WELL-TO-WHEEL CARBON NEUTRALITY ANALYSIS IN THE BRAZILIAN AUTOMOTIVE SECTOR

Preliminary study focused on light vehicles in Brazilian context

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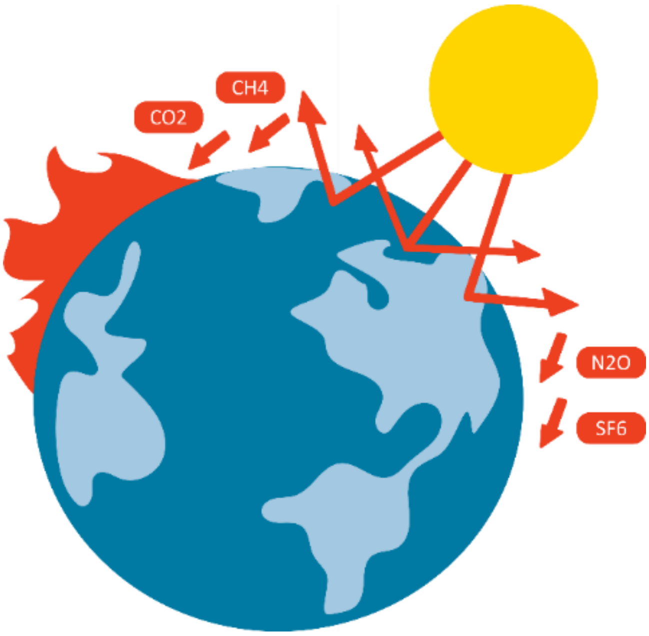
1 INTRODUCTION

To mitigate the effects of climate change on Earth, in 2015, at the United Nations Climate Change Conference, commitments were established to move towards carbon neutrality later this century.

Carbon dioxide (CO_2) emissions are one of the main causes of climate change. CO_2, along with other greenhouse gases (GHG) traps solar radiation and reheats the earth's surface. The greenhouse effect is a natural phenomenon and essential for life on planet Earth, it provides the maintenance of the planet's average temperature. However, with the advent of the Industrial Revolution, the burning of fossil fuels, such as coal, oil and natural gas, potentiated this effect, and the increase in temperature, generating global warming, which can lead to catastrophic events, such as more frequent and intense droughts, storms and extreme heat waves, rising sea levels, melting glaciers, loss of biodiversity and various damages to people's lives, even causing climate migrations.

Figure 1 - Illustrative representation of the Greenhouse Effect



Carbon dioxide can be emitted through natural and artificial processes, such as the emission of carbon dioxide by means of transportation. According to Brazil's carbon emissions in 2019, transportation accounted for 9.03% of the country's total carbon emission. And when prioritizing only automobiles, it is seen that they accounted for 2.8% of all carbon emission in Brazil, i.e., it is a very relevant portion.

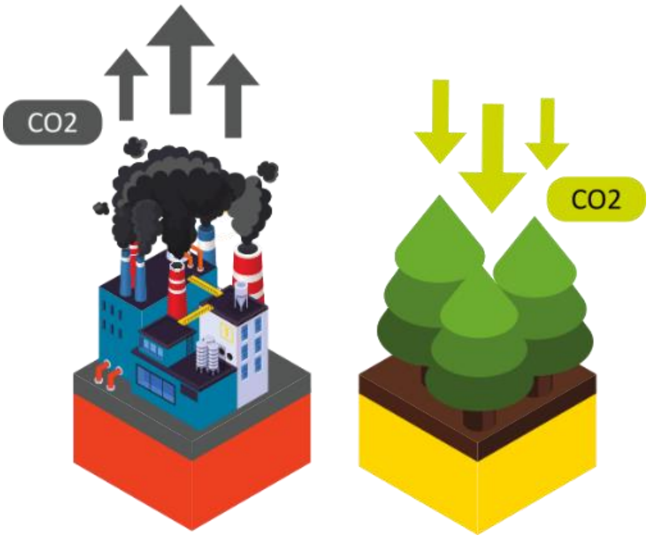
This article brings a preliminary study focused on the well-to-wheel for automotive vehicles, through public data and information made available by the competent agencies and reflects, with mathematical formulations and hypothetical scenarios, what the passenger car industry would need to apply to achieve carbon neutrality in its segment.

2 INTRODUCTION TO CARBON NEUTRALITY

2.1 WHAT IS CARBON NEUTRALITY?

Carbon neutrality is when one emits the same amount of CO_2 into the atmosphere as it takes out in different ways, which leaves a zero balance, also called a zero-carbon footprint. It is an offsetting of carbon in the atmosphere, that is, they are ways to compensate the carbon we emit with what we take out or capture.

Figure 2 - Illustrative representation of carbon capture by forests



There are different ways to achieve the mentioned balance. The healthiest consists in not emitting more CO_2 than the planet's forests and plants can naturally absorb, which function as carbon sinks through the process of photosynthesis (they assimilate atmospheric CO_2 and transform it into oxygen), helping to reduce emissions.

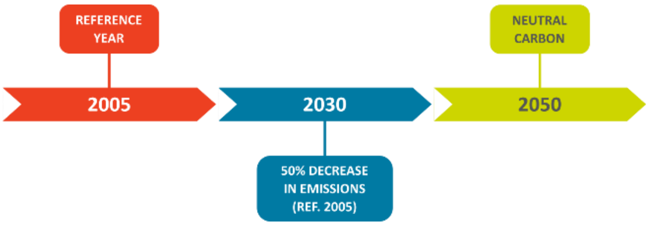
It is important to understand that carbon neutralization is not the prohibition of CO_2 emission, in fact, it is very difficult nowadays not to emit CO_2 where most industrial activities are derived from some fossil fuel burning, even for electricity generation.

Neutralization is related to compensation, it is necessary to take compensatory measures, such as planting trees, new carbon capture technologies, and more efficient and less polluting ways to carry out certain activities, so that all carbon emitted into the atmosphere can be completely compensated.

2.2 WHAT ARE BRAZIL'S GOALS?

In the last United Nations Climate Change Conference (COP26), Brazil updated its goals for contributing to the reduction of the planet's average temperature. The country has committed to reduce GHG emissions by 50% by 2030, in relation to the emissions in 2005. In addition, the country stated the goal of achieving carbon neutrality by 2050.

Figure 3 - Brazilian commitment for decarbonization, presented at COP26



2.3 ROLE AND PARTICIPATION OF THE AUTOMOTIVE INDUSTRY IN THE CARBON NEUTRALITY PROCESS

The automotive industry has a very important role in contributing to the greenhouse effect. As mentioned earlier, emissions from transportation in Brazil represent a share of 9.03% of the country's total emissions.

The entire production chain needs to be addressed so that systemic solutions can be applied, from the production of more sustainable fuels to more efficient motor vehicles, to greener industrial processes. All this to reduce the carbon footprint of automobiles.

An entire class of industry, with different players and protagonists will be impacted, but for everything to align and move in an organized way towards carbon neutrality in 2050, it is essential that the government establishes clear public policies for all sectors involved.

In fact, it is of utmost importance that the automotive industry collaborates with the reduction of carbon emissions, however, there is a lack of public policies that present goals and scenarios on how these industries can achieve neutralization.

In this article, we will discuss 3 pillars that are considered essential for the light car industry to reach carbon neutrality. The 3 pillars are: new technologies, the circulating fleet liability, and the use of biofuels.

3 PRELIMINARY STUDY FOR CARBON NEUTRALITY

The preliminary study was based on three important areas to walk the path of carbon neutralization, these being: CO_2 emissions, the well-to-wheel concept, and the impact of circulating fleet.

3.1 CO_2 EMISSIONS

3.1.1 History of CO_2 emissions in Brazil

In 2019, according to the SEEG (System of Estimates of Emissions and Removals of Greenhouse Gases) Brazil reached the mark of 2.1G [1] tons of CO_2 equivalent (CO_2e). The country's emissions are divided into five sectors: energy, industrial processes, waste, agriculture and livestock, and land use change and forests.

Figure 4 – History of CO_2e emissions per sector in Brazil, according to the SEEG

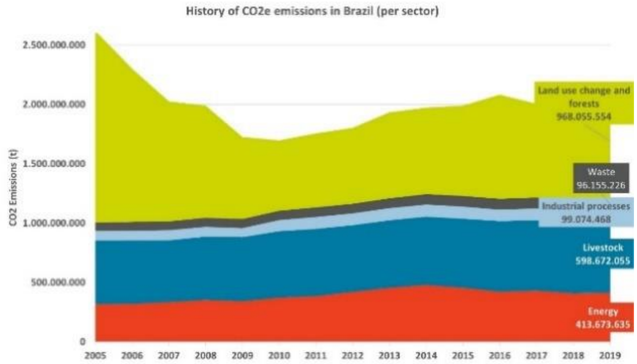
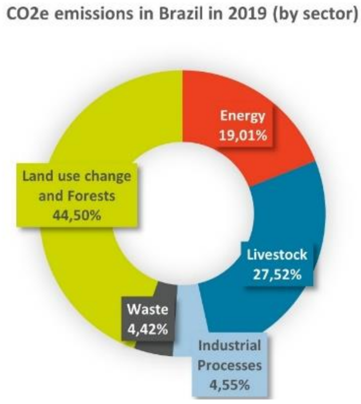


Figure 5 – Percentage of CO_2e emissions by sector in Brazil in 2019, according to the SEEG



The automotive industry is classified within Energy. The energy sector is responsible for 19.01% of Brazil's total emissions. The emissions related to transportation correspond to 9.03% in relation to the country's total. Remembering that within Transport, there are all kinds of transport, from air, through road and even rail and sea.

