These pressures contributed to the fall of the military regime and consequently the beginning of a democratic government in the country. Under democracy, the ethanol account was difficult to maintain, exerting greater pressure on ethanol producers. This situation, together with the increasing sales of ethanol cars, culminated in the 1989 crisis. That year the Brazilian Government had to import methanol to satisfy the ethanol deficit in the gas stations. This fact created a great unhappiness of consumers with ethanol vehicles (E100) nicknamed "duck cars". E100 cars sales dropped fast as consequence.

The 1990s started with this new reality in which subsidies to ethanol were removed and producers had to work out their own financial stability. These years were marked by the expansion of sugar production and in less than 10 years Brazil become the largest sugar exporter in the World. Sugar paid well and the model sugar-ethanol production was consolidated in the 1990s. However, the ethanol marked suffered a drawback as the E100 cars production practically went to zero in this decade.

The first decade of 21st century started with a well consolidated sugar-ethanol sector but with doubts of the Brazilian automobile sector. The advent of flex-fuel engine by Ford and their introduction in Brazil represented a good opportunity to regain confidence and enthusiasm on E100 fuel. Consumers, once sceptical of the E100 vehicles, could now regain new confidence with the flex-fuel cars. However, there was a price to be paid, and that was the decrease in engine efficiency. Consumers were happy because they paid less for the fuel and have the warranty that in case there was a shortage of ethanol, they could still run their cars on petrol. The flex-fuel cars were so successful that several manufacturers decided to stop producing gasoline vehicles and manufactured exclusively flex-fuel versions.

Another important point is that the introduction of flex-fuel cars reactivated the E100 market e.g., the E100 market (hydrous ethanol of around 93-94% by volume). So, now with the flex-fuel cars there was much more security for the consumers and the government with the risks associated with oil price fluctuations and commodities such as sugar, for instance. For further details see Cortez et al (2014b).

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With current high prices of fuels, including ethanol E100, there is a consumer's mistrust with the overall vehicle the engine performance in the Brazilian market. Consumers are aware that in the developed nations, the automakers are selling cars with have better engine efficiency and this is a source of frustration in Brazil. As it will be discussed further below, the Brazilian Government is aware of the need to improve engine efficiency for light vehicles and the creation of ROTA2030 program has this objective in mind. In addition, there exist an unwillingness of the sugar-ethanol sector to expand its production capacity because of the uncertainties with the Brazilian economy. Ethanol production has grown very slowly, if not stagnated, in the last decade. The only exception is corn ethanol which is growing quickly and already represents around 10% of ethanol produced in Brazil. Therefore, the question with the ethanol market would be what to do with the E100 fuel and flex-fuel cars? Would it be a good idea simply stop producing flex-fuel cars and gradually turn hydrous into anhydrous ethanol to supply more ethanol for blending? The recent USA increase of ethanol blending to B1[7]5 maybe is an indication of how ethanol can be part of the strategy to mitigate GHG emissions.

5.3.3. TECHNOLOGICAL ALTERNATIVES FOR FUEL ETHANOL

Although 1G biofuels, in many aspects, still have their comparative advantage in Brazil, the transition is posing new challenges as well as opportunities faster than we can imagine. The first possibility is to introduce technologies that can gradually introduce electrification combined with ethanol. This could take advantage of the existing E100 infrastructure and existing flexibility in light vehicle fuel market. According to Federal Government's Annual Statistics 2021[8] the present number of gas stations has grown, with over 41,000and 180+ distributors, with BR, IPIRANGA, and RAÍZEN being the most important, employing more than half million workers. Practically in all gas stations E100 and E27.5 is available.

In 2021, TOYOTA introduced the flex-fuel Corolla Altis Hybrid[9] petrol-electric model. This can be viewed as a trial to provide greater fuel flexibility to the consumer and a hope that the hybrid technology can compensate the lower performance of flex-fuel engines. These vehicles tend to be more expensive, of course, because they incorporate both the combustion and the electric engines.

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7 https://www.tomorrowsworldtoday.com/2022/04/25/biden-announces-e15-rule-change-poet/

8 https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/anuario-estatistico/anuario-estatistico-2021

9 https://www.toyota.com.br/modelos/corolla/

Using a different strategy, focused on fuel cells, NISSAN is developing a new ethanol-hydrogen engine. The new model NISSAN Solid Oxide Fuel Cell - SOFC[10] will not need an electric battery because ethanol E100 is used to produce the required hydrogen. The technology allows E100 to be converted into hydrogen using ethanol reformers and then use the hydrogen in a conventional lithium-ion fuel cell. A prototype has already been tested and is scheduled to be in the Brazilian market quite soon.

The key feature of fuel cell technology is to escape from Carnot´s limiting efficiency. All combustion engines or cycles, including Otto, Diesel, Brayton, and Rankine, are subject to Carnot´s efficiency as upper limit. The fuel cell technology breaks with that paradigm since it is not a thermal but an electrochemical reaction involving no combustion. The expected overall efficiency is the product of the reformer and the fuel cell efficiency.

There is ample room for more efficient ethanol engines. For example, FIAT[11] was developing a high-efficient ethanol engine though it gave up in 2021. It is difficult to speculate the company decision, but the most likely reason was the way the company evaluated the perception of Brazilian consumers on the future of E100. Nonetheless, this could be a viable technical alternative which should be considered further. However, the Brazilian automotive industry, basically multinational corporations, are less willing to find a solution that will only be valid in Brazil. As mentioned before, this situation happened in 1979 with the ethanol-based engine. At that time the government intervened to sort out this resistance from the car manufacturers. But those were different times, when the Brazilian Federal Government was a military dictatorship and had more capacity to literally dictate policies.

5.3.4. HOW ETHANOL ENGINES COMPARE WITH THE ELECTRIC CARS?

Sugarcane ethanol produced in Brazil has a very low GHG emissions and can adequately compete with electric cars, especially if the electricity is not sustainable. Table 5.6 published by CNPEM (2018), compares different engine technologies using ethanol with flex-fuel using gasoline and ethanol.

10 https://quatrorodas.abril.com.br/noticias/nissan-e-ipen-renovam-parceria-para-pesquisas-de-veiculos-eletricos/

11 https://quatrorodas.abril.com.br/noticias/fiat-desiste-de-lancar-motor-1-3-turbo-a-alcool-super-eficiente-no-brasil/

Table 5.6 Comparison of different engine technologies using ethanol with flex-fuel using gasoline and ethanol. Source: CNPEM (2018).

Type of vehicle	Source of energy	Emissions[12] (gCO_2e/MJ)	Energetic efficiency[13] (MJ/km)	Energy Emissions gCO_{2e}/km	Total Emissions (energy+vehicle)[14] gCO_{2e}/km
Flex	Gasoline A	87.4	2.19	191	226
Flex	Gasoline C (E27)	73.8	2.19	162	196
Flex	Ethanol (E100)	20.8	2.19	46	80
Hybrid	Ethanol (E100)	20.8	1.64	34	74
Electric	electricity	55.5	0.72	40	96

Ethanol may not have a comparatively good energetic consumption as electric cars or fuel cell cars but has very good CO_2 emissions/km when compared with gasoline, and other available fuels, in general. Although fuel cells using ethanol were not considered in this study, they could also be a good alternative both for mitigating GHG emissions/km and to increase energy efficiency (MJ/km).

