# CO2 REDUCTION IN BRAZILIAN ROAD AND RAIL TRANSPORT

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**Abstract**

For several years, the use of oil for driving vehicles, generating power and many other activities has caused the world to become highly dependent on it, which is running out. Biodiesel stands out among these alternatives as a potential replacement for petroleum diesel, and it is obtained through the transesterification of vegetable oils or animal fat. In addition to being renewable, biodiesel reduces Brazil's dependence on petroleum and emits less greenhouse gases such as $CO_2$, which is the focus of this article. Based on calculations performed considering petrodiesel consumption in Brazil, this study aims at quantifying $CO_2$ emissions until 2025 and the avoided emissions when methyl biodiesel produced from soybean oil is used as part of the fuel, considering the blend percentages determined by the Brazilian government for the established period.

**Keywords:** Biodiesel; Road transportation; Rail transportation; $CO_2$ emissions; Greenhouse gases.

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## 1. Introduction

In the end of the 18th century, the development of internal combustion engines started, progressing slowly but steadily in its first 100 years. In 1892, Rudolph Diesel was awarded a patent for a compression-ignition engine fueled by coal dust, but the original project did not function properly (Ma and Hanna, 1999).

After its discovery in 1859 in Pennsylvania, petroleum was used mainly to produce kerosene. However, Rudolph Diesel altered his project, employed its many byproducts in his experiments with other fuels andhe built his first successful prototype in 1895. One of the first reports of vegetable oil being used in diesel engines dates from 1900, when the creator of the new engine used peanut oil for a showing at the Paris Exhibition (Altin et al., 2001).

Low oil prices lasted until late 20th century, causing diesel engines and diesel fuel to evolve simultaneously. Few references mention the use of alternative fuels in diesel engines before the 1970s. In the 1930s and 1940s, for instance, vegetable oils were occasionally employed as fuel, but only in emergency situations. However, with recent oil price raises and growing environmental concerns, interest was renewed in vegetable oils and their derivatives, such as biodiesel (Pinto et al., 2001).

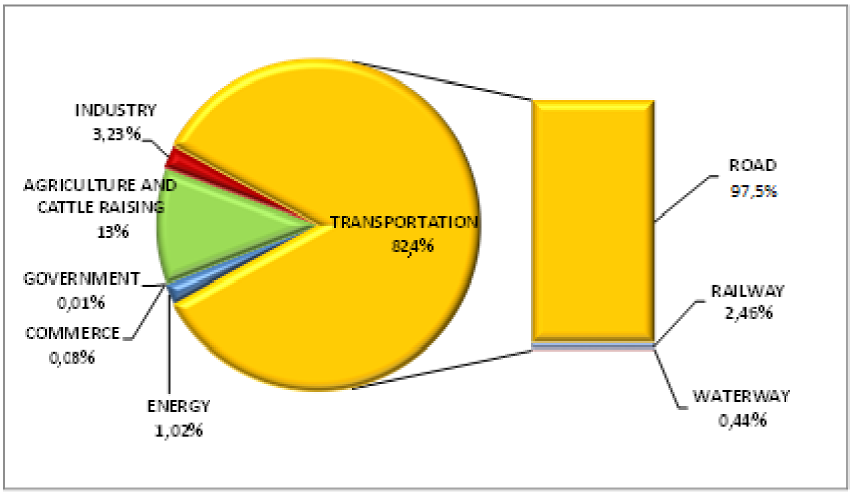
Among the interested countries, Brazil presents a high potential for the production of biodiesel, an alternative fuel to petroleum diesel (also known as petrodiesel). Biodiesel is produced through the transesterification of oils or fats from beef tallow or crude vegetable oils such as castor oil, peanut oil, sunflower oil, soybean oil and other regional crops grown in Brazil, as well as waste frying oil. It is a usable fuel by itself or as part of a blend with petrodiesel, and it can be employed in decentralized power generation units, production equipments, agricultural and civil construction machinery and vehicles used for passenger and cargo transportation.

Transportation accounts for more than 50% of the global consumption of oil derivatives (IEA, 2017). In Brazil, it accounts for approximately 82.4% of the final energy consumption of petrodiesel, the main oil product imported by the country. Of this percentage, 97,5% is destined exclusively to the transportation of cargo and passengers by road (EPE, 2022), which is the main mode of transportation in Brazil, accounting for more than 61% of all cargo shipment in the country (CNT, 2018).

In 2022, approximately 61% of all passenger trips in collective modes of transportation in Brazil were taken on diesel buses (ANTT, 2022).Considering the $CO_2$ emissions, the used vehicles by people generate 29,3 million tons of pollutants per yearon their dislocations.

Figure 01 below presents petrodiesel consumption per economic sector in Brazil:

**Figure 1 -** Diesel consumption by sector




**Source:**data sourced fromEPE (2022)

Brazil has searched for energy alternatives to petroleum diesel with the purposes of mitigating environmental impacts caused by the use of oil products and increasing energy safety. Moreover, an alternative and renewable energy source such as biodiesel plays an important role in lessening the country's dependence on diesel and lowering its $CO_2$ emissions.

**2. Road transportation and Rail transportation in Brazil**

The Brazilian automotive market is expected to keep expanding for at least 20 more years, aggravating environmental issues as greenhouse gas emissions and infrastructure issues as the conditions of public roads, cargo transportation and mobility (CNT, 2018).Industries and transportation are responsible for the highest greenhouse gas emissions.

Concerning infrastructure, the main objective is to attain a higher efficiency through intermodal integration. In Brazil, 64.86% of all cargo is transported by road, which shows how much the Brazilian economy relies on this mode of transportation. Many infrastructure problems have affected transportation in Brazil over the last decades and influenced the logistics of regional transportation of cargo and passengers (CNT, 2018).

According to ANP (2020), these problems harm economic sectors such as agribusiness, complicating the sale of produced goods. Due to its continental dimensions and geographical characteristics, Brazil should not have roads at the core of its transportation system. Investments aimed at creating a more balanced system with a higher participation of railroads and waterways would add strategic value to the country and respond to environmental demands related to energy consumption and greenhouse gas emissions, as well as the demands from corporations and industries for lower logistic costs.

PNLT (2012) states that it is necessary to decrease the volume of cargo transported in road and invest in more environmentally efficient modes of transportation. Still according to PNLT, in order to eliminate the bottlenecks related to Brazilian roads, the ideal would be to increase the participation of railroads in the transportation system from the current percentage of 25% to 32%, and waterways from 13% to 29%, over a period of 15 to 20 years. Pipeline transportation and air transportation would reach 5% and 1% respectively, and the participation of roads would decrease from 64.86% to 33%.

Nevertheless, roads need to be discussed as they are the main mode of transportation for cargo and passengers in Brazil. Besides, past governments highly encouraged their expansion and use, causing other types of transportation to become less used and poorly preserved.

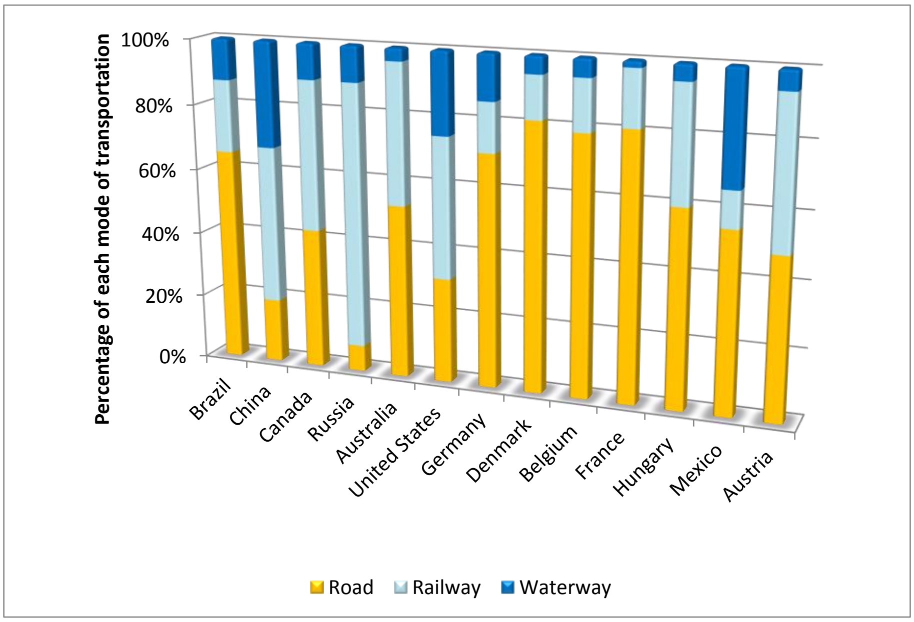
The participation of roads, railroads and waterways in the Brazilian transportation system is significantly different from other countries with continental dimensions. As previously mentioned, the percentage of cargo transported by road is excessively high in Brazil.