[1] Information according to the methodology of SEEG

Figure 6 - Percentage of CO_2e emissions by energy subsectors in Brazil in 2019, according to the SEEG

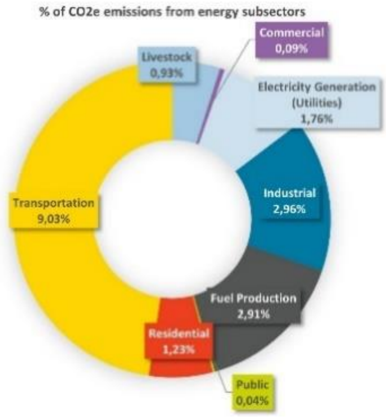
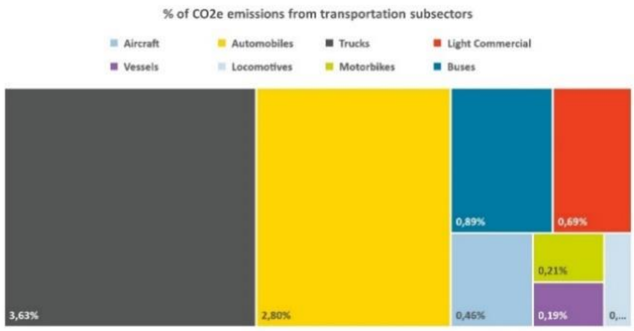


Figure 7 - Percentage of CO_2e emissions by transportation subsectors in Brazil in 2019, according to the SEEG

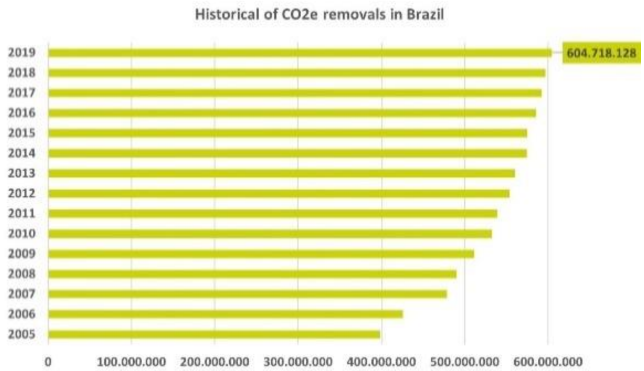


3.1.2 *CO_2 emission removals in Brazil*

According to SEEG data, in 2019 about 604M tons of CO_2e were removed, these removals in Brazil, happen through forests, they are the trees and plants that by performing photosynthesis capture oxygen from the atmosphere.

All this removed CO_2 can be compensated with the country's CO_2 emissions, including the share from cars, of course, keeping the respective proportion of their share.

Figure 8 – Historical of CO_2e removals in Brazil in 2019, according to the SEEG

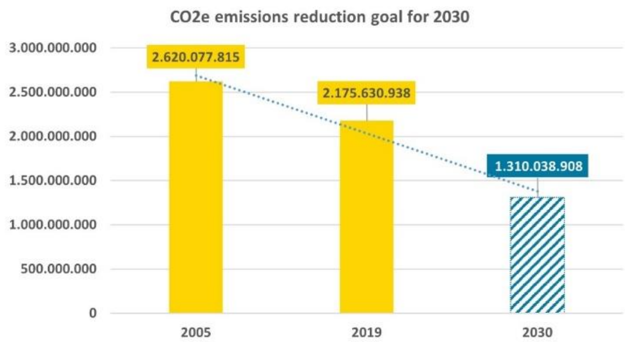


3.1.3 *Final considerations*

As mentioned before, Brazil announced at COP26 the commitment to reduce GHG (Greenhouse Gas) emissions by 50% by 2030, compared to 2005, and to be CO_2 neutral by 2050. But what does this represent?

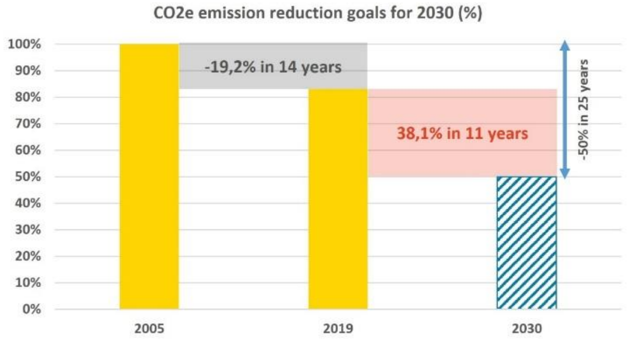
According to the SEEG, Brazil emitted 2.6G tons of CO_2e in 2005, that is, the goal that should be reached in 2030 is approximately 1.3G tons of CO_2e.

Figure 9 - Brazilian CO_2e reduction goals in tons, according to COP26



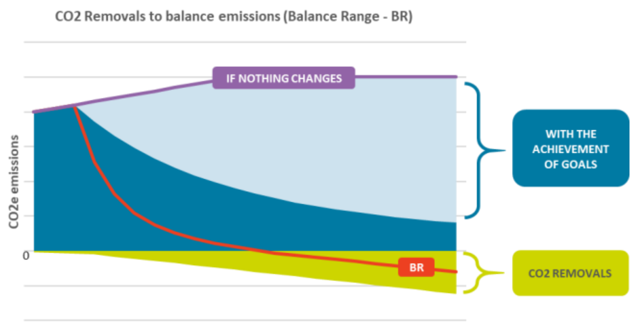
In 2019, Brazil emitted 2.1G tons of CO_2e, this shows that in a period of 14 years there was a decrease of approximately 19.2% of GHGs that were emitted, however, according to the goal set until 2030, the country will have to decrease at least 38.1% of emissions in just 11 years.

Figure 10 – Brazilian CO_2e reduction goals in percentage, according to COP26



By 2050, the country has committed to achieving carbon neutrality, but this does not mean that Brazil should emit zero carbon. Therefore, it is necessary to reach a balance range (BR) by 2050. This range represents how much carbon dioxide is allowed to be emitted into the atmosphere, considering the amount of removal in the respective year.

Figure 11 – Chart representation of the balance range



3.2 WELL TO WHEEL

3.2.1 What is the "from well to wheel" concept?

The Well-to-Wheel (WtW) concept means measuring CO_2 emissions from obtaining the fuel (in its raw form), transporting, and refining it, to combustion in the engines and vehicle exhaust. This is the so-called closed life cycle. The life cycle of CO_2e emissions can be represented by a calculation, which analyzes the amount of carbon emitted in the manufacturing processes, in the consumption phase and in the recycling or end of life of the product.

Figure 12 – Calculation of the "well-to-wheel" concept

$$CO_2e = CO_2e + \left[\frac{gCO_2e}{MJ}\ x\ \frac{MJ}{km}\right] x\ km + CO_2e$$

When analyzing carbon emissions in the transportation sector, it is of great importance to apply the "well-to-wheel" concept. This ensures that all CO_2 emissions are considered, from the production of the fuel to the exhaust of the vehicle.

Everything changes in favor of biofuel when considering the emissions "from tank to wheel", because ethanol is considered a recyclable hydrocarbon and almost all CO_2 emitted after combustion in the engine is reabsorbed by the sugarcane plantation itself.

Taking this into consideration, "from well to wheel" the 1st generation hydrous ethanol would emit 20.79 grams of CO_2e per MJ spent throughout its extraction, transport and burning chain. The gasoline used in Brazil, on the other hand, with the addition of 27% anhydrous alcohol (E27), in this same account would emit 74.1 gCO_2e/MJ.