Also, according to an AEA[15] publication (AEA, 2017), Figure 5.1, ethanol can compete in equal terms with electric cars as far as GHG emissions/km is concerned.

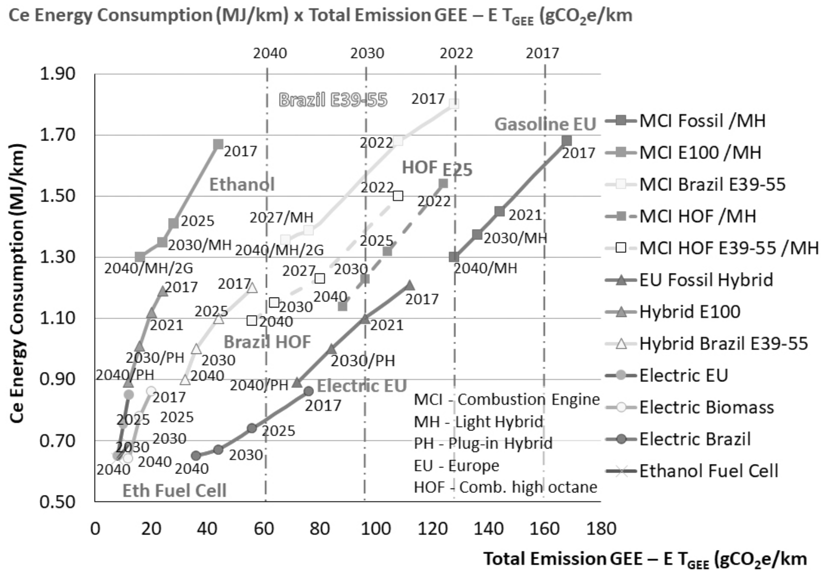


Figure 5.1 Energetic consumption vs total GHG emissions from well to wheel. Source: AEA (2017).

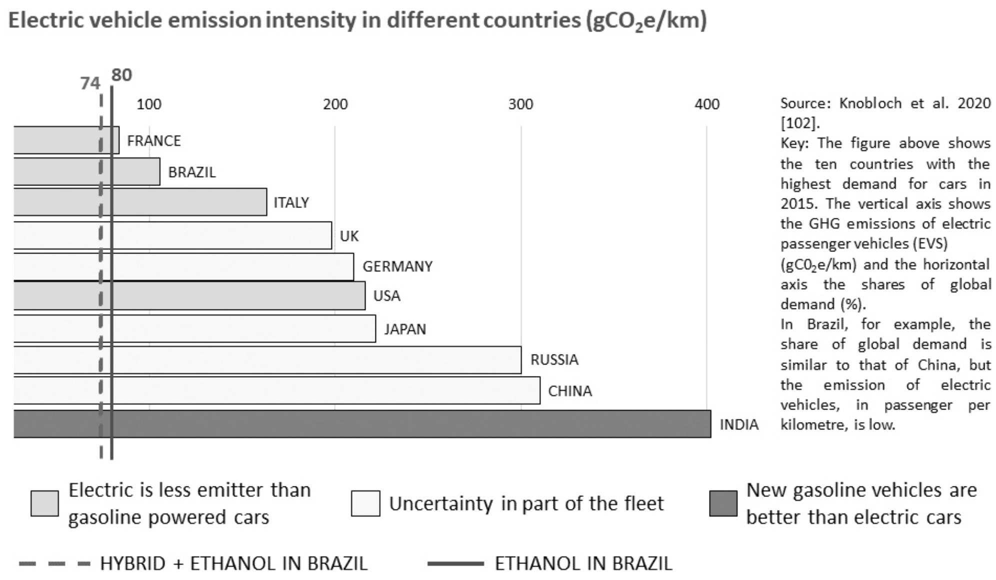
12 Based on RENOVABIO data

13 Based on Ecoinvent v3.1

14 Includes vehicle assembling and maintenance considering 288,394 km for a combustion engine vehicle, 216,296 for electric vehicles, and 100,000 km for the batteries

15 Associação Brasileira de Engenharia Automotiva – AEA (Brazilian Automotive Engineering Association)

Also, in the same direction, Figure 5.2 shows another interesting study, done by RAÍZEN (2022), comparing GHG emissions for electric passenger cars used in different countries and hybrid+ethanol in Brazil, plus ethanol in Brazil.



[12] The assumptions, parameters, and approaches adopted in the LCA can generate different results and interpretations for the individual transport technology.
The comparison between technologies can generate extremely heterogeneous and diverse results. This is mainly due to the different choices regarding the system boundary (border), level of detail in data collection (primary sources and aggregated data), assumptions and modelling [89]. Factors such as: vehicle performance, manufacturing, and type (materials, production process, weight, steel demand); technical characteristics (travel distance, charging time and schedule, efficiency, battery capacity), scope, time window, raw material extraction and production, final disposal, and other parameters can directly influence the results related to GHG emissions [258], [79].

Figure 5.2 GHG emissions (gCO2e/km) for electric passenger cars used in different countries compared with hybrid+ethanol in Brazil, and ethanol in Brazil. Source: (RAÍZEN, 2022).

And Table 5.7 shows also a RAÍZEN study comparing different electric car models with flex fuel engines using different fuels demonstrating their competitivity for GHG emissions.

Table 5.7 Comparative analysis of different electric car models (hybrid, hybrid plug-in, and electric) with flex fuel engines using gasoline A, gasoline C, and E100. Source: (RAÍZEN, 2022).

Region	Vehicle type	Vehicle's power source	Total (power and vehicle)
Brazil	Flex [83], [102]	Gasoline A	226
	Flex [83], [102]	Gasoline C [E27]	196
	Flex [83], [102]	Ethanol [E100]	80
	Hybrid [83], [102]	Ethanol [E100]	74
	Hybrid Plug-in [85]	Gasoline w/Electric	242
	Electric [83],[85]	Electricity	96-151

Region	Vehicle type	Vehicle's power source	Total (power and vehicle)
European Union	Electric [101]	Electricity	130
	Hybrid [89]	Gasoline	150-250
	Hybrid Plug-in [101]	Gasoline/Electric	90-190
United States China India	Electric [98]	Electricity	293
	Hybrid [106]	Gasoline	370
	Electric [107], [108], [86]	Electricity	91-265
	Gasoline [107]	Gasoline	199-250
	Electric [109], [103]	Electricity	289-400
Potential Technology	Hydrogen Gas [100]	Solar	92
	Hydrogen Gas [100]	Natural gas	450
	Liquid Hydrogen [100]	Solar	277
	Liquid Hydrogen [100]	Natural gas	660

Based on these data, it can be stated that there is no reason why sustainable ethanol production should not be expanded and used as an important component of the Brazilian GHG mitigation plan. It can be concluded that:

- Sugarcane fuel ethanol used in flex-fuel combustion engines already competes adequately in terms of the GHG emissions/km,
- The three other technologies (improve/dedicated E100, hybrid and fuel cells using fuel ethanol) could improve considerably the possibilities for ethanol.

Therefore, it could be concluded that the implementation and imports of electric models to Brazil is not only unnecessary but could be harmful.