Figure 2 below presents the participation of roads, railways and waterways in cargo transportation of different countries.

It can be noted that all countries with large territories (except for Brazil) use railways more often. Additionally, roads play a smaller role in their transportation systems.

The graph shows as well that countries with smaller territories use mainly roads, and it is surprising to find Brazil in a similar situation as theirs since roads are not the most efficient mode of transportation for a larger country.

**Figure 2 -** Modes of transportation in different countries (ton x km)

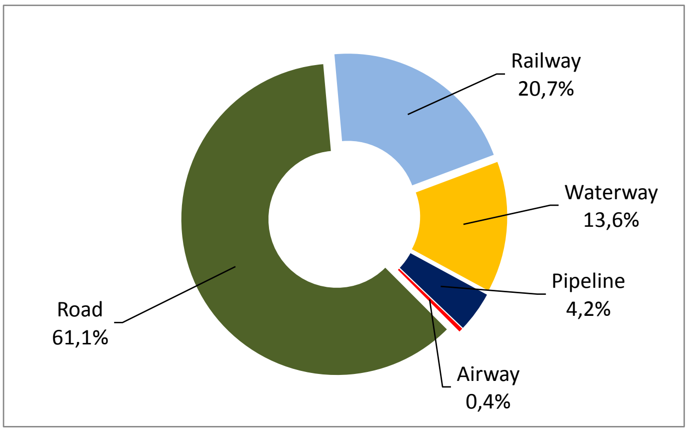



**Source:**data sourced fromCOPPEAD/UFRJ (2004) and CNT (2018)

These circumstances can be interpreted as a result of the excessively low road freight rates, a barrier for multimodal transportation and for improving other modes of transportation. The average road freight rate is too low compared with the incurred costs, which compromises the efficiency of the sector, prevents the expansion of other modes of transportation (such as railways) and affects society negatively.

Consequently, the unbalanced transportation system is the most significant obstacle faced by cargo transportation in Brazil. While large countries such the United States, Canada, China and Russia use mainly railways and waterways, Brazil relies excessively on roads, (Fig. 3).

**Figure 3 -** Cargo transportation in Brazil




**Source:**Data sourced fromCNT (2018)

According to CNT (2018), approximately 61.1% of all cargo was transported by road in 2018, totalizing 1.5trillion TKU (Tons per useful kilometer).

Road transportation might be considered less appropriate for cargo shipping than railways due to transportation safety and restrictions regarding cargo size and weight. However, road transportation offers reasonably fast and reliable deliveries for LTL (less-than-truckload) shipping, and the shipper only needs to fill one truck before transporting the cargo. In railroads, an entire carriage needs to be filled. In addition, road transportation is preferred for small loads as well (Murta et al., 2018).

Road transportation should be used mainly for high or medium value-added industrial goods of small volume in short distance routes. Due to the low freight rates in Brazil, roads are essential to the transportation of commodities such soy, petroleum products and cement.

Araújo (2013) states that the preference for roads in Brazil can be interpreted as a result of the low freight rates, which do not reflect the real costs of the activity. As a result, vehicles used by transport operators tend to depreciate more rapidly since the main goal is to obtain more work contracts.

According to Murta et al.(2018), roads are the second most energy-intensive mode of transportation (airways are the first). As a result, Brazil's preference for roads contributes significantly to the high diesel consumption of the country's transportation system.

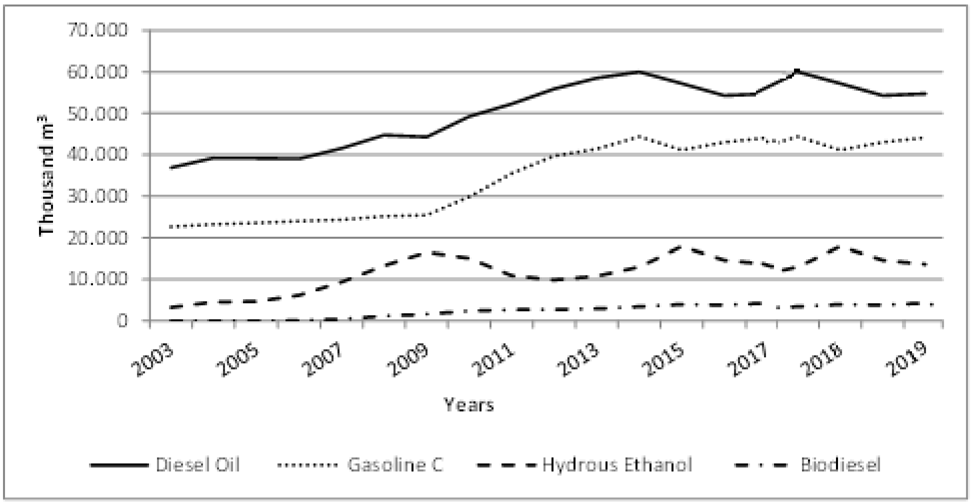
Currently, Brazilian rail network in operation has 29.291 km of extension, being almost the totality (28.066 km) operated by private companies, through sixteen concessions (CNT, 2018). The main features of the project, historical, economic and geographical, is the interconnection of areas of agricultural production and mineral exploration of the country's interior with the ports, used for the export of goods.The largest concentrations of railways are located in the states of Rio Grande do Sul, São Paulo, Minas Gerais and Rio de Janeiro.

*2.1. Fuelconsumption*

The high demand for new vehicles led to the growth of another branch of the market: fuels. Figure 4shows that petrodiesel was the most consumed fuel in the country between 2003 and 2019. However, the fuel market started changing its products in 2005 when biodiesel started being added to petrodiesel, its most important product.

Petrodiesel is most commonly used by trucks, buses and by a small percentage of light commercial or automotive vehicles. The expansion of its consumption started to decrease in 2010 (11.15%) and 2011 (6.14%), most likely owing to the use of intelligent vehicles for cargo transportation and airways for both passenger and cargo transportation.

**Figure 4 -** Sale of automotive fuels in Brazil




**Source:**data sourced fromANP (2020)

During this period, there were fluctuations in gasoline consumption. It decreased in 2006, growing again the following year. In 2009, it decreased once more due to a higher consumption of ethanol. However, ethanol supply declined in 2011, causing gasoline consumption to rise again. Ethanol consumption, in its turn, went through very similar fluctuations. It decreased until 2003, probably due to the lower production of ethanol vehicles. With the arrival of flexible-fuel vehicles in the end of 2009, ethanol prices became higher and its demand decreased.

Petrodiesel production increased significantly in 2013, growing 4.65% compared with 2012 and reaching almost 59 billion liters. From 2016 to 2018 the growth was almost 1,5% with a consumption of 61.8 billion liters (ANP, 2020), startingto go backin 2019 andin theyearofthepandemic (2020).Eventhough, accordingtoUbrabio (2022), theproductionandconsumptionof biodiesel in 2020wasplus 7 billion, making Braziloccupythe 2nd position as thelargestproducerandconsumer in the world, behindonlytheUnited States.

Based on this data, vehicle sales are expected to increase, leading to higher fuel production and consumption and aiding the economy and development of the country. However, this economic dynamics of demand and production also involves negative aspects such as the air pollution caused by transportation. The Ministry of the Environment stated that, since industries are well spread throughout the country, the transportation sector has become the main polluter of urban centers owing to cargo transportation.