Figure 13 - Illustrative representation of the concept "from well to wheel"

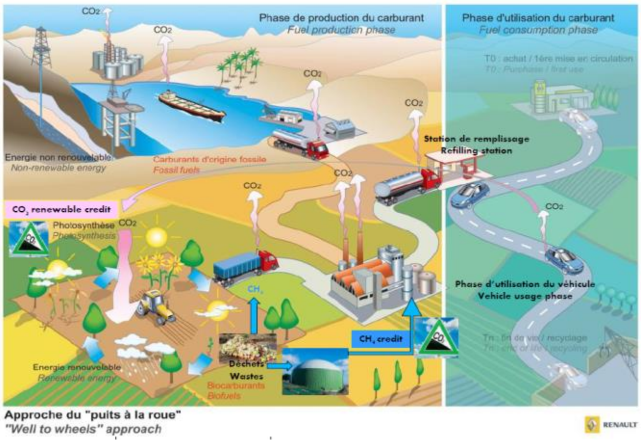
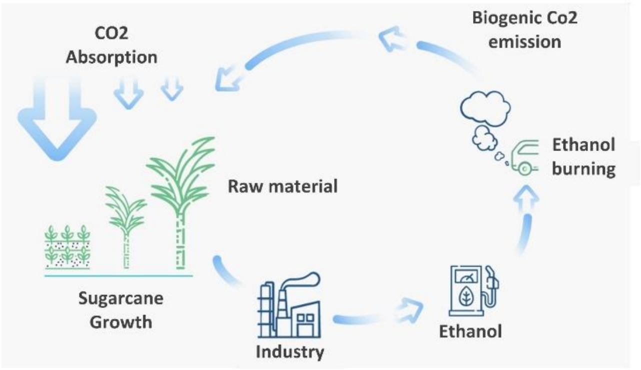
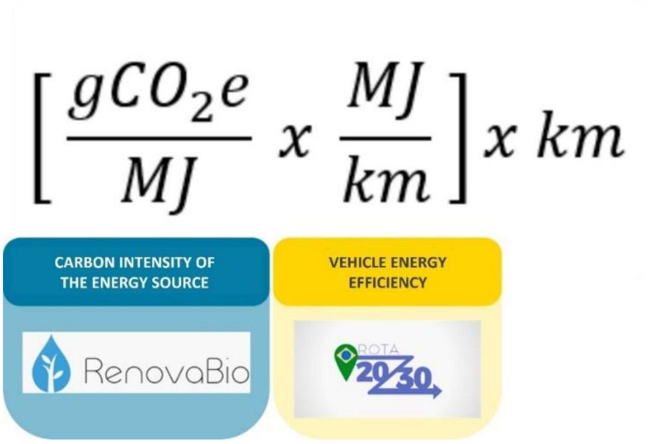


Figure 14 - Biofuel Life Cycle



Therefore, the "well-to-wheel" concept prioritizes the second part of the calculation that was presented above. At this point the CO_2e emission is calculated according to the energy source used, the energy efficiency of the vehicle, and the distance traveled.

Figure 14 – Usage phase of the "well-to-wheel" concept calculation and RenovaBio and Rota2030 sources

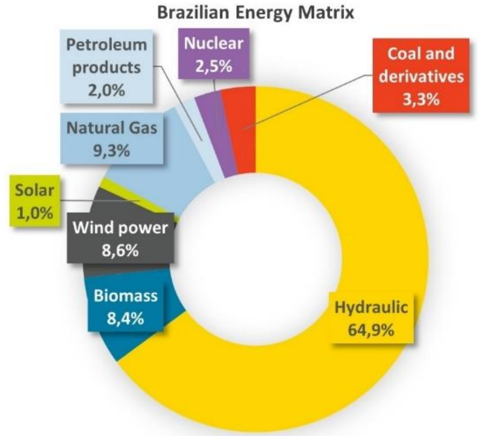


The energy source that has been used has a carbon intensity (gCO2e/MJ), this represents the carbon intensity emitted into the atmosphere by the energy source since its production. This intensity must be multiplied by the energy efficiency of the vehicle in question, or for example, by the average energy efficiency of certain vehicles in a country. Then there is the value of how many grams of carbon is emitted per kilometer (gCO_2e/km).

3.2.2 *Brazilian energy matrix*

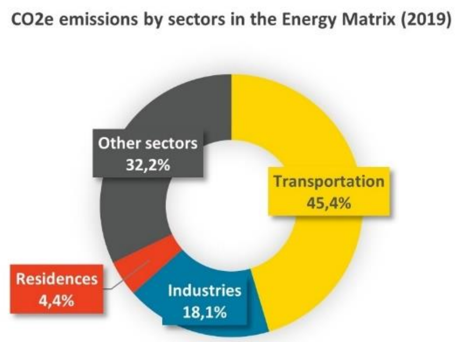
With the focus on decarbonization, and the great potential of Brazil for biofuels, there is a forecast of growth in the use of sustainable energy matrix encouraged by the need for low carbon energy transition. The data of CO_2e emissions in Brazil also consider the energy matrix, according to BEN2020 (National Energy Balance) the Brazilian energy matrix has hydraulic energy as the largest use, representing 64.9% of it.

Figure 15 – Brazilian Energy Matrix Chart in 2019, according to BEN2020



Even using a large share of renewable resources, in 2019 the total carbon emitted from the use of electricity in the country was 419.1Mt. In which, 45.4% (190.5Mt) of CO_2e emissions corresponded to the use of electricity in transportation.

Figure 16 - Chart of the percentage of CO_2e emissions by energy sectors in 2019, according to BEN2020



Within the transport sector it is possible to identify the energy consumption of fuels, specifically in road transport. In 2019 diesel oil accounted for almost half of fuel use in the road transport sector, followed by gasoline, which remains one of the largest fuel sources used. However, the consumption of biofuels, such as biodiesel, hydrated and anhydrous ethanol, are growing compared to previous years.

Figure 17 – Fuel consumption in 2010, according to BEN2020

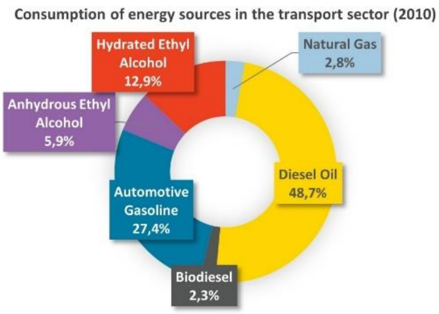
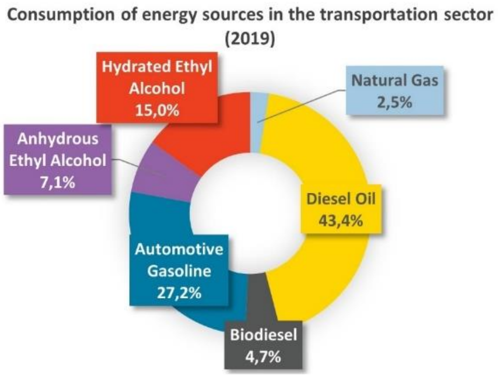


Figure 18 – Fuel consumption in 2019, according to BEN2020



With the BEN2020 updates it is seen that for the Brazilian electricity sector it is correct to use carbon intensity as 25gCO2e/MJ [2].

3.2.3 Carbon intensity of energy sources

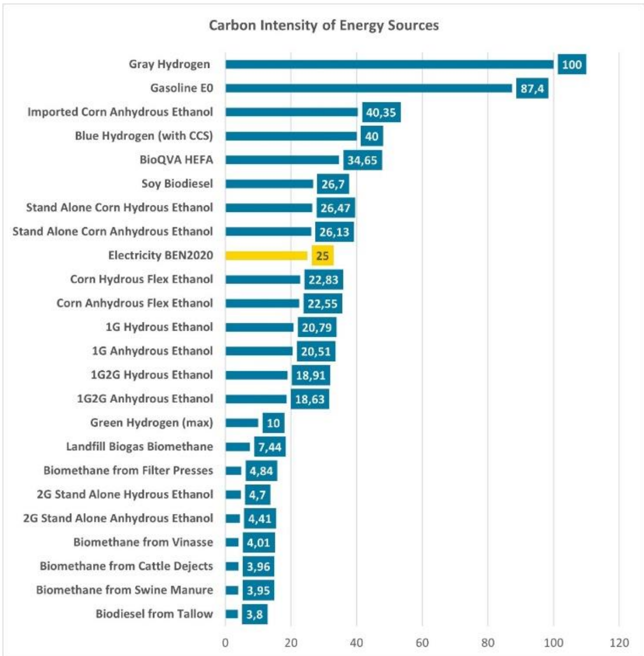
As previously seen, carbon intensity is the indicator of the carbon footprint of the energy source used. Electricity in Brazil has a carbon intensity of 25 gCO2e/MJ, this value is significantly low, compared to gasoline that has the intensity of 87.4 gCO2e/MJ, for example.

[2] In this study, the updated intensity (BEN 2021 - 21.88 gCO2e/MJ) was used.

Figure 19 – Table of carbon intensity of fuels, according to RenovaBio - National Policy for fuels

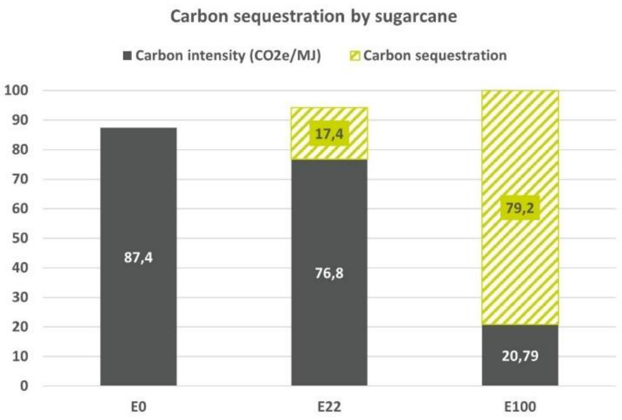
FUELS	CARBON INTENSITY (CO2e/MJ)
1G Anhydrous Ethanol	20,51
2G Anhydrous Ethanol Stand Alone	4,41
1G2G Anhydrous Ethanol	18,63
Flex Corn Anhydrous Ethanol	22,55
Stand Alone Corn Anhydrous Ethanol	26,13
Anhydrous Corn Ethanol Imported	40,35
1G Hydrous Ethanol	20,79
2G Stand Alone Hydrous Ethanol	4,7
1G2G Sugar Ethanol	18,91
Flex Fuel corn anhydrous ethanol	22,83
Stand Alone Hydrous Corn Ethanol	26,47
Soy Biodiesel	26,7
Tallow Biodiesel	3,8
Biomethane from Landfill Gas	7,44
Biomethane from Filter Presses	4,84
Biomethane from Bagasse	4,01
Biomethane from Swine Manure	3,95
Biomethane from Cattle Manure	3,96
HEFA BioQAV	34,65
Gasoline E0	87,4

Figure 20 – Chart of the carbon intensity of energy sources in the transport sector



Thus, it is clearer to understand the power of biofuels, they have a low carbon intensity index and are consequently very favorable to the environment. This happens because of the use of natural resources, such as sugarcane, for example. When the sugarcane is planted, photosynthesis takes place; the plant needs carbon dioxide to grow, so most of the CO_2 that is emitted into the atmosphere by ethanol production has already been captured by the plant even before the fuel is produced.