5.3.4.1. Brazilian government policies for fuel ethanol

To meet with these needs, and comply with the Paris Agreement 2015, the Brazilian federal government approved in 2017 the RENOVABIO program to promote sustainable biofuels. In accordance with the Paris Agreement, Brazil accepted to reduce the GHG emissions by 37% in 2025 and 43% in 2030, relatively to 2005 levels.

Implemented by the Brazilian Agency ANP, RENOVABIO is the most recent National Biofuels Policy (*Law n. 13.576/2017*), with the specific objective to increase the production of sustainable biofuels in Brazil. RENOVABIO establishes targets to encourage biofuels market and reduce GHG emissions. It can be viewed as a transitional policy valuing ethanol and promote energy efficiency in transportation. RENOVABIO authorizes private companies to issue decarbonization credits known as CBios,[16]

16 CBio corresponds to one ton of carbon dioxide equivalent (tCO_2e)

to encourage renewable biofuels such as bioethanol, biodiesel and biomethane. The CBios are traded at the Sao Paulo stock market and in December 2021 its price was nearly US$10/t$CO_2$e.[17] Another complementary federal program is ROTA2030 (Law number 13.755/2018) which is intended for the automotive chain with the objective of supporting technological development, competitiveness, innovation, vehicle safety, environmental protection, energy efficiency and overall quality of automobiles. While RENOVABIO focuses on GHG emissions reduction, ROTA2030[18] focus is engine efficiency for example, reduction on GHG per km:

$$\underset{RENOVABIO}{\left(\frac{CO_2}{litre}\right)} \quad x \quad \underset{ROTA2030}{\left(\frac{litre}{km}\right)} \quad \left(\frac{CO_2}{km}\right)$$

Therefore, it can be concluded that the Brazilian federal government still remains an important protagonist in the automotive sector. The government is trying, somehow, "to run after the damage", as it is saying in Brazil, since there is a general feeling that ethanol as a fuel was about to be taken over by the electric car. Thus, it would be incorrect to say that, eventually, ethanol fuel will be replaced by electric vehicles, for both passenger cars and small commercial vans.

5.3.4.2. Complementary strategies ethanol with electric mobility

As indicated previously, imports of electric models (vehicles, motorcycles) would not be effective in terms of reducing GHG emissions for light vehicles. Besides, this policy could be risky because Brazil, being an atypical country in terms of natural resources, e.g., land, water, and sunshine, has excellent possibilities and opportunities to integrate biofuels and food, contrary to other countries where there could exist a conflict between food and biofuels. The math of GHG emissions is not always 1 + 1 = 2. Sometimes 1 + 1 < 2 as explained in chapter 4, with the introduction and expansion of corn ethanol. Having a prosperous agribusiness opens a tremendous opportunity for Brazil, since food is and will be the key most important item for human beings. And integrating the residual part of food production with the production of fuels may be a clever way to do so. This could be accomplished while achieving a substantial reduction of GHG in land change and beef cattle related emissions.

In addition, Brazil could, as it was discussed before, gradually adopt the electric cars in this transition without necessarily abandoning, sustainable fuel ethanol, from sugarcane or corn. This new strategy could be an effective way to take advantage of the climate change crisis, to promote sustainable economic development once again.

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17 www.renovabio.org

18 https://www.rota2030.com.br/#:~:text=O%20que%20%C3%A9%20o%20Rota,e%20a%20qualidade%20dos%20autom%C3%B3veis.

5.4. PERSPECTIVES FOR BIODIESEL

Vegetable oils have been considered as diesel substitute since the 1970s. In a book published by Melo and Fonseca (1981) they state that the area required to substitute diesel would be much larger than to substitute gasoline with sugarcane ethanol. Actually, Brazil does not growth an energy crop to produce vegetable oil as good as sugarcane ethanol. While overall productivity for sugarcane ethanol is around 7,000 litres/ha/yr, for soybean biodiesel it is around 400 litres/ha/yr. With palm oil the result could be much better, but Brazil was never able to obtain good results with palm oil. There have been a few projects e.g., PETROBRAS and VALE, but so far failed to demonstrate any significant increase in agricultural yields.

In 2010, PETROBRAS informed of the construction of a biodiesel plant using palm oil in Pará, with investment both in agriculture and industry. With three others previously constructed plants (Montes Claros, MG, Candeias, BA, and Quixadá, CE), PETROBRAS planned to produce 108.6 million litres of biodiesel with soybeans as the main feedstock. Unfortunately, the original plans were not successful. PETROBRAS biodiesel from palm oil was a failure, due primarily to agronomic difficulties.[19] On the other hand, Petrobras green diesel and hydrotreated vegetable oil (HVO) is doing well at its President Getúlio Vargas Refinery (REPAR), in Araucária, Paraná. They process 2 million litres of soybeans oil and 40 million litres of diesel with renewable content.[20]

VALE also implemented BIOPALMA, a palm oil plantation and a biodiesel plant in Pará in 2012. This plant produces 25 tons of oil/h, and the main idea is to produce B20 (20% biodiesel + 80% mineral diesel). The B20 produced by VALE will have significant applications, including fuel for the iron ore trains from Carajás, Pará, to the Ponta da Madeira harbour in Maranhão State, about 900 km. Other possibility is to fuel large trucks in operation at the Carajás iron ore mine.

Again, the main challenge remaining is the sustainable production of feedstocks for biodiesel. It seems then inevitable the integration with food production, considering the economic advantages. Today nearly 78% of biodiesel produced in Brazil uses soybeans as feedstock. This is because soybean cake covers production costs, and therefore, biodiesel remains a marginal beneficial activity.

Although this food-biofuel integration is positive, it has its limitations since no significant expansion is foreseen, unless more soybeans cake can be produced and consumed. In 2021 started with B12, then increased to B13 for two months, and because of the Russian war with Ukraine, and corresponding commodity price increase, the Brazilian Federal Government reduced the blend to B10. This shows how difficult it is to maintain a certain blend based on commodity prices, although this seems to be a reasonable price to pay, and that flexibility and adjustment are necessary.

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19 https://www.poder360.com.br/luanda-leaks/petrobras-enterra-centenas-dende/

20 https://petrobras.com.br/fatos-e-dados/concluimos-testes-para-producao-de-diesel-renovavel.htm

It can be stated that in the short-term the future of biodiesel in the country depends on soybean integration, therefore with a slow yearly increment. If greater and faster production is achieved, more efforts should be made to improve agricultural yields such as palm oil.

5.5. EMERGING MARKETS FOR BIOFUELS

5.5.1. AVIATION

Worldwide, in the transportation sector, aviation is the 4^{th} most important emitter of CO_2 (Table 5.8 below):

Table 5.8 Distribution of CO_2 emissions in the transportation sector worldwide, in 2020. Source: Statista.[21]

Sector	%
Passenger cars	41
Medium and heavy trucks	22
Shipping	11
Aviation	8
Buses and minibuses	7
Light commercial vehicles	5
Two/three wheelers	3
Rail	3

As stated in Chapter 1, the interest in aviation Sustainable Aviation Fuels (SAF) has increased dramatically in recent years. Currently all major airlines are scrambling to find SAF, driven primarily by environmental considerations, but the main constrain remains the cost of sustainable feedstocks. Both IATA and ICAO have introduced specific policies to reduce emissions. In a few years, the vision and attitudes of air travel have shifted significantly in favour of achieving carbon neutrality, and despite high costs, SAF is increasing dramatically e.g., in 2021 production and use was estimated between 100 to 150 million litres, a 50% increase over the previous year. By 2030, projections are that SAF could provide at least 5% of global demand (IATA, 2021).