### 3. Greenhouse gas emissions caused by transportation

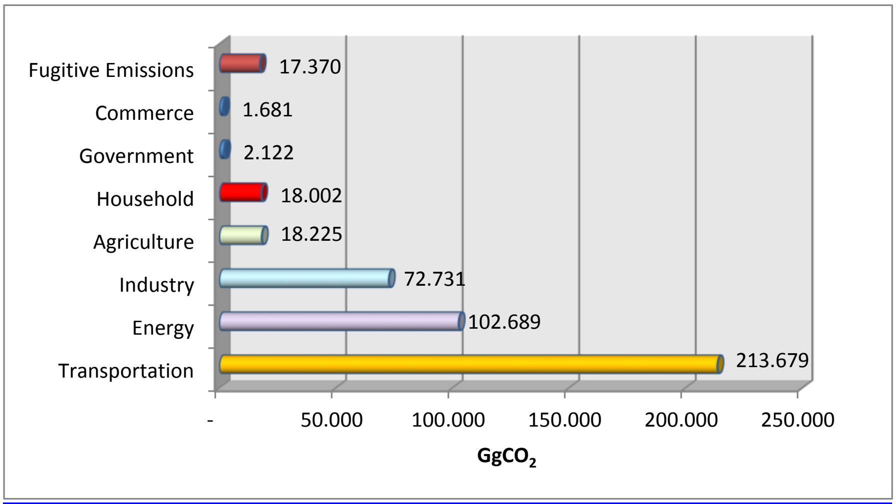
The atmospheric $CO_2$ increases of nearly 3 ppm in both 2015 and 2016 were record highs, raising the concentration to 402.8 ppm in 2016. During the same period, $CO_2$ emissions from fossil fuel and industry remained approximately constant. The much smaller but more variable $CO_2$ emissions from land-use change were higher than average in 2015, due to increased fires at some deforestation frontiers. Total $CO_2$ emission (fossil fuels, industry, and land-use change) grew 1.1% in 2015 to a record high of 41.5 billion tons, and declined 2.1% in 2016 (Peters et al., 2017).

According to the UN (2014), 78% of all greenhouse gas emissions are related to fossil fuel burning, including activities related to transportation and industries. Air pollution is harmful to human health as it causes premature deaths, respiratory diseases and less quality of life. In addition, burning fossil fuels causes monetary loss and diminishes interest in future investments in the country (MME, 2018).

Air pollution caused by burning fuel in the main urban centers is not limited to light (or automotive) vehicles; it is related to the road transportation of cargo as well. In Brazil, the transportation network relies mostly on roads, which also occurs in other countries.

The energy matrix is the second factor to be analyzed. 46% of the Brazilian matrix is composed of renewable energy, while in China this percentage is only 0.5%. Coal accounts for 70.4% of the total, having the highest potential for greenhouse gas emissions.

**Figure 5-** Total $CO_2$ emission per sector in Brazil




**Source:**data sourced fromMME (2018)

In order to control these emissions without harming the expansion of the sector, it is necessary to invest in renewable energy sources with lower emission potentials, such as biomass and especially biofuels to be used for transportation.

## 4. Production and use of biodiesel in Brazil

Biofuels are produced from renewable biomass, and they can replace partially or completely the fuels produced from oil or natural gas in engines and power generators. In Brazil, the main liquid biofuels are ethanol extracted from sugar cane and biodiesel, which is produced from vegetable oils or animal fat and may be added to petrodiesel in varying proportions (Murta et al., 2018).

Theoretically, biodiesel is capable of replacing petrodiesel in all possible applications. Its participation in the Brazilian energy matrix has grown gradually, aiming at specific markets to ensure the efficiency of its expansion.

According to Pereira et al. (2012), biodiesel consumption can be divided into two markets: automotive vehicles and stationary power generation. The latter is used mainly in power generation facilities for specific purposes or to attend to regional needs, usually in remote locations or in areas where energy supply is irregular. The volume involved is not significant, but it leads to considerable savings in transportation costs and, most importantly, it promotes social inclusion and citizenship for local communities.

The automotive market can be subdivided into two groups. The first is composed of the largest consumers, which have limited geographical circulation: urban transportation companies, railways and waterway transportation, among others. The second is retail sale in regular fuel stations, related to the interstate transportation of cargo and passengers, light vehicles and consumers in general. It is worth mentioning that biodiesel in Brazil is used mainly for vehicles – its use for power generation is secondary.

In 2005, Law 11097 instituted the National Biodiesel Production & Use Program (PNPB) to encourage small producers and promote socioeconomic development. Additional regulations were later included into the program, determining that a 2% biodiesel blend (B2, composed of 2% biodiesel and 98% diesel) would be mandatory from January 2008 onwards, and this percentage would be raised again in July 2008 (3%) and July 2009 (4%). The original legislation stated that 5% of biodiesel would be added to diesel starting January 2013, but this increase came into force in January 2010. The government stipulated as well that the percentage of biodiesel in the blend would reach 6% in July 2014 and 7% in November 2014 until February 2017. From March 2017 the mixbecameof 8% and March 2018, 10% (MME, 2018; UBRABIO, 2020).Also in 2018, the CNPE established a schedule for theevolutionofthemandatoryblendof biodiesel by 1 percentage point per year, untilreaching B15 in 2023, throughResolution No. 16/2018. Withthe new schedule, Brazilreliedonthe B11 blend in 2019, andreached B12 onMarch 1, 2020. The blendisexpectedto continue evolving, withincreasesscheduled for March 1 ofeachyear (UBRABIO, 2020).

Still being MME (2018), the percentage of biodiesel in the mix with the diesel will pass to 9% on 2018 andin the futureto 10% on 2019. In 2025, the percentagein force will beof 15% and in 2030 will pass to 20%, what will demand higher productive quantities of this biofuel.

Accordingto APROBIO (2016), the production of biodiesel should reach 18 billionof liters in 2030 and the consumptionof diesel should arrive 90 billionof liters.

As 2016, 53 biodiesel production plants had operation licenses granted by the National Agency of Petroleum, with a total capacity of 20,366.10 $m^3$/day. TheMidwest and South regionsaccount for 85.37% of Brazilian biodiesel production (ABIOVE, 2018).

Oilseed plantation and biodiesel production are much less energydemanding than fuel burn, leading to highly positive energy balances. The transformation of biodiesel into energy has a closed carbon cycle. Carbon dioxide emissions from fuel burn are reabsorbed through photosynthesis while the plant grows (Pereira et al., 2012).

Many oilseed processing plants in Brazil are capable of producing biodiesel from feedstock such as soybean, palm, castor, babassu, sunflower and peanut, and feedstock sources are found in the country. In each region, a particular source prevails.

According to APROBIO (2016), in Brazil, biodiesel is mostly produced from soybean oil (77%), beef tallow (18%) and others (5%).

Plantation areas are very common in South America and require no need for deforestation. They are largely used in biomass production as a source for vegetable oils, which shows that biodiesel production can be expanded without harming the environment.

Potential demand for biodiesel may be found in urban areas, railways, roads, water transport of cargo and passengers, power generators and stationary engines. Among different feedstocks, palm oil stands out for its high biodiesel yield per hectare (Pereira et al., 2012).

According to ANP (2020), initiatives such as the National Biodiesel Production & Use Program (PNPB), which focuses on the country's biodiesel supply, stimulate a higher market demand for biofuels and encourage private investments in the sector. The PNPB acknowledges the fact that economic incentives for biodiesel production in Brazil are associated with the evolution of the internal market and the conquest of international markets. Public policies should provide conditions for industries to work efficiently, promoting social inclusion and developing all regions, in accordance with the wider concept of sustainability. In this sense, Brazil's ample potential is different, although its market participation is still small in comparison with Germany and the United States as shown in Table 1.

## 5. Calculation methodology

In order to calculate the redistribution of the transport matrix and the reduction of carbon dioxide emitted by the two transport systems together, the methodology was divided into two parts: First, the method that allows a better distribution of cargo transported by road and rail systems in Brazil. Next, the methodology for calculating the emissions avoided by the matrix redistribution and the use of biodiesel in a regulatory manner is taken into account.