Figure 21 - Carbon sequestration chart in sugarcane plantation



In Brazil we also use E27, a mixture of anhydrous ethanol and gasoline. Because it is a mixture, there is no established value for carbon intensity, but there is a way to calculate this value through intensity and density data of anhydrous ethanol and gasoline.

Figure 22 – Calculation of the carbon intensity of the blended gasoline - EXX

$$ICexx = \frac{[[ICe0 * DENe0 * (100 - EXX)] + [ICanidro * DENanidro * EXX]]}{[[DENe0 * (100 - EXX)] + [DENanidro * EXX]]}$$

$ICexx =$ *Carbon intensity of EXX*

$ICe0 =$ *Carbon intensity of E0* $\left(87{,}4 \frac{gCO2e}{MJ} \rightarrow RenovaBIO\right)$

$DENe0 =$ *density of E0* $(31{,}65 \frac{MJ}{L})$

$EXX =$ *number of EXX that you want to find the intensity*

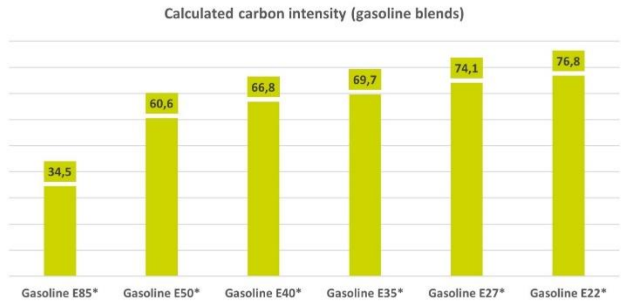
(example: 22 → to E22, or 22% of alcohol)

$ICanidro =$ *Carbon intensity of Anhydrous Ethanol*

(1G Anhydrous Ethanol → RenovaBIO)

$DENanidro =$ *density of Anhydrous Ethanol* $(21{,}18 \frac{MJ}{L})$

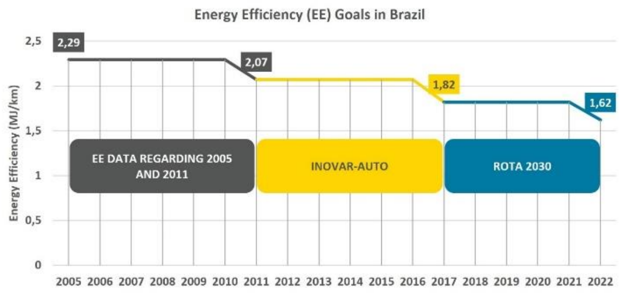
Figure 23 – Main gasoline blends and their calculated carbon intensities



3.2.4 *Energy efficiency goals*

Besides the goals that Brazil committed to at COP26, there are also public policies that aim to increase the country's average energy efficiency to contribute to the reduction of GHG emissions.

Figure 24 – EE Goals in Brazil, according to public policies: Inovar-Auto and Rota2030



Inovar-Auto was a program to encourage technological innovation and densification of the production chain of automotive vehicles, which took place from 2013 to 2017. It was a Brazilian government program that stimulated competition and productivity in the automotive sector. One of the goals that was set was to decrease Brazil's average energy efficiency by 12.08% compared to 2011.

Figure 25 – Energy Efficiency Goal for the year 2017, according to the Inovar-Auto program

GOALS	ENERGY CONSUMPTION (MJ/km)	EE INCREASE (%)
Baseline	2,07	
Goal for enabling	1,82	12,08%

The most recent government program is Rota 2030, which aims to achieve an 11% improvement in the average energy consumption of cars in Brazil by 2022. This means that by 2022 the average energy efficiency should reach at least 1.62 MJ/km.

3.2.5 Final considerations

Over the years new goals may be established for the automotive sector, in this study future goals were treated as a hypothesis of an increase in the energy efficiency rate, causing an improvement of 11% every 5 years.

Figure 26 - Hypothetical projection of future goals, 11% improvement every 5 years

Achieving the goals of reducing carbon emissions in the road transport sector by 2050 will require the adoption of several simultaneous cross-cutting measures. These include increasing the energy efficiency of vehicles, increasing the use of biofuels to replace or in combination with fossil fuels, the adoption of electricity generated from renewable sources, and the use of green hydrogen from renewable sources such as ethanol.

The use of biofuels will be the protagonists throughout the energy transition until we reach carbon neutrality by 2050. In addition, the use of sustainable electricity produced from renewable sources, such as hydropower, will make the carbon intensity of our energy sources very low, especially when compared to today's fossil resources.

However, it is of utmost importance that new public policies for the long term be established so that investments and technological resources are budgeted by the automotive industry for the reduction of emissions and the improvement of the energy efficiencies of vehicles.

3.3 CIRCULATING FLEET

3.3.1 Impact on CO_2 emissions by circulating liabilities (old vehicles)

Cars have a significant percentage within the total CO_2e emissions in Brazil. As seen earlier, they contribute 2.8% of the total amount emitted in Brazil in 2019. Over the years, with the arrival of government incentive programs such as Inovar-Auto, the increase of new technologies in the market, led to an improvement in the energy efficiency of new vehicles.

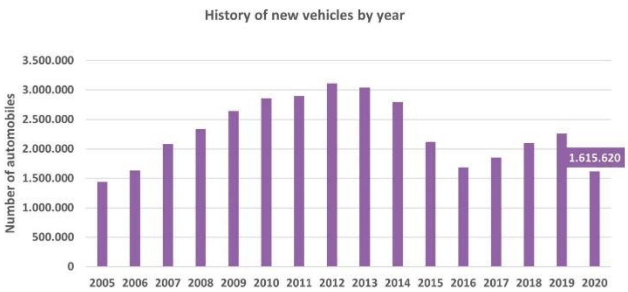
However, it is a fact that old vehicles, and all the circulating liabilities have a higher EE value. These represent the vehicles which emit the most CO_2e into the atmosphere.

In this study, we developed a way to "dilute" the positive effects of new technologies with better energy efficiency within all old current liabilities and low energy efficiency. In the long run, the increase of new vehicles in the fleet leads to a reduction in EE or CO2 emissions, but the weight and participation of this volume of new cars may not be sufficient to balance the balance with the entire old fleet in Brazil. We shall see below the proposals and hypotheses adopted in the calculation to bring this balance and achieve carbon neutrality in all the country's circulating liabilities.

3.3.2 New vehicle registration

FENABRAVE (National Federation of Motor Vehicle Distribution) has updated records of new vehicle registrations month by month. According to data from the year 2005 to the year 2020, the average number of new car registrations is approximately 2,281,341 per year.

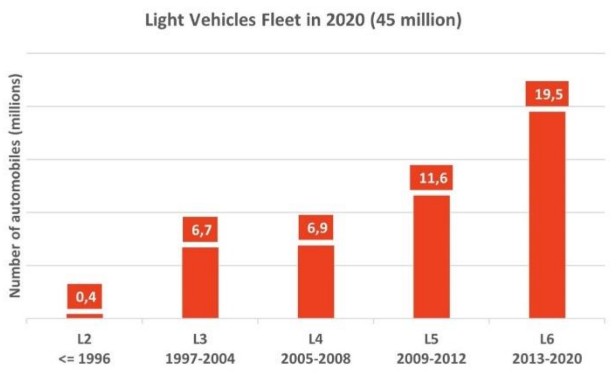
Figure 27 – Chart showing the history of new vehicle registrations by year, according to FENABRAVE



The increase of new technologies aimed at reducing CO_2, or pollutant emissions, has been incorporated into vehicles over the years. Thus, the Energy Efficiency of vehicles can be associated with the year they were manufactured. Older cars are less efficient than the new cars launched during the Inovar-Auto program, for example.

According to an ANFAVEA study, conducted by BCG and presented in August 2021, by the year 2020 Brazil has 45 million light vehicles in the circulating fleet. The study grouped the volume of the circulating fleet according to the pollutant emissions standard. Thus, we can see in the chart below, the division of the fleet by years and by type of fuel.

Figure 28 – Light vehicle fleet breakdown chart in 2020 by year of manufacture, according to ANFAVEA



There are at least 400,000 old vehicles circulating the country, so energy efficiency needs to be weighed between old and new ones. The use of old vehicles needs to be considered when analyzing the country's CO_2e emissions.