This projection could easily be overcome if present trends continue as all major airlines are investing in SAF e.g., investigating and testing new fuels. Advances in process technology are cutting costs considerably and opening the utilization of new feedstocks much faster than envisaged a few years ago. Although there is a long way to go since aviation requires a very high-quality fuel, the future looks much brighter!

21 https://www.statista.com/statistics/1185535/transport-carbon-dioxide-emissions-breakdown/

For example, British Airways has become the first airline in the world to use SAF on a commercial scale, after the company Phillips 66 Ltd delivered the first batch. The company is currently producing about 500,000 litres/day from waste feedstocks (Biofuels Inter. March 30/22)

Brazil is the world's 4th largest domestic air market. This is due to the country size combined to a lack of good road and railroad infrastructure. According to IATA (2019) with a gross value added of R$ 18.8 billion to the national economy and generating more than 800,000 direct and indirect jobs, the Brazilian aviation market has the potential to grow almost 5 times in 20 years. Airlines, airport operators, aircraft manufacturers and service providers employ about 167,000 people directly and over 372,000 indirectly.

The Brazilian aviation sector does not allow foreign companies to operate domestically although there is no restriction for international flights. The main private companies operating are currently LATAM, GOL, and AZUL, all involved in a common effort to use sustainable biofuels. Typically, they operate using BOEING, AIRBUS aircrafts, but EMBRAER, a Brazilian airplane manufacturer, is also an important player, particularly in the mid-size craft production.

For instance, GOL used biofuel blend with kerosene in their regular flight from Recife to Fernando de Noronha, a paradise island near the Brazilian Northeast coast.[22] During the 2010 decade, AZUL also made few experimental flights using sugarcane derived biofuel produced by AMYRIS.[23] The company SOLAZYME also produced sugarcane derived biofuel for aviation.

Brazilian airlines have demonstrated strong interest to promote the development and use of SAF. Naturally, the main idea is to comply with established targets to reduce GHG emissions but also for marketing and economic benefits.

Specifically for the aviation sector, the target is to have a carbon neutral after 2020, and a 50% reduction in GHG emissions up to 2050, compared with 2005 levels (FREIRE, 2011). The 41st Assembly of ICAO agreed to aim for zero CO_2 emissions by 2050 (see Chapter 1). Progress ais being made by the aviation sector to improve operations with higher load factors and utilizing bigger planes. Of course, the pandemic created difficulties, with less passenger flights, but the industry is still pursuing its goals.

The difficulties associated with biofuels for aviation are mainly economic. All major airlines such as Air France[24] recognizes that "SAF is currently much more expensive than fossil fuel". Most airlines are investigating and testing new fuels, but they must also comply with the American Society of Testing of Materials (ASTM). ASTM is the

22 https://www.gazetadopovo.com.br/economia/brasil-e-apenas-um-espectador-no-avanco-dos-biocombustiveis-para-avioes-1u4ee5hd6dx6x5s6a4brzc1oe/

23 https://www.biodieselbr.com/noticias/biocombustivel/bioqav/azul-gol-voos-experimentais-cana--acucar-oleo-milho-190612

24 https://wwws.airfrance.com.br/information/developpement-durable/sustainable-aviation-fuel

only authority to certify biofuels for aviation accepted by the insurance companies. The insurance companies follow exactly the recommendations established by the turbine manufacturers, so it prevails the "drop-in" approach in the development of biofuels for aviation.

Considering this premise, a roadmap for sustainable biofuels for aviation in Brazil was conducted in 2014 by BOEING/EMBRAER with support from FAPESP (BOEING/EMBRAER/FAPESP, 2013; CORTEZ, 2014a). The project analysed different possible pathways for biofuels for aviation with Brazilian feedstocks, and the complexity of established conversion industry. The drop-in approach was the main boundary condition in this project. The project made the following recommendations:

- Filling R&D gaps in the production of sustainable feedstocks,
- More incentives to overcome conversion technologies barriers including scaling up issues,
- Greater involvement and interaction between private and government stakeholders,
- Creation of a national strategy to make Brazil a leader in the development of aviation biofuels.

One conclusion of this study "is that the substation of petroleum in aviation represent a very important niche for sustainable biofuels. Brazil has a great opportunity in this area to become a global player. There are important challenges to be overcome to create the basis for this new emerging industry. Brazil cannot afford no participate".

Although there are today several pathways that have been certified by ASME, none satisfy both requirements: have a GHG emissions mitigation potential and reasonable costs to compete with KAV without any subsidy. Therefore, since the aviation sector needs to find a solution in the present decade (up to 2030) there're only three possible options today: subsidize the most reasonable pathways; compensation; or the non-drop-in approach.

Figure 5.3 summarizes the difficulties to mimic aviation kerosene, a specific fuel utilized in jet planes and used as reference for ASTM certification. According to the figure below, the best feedstock to produce a sustainable aviation biofuel remains vegetable oils such as soybean, camelina and palm oil. Note, they are close to the centre in the figure. As we come to the edge, the feedstock costs tend to decrease but the technical difficulties increase.

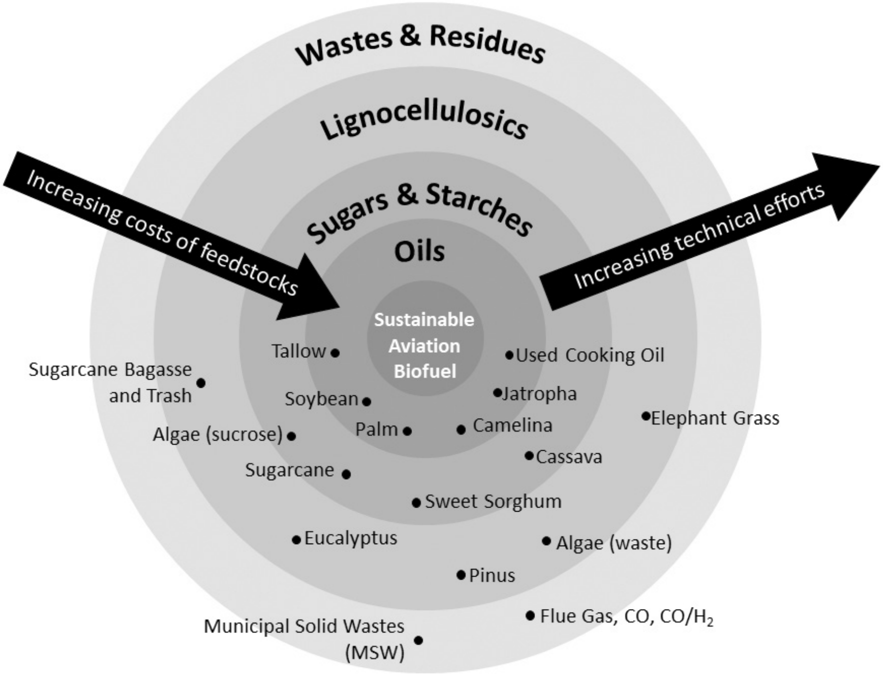

Figure 5.3 Raw materials and their relative position according to costs and technical efforts to be converted into sustainable aviation biofuel. Source: Cortez (2014a).