**Table 1 -** Biodiesel production in the world

| Production of Biodiesel and Share of the World Market | | | |
|---|---|---|---|
| **Position** | **Countries** | **Ton (Milion)** | **%** |
| **1** | USA | 4,113 | 14.4 |
| **2** | Germany | 3,352 | 11.7 |
| **3** | Argentina | 3,074 | 10.8 |
| **4** | Indonesia | 2,936 | 10.3 |
| **5** | Brazil | 2,567 | 9.0 |
| **6** | France | 2,360 | 8.3 |
| **7** | The Netherlands | 1,720 | 6.0 |
| **8** | Spain | 1,212 | 4.2 |
| **9** | Thailand | 1,009 | 3.5 |
| **10** | Poland | 739 | 2.6 |
| **11** | Malaysia | 696 | 2.4 |
| **12** | Italy | 580 | 2.0 |
| **13** | China | 400 | 1.4 |
| **14** | Belgium | 374 | 1.3 |
| **15** | South Korea | 358 | 1.3 |
| | Others | 3,059 | 10.7 |
| | **World** | **28,549** | **100.0** |

**Source:**Data sourced from MME (2018)

### 5.1. Methodology for redistribution of the freight transport matrix

As seen in chapter 2, the transportation matrix in Brazil has strong concentration in the road system, which causes high fuel consumption due to its lower energy efficiency.

According to PNLT (2012), the railway transport system could have its infrastructure expanded and, consequently, be more used for the displacement of loads. This would promote a more balanced division of the loads to be carried by both modes.

To become an example of calculation of fuel consumption, it becomes necessary the application of methodology, which contemplates a new version of the PNLT property. New energy consumption therefore requires a better balance between the road and the rail system.

To calculate fuel consumption, it is necessary to apply a methodology which considers the new distribution proposed by the PNLT. That is, the methodology allows to calculate the new fuel consumption considering a greater balance between the road and rail system.

#### *5.1.1. Projectionoffuelconsumption*

Based on official fuel consumption data from road and railway transport systems,it becomes possible the projection of future consumption by statistical regression technique.This technique uses historical data of fuel consumption in both modals to be possible to make the projection of the consumption for future horizons (Downing et al., 2006).

#### *5.1.2. Calculation of fuel consumption considering matrix redistribution*

Based in the proposal PNLT (2012) of rebalancing loads to the road and railway systems, it makes a redistribution of the entire load carried by both modals considering the new percentages of participation of each one in the matrix of charge transport(equations 2 and 3).

$W_{ROAD} = W_{TT}\ x\ P_{ROAD}$ (2) $\qquad\qquad W_{RAIL} = W_{TT}\ x\ P_{ROAD}$ (3)

Where $W_{ROAD}$ and $W_{RAIL}$: weight in tons, for each mode of transport (T);
$W_{TT}$: total load carried by both modes (T);
$P_{ROAD}$ and $P_{RAIL}$: percentage of participation of each mode (%).

Then, multiply the new amount of load, in TKU, referring for each modal by its consumption in volume per transported TKU, according calculated in the previous item.

The equation 4 and 5 explain this procedure.

$AC_{ROAD} = CS\ x\ W$ (4) $\qquad\qquad AC_{RAIL} = CS\ x\ W$ (5)

Where *AC (fuel):* new apparent consumption for each mode of transport (L);
*CS:* fuel consumption per TKU for each mode of transport (L/TKU);
*W*: weight in tons, for each mode of transport (T).

#### *5.1.3. Projection of the fuel consumption with the new matrix*

Considering the new fuel consumption in each transport modal, calculate the percentage of consumption in each modal, according to equation 6. This percentage of reduction or increase must be applied in the historical series of consumption of these modals so it can make the correction of these consumptions according to the new configuration of the transport matrix after the redistribution of the loads transported between road and railway.

$$PR = ((AC_{REGULAR} - AC_{NEW}) \div AC_{REGULAR})) \times 100 \qquad (6)$$

Where *PR:* percentage of reduction or increase of consumption (%);
$AC_{REGULAR}$: new apparent consumption for each mode of transport (L);
$AC_{NEW:}$ new apparent consumption for each mode of transport (L).

*5.2. Methodology for calculating the reduction of $CO_2$ emissions*

For calculating the $CO_2$ emissions reduced through the use of biodiesel in the Brazilian road system, the Top Down methodology developed by the Intergovernmental Panel on Climate Change (IPCC, 1996) was applied, allowing for the use of the final fuel consumption of buses urban transportation in Rio de Janeiro City (Fetranspor, 2018).

Before calculating $CO_2$ emissions, it is necessary to obtain the fuel consumption level. In the IPCC's emission inventory, consumption represents the amount of fuel consumed.

Nevertheless, not all petrodiesel consumed in Brazil will be replaced by biodiesel – the substitution of petrodiesel for biodiesel will follow the percentage variations determined by the governmental legislation described in section 4 of this article. As a consequence, the calculation of carbon emissions were made for the petrodiesel and biodiesel levels.

Once consumption was discovered, the methodology was employed in six stepsdescribed below: calculation of energy consumption, calculation of carbon quantity, calculation of fixed carbon quantity, calculation of net carbon emissions, calculation of real carbon emissions and calculation of real $CO_2$ emissions.

### *5.2.1. Calculation of energy consumption*

Each fuel has a different energy content, therefore the apparent fuel consumption had to be converted into a common energy unit as shown in Equation 7.

$$FC\ (fuel) = AC\ (fuel) \times F_{conv} \times 41.841 \times 10^{-3} \qquad (7)$$

Where *FC (fuel):* Energy consumption of a given fuel (TJ);
*AC( fuel):* Apparent consumption of a given fuel ($m^3$);
$F_{conv}$: Conversion factor ($tEP/m^3$);
$41.841 \times 10^{-3}$ *TJ* = 1 tEP - Brazil.

This study used 0.848 $tep/m^3$ as a conversion factor for petrodiesel and 0.777 $tep/m^3$ for biodiesel as determined by BEN (2017) and DOE (1998).

### *5.2.2. Calculation of carbon quantity*

Similar to energy contents, each fuel also has different carbon quantities. The carbon quantity of each fuel was calculated using Equation 8.

$$CQ\ (fuel) = FC\ (fuel) \times F_{emission} \times 10^{-3} \qquad (8)$$

Where *CQ (fuel)*: Carbon quantity of a given fuel (GgC);
*FC (fuel)*: Energy consumption of a given fuel (TJ);
$F_{emission}$: Carbon emission factor (tC/TJ).

The present study used 20.20 tC/TJ as the emission factor for petrodiesel and 19.88 tC/TJ for biodiesel, according to the IPCC (1996).

*5.2.3. Calculation of fixed carbon quantities*

Some fuels are used for non-energy purposes, causing part of the carbon to stay fixed or stored. In this study, the petrodiesel volume calculated was used with an energy purpose, thus the fixed carbon quantity is zero. For biodiesel, the fraction of stored carbon is 40%, which is the quantity sequestered in biomass renewal, according to equation 9.

$$CF = CQ\ (fuel)\ x\ FF \qquad (9)$$

Where *CF:* fixed carbon quantities (GgC);
*CQ (fuel)*: Carbon quantity of a given fuel (GgC);
*FF*: fraction of carbon fixed (%).

*5.2.4. Calculation of net carbon emissions*

Net carbon emissions are the mass balance between the carbon in the fuel minus the amount of fixed carbon from non-energy uses, according to equation 10.

$$NCE = CQ\ (fuel) - CF \qquad (10)$$

Where *NCE:* net carbon emissions (GgC);
*CF:* fixed carbon quantities (GgC);
*CQ (fuel)*: Carbon quantity of a given fuel (GgC).

*5.2.5. Calculation of real carbon emissions*

When an emission inventory is being elaborated, not all carbon in the fuel is considered oxidized since total combustion hardly occurs. Approximately 1% of carbon will not oxidize, being incorporated to ashes or other byproducts. Consequently, real carbon emissions are equivalent to 99% of net carbon emissions, according to equation 11.

$$RCE = NCE\ x\ FO \qquad (11)$$

Where RCE: real carbon emissions (GgC);
*NCE:* net carbon emissions (GgC);
*FO:*fraction of carbon oxidized (%).

*5.2.6. Calculation of real $CO_2$ emissions*

With the level of real carbon emissions, it was possible to calculate the real $CO_2$ emissions from energy use by considering the carbon content of the molecule: every 44 tons of $CO_2$ has 12 tons of carbon. Consequently, the real $CO_2$ emissions will be equivalent to 44/12 of the real carbon emissions, according to equation 12.

$$CO_2E = RCE\ x\ (44 \div 12) \qquad (12)$$

Where $CO_2E$: real $CO_2$ emissions (GgC);

RCE: real carbon emissions (GgC).