3.3.3 Final considerations

Over the years, the trend is for new vehicles to become increasingly efficient due to new technologies and improvements in the use of biofuels and electricity. The entry of these new cars, combined with the rate of exit of circulation of old vehicles, is characterized as the renewal of the fleet.

It was observed that the exit rate from circulation is very low, interfering with the advance of the fleet renewal effect until 2050. Therefore, it will be necessary that discussions for the establishment of public policies for the renewal or even the limitation of the fleet, be debated by the competent public agencies so that the path of carbon neutrality can be achieved. The life cycle of automobiles will need to be debated and organized for the entire industrial sector.

4 MATHEMATICAL FORMULATION

The calculations of the carbon neutralization study were divided into 3 main pillars:

- Circulating fleet
- Fuels and energy matrix
- Technologies and Energy Efficiency

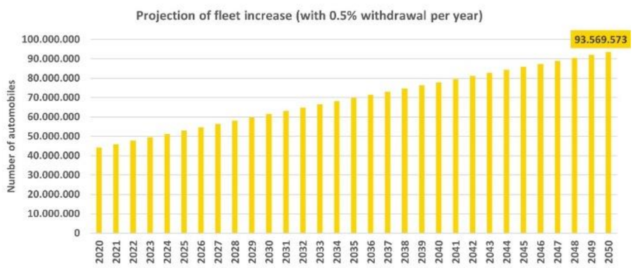
4.1 FLEET

Due to the large volume of old cars in circulation in Brazil, the carbon footprint left by all these circulating liabilities brings great impact and difficulty to the path of decarbonization in the transport sector. These vehicles have low energy efficiency (higher CO_2 emissions), and almost all of them use fossil fuels. It is of extreme relevance to include the impact of the circulating fleet in the carbon neutrality calculations, considering this large volume as the most efficient and sustainable new vehicles using biofuels, and if necessary, even suggesting the application of policies to restrict the use of old cars (fleet limitation) to achieve carbon neutrality of cars in the country. Another interesting alternative to reduce the carbon footprint of the old fleet is to stimulate the transformation of these vehicles to electric propulsion (retrofit).

4.1.1 Weighted energy efficiency in the circulating fleet

For this study, we considered 2 million new vehicles sold per year, approximately the average of the last 17 years. In addition, the rate of vehicle exits from one year to the next was calculated, based on the fleet data from SENATRAN (National Traffic Secretary). This exit rate was applied to the oldest fleet, that is, to the oldest cars in the fleet.

Figure 29 – Projection of circulating fleet increase using the natural elimination of 0.5% per year



The fleet was grouped in intervals of manufacturing years according to the study presented by ANFAVEA. To calculate the total energy efficiency of the circulating fleet, in each year interval, our study weighted the volume of vehicles in each grouping with the EE estimate at the time. For the future, we applied an assumption of an 11% improvement in energy efficiency every 5 years.

Figure 30 – EE table according to the range of manufacturing years

RANGE	EE (MJ/km)
]1900 - 1996]	2,29
]1996 -2004]	2,29
]2004 -2008]	2,29
]2008 -2012]	2,07
]2012-2020]	1,82
]2020 -2025]	1,62
]2025 -2030]	1,44
]2030 -2035]	1,44
]2035 -2040]	1,28
]2040 -2045]	1,14
]2045 -2050[	1,02
2050	0,90

Therefore, each year there has been the incorporation of new vehicles with better energy efficiency and the removal of old cars according to the exit rate found in the older cars. In this way, the fleet renewal effect has evolved, even if slowly, due to the large number of "old" cars.

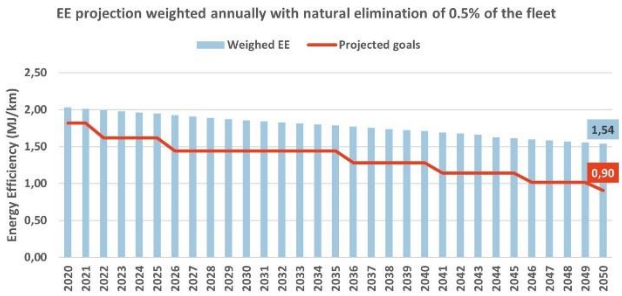
To estimate the weighted EE for each year until 2050, a calculation was made that weighted the EE of each manufacturing year range by the number of vehicles in the fleet for the year.

Figure 31 – Calculation of the weighted EE by year

$$\boldsymbol{Weighed\_MJ} = \frac{\sum fleet\_i * MJ\_i}{\sum fleet} \; for\ each\ i\ =\ each\ year\ grouped$$

$$Weighed\_MJ = \frac{MJ}{km} considering\ the\ elimination\ of\ natural\ fleet$$

Figure 32 – EE projection chart weighted annually with natural elimination of 0.5% of the fleet



According to the chart in Figure 33, it is seen that the energy efficiency of the circulating fleet in 2050 is 1.54 MJ/km.

4.1.2 Fleet Limitation

In the study, the option of fleet limitation was added, considering only vehicles up to 20 years old. For example, projecting the fleet limitation effect to 2050, only cars with a production year starting in 2030 will be in circulation.

Figure 33 – Projection of circulating fleet increase using the 20-year fleet limitation

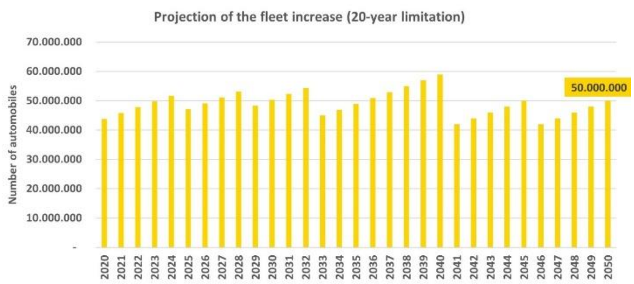
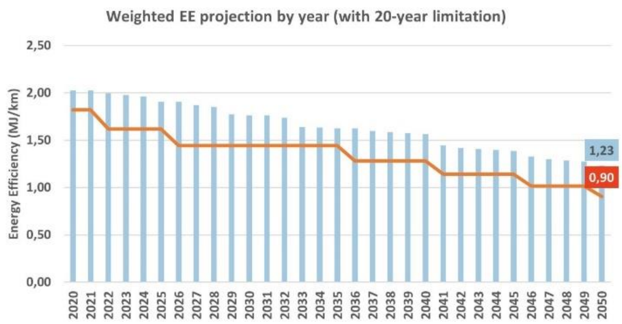


Figure 34 – Chart de projeção da EE ponderada anualmente com limitação de fleet de 20 anos



With this, the fleet renewal effect becomes much more efficient, since old cars, with low EE will be disregarded from the weighting as new vehicles, with higher EE will be increased in the circulating fleet. Throughout the study the effect of limiting the circulating fleet to achieve carbon neutrality will be pointed out.

4.1.3 Final considerations

This study considered the increase in the volume of new vehicles in circulation per year based on FENABRAVE's sales history, in addition to the application of a circulation exit rate observed in SENATRAN data. In addition, a limiting factor for older vehicles was increased, eliminating cars over 20 years of age. This limitation of old cars enhances the effect of fleet renewal and improvement of EE of all current, essential, and beneficial measures for the path of decarbonization.

4.2 FUELS

Fuels play a very important role in the pursuit of carbon neutrality. We can consider them as the main actors that will guide us to meet the goals of decarbonization. The analysis of carbon intensities and the use of biofuels, whether used in a pure way or mixed with fossil fuels, are paramount for the projection of calculations in the approach of the well-to-wheel.

4.2.1 History of fuel sales in Brazil

According to the ANP (National Petroleum Agency) in 2020 about 55 million m³ of gasoline and hydrated ethanol were sold in Brazil. With this data it is possible to analyze the fuel use factor in Brazil. It is understood as a factor of use (Fu), the consuming portion of pure hydrated ethanol, or also known as E100. This fuel is the one found in gas stations throughout Brazil and identified in the pumps as "Ethanol".

The sale of hydrated ethanol in 2020 represented 35%, a much higher percentage than was sold in 2005, which was only 17%.

Figure 35 – History of sales of 1G Hydrated Ethanol and Gasoline type C, according to ANP

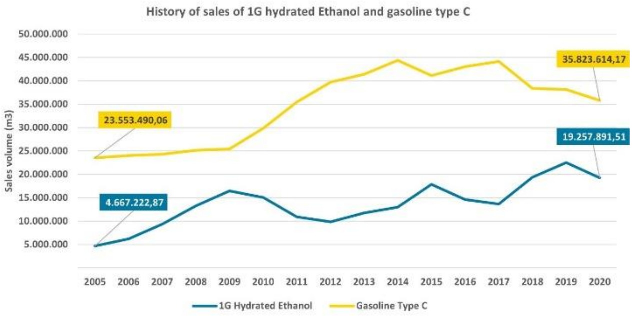
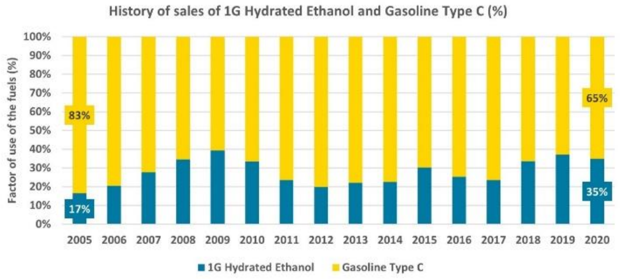


Figure 36 – History of the factor of use of 1G Hydrated Ethanol and Gasoline type C



The factor of use of ethanol in Brazil is in the calculation of a "virtual" carbon intensity that we can call ICflex. This flex carbon intensity weights the effect of the carbon intensity of gasoline with the carbon intensity of ethanol as a function of the sales volume observed in the ANP data.