Brazil is one of few countries to have a specific policy on the use of biofuels in aviation. However, the initial strong motivation shown a decade ago, has decreased probably due to the economic crisis after 2012 and the difficulties associated with high production costs of biofuels for aviation.

In the BOEING/EMBRAER/FAPESP report several pathways for biofuels were analysed and are presented in Table 5.9 and Figure 5.4 below. As mentioned in the report, they present an overview of all identified pathways pertinent to Brazil, including the status of ASTM approval process.

Table 5.9 Identified and analysed pathways to produce biofuels for aviation in Brazil. Source: BOEING/EMBRAER/FAPESP (2013).

1	Oil-bearing plants through HEFA
1A	Tallow and fats through HEFA
1B	Used cooking oil through HEFA
1C	Sugar-bearing plants through fermentation of lipids and HEFA
1D	Ligno-cellulose through hydrolysis to sugars to lipids and HEFA
2	Sugar-bearing plants through fermentation to ethanol and ATJ
2A	Ligno-cellulose through hydrolysis to fermentable sugars to alcohol and ATJ
2B	Flue gas (CO, CO/H_2) through fermentation to alcohols and ATJ

2C	Ligno-cellulose through gasification to CO/H_2 to alcohols to ATJ
2D	MSW through fermentation to organic acids to alcohols to ATJ
3	Ligno-cellulose through gasification & reforming to syngas to FT
3A	Ligno-cellulose through pyrolysis to biochar &bio-oil to gasification to syngas to FT
4	Sugar-bearing plants though fermentation by GMO to hydrocarbons (DSHC)
4A	Ligno-cellulose though hydrolysis to sugars to hydrocarbons (DSHC)
5	Ligno-cellulose through fast pyrolysis to bio-oil via deoxygenation (HDCJ)
5A	Ligno-cellulose through direct liquefaction to bio-oil via deoxygenation (HDCJ)

According to the information above, up to June 2014 ASTM had already approved three biofuel pathways for jet fuel production: D7566 HEFA A2 which can use used cooking oil, oil-bearing plants, or tallow; D7566 SIP (DSHC) which can use MSW, starches, sugar-bearing plants, or flue gas; and D7566 FTA1 which can use algae or ligno-cellulose. Therefore, there is already the technology to convert the main feedstocks into aviation biofuel.

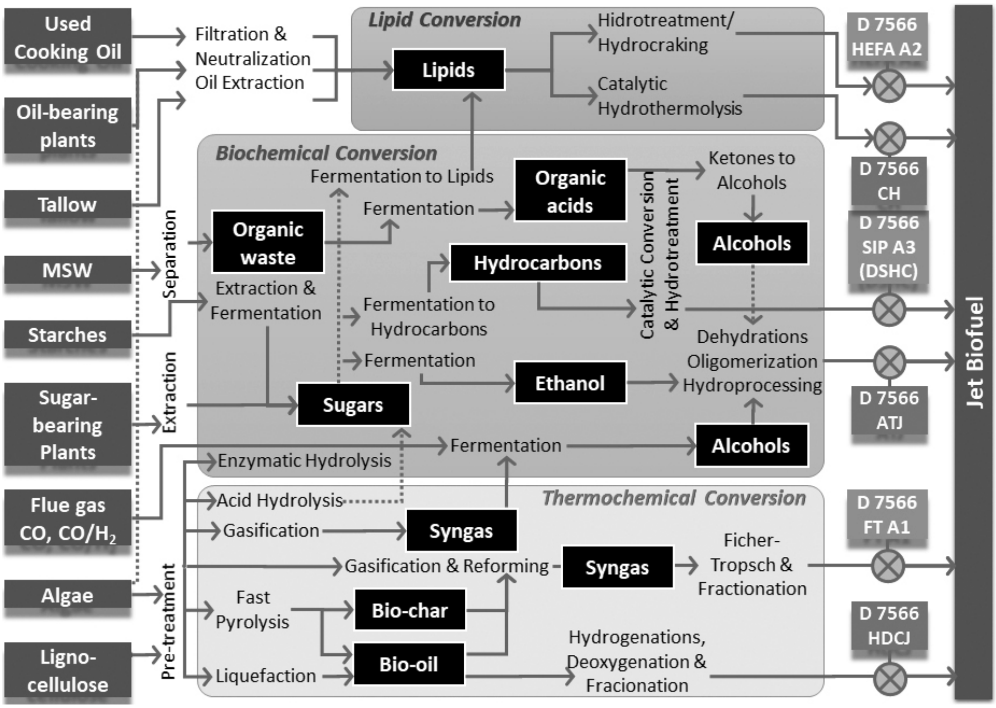

Figure 5.4 Identified pathways to produce sustainable jet biofuel in Brazil. Source: BOEING/EMBRAER/FAPESP (2013).

However, costs remain a critical factor. Costs to produce biofuels for aviation depend basically on two factors if a drop-in solution is to be pursued: i) the costs of the sustainable feedstocks and ii) processing technology (CORTEZ, 2014a). As seen above, in the drop-in approach, vegetable oils are typically closer to aviation kerosene (KAV) but are also expensive and compete with food and agriculture land. On the other hand, if a low-cost raw material is selected, the processing technology to comply with ASTM criteria will economically gain importance. From the GHG emissions mitigation potential, biofuel will heavily depend on the feedstock. Therefore, its correct identification is a crucial part of the process.

Although there are today more ASTM approved and certified pathways, none satisfy both requirements: have a GHG emissions mitigation potential and reasonable costs to compete with KAV without any subsidy. Therefore, since the aviation sector needs to find a solution in the present decade (until 2030) there're only three options today, as it was explained before.

Subsidy is a limited possibility and politically difficult solution. If necessary, airlines will accept subsidies only in few less expensive flights. The criteria may involve flights with commercial return such as tourist destinations. Broader subsidies are less likely to occur because it requires government participation. Considering the international nature of airlines, a possible alternative could be an international policy agreement.

Compensation is a good possibility from the GHG emissions mitigation point of view but is not a good option from the marketing point of view. There are several good technical opportunities for compensation. Brazil, for example, has around 200 Mha of pastureland, maybe 25% of that is either degraded or at high risk of degradation. Although, typically enterprises prefer a more direct way to reduce GHG emissions, LATAM has recently announced a new marketing strategy labelled "Sustainability: a necessary destination" (Folha, April 22nd, 2022) to compensate carbon emissions of its main routes on Fridays by means of projects to capture CO_2 emissions.

Finally, the non-drop-in approach could be an interesting way to address this problem. Instead of trying to look for an ideal and low-cost biofuel, the turbine companies could try to develop a turbine based on the characteristics of a low cost and sustainable biofuel.

5.5.2. MARITIME

Brazil has basically three markets for water transportation: long distance international maritime; coastal maritime; and fluvial transportation.

The long-distance maritime transportation is dominated by two companies, PETROBRAS for crude oil and its products,[25] and VALE, basically, for iron ore transportation. In addition to these two companies there are also large ships transporting agricultural commodities. Other maritime transport modalities such as containers,

25 Brazil exports crude oil and import its products. This happens because there is a lack of refining facilities.

passengers, and fishing are relatively small by comparison with the large bulk transport and their fuel requirements.