## 6. Results

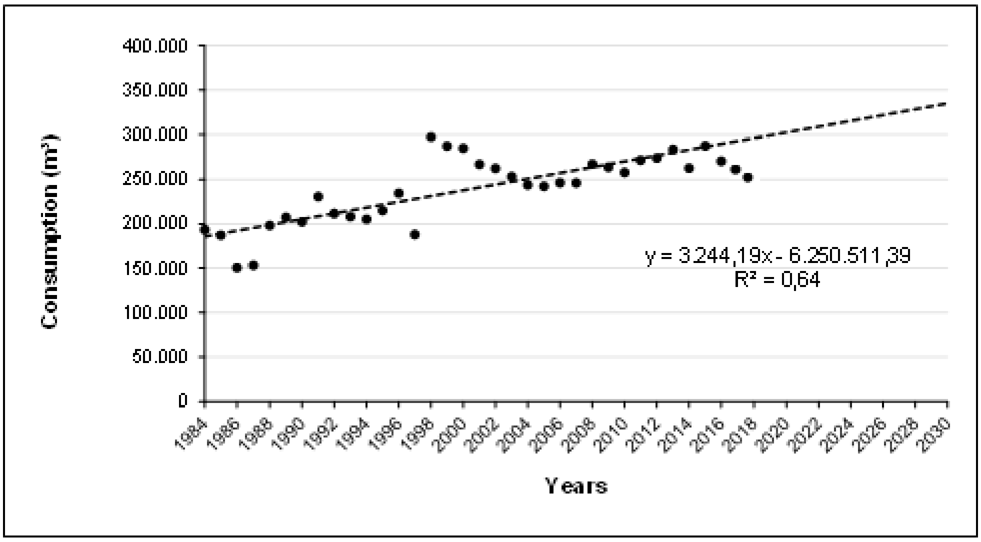
The results of this work were elaborated from two scenarios considered. The first scenario is in $CO_2$emission only for the regulatory use of biodiesel in the modes road and railway of transport.The second scenario considers the same;and it also considers the redistribution of the total loads carried by these two transport modes, as suggested by PNLT (2012).

Based on the consumption data gathered by BEN (2017), a projection of petrodiesel consumption, for the roads and rail modes of transport, was elaborated for the years 2017-2035 (future emissions) using real consumption levels from 1990 to 2016 (past emissions).

The calculations of $CO_2$ emissions considered the period comprising the year of 2005, when biodiesel began to be used in a regulatory way in the Brazil(ANP, 2020).

A linear regression was used to obtain the growth trend of both shown in Figure 6 and 7:

**Figure 6 -** Growth trend for petrodiesel consumption for Road

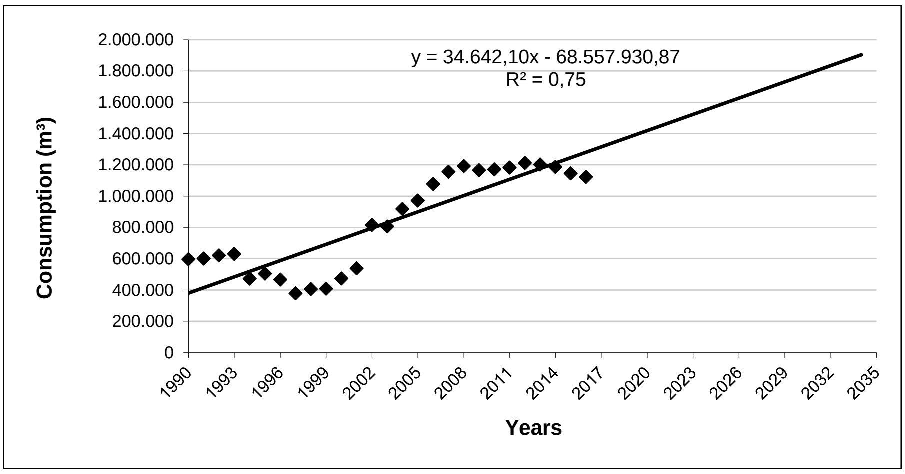



**Source:** data sourced fromFetranspor (2018); IEA(2021)

It is observed (fig 6), that there is a progressive increase of the petrodiesel consumption by transport road system, which facilitates future projection by the linear regression method.

It can be verified that the equation found for the regression has $R^2$ equal to 0.96, which allows the use of the equation with great reliability (Downinget al., 2006).

**Figure 7 -** Growth trend for petrodiesel consumption for Rail




**Source:** Data sourced fromBEN (2017)

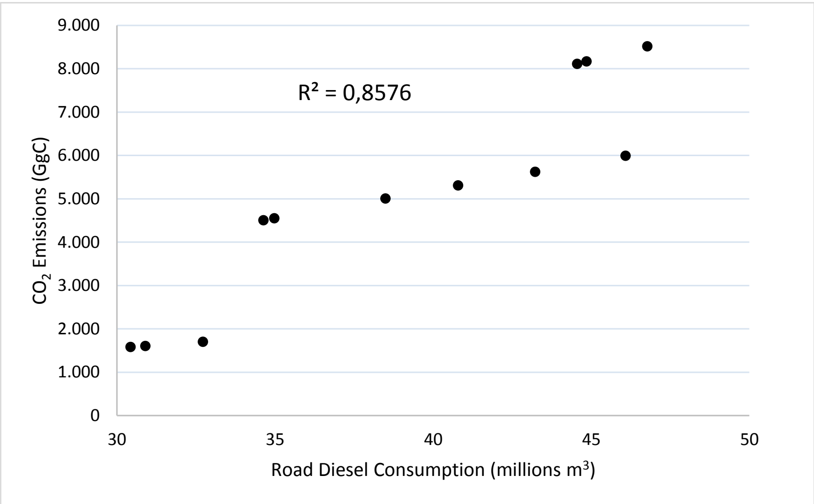
In the same way, it can be observed at figure 7, that the fuel consumption by the railway system, despite be about 35 times lower than the road in the year of 2017, the same it also presents increases year after year.

It should be noted that between 1994 and 2002 there was a decrease in fuel consumption, which can be explained by the lower use of the rail system for load transport.

Using the same linear regression technique, it was obtained the equation of the line with $R^2$ equal to 0.75, which can also be used reliable manner, according to Downing (2006).

In order to prove the relationship between the increase in fuel consumption and the increase in $CO_2$ emissions, a correlation graph was elaborated with these two study variables:

**Figure 8 -** Correlation between fuel consumption and $CO_2$ emissions




**Source:** Prepared by author (2018) and data sourced from BEN (2017)

The correlation graph was prepared only for the consumption and emissions of the road system, since the railway system will follow the same correlation trend.

It can be observed from the information contained in Figure 8 that the $R^2$ found was 0.86, which shows a strong correlation between the analyzed variables, (Downing et al., 2006).

It is concluded that the calculations of $CO_2$ emissions performed for both systems under study, based on the fuel consumption projected for them from 2017 to 2035 should be within the parameters of statistical reliability, as explained by Downing et al. (2006).

### *6.1. Scenario1*

Based on the values provided by the regression, the biodiesel and diesel consumption levels, for both transport modes, were estimated considering the regulations of the Brazilian government regarding blend percentages and the dates in which they come into force.

Consequently, by taking into account only the volumetric consumption of fuels for the percentages of 2%, 5%, 7%, 8%, 9%, 10%, 15% e 20% (for the periods of 2005-2007, 2008-2013, 2014-2016, 2017, 2018, 2019-2024, 2025-2029 and 2030) of the total petrodiesel and biodiesel consumption by the road e rail in Brazil, the results shown in Tables 3 and 4 were obtained by applying the methodology for calculating $CO_2$ emissions.