Figure 37 – Flex carbon intensity calculation

$$\boldsymbol{ICflex = ICexx * FUexx + ICe100 * FUe100}$$

$ICflex = Flex\ carbon\ intensity$

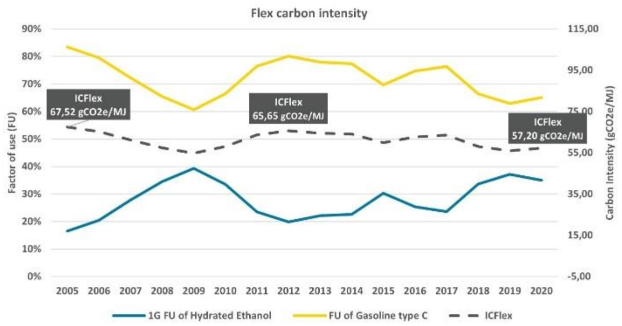
$ICexx = EXX\ carbon\ intensity$

$FUexx = EXX\ factor\ of\ use$

$ICe100 = E100\ carbon\ intensity$

$FUe100 = E100\ factor\ of\ use$

Figure 38 – History of flex carbon intensities per year



4.2.2 Ethanol consumption

Ethanol is a fuel that has a low carbon footprint. Its carbon intensity is 20.79 gCO2e/MJ (for 1G hydrous ethanol).

In Brazil, ethanol consumption is increasing more and more, and there are also blends with gasoline (anhydrous ethanol). Type C gasoline, also known as regular gasoline or gasoline with additives, is currently available at service stations, and its composition is between 25% and 27% of 1G Anhydrous Ethanol.

To calculate the absolute ethanol consumption (anhydrous + hydrated) per year, the ethanol contained in gasoline was considered as 22% v/v (E22). Although it does not represent the gasoline sold at service stations, it was adopted as a premise of the study because it is close to the reference value for approvals in Brazil.

Thus, the calculation of absolute ethanol consumption, weighted the portion coming from the mixture with type C gasoline (anhydrous ethanol) with the other portion of pure ethanol sold at gasoline stations (hydrated ethanol). In addition, we considered the consumption coming from the circulating fleet. The larger the fleet, the larger the volume consumed.

Figure 39 – Fuel consumption calculation considering the circulating fleet for the next years

$$\boldsymbol{CONSfleetj} = \frac{CONSfuel2020}{FLEET_{2020}} * FLEETano_j$$

$CONSfleetj = Fuel\ consumption\ (ref.2020) by\ year\ fleet$

$CONSfuel2020 = Fuel\ consumption\ for\ the\ year\ 2020$

$FLEETanoj = Fleet\ of\ cars\ circulating\ in\ the\ year$

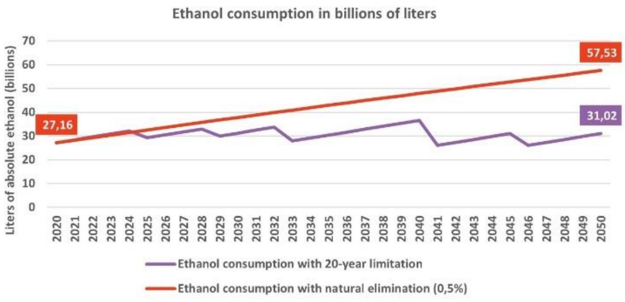
Figure 40 - Calculation of ethanol consumption in billions of liters, considering the consumption of the circulating fleet

$$\boldsymbol{Lethanol} = CONSfleetj * (1 - \%EV) * [FUe100 + \left(FUexx * \frac{EXX}{100}\right)]$$

$Lethanol = Liters\ of\ ethanol\ (in\ billions)$

$\%EV = Percentage\ of\ tram\ in\ the\ year$

Figure 41 – Projection of ethanol consumption in billions of liters

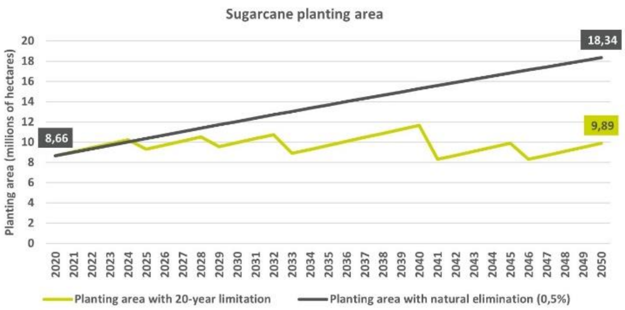


4.2.3 *Planting area*

In the previous topic the calculation of ethanol consumption per year was presented, so it was necessary to evaluate how much this consumption would impact the sugarcane plantation areas, one of the main raw materials for ethanol production in Brazil.

According to CONAB (National Supply Company), to produce about 1 billion liters of ethanol, an area of 318.76 thousand hectares in sugarcane is needed. The higher the ethanol consumption, the larger the sugarcane planting area.

Figure 42 – Projection of the sugarcane planting area in million hectares



4.2.4 *Final considerations*

The well-to-wheel approach to calculation made it possible to simultaneously address the two main actors that directly impact the decarbonization path in the automotive industry: the fuels and the energy efficiency of automobiles.

In the case of fuels, Brazil is very privileged due to its bioenergy matrix availability, especially for the use of ethanol, which comes from sugarcane and has low carbon intensity if compared to fossil fuels. However, the indiscriminate increase of this type of product, aiming at carbon neutrality, can have great impacts on sectors such as agriculture, for example, which will have to manage a large increase in sugarcane plantations to supply the new demand for ethanol throughout the country.

On the energy efficiency side, the use of new technologies coming along with new vehicles contributes to increased efficiency. On the other hand, the country's large circulating fleet liability does not permit that this global efficiency improvement effect be sufficient to reach carbon neutrality in 2050. Thus, the study brings as a hypothesis, the limitation of old fleet in 20 years for the fleet renewal effect to be achieved to reach carbon neutrality. This is only a hypothesis for the calculation, remembering that all discussion of issues of this magnitude must be raised and directed to the debate in the layers of competent government agencies or institutions whose responsibilities are attributed to them.

Biofuels are effective in decreasing the carbon footprint, but the more they are consumed, the larger the area for planting the raw material. Therefore, it was crucial to take energy efficiency into account; after all, the more energy-efficient the vehicles, the less fuel they will have to use. Therefore, the energy efficiency improvement was considered in a new calculation: weighted ethanol consumption.

Figure 43 – Calculation of fuel consumption per year, considering fleet fuel consumption and energy efficiency improvement

$$\boldsymbol{CONSfleetj_{weighted}} = \frac{CONSfleetj}{eeICE_{2020}} * eeICE_j$$

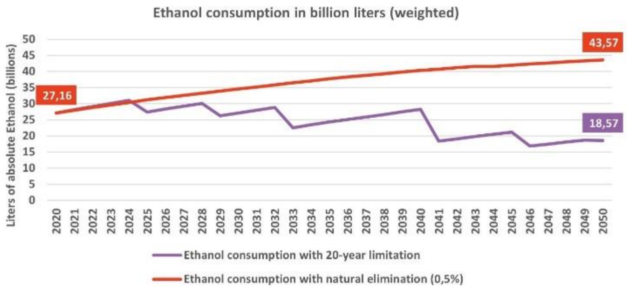
$eeICE_{2020} = Energy\ efficiency\ (MJ\ weighted)\ referring\ to\ the\ year\ 2020$

$eeICE_j = Energy\ efficiency\ (MJ\ weighted)\ of\ the\ year$

Figure 44 – Calculation of ethanol consumption in billions of liters, considering circulating fleet consumption and energy efficiency improvement

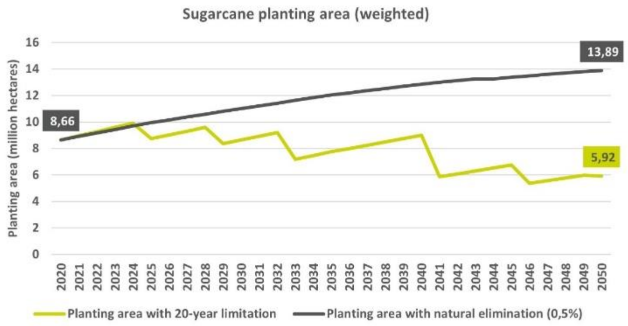
$$\boldsymbol{Lethanol_{weighted}} = CONSfleetj_{weighted} * (1 - \%EV) * [FUe100 + \left(FUexx * \frac{EXX}{100}\right)]$$

Figure 45 – Projection of weighted ethanol consumption in billion liters



The energy efficiency that the calculation considers is that which has already been weighted annually according to the car's year of manufacture $(MJ_{weighed})$. Thus, the sugarcane planting area changes according to the weighting.