The ships employed among these companies are usually very large, often between 100-300,000 tons[26] transporting low-cost bulk materials such as oil, liquid fuels, iron ore, and grains. Therefore, the cost of maritime fuel cannot be excessive otherwise it makes the business uncompetitive. Although costal and fluvial transportation are lower than maritime, the same criteria (low-cost fuel) should apply.

Typically, the most utilized fuels in maritime transport sector are Heavy fuel oil (HFO), light fuel oil (LFO), and marine gasoil (MGO). The HFO, also named bunker oil, is the most common and consumed in high quantities, 250 million tons per year (RODRIGUE, 2020). All these fuels contain high amounts of sulphur[27] and are subjected to serious restrictions by The International Maritime Organization (IMO), a regulatory branch of the United Nations for the navigation sector. The IMO is committed to reduce the carbon impact of shipping by at least 50% compared to 2008 levels by 2050.[28]

Ongoing studies in Brazil are investigating the possibilities for fossil maritime fuels substitution, including sustainable biofuels. SZKLO et al. (2020) studied several fuels such as Straight Vegetal Oil (SVO), Hydrotreated Vegetable Oil (HVO), biomass FT-diesel, biomethanol (CH_3OH), and FT synthetic renewable H_2 and captured CO_2 (electrodiesel/e-diesel). In relation to GHG emissions, all studied fuels shown high mitigation potential (average 75%), with e-diesel close to 97%. As for production costs, HVO is the alternative with lowest cost followed by FT-diesel, biomethanol, and e-diesel. However, e-diesel production costs are almost five times higher than HFO.

HFO seems to be recognized as a promising biofuel for maritime applications. Since 2020, Petrobras[29] has been producing Hydrotreated Vegetable Oil (HVO) for certain applications.

Galindo et al. (2020) studied blends using sugarcane and eucalyptus pyrolysis with ethanol and diesel. The study emphasized the difficulties of high levels of water in the biomass bio-oil, although few maritime engines accept some water content. Typically, studied blends were in the order of 10% of bio-oil, 60% of ethanol, and 30% of diesel achieving properties close to maritime diesel with low flash point. However, blends of 65% of bio-oil, 10% of ethanol, and 25% of diesel showed better flash point, although with lower stability causing phase separation.

Wei (2021) also studied the following alternatives: liquefied natural gas, methanol, ammonia, biodiesel, SVO, HVO and HPO.

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26 A valemax ship can transport up to 400,000 tons. http://www.vale.com/brasil/PT/initiatives/innovation/valemax/Paginas/default.aspx

27 The maritime transportation sector responds for about 15% of global sulfur emissions.

28 https://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

29 https://petrobras.com.br/fatos-e-dados/petrobras-defende-concorrencia-no-segmento-de-biocombustiveis.htm

Table 5.10 shows a summarized comparison between possible feedstocks and their correspondent biofuel, including potential advantages and disadvantages.

Table 5.10 Potential Biofuels for Maritime Applications. SOURCE: Compiled by the authors.

<table>
<tr><th>Feedstock</th><th>Conversion Technology</th><th>Biofuel type</th><th>Possible Advantages</th><th>Possible Disadvantages</th></tr>
<tr><td>Sugarcane/Energycane (whole), Eucalyptus, Crop Residues (palm)</td><td rowspan="3">Pyrolysis</td><td rowspan="3">Bio-oil:
Blended “as is”
Blended after upgrade (catalytic reform)
Blended after refinery (biocrude)</td><td>AGR, CEff, LC, GHG</td><td>Maybe need to upgrade</td></tr>
<tr><td>Sugarcane bagasse from existing mills</td><td>CEff, LC, GHG, no additional AGR</td><td>Dependence from sugar mills</td></tr>
<tr><td>Urban Wastes</td><td>CEff, LC, GHG, no additional AGR</td><td>Variable feedstock composition</td></tr>
<tr><td>All fibre above</td><td>Fisher-Tropsch</td><td>FT-diesel</td><td>AGR, CEff, LC, GHG, drop-in</td><td></td></tr>
<tr><td>All feedstocks above</td><td>Gasification, biodigestion and reforming</td><td>Hydrogen</td><td>GHG</td><td>High cost, complex logistics</td></tr>
<tr><td>All feedstocks above</td><td>Haber/bio-hydrogen</td><td>Ammonia</td><td>GHG</td><td>High cost, complex logistics</td></tr>
<tr><td rowspan="2">Sugarcane/Energycane</td><td>Fermentation</td><td>Ethanol</td><td>AGR, CEff, LC, GHG, commercial technology</td><td>Needs more land</td></tr>
<tr><td>Fermentation (ABE Process)</td><td>Butanol</td><td>AGR, CEff, LC, GHG, commercial technology</td><td>Needs more land</td></tr>
<tr><td>Eucalyptus</td><td>Hydrogenation of carbon dioxide</td><td>Methanol</td><td>AGR, CEff, LC, GHG</td><td>Needs more land</td></tr>
<tr><td rowspan="3">Palm Oil</td><td>Hydrogen catalysis</td><td>Hydrogenated Vegetable Oil-HVO</td><td>AGR, CEff, LC, GHG</td><td>Possible competition with Food</td></tr>
<tr><td>none</td><td>Straight Vegetable Oil-SVO</td><td>AGR, CEff, LC, GHG, commercial technology</td><td>Possible competition with Food</td></tr>
<tr><td>FAME (methanol catalysis)</td><td>Biodiesel</td><td>AGR, CEff, LC, GHG, commercial technology</td><td>Possible competition with Food</td></tr>
</table>

High agricultural productivity: AGR; High Conversion efficiency: CEff; Low Cost: LC; Low GHG Emission: GHG

Another alternative under consideration is “green hydrogen” (H2V) which is gaining importance in Brazil. Just recently, three new production hubs were opened near the harbours of Pecém, Suape, and Açú. These three new facilities required at total investment of around US$ 20 billion.[30]

To implement a successful strategy to reduce GHG emissions in the maritime transportation sector, the basic bottom lines are the same as for the aviation sector: subsidies, compensation, or non-drop-in.

Subsidies are even less likely to succeed because no one, not even governments, will feel like to cover these costs. Besides, at least in Brazil, passengers are not the customers who will benefit most, so marketing will be much less effective.

Compensation seems to be a plausible way to go because of very large deforestation areas could benefit from a global policy to reclaim endangered areas worldwide.

Non-drop-in strategy seems also to be a good option. Probably ASTM criteria will be much less rigid for water transportation than with the aviation sector, so the development of a low-cost sustainable biofuel for the maritime sector seems to be a reachable target. Of course, the engine manufacturers will have to agree with the premises. It is important to note that the quality of fuels used in maritime transport are far less rigorous than aviation and this will be a great advantage.