**Table 2 -** Results of applying the methodology for road petrodiesel and biodiesel $CO_2$emissions

| Year | Share of Petrodiesel consumption ($m^3$) | Share of Biodiesel consumption ($m^3$) | Total BX consumption ($m^3$) | Petrodiesel Real $CO_2$ Emissions (GgC) | Biodiesel Real $CO_2$ Emissions (GgC) | Total BX Real $CO_2$ Emissions (GgC) |
|---|---|---|---|---|---|---|
| 2005 | 29.820.181 | 676.195 | 30.496.375 | 77.637 | 971 | 78.607 |
| 2006 | 30.280.589 | 686.635 | 30.967.223 | 78.835 | 986 | 79.821 |
| 2007 | 32.059.720 | 726.978 | 32.786.698 | 83.467 | 1.044 | 84.511 |
| 2008 | 33.228.150 | 1.943.167 | 35.171.317 | 86.509 | 2.790 | 89.299 |
| 2009 | 32.895.869 | 1.923.735 | 34.819.604 | 85.644 | 2.762 | 88.406 |
| 2010 | 36.564.722 | 2.138.288 | 38.703.009 | 95.196 | 3.070 | 98.266 |
| 2011 | 38.748.444 | 2.265.991 | 41.014.435 | 100.881 | 3.253 | 104.134 |
| 2012 | 41.060.796 | 2.401.216 | 43.462.012 | 106.902 | 3.447 | 110.349 |
| 2013 | 43.777.625 | 2.560.095 | 46.337.720 | 113.975 | 3.675 | 117.650 |
| 2014 | 43.495.863 | 3.637.647 | 47.133.510 | 113.241 | 5.222 | 118.463 |
| 2015 | 41.710.725 | 3.488.352 | 45.199.077 | 108.594 | 5.008 | 113.602 |
| 2016 | 41.434.266 | 3.465.231 | 44.899.497 | 107.874 | 4.975 | 112.849 |
| 2017 | 42.672.234 | 4.122.921 | 46.795.155 | 111.097 | 5.919 | 117.016 |
| 2018 | 43.218.196 | 4.749.252 | 47.967.448 | 112.518 | 6.818 | 119.336 |
| 2019 | 43.741.964 | 5.400.242 | 49.142.206 | 113.882 | 7.753 | 121.635 |
| 2020 | 44.740.658 | 5.523.538 | 50.264.196 | 116.482 | 7.930 | 124.412 |
| 2021 | 45.739.351 | 5.646.833 | 51.386.185 | 119.082 | 8.107 | 127.189 |
| 2022 | 46.738.045 | 5.770.129 | 52.508.174 | 121.682 | 8.284 | 129.966 |
| 2023 | 47.736.738 | 5.893.425 | 53.630.163 | 124.282 | 8.461 | 132.743 |
| 2024 | 48.735.432 | 6.016.720 | 54.752.152 | 126.882 | 8.638 | 135.520 |
| 2025 | 46.971.119 | 9.210.023 | 56.181.142 | 122.289 | 13.222 | 135.511 |
| 2026 | 47.914.329 | 9.394.967 | 57.309.296 | 124.745 | 13.487 | 138.232 |
| 2027 | 48.857.540 | 9.579.910 | 58.437.450 | 127.200 | 13.753 | 140.953 |
| 2028 | 49.800.751 | 9.764.853 | 59.565.604 | 129.656 | 14.018 | 143.674 |
| 2029 | 50.743.961 | 9.949.796 | 60.693.758 | 132.112 | 14.284 | 146.396 |
| 2030 | 48.646.750 | 13.512.986 | 62.159.736 | 126.652 | 19.399 | 146.051 |
| 2031 | 49.534.478 | 13.759.577 | 63.294.055 | 128.963 | 19.753 | 148.716 |
| 2032 | 50.422.205 | 14.006.168 | 64.428.374 | 131.274 | 20.107 | 151.381 |
| 2033 | 51.309.933 | 14.252.759 | 65.562.692 | 133.585 | 20.461 | 154.046 |
| 2034 | 52.197.661 | 14.499.350 | 66.697.011 | 135.896 | 20.815 | 156.712 |
| 2035 | 53.085.388 | 14.745.941 | 67.831.330 | 138.208 | 21.169 | 159.377 |

**Source**: Prepared by author (2018)

Considering a current consumption data and with base in the information of Table 2, accounting to the total of the period from 2005 to 2035, 3,535 tons of $CO_2$ by the use of oil load and 289 tons of residues of the biodiesel portion. That way, the total road mode emissions in this period were 3,824 MTon of $CO_2$ by the joint use of the mixture in the regulatory percentages, previously explained.

If the portion of biodiesel were replaced by petrodiesel, the emissions in the period would be 472 MTon. That is, comparing only this portion of biodiesel in the regulatory percentages, the emission economics were of the order of 38.73% (183 MTon).

If there were no compulsory regulations for the use of biodiesel in Brazil and the road fleet used only petrodiesel, the emissions would rise to 4,007 Mton $CO_2$ (4.79%).

Correlating the emissions by the use only of petrodiesel in comparison to the petrodiesel / biodiesel blend in the period considered the emissions would be reduced by 4.57% of the total fuel consumed in Brazil by road mode of transports.

**Table 3 -** Results of applying the methodology for rail petrodiesel and biodiesel $CO_2$ emissions

| Year | Share of Petrodiesel consumption (m3) | Share of Biodiesel consumption (m3) | Total BX consumption (m3) | Petrodiesel Real CO2 Emissions (GgC) | Biodiesel Real CO2 Emissions (GgC) | Total BX Real CO2 Emissions (GgC) |
|---|---|---|---|---|---|---|
| 2005 | 952.462 | 21.598 | 974.060 | 2.480 | 31 | 2.511 |
| 2006 | 1.056.349 | 23.953 | 1.080.302 | 2.750 | 34 | 2.785 |
| 2007 | 1.132.167 | 25.673 | 1.157.840 | 2.948 | 37 | 2.984 |
| 2008 | 1.132.799 | 66.246 | 1.199.045 | 2.949 | 95 | 3.044 |
| 2009 | 1.106.660 | 64.717 | 1.171.377 | 2.881 | 93 | 2.974 |
| 2010 | 1.111.916 | 65.024 | 1.176.941 | 2.895 | 93 | 2.988 |
| 2011 | 1.122.399 | 65.637 | 1.188.036 | 2.922 | 94 | 3.016 |
| 2012 | 1.151.038 | 67.312 | 1.218.350 | 2.997 | 97 | 3.093 |
| 2013 | 1.141.925 | 66.779 | 1.208.704 | 2.973 | 96 | 3.069 |
| 2014 | 1.103.214 | 92.264 | 1.195.478 | 2.872 | 132 | 3.005 |
| 2015 | 1.064.736 | 89.046 | 1.153.782 | 2.772 | 128 | 2.900 |
| 2016 | 1.044.014 | 87.313 | 1.131.327 | 2.718 | 125 | 2.843 |
| 2017 | 1.209.970 | 116.905 | 1.326.875 | 3.150 | 168 | 3.318 |
| 2018 | 1.228.343 | 134.983 | 1.363.325 | 3.198 | 194 | 3.392 |
| 2019 | 1.246.022 | 153.830 | 1.399.852 | 3.244 | 221 | 3.465 |
| 2020 | 1.277.200 | 157.679 | 1.434.879 | 3.325 | 226 | 3.552 |
| 2021 | 1.308.378 | 161.528 | 1.469.906 | 3.406 | 232 | 3.638 |
| 2022 | 1.339.556 | 165.377 | 1.504.933 | 3.488 | 237 | 3.725 |
| 2023 | 1.370.734 | 169.226 | 1.539.960 | 3.569 | 243 | 3.812 |
| 2024 | 1.401.912 | 173.076 | 1.574.987 | 3.650 | 248 | 3.898 |
| 2025 | 1.353.473 | 265.387 | 1.618.860 | 3.524 | 381 | 3.905 |
| 2026 | 1.382.919 | 271.161 | 1.654.080 | 3.600 | 389 | 3.990 |
| 2027 | 1.412.365 | 276.934 | 1.689.299 | 3.677 | 398 | 4.075 |
| 2028 | 1.441.811 | 282.708 | 1.724.519 | 3.754 | 406 | 4.160 |
| 2029 | 1.471.257 | 288.482 | 1.759.738 | 3.830 | 414 | 4.245 |
| 2030 | 1.412.426 | 392.340 | 1.804.766 | 3.677 | 563 | 4.240 |
| 2031 | 1.440.139 | 400.039 | 1.840.178 | 3.749 | 574 | 4.324 |
| 2032 | 1.467.853 | 407.737 | 1.875.590 | 3.822 | 585 | 4.407 |
| 2033 | 1.495.567 | 415.435 | 1.911.002 | 3.894 | 596 | 4.490 |
| 2034 | 1.523.280 | 423.133 | 1.946.414 | 3.966 | 607 | 4.573 |
| 2035 | 1.550.994 | 430.832 | 1.981.826 | 4.038 | 619 | 4.657 |

**Source**: Prepared by author (2018)

According to what is described in the Table 3, it is estimate that the total of understood emissions in the period from 2005 to 2035 should reach 103 MTon $CO_2$ by the use of the portion of petrodiesel and 8 MTon of emissions by the biodiesel portion. Like that, the total emissions of the railway system in this period reached 111 MTon of $CO_2$ by the joint use of the mixture in the regulatory percentages, explained previously.