Figure 46 - Projection of the weighted sugarcane planting area in million hectares



Finally, in addition to fleet renewal, it is necessary to increase the consumption of biofuels, which are very important in Brazil. Increasing consumption will not necessarily increase the area of sugarcane plantations, since it is necessary to take EE.

4.3 TECHNOLOGIES

The third important pillar for carbon neutralization is that which considers the technological evolution of vehicles and engines to ensure that the projected rate of improvement in energy efficiency is achieved. As mentioned earlier, this rate is projected to future at 11% improvement every 5 years, based on the regulatory developments in energy efficiency applied to Brazil in recent years.

To achieve these projected energy efficiency levels in 2050, a significant level of electric and hybrid vehicles must be considered. This seems the most natural way to reach the future goals.

4.3.1 Electric and hybrid vehicles

In this study, the progressive entry of electric and hybrid vehicles into the market was considered to obtain an improvement in energy efficiency to the projected values.

Among the hybrids, technologies ranging from "mild hybrids" to "hybrids" are projected, considering an improvement in the energy efficiency rate of 10 to 20% over vehicles with conventional engines.

When it comes to electric vehicles, it is necessary to take electricity as an energy source into consideration. Therefore, it is correct to say that the carbon footprint of an electric vehicle in Brazil is approximately 25gCO2e/MJ [3].

4.3.2 Final considerations

To help on the path to decarbonization, it is necessary that sales of electric and hybrid vehicles increase in Brazil.

The projection for the sales of electric vehicles was made from an arithmetic progression, being possible to change the percentage of electric cars in the total circulating fleet of 2050. For example, to obtain 50% electric vehicles in 2050, the following sales projections per year were calculated, starting from 2025:

Figure 48 – Projections of EV sales

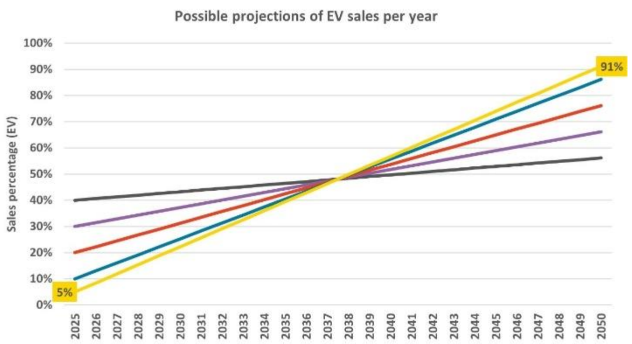


Figure 49 - Arithmetic progression calculation (EV sales) – Part 1

$$\boldsymbol{SalesEV_{2025}} = (\%EV_{2025} * increase\_fleet)$$

$SalesEV_{2025} = Total\ amount\ of\ electric\ vehicles\ sold\ in\ 2025$

$\%EV_{2025} = Total\ amount\ of\ electric\ vehicles\ in\ 2025's\ fleet\ (5\%\ hypothesis)$

$increase\_fleet = Total\ amount\ of\ automobiles\ sold\ (2.000.000\ hypothesis)$

$$\boldsymbol{SalesEV_{2050}} = \frac{[(fleet_{2050} * \%EV_{2050}) * 2]}{26} - SalesEV_{2025}$$

$SalesEV_{2050} = Total\ amount\ of\ electric\ vehicles\ sold\ in\ 2050$

$fleet_{2050} = Total\ amount\ of\ automobiles\ in\ 2050's\ fleet\ (50.000.000\ hypothesis, with\ 20-year\ limitation)$

$\%EV_{2050} = Total\ amount\ of\ electric\ vehicles\ in\ 2050's\ fleet\ (50\%\ hypothesis)$

[3] In this study, the updated intensity (BEN 2021 - 21.88 gCO2e/MJ) was used.

Figure 50 - Arithmetic progression calculation (EV sales) – Part 2

$$\boldsymbol{ratio} = \frac{(SalesEV_{2050} - SalesEV_{2025})}{26-1}$$

$ratio = Value\ of\ sales\ incresing\ over\ year$

$$\boldsymbol{SalesEV_j} = SalesEV_{j-1} + ratio \quad \rightarrow 2025 < j < 2050$$

$SalesEV_j = Total\ amount\ of\ electric\ vehicles\ sold\ in\ year\ "j"$

$$\%\boldsymbol{SalesEV_j} = \frac{SalesEV_j}{increase\_fleet}$$

$\%SalesEV_j = Percentage\ of\ electric\ vehicles\ sold\ in\ year\ "j"$

5 CARBON NEUTRALITY

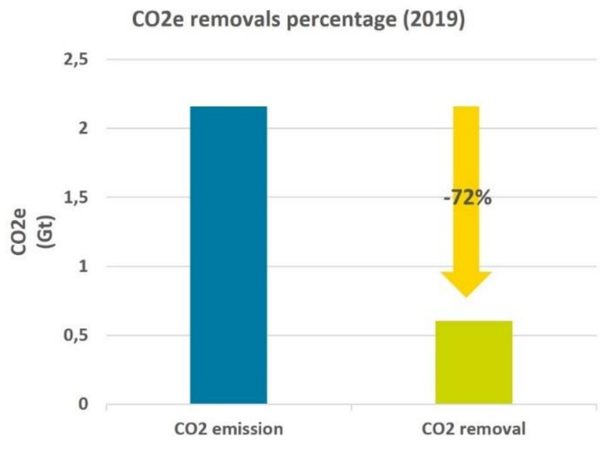
An integration of the mathematical models mentioned above was made, making it possible to analyze various scenarios and make comparisons between the three pillars, fleet, fuels, and technologies.

From these simulations, it was possible to analyze the projection of carbon gas emissions per kilometer (gCO2e/km) over the years, until reaching carbon neutrality in 2050.

5.1 PROJECTION FOR CARBON NEUTRALITY OF AUTOMOBILES IN 2050

At the beginning of this article, it was discussed about carbon gas emissions in Brazil, as it was mentioned, the country emitted about 2.1G tons in 2019 and removed about 604,000 tons of carbon. Taking this data into consideration the percentage that this removal represents in relation to the total emission was calculated.

Figure 51 – CO2e removals in 2019



When analyzing the chart above, there was a 72% drop, 28% of emissions were captured, this leads to a balance range (FE), because it is these 28% that represent how much carbon can be emitted for Brazil to reach neutral carbon neutral carbon. These values are for the year 2019 but were used as a reference to project a neutrality value for 2050.

In the previous chapters, the gasoline used for homologation in Brazil was presented, which is the same gasoline used as a reference in this study: E22 gasoline, a blend of gasoline with 22% anhydrous 1G ethanol.

When considering fuel sales in Brazil in 2020, the study used as a reference an automobile that uses 35% E100 (100% hydrous 1G ethanol) and 65% E22 gasoline. It was from this car reference that it was possible to calculate the emission of gCO2e/km.

Figure 52 – Carbon Emissions per km driven calculation

$$\boldsymbol{IC_{2020}} = 35\% * IC_{E100} + 65\% * IC_{E22}$$

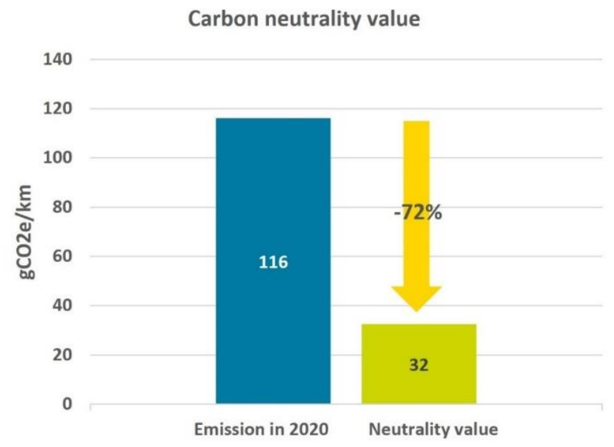
$$IC_{2020} = Carbon\ Intensity\ of\ 2020, considering\ E22\ and\ E100\ flex$$

$$\boldsymbol{Emissions\_per\_km_{2020}} = IC_{2020} * Weighed\_MJ_{2020}$$

$$Emissions\_per\_km_{2020} = Carbon\ emissions\ per\ km\ driven\ in\ 2020$$

The value of 116 gCO2e/km represents how much carbon per kilometer the cars emitted in 2020, from this data it is possible to check what will be the maximum emission value to achieve carbon neutrality.

Figure 53 - Projection for carbon neutrality of automobiles in 2050



Finally, the value projected to achieve carbon neutrality is 32gCO2e/km. In this study, the 32gCO2e/km was used as a reference for all years 2020 to 2050.

5.2 REFERENCE SCENARIO

A complete chart was simulated, using the three pillars of the study and by means of the tool created in Microsoft Excel.