In case the non-drop-in strategy becomes a plausible option, fast pyrolysis bio-oil (FPBO) obtained from low-cost fibrous biomass, could be a candidate, at least for the transition phase (CORTEZ et al, 2021). Another important route could be the use of ammonia as fuel for maritime transport, as indicated in the recent development made by Monash University from Australia.[31]

5.5.3. RAILWAY

Train is not an important sector for passenger transport in Brazil at national level. However, for load/goods transportation is relatively important, particularly for minerals such as iron ore and bauxite, oil derived products, and grains. Although the railway sector is limited in Brazil, there is a trend to grow, particularly in relatively small but important segments.[32]

In the railway sector in Brazil diesel is the most utilized fuel. The most important perspectives for biofuels in the railway sector are also related to VALE and then

30 https://www.capitalreset.com/o-brasil-na-corrida-pelo-hidrogenio-verde-com-us-20-bi-em-projetos/

31 https://www.ammoniaenergy.org/articles/three-new-australian-ammonia-production-projects/

32 https://www.gov.br/antt/pt-br/assuntos/ultimas-noticias/transporte-de-cargas-pelas-ferrovias-do-pais-cresce-30-em-marco#:~:text=Transporte%20de%20cargas%20pelas%20ferrovias%20do%20pa%C3%ADs%20cresce%2030%25%20em%20mar%C3%A7o,-Revolu%C3%A7%C3%A3o%20ferrovi%C3%A1ria%20em&text=A%20produ%C3%A7%C3%A3o%20de%20transporte%20ferrovi%C3%A1rio,mesmo%20per%C3%ADodo%20do%20ano%20passado.

PETROBRAS. Both companies have been conducting independent studies investigating the most sustainable fuels for their operations. It seems, by the nature of their business, that VALE is more likely to adopt biodiesel as part of their energy transition.

If Brazil ever implements modern railways for passenger transport, probably the model will be to use electric trains or hydrogen. Then, the main problem would be to ensure electricity comes from renewable sources adding more demand to the electricity matrix. For this reason, railways are not considered a real alternative for biofuels.

5.5.4. BIOCHEMISTRY

As it was shown on chapters 2 and 4, Brazil did encourage a biomass-based chemical industry. Table 5.11 shows the result of a survey of chemical products that could be produced from ethanol (SCHUCHARDT, 2001).

Table 5.11 Basic processes of the alcohol-chemical industry. Source: BNDES (2008) adapted from Schuchaedt (2001).

Processes	Main Products	Typical application
Dehydration	Ethene Propene Ethylene-glycol	Plastic Resins Solvents Ethyl Ether Textile Fibres
Dehydrogenation Oxygenation	Acetaldehyde	Acetic Acid Acetates Dyes
Estherification	Acetates Acrylates	Solvents Textile Fibres Adhesives
Halogenation	Ethyl chloride	Cooling Fluids Medicine Products Plastic Resins
Ammonolysis	Diethylamin Monoethylamine	Insecticide Herbicide
Dehydrogenation Dehydration	Butadiene	Synthetic Rubbers

Markets for these products are important. However, there are two factors involved: first bioethanol local price in comparison with fossil fuels. The second is the market, Brazilian and global, to accept to pay a premium, at least temporarily, until they become competitive.

Already, several enterprises have begun this pathway. Oxiteno from the Ultrapar group, uses bioethanol from sugarcane to produce ethylene since the 2080s. More recently Oxiteno has done R&DD work with UNICAMP to produce ethylene and ethylene-glycol from sugarcane cellulose pre-treated by hydrolysis.

Another Brazilian company that has explored this area is Coperbo, a Pernambuco state rubber company. Coperbo has a long history in this area, beginning as early as 1965 transforming synthetic rubber from bioethanol. Later in 1975, it created the National Alcohol-Chemical Company which was later controlled by Union Carbide and then by Dow Chemical.

Several biodegradable plastics, such as polymers that present very low carbon footprint, such it is the case of P(3HA), based on soybean oil, and P(3HB), based on glucose (AKIYAMA et al, 2003). Figure 5.5 shows a comparison with GHG emissions of plastics of fossil origin (— low density polyethylene (LDPEP), high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (b-PET)).

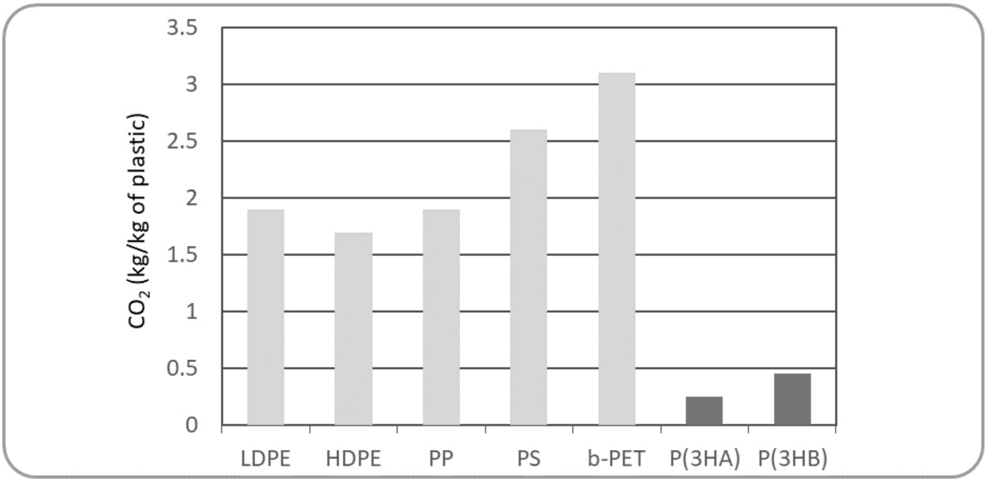

Figure 5.5 GHG emissions in the production of various plastics of fossil and biomass origin. Source: AKIYAMA et al. (2003).

More recently, Braskem has made important investments on bioplastics obtained from sugarcane bioethanol in Brazil. For further details on t biomass-based biorefineries see Macedo and Horta Nogueira (2005).

Taking into consideration current trend in the chemical sector to be as sustainable as possible, ethanol- based chemical products are bound to have a good future.

5.6. SUSTAINABILITY ISSUES AND GLOBAL COMMITMENT

Much has been said on sustainability of biofuels. Also, much of sustainability criticism is directed to feedstock and agricultural production, and land use issues.

First, it important to state that bioethanol and biodiesel production have been adapted from food crops such as sugarcane and soybeans with their own characteristics. So, it is not fair to create a series of additional requirements, e.g., on fertilizers, land use, and productivity when they were not conceived for this end. It would be more appropriate to design and implement totally new production systems, but the reality was adaptation. The development of specifically growing energy crops would be more realistic and fairer when evaluating the sustainability of biofuels.

Probably the major study carried out in Brazil on sugarcane ethanol sustainability, was coordinated by Isaias Macedo (2007). The study included 12 of the most important topics, such as: urban and rural air quality, contribution to GHG mitigation, impacts on water supply, soil occupation; new areas and biodiversity, preservation of agricultural soils, use of agricultural chemicals, use of fertilizers, sugarcane varieties, pests, and diseases control, competitivity of the Brazilian sugarcane industry, and employment and revenue.