If the portion of biodiesel in the railway system were replaced by petrodiesel, the same way that in the road system emissions in the period would be 14 MTon. That is, comparing only this portion of biodiesel in the regulatory percentages, the emission economics, also, were of the order of 38.73% (6 MTon).

If there was no obligation to use biodiesel in Brazil and the road fleet used only petrodiesel, the emissions would rise to 116 Mton of $CO_2$ (4.76%).

It correlating the emissions by using only petrodiesel in comparison with the petrodiesel / biodiesel blend in the considered period the emissions would be reduced by 4.54% of the total of fuel consumed in the Brazil by road mode of transports.

*6.2. Scenario 2*

As already explained, the scenario 2 considers, for the calculation of $CO_2$ emissions, both the regulatory use of biodiesel in the percentages shown in the scenario 1, as well as the redistribution of the load transport matrix.

According to PNLT (2012), the Brazilian transport matrix has a strong concentration of loads in road transport, in detriment to the others.This fact, in addition to causing large negative externalities, as previously seen, also promotes increased fuel consumption and $CO_2$ emissions.

It is known that from the point of view of energy efficiency, the road system is less efficient than the railroad, when compared the consumption rates per TKU transported.In view of this, the PNLT (2012) proposes that the percentages of load transported by these two modes of transport be rebalanced, so that the loads are better distributed between both.

The proposal states that the road system would reduce its participation to 38% up to 2031 and, thus, railroad participation would rise to 43% over the same period, if all infrastructure projects mentioned in PNLT (2012) were properly implemented.

According to EPL (2018), total loads transported by all modes of transport in 2015 was about 2.4 trillion TKU, with 1.55 trillion transported by the road system; 0.36 trillion carried by railway; 0.38 trillion transported by waterway; 0,11 trillion for the pipeline and 600 million TKU transported by airway.

Based on this information and using the methodology for redistribution of the transport matrix, it became possible to rebalance the participation of each mode in the matrix and, thus, to adjust the fuel consumption of each one, adapting them to the new reality.

It was assumed, as a premise, if this rebalancing of the transport matrix had already been carried out in the past, the gains already would be perceived.Therefore, it was considered that this rebalancing proposed by PNLT (2012) would come into operation since 2005, just when the use of biodiesel in Brazil started, according to ANP (2020).

Based on these assumptions, it was possible to compare $CO_2$ emissions by rebalancing the transport matrix in 2005 to 2035, additionally to the use of biodiesel in a regulatory manner.

Adopting the participation percentages proposed for each mode of transport and applying them to the total transported by both in the year of 2015, according to the National Integrated Logistics Plan (EPL, 2018), it was possible to establish the participation in TKU transported for each mode.

On the basis of only those two transport systems under study (road and rail), the new share of each consumption by TKU (L / TKU) transported, thus obtaining the new values of consumption of fuels for each mode in the year 2015. That is, if the redistribution of the transportation matrix was already in force by the year 2015, the new annual consumption of the road system would reduce by 42%, consuming 25.89 billion liters and not more 44.85 billion liters.The railway system would have increased by 183%,proportional to the highest load amount expected, going from 1.14 billion liters to 3.24 billion liters.

These percentages of reduction of road consumption and increase of railway consumption were directly applied to the historical series of consumption of each mode, in order to adjust the values to the new reality.

**Table 4**–Resultsofapplyingthemethodology for Road petrodieseland biodiesel $CO_2$emissions

| Year | Share of Petrodiesel consumption ($m^3$) | Share of Biodiesel consumption ($m^3$) | Total BX consumption ($m^3$) | Petrodiesel Real $CO_2$ Emissions (GgC) | Biodiesel Real $CO_2$ Emissions (GgC) | Total BX Real $CO_2$ Emissions (GgC) |
|---|---|---|---|---|---|---|
| 2005 | 17.214.217 | 390.345 | 17.604.562 | 44.817 | 560 | 45.378 |
| 2006 | 17.479.996 | 396.372 | 17.876.367 | 45.509 | 569 | 46.078 |
| 2007 | 18.507.030 | 419.661 | 18.926.691 | 48.183 | 602 | 48.785 |
| 2008 | 19.181.526 | 1.121.727 | 20.303.253 | 49.939 | 1.610 | 51.549 |
| 2009 | 18.989.711 | 1.110.509 | 20.100.221 | 49.440 | 1.594 | 51.034 |
| 2010 | 21.107.620 | 1.234.364 | 22.341.984 | 54.954 | 1.772 | 56.726 |
| 2011 | 22.368.212 | 1.308.083 | 23.676.295 | 58.236 | 1.878 | 60.113 |
| 2012 | 23.703.057 | 1.386.144 | 25.089.201 | 61.711 | 1.990 | 63.701 |
| 2013 | 25.271.394 | 1.477.859 | 26.749.253 | 65.794 | 2.122 | 67.916 |
| 2014 | 25.108.742 | 2.099.895 | 27.208.637 | 65.370 | 3.015 | 68.385 |
| 2015 | 24.078.240 | 2.013.712 | 26.091.952 | 62.688 | 2.891 | 65.578 |
| 2016 | 23.918.649 | 2.000.365 | 25.919.014 | 62.272 | 2.872 | 65.144 |
| 2017 | 24.633.288 | 2.380.028 | 27.013.316 | 64.133 | 3.417 | 67.549 |
| 2018 | 24.948.454 | 2.741.588 | 27.690.042 | 64.953 | 3.936 | 68.889 |
| 2019 | 25.250.808 | 3.117.384 | 28.368.192 | 65.740 | 4.475 | 70.216 |
| 2020 | 25.827.321 | 3.188.558 | 29.015.880 | 67.241 | 4.577 | 71.819 |
| 2021 | 26.403.835 | 3.259.733 | 29.663.567 | 68.742 | 4.680 | 73.422 |
| 2022 | 26.980.348 | 3.330.907 | 30.311.255 | 70.243 | 4.782 | 75.025 |
| 2023 | 27.556.861 | 3.402.082 | 30.958.943 | 71.744 | 4.884 | 76.628 |
| 2024 | 28.133.374 | 3.473.256 | 31.606.630 | 73.245 | 4.986 | 78.231 |
| 2025 | 27.114.894 | 5.316.646 | 32.431.540 | 70.594 | 7.633 | 78.226 |
| 2026 | 27.659.379 | 5.423.408 | 33.082.786 | 72.011 | 7.786 | 79.797 |
| 2027 | 28.203.863 | 5.530.169 | 33.734.032 | 73.429 | 7.939 | 81.368 |
| 2028 | 28.748.348 | 5.636.931 | 34.385.279 | 74.846 | 8.092 | 82.939 |
| 2029 | 29.292.833 | 5.743.693 | 35.036.525 | 76.264 | 8.246 | 84.509 |
| 2030 | 28.082.181 | 7.800.606 | 35.882.787 | 73.112 | 11.199 | 84.310 |
| 2031 | 28.594.637 | 7.942.955 | 36.537.592 | 74.446 | 11.403 | 85.849 |
| 2032 | 29.107.093 | 8.085.304 | 37.192.397 | 75.780 | 11.607 | 87.387 |
| 2033 | 29.619.550 | 8.227.653 | 37.847.202 | 77.114 | 11.812 | 88.926 |
| 2034 | 30.132.006 | 8.370.002 | 38.502.008 | 78.449 | 12.016 | 90.464 |
| 2035 | 30.644.462 | 8.512.351 | 39.156.813 | 79.783 | 12.220 | 92.003 |

**Source**: Prepared by author (2018)

According to Table 4, total emissions from 2005 to 2035 of 2,040 MTon $CO_2$ are accounted for by the use of the petrodiesel portion and 167 MTon of emissions by the biodiesel portion.In this way, the total emissions of road mode in this period were 2,208 MTon of $CO_2$ by the joint use of the mixture in the regulatory percentages, explained previously.