Figure 54 – Reference scenario chart parameters

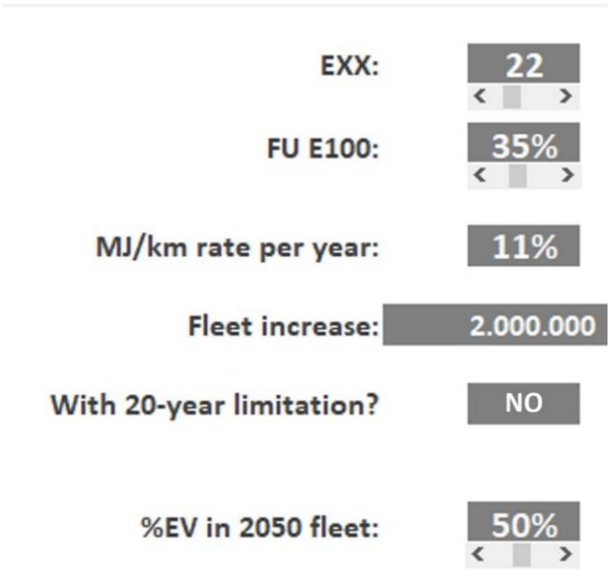
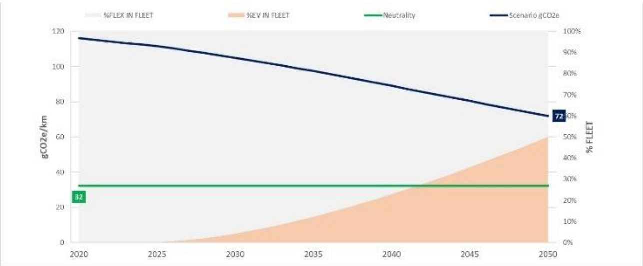
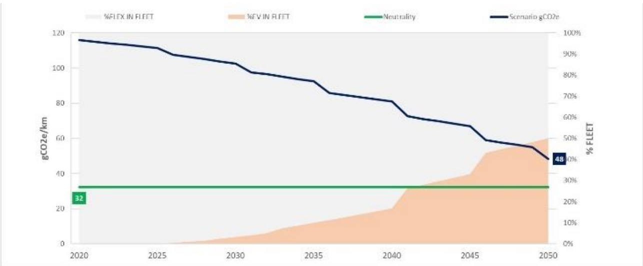


Figure 55 – Reference Scenario



When analyzing the chart, one can conclude that if Brazil continues to use 65% of E22 gasoline and 35% of E100 gasoline, it will not achieve carbon neutrality by 2050. No matter how much the country increases the sales of electric and hybrid vehicles.

Figure 56 - Reference Scenario with 20-year limitation

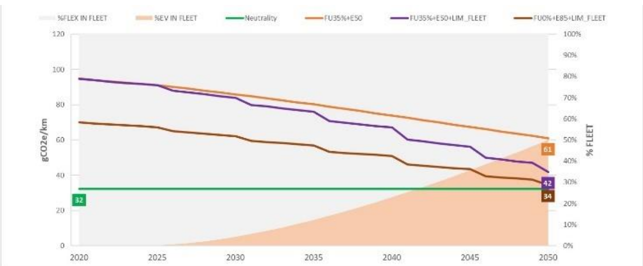


In the chart above it is possible to make the same analysis, but with the fleet limitation, even though there is a fleet renewal, limiting in 20 years the old cars, it still does not reach neutrality in 2050.

5.2.1 *Final considerations*

From the main reference (E22) an analysis was made with other possible scenarios, increasing the quantity of Anhydrous Ethanol in gasoline, and adding the fleet limitation in some of them.

Figure 57 – Other scenarios



However, it was evident that only with these new gasoline blends and fleet limitations, it would not be possible to achieve carbon neutrality by 2050.

Therefore, the study went deeper into the best scenario presented, the E85 mixture scenario, from which analyses were made to reach the balance range of 32gCO2e/km, that is, carbon neutralization in Brazil.

6 PROPOSED SCENARIO OF PRELIMINARY CARBON NEUTRALITY STUDY

After deepening into the reference scenarios that were seen in the previous chapter, it was necessary to include new hypotheses that integrated the three pillars of the study, fleet, fuels, and technologies. By balancing these pillars, it was possible to arrive at an example scenario, which can be used as the basis for new trends in biofuels, regulations, and technologies.

6.1 SCENARIO FOR AUTOMOBILES

Among the reference scenarios, the most appropriate for the continuation of the study was the scenario that uses E85 gasoline as the sole fuel and a 20-year limitation. The parameter to be analyzed was the percentage of electric vehicles in the year 2050, after some tests it was concluded that increasing the hypothesis by 10%, that is, estimating that in 2050 the percentage of electric cars in the circulating fleet is 60%, it is possible to achieve carbon neutrality. Sales of electric cars are progressive and start hypothetically from 2025.

Figure 58 – Chart parameter (%EV in 2050’s fleet)

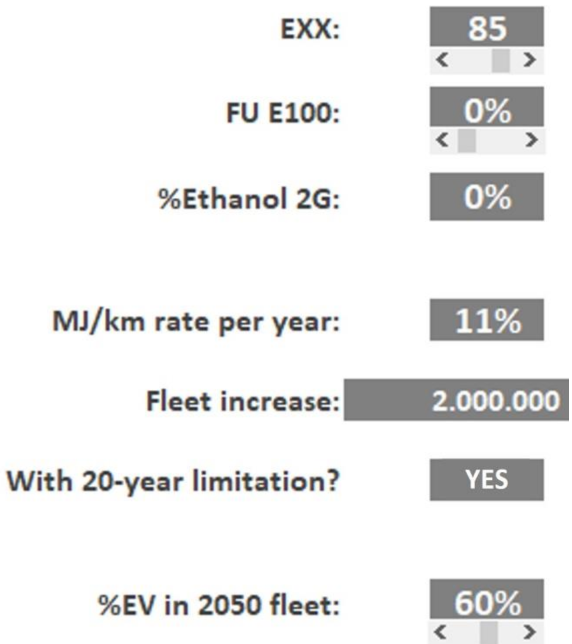


Figure 59 – E85 scenario with 60% electric cars in 2050's fleet

The increase of electric vehicles in 2050's fleet has contributed to carbon neutrality, but to help achieve it, a calculation was made using second-generation ethanol (which will be further approached in a future study). The use of 10% of 2G Ethanol was essential to achieve carbon neutralization in 2050.

Figure 60 – Chart parameters (Ethanol 2G)

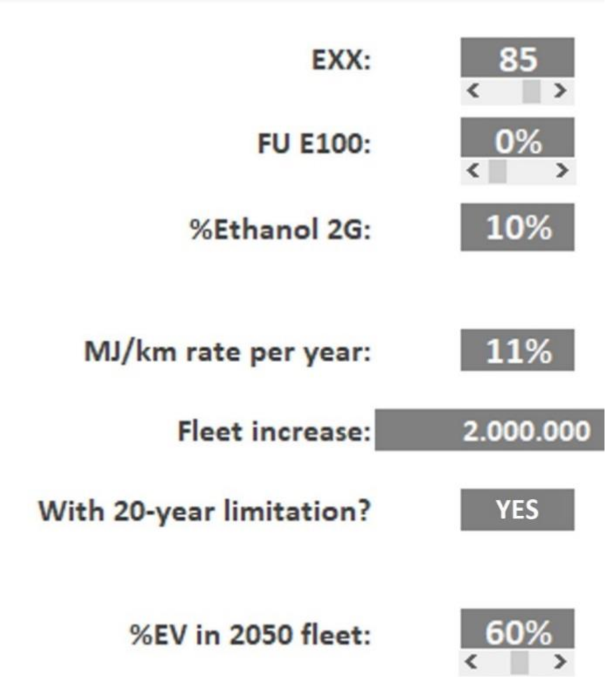
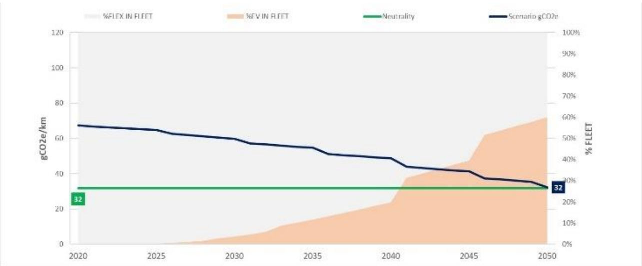


Figure 61 - Scenario that achieves carbon neutrality by 2050



7 CONCLUSION OF THE STUDY

This article brought a preliminary study focused on the well to wheel for automotive vehicles, through public data, calculations, and technical concepts, it was possible to present scenarios for the decarbonization path and a hypothetical one for the carbon neutralization to be achieved by 2050.

Carbon neutralization is currently being discussed a lot, Brazil has macroscopic goals, but does not have a detailed path for each sector of the economy. The automotive industry is responsible for an important part of the country's carbon emissions, and it is extremely important that public policies are created to help this industry on the path to decarbonization. The study presented here aims to assist in the construction of technological and regulatory trends.

During the study, mathematical models based on well-to-wheel concepts were made, and the efficient integration of these models ensured good results in the scenario simulations. In each hypothesis it was possible to balance the pillars of the study, through the parameters incremented in the simulation tool. Thus, it was easy to visualize how impactful each of the pillars is.

This study concludes the need for the integration of biofuel use, electrification, and fleet renewal in Brazil, avoiding the need for a single solution, such as the complete electrification that is happening in the richest countries.

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