Of course, much can be improved, but substantial gains have already been incorporated by sugarcane sector, particularly after PROALCOOL and it would be reasonable to state that Brazilian agriculture has benefitted substantially, particularly in sustainability issues and technology driven by the constant scrutiny imposed to the biofuels sector. Also, it is important to state that the Brazilian overall productivity is increasing. According EMBRAPA between 1977 and 2017, the production of grains grew from 47 to 237 million tons, nearly 5 times. Over the same period agricultural land went from 37.3 to 60.9 Mha, less than the double.[33]

FINAL REMARKS

Brazil has constructed, particularly after the oil shocks of 1970s two strong biofuels programs, one on ethanol and another for biodiesel for partial substitution with mineral fuels. Probably no other country has made proportionally such considerable effort than Brazil. Combined with a state policy to increase domestic oil production, Brazil has greatly improved its energy security while improving the environment and guaranteeing jobs internally.

However, the world scenario has changed, particularly in the last twenty years, and global warming became a great concern forcing a transition to cleaner energy. Since Brazil is a relatively small economy worldwide (circa 3% of world GDP), it is natural that the technology changes in transport will not necessarily consider the Brazilian specificities. The world is gradually adopting an energy transition that probably will conduct to different fuels n the coming two, three of four decades. The main driver to this energy transition is of course the reduction of GHG emissions, and greater energy independency.

33 https://revistacultivar.com.br/noticias/em-40-anos-agricultura-brasileira-produz-5-vezes-mais-e--area-plantada-sequer-dobra

On the other hand, biofuels produced in Brazil already generate low GHG emissions, therefore it would not be reasonable to abandon the present infrastructure and built another if there are not any environment gains. Additionally, this transformation would require significant investments in a country that needs significant investments in other important areas too. In addition, there are many direct and indirect economic and social benefits generated by biofuels which cannot be ignored without serious political consequences.

Considering these issues, together with the interests of the automobile industry, it is not clear what will be the future of biofuels in Brazil. In the best scenario, this transition will probably take few decades, giving time to the economy for a long-term adjustment and transition

As for the use of biofuels in other transportation modes, the scenario is not clear either. In all these scenarios e.g., aviation, maritime and biochemistry, except for rail transport, it seems that electrification is not the right choice. Most likely the best alternatives will favor biofuels and green fuels, such as green hydrogen.

Another alternative examined in this chapter was the possibility to integrate existing oil refining infrastructure with bioenergy feedstocks and conversion processes. Although this seems to be an attractive possibility, it is not sure the oil companies, particularly the large ones, may consider this possibility, yet.

REFERENCES

ABVE. (2021). *Eletrificados batem todas as previsões em 2021*. Available at https://www.abve.org.br/eletrificados-batem-todas-as-previsoes-em-2021/

AEA – Associação Brasileira de Engenharia Automotiva. (2017). *Eficiência Energética Sustentável*. Associação Brasileira de Engenharia Automotiva, 16 p. Available at http://antigo.mme.gov.br/documents/36224/930011/participacao_pdf_0.19998126556324192.pdf/c027c514-5c5e-1cf2-e155-acfb453b44e4.

AKIYAMA, M. et al. (2003) Environmental life cycle comparison of polyhydroxyalkanoates produced from renewable carbon resources by bacterial fermentation. *Polymer Degradation and Stability*, v. 80, issue 1, pp. 183-194. Available at https://www.sciencedirect.com/science/article/pii/S0141391002004007?via%3Dihub.

BNDES. (2008). *Sugarcane-based Bioethanol*: energy for sustainable development, BNDES-CGEE, Rio de Janeiro, Brazil, 304 p. Available at https://web.bndes.gov.br/bib/jspui/bitstream/1408/6305/1/2008_Sugarcane-based%20bioethanol_energy%20for%20sustainable_P.pdf.

BOEING/EMBRAER/FAPESP. (2013). *Flightpath to Aviation Biofuels in Brazil*: Action Plan, BOEING/EMBRAER/FAPESP Project, June 2013, 56 p.

CANALTECH. (2021). *10 carros elétricos mais vendidos no Brasil em 2021*, by AMARAL, P., jan. 7th. Available at https://canaltech.com.br/carros/carros-eletricos-mais-vendidos-brasil-2021/.

CNPEM. (2018). *Eletrificação de Veículos e o Futuro do Etanol Combustível no Brasil*. (In Portuguese), Separata CNPEM, December, 16 p.

CORTEZ, L.; FRANCO, T. T.; VALENÇA, G.; ROSILLO-CALLE, F. (2021). Perspective Use of Fast Pyrolysis Bio-Oil (FPBO) in Maritime Transport: The Case of Brazil. *Energies 2021*, 14(16), 4779. Available at https://doi.org/10.3390/en14164779

CORTEZ, L.A.B. (ed.) (2014a). *Roadmap for Sustainable Aviation Biofuels for Brazil* – a flight to aviation biofuels in Brazil, São Paulo, Blucher, 272 p. Available at http://pdf.blucher.com.br.s3-sa-east-1.amazonaws.com/openaccess/roadmap-aviation/completo.pdf.

CORTEZ, L. A. B.; SOUZA, G. M.; CRUZ, C. H. B.; MACIEL, R. (2014b). An Assessment of Brazilian Government Initiatives and Policies for the Promotion of Biofuels Through Research, Commercialization, and Private Investment Support. In *Biofuels in Brazil*, Springer, p. 31-60. Available at https://link.springer.com/book/10.1007/978-3-319-05020-1.

FOLHA de São Paulo. (2022). *Sextas Compensam*, LATAM advertisement, April 22nd.

FREIRE, G. (2011). Aviation Biofuel in Brazil. Challenges and perspectives. In: *Brazilian Bioenergy Science & Technology Conference*.

IATA – International Air Transport Association. (2021). *Annual Report*, pp. 28. Available at www.iata.org.

MACEDO, I. C.; HORTA NOGUEIRA, L. A. (2005) "Biocombustíveis". *Cadernos NAE 2*, Brasília, Centro de Gestão de Estudos Estratégicos e Núcleo de Assuntos Estratégicos (CGEE/NAE).

MELO, F. H. de; FONSECA, E. G. da. (1981). *Proálcool, Energia e Transportes*, Pioneira, 164 p.

RAÍZEN. (2022). *Sustainability of Raízen´s Ethanol*: ethanol production from sugarcane for thriving and sustainable economy. Raízen Technical Report prepared by Raízen with advisory services from Agroícone and verification by PwC (PricewaterhouseCoopers Independent Auditors), 66 p.

RODRIGUE, J. P. (2020). *The Geography of Transport Systems*, 5th ed., Routledge, New York.

SCHUCHARDT, U. et al. (2001). A indústria petroquímica no próximo século: como substituir o petróleo como matéria prima? *Química Nova*, v. 24, n. 2, pp. 247-251.

SODRE, E. (2022). Gasolina cara reduz vantagem de carros mais econômicos. (In Portuguese). Article published at *Folha de São Paulo*, April 22nd.

SZKLO, A. et al. (2020). *Perspectivas de Produção de Combustíveis Marítimos de Emissão Neutra de Carbono no Brasil*. (in Portuguese), Elaborated by Cenergia, PPE/COPPE, UFRJ, ICS, Rio de Janeiro, Brazil, 41 p.

WEI, H. K. (2021). *Análise Comparativa do Porto ao Navio de Combustíveis Alternativos para Transporte Marítimo*. MSc dissertation, COPPE, UFRJ, Rio de Janeiro, Brazil, 128 p.