If the portion of biodiesel was replaced by petrodiesel, the emissions in the period would be 273 MTon. That is, by comparing only this portion of biodiesel in the regulatory percentages, the emission savings were of the order of 38.73% (106 MTon).

If there were no compulsory regulations for the use of biodiesel in Brazil and the road fleet used only petrodiesel, emissions would rise to 2,314 Mton $CO_2$ (4.79%).

Correlating emissions by using only petrodiesel compared to the petrodiesel / biodiesel blend in the period considered emissions would be reduced by 4.57% of the total fuel consumed in Brazil by road transport mode.

**Table 5 -** Results of applying the methodology for rail petrodiesel and biodiesel $CO_2$ emissions

| Year | Share of Petrodiesel consumption (m3) | Share of Biodiesel consumption (m3) | Total BX consumption (m3) | Petrodiesel Real CO2 Emissions (GgC) | Biodiesel Real CO2 Emissions (GgC) | Total BX Real CO2 Emissions (GgC) |
|---|---|---|---|---|---|---|
| 2005 | 2.699.328 | 61.209 | 2.760.537 | 7.028 | 88 | 7.116 |
| 2006 | 2.993.749 | 67.885 | 3.061.634 | 7.794 | 97 | 7.892 |
| 2007 | 3.208.621 | 72.758 | 3.281.379 | 8.354 | 104 | 8.458 |
| 2008 | 3.210.413 | 187.743 | 3.398.156 | 8.358 | 270 | 8.628 |
| 2009 | 3.136.333 | 183.411 | 3.319.744 | 8.165 | 263 | 8.429 |
| 2010 | 3.151.229 | 184.282 | 3.335.512 | 8.204 | 265 | 8.469 |
| 2011 | 3.180.937 | 186.020 | 3.366.957 | 8.282 | 267 | 8.549 |
| 2012 | 3.262.102 | 190.766 | 3.452.869 | 8.493 | 274 | 8.767 |
| 2013 | 3.236.276 | 189.256 | 3.425.532 | 8.426 | 272 | 8.697 |
| 2014 | 3.126.567 | 261.481 | 3.388.049 | 8.140 | 375 | 8.515 |
| 2015 | 3.017.517 | 252.361 | 3.269.878 | 7.856 | 362 | 8.218 |
| 2016 | 2.958.792 | 247.450 | 3.206.241 | 7.703 | 355 | 8.058 |
| 2017 | 3.429.119 | 331.316 | 3.760.435 | 8.928 | 476 | 9.403 |
| 2018 | 3.481.188 | 382.548 | 3.863.736 | 9.063 | 549 | 9.612 |
| 2019 | 3.531.293 | 435.962 | 3.967.255 | 9.194 | 626 | 9.820 |
| 2020 | 3.619.653 | 446.871 | 4.066.523 | 9.424 | 642 | 10.065 |
| 2021 | 3.708.012 | 457.779 | 4.165.792 | 9.654 | 657 | 10.311 |
| 2022 | 3.796.372 | 468.688 | 4.265.060 | 9.884 | 673 | 10.557 |
| 2023 | 3.884.732 | 479.597 | 4.364.329 | 10.114 | 689 | 10.802 |
| 2024 | 3.973.092 | 490.505 | 4.463.597 | 10.344 | 704 | 11.048 |
| 2025 | 3.835.815 | 752.121 | 4.587.936 | 9.987 | 1.080 | 11.066 |
| 2026 | 3.919.266 | 768.484 | 4.687.750 | 10.204 | 1.103 | 11.307 |
| 2027 | 4.002.717 | 784.847 | 4.787.564 | 10.421 | 1.127 | 11.548 |
| 2028 | 4.086.168 | 801.209 | 4.887.378 | 10.638 | 1.150 | 11.789 |
| 2029 | 4.169.619 | 817.572 | 4.987.191 | 10.856 | 1.174 | 12.029 |
| 2030 | 4.002.889 | 1.111.914 | 5.114.803 | 10.422 | 1.596 | 12.018 |
| 2031 | 4.081.431 | 1.133.731 | 5.215.162 | 10.626 | 1.628 | 12.254 |
| 2032 | 4.159.973 | 1.155.548 | 5.315.522 | 10.830 | 1.659 | 12.489 |
| 2033 | 4.238.515 | 1.177.365 | 5.415.881 | 11.035 | 1.690 | 12.725 |
| 2034 | 4.317.058 | 1.199.183 | 5.516.240 | 11.239 | 1.722 | 12.961 |
| 2035 | 4.395.600 | 1.221.000 | 5.616.599 | 11.444 | 1.753 | 13.197 |

**Source**: Prepared by author (2018)

According to what is described in Table 3, it is estimate that the total of understood emissions in the period from 2005 to 2035 should reach 291 MTon $CO_2$ by the use of the portion of petrodiesel and 24 MTon of emissions by the portion of biodiesel.Thus, the total emissions of the railway system in this period arrived to 315 MTon of $CO_2$ by joint use of the mixture in the regulatory percentages, explained previously.

As the same way that in the road system, if the portion of biodiesel in the railway system was replaced by petrodiesel, the emissions in the period would be of 39 MTon. That is, comparing only this portion of biodiesel in the regulatory percentages, the economy of emission, also, was of the order of 38.73% (6 MTon).

If there was no mandatory for the use of the biodiesel in Brazil and the road fleet used only petrodiesel, the emissions would rise to 291 Mton CO2 (4.76%).

Correlating the emissions by using only petrodiesel in comparison with the petrodiesel / biodiesel blend in the period considered the emissions would be reduced in 4.54% of the total of fuel consumed in Brazil by road mode of transports.

### *6.3. Comparison between scenarios*

As described, the reduction or increase of the emissions would occur for two reasons: the use of regulatory biodiesel and the redistribution of the matrix of transports.

That way, it observes that there was a great reduction of fuel consumption in the period from 2005 to 2035 for the road system, passing from 1.6 trillion liters of the petrodiesel / biodiesel blend to 0.9 trillion of liters. That is, an economy of 0.7 trillion of liters, which represents 42.27% of reduction in the consumption.

In relation to emissions, both portion of petrodiesel and the portion of biodiesel suffered reduction of 42%, when compared the two scenarios.

The railway system, due to the increase of the participation in the loads transport, required higher fuel volumes, thus, their increased values in 183%, consuming in the same period, 128 billion of liters of the blend.That is, 83 billion more than in scenario 1.

The emissions followed the same proportionality of increase, both portion of petrodiesel and the portion of biodiesel, being, therefore emitted 183.41% more $CO_2$ in the period in question.

When comparing the total consumption of both modes of scenario 1 for the scenario 2, it is observed that this consumption decreases 0.6 trillion liters of fuel, equivalent to 35.91% of reduction.

Similarly, the $CO_2$ emissions presents, due to the consumption of the petrodiesel portion, fall of 35.90%. Meanwhile, the biodiesel portion presents reduction of 35.94% in the emissions. The total emissions of the mixture had decrease of 35.90%

Still comparing both scenarios, based on the portion of emissions of the petrodiesel road before of the redistribution and comparing it with the portion of biodiesel emissions after the redistribution, there is a reduction of 64.63%(305 MTon).

Doing this same procedure for the railway system, there would be an increase of 73.64% (10 MTon), for reasons already explained.

However, if the portions of petrodiesel before the redistribution and the portion of biodiesel after redistribution are compared to the two systems together, is perceived a reduction of 60.75% (295 MTon).

If emissions related to load transported are calculated, it has the road system emitting 73.39 $KgCO_2$ / 1,000 TKU before redistribution of the transport matrix and after redistribution it would pass to emit 42.36 $KgCO_2$ / 1,000 TKU. In other words, a reduction of 42.27% in the $KgCO_2$ emissions for each 1,000 TKU.

For the railway system, it emitted 8.13 $KgCO_2$ / 1,000 TKU before redistribution and passed to emit 23.03 $KgCO_2$ / 1,000 TKU. Therefore, there was an increase of 183.41% due to the higher load movement.

When compared together, the emissions before redistribution were 61.16 $KgCO_2$ / 1,000 TKU and passed to 38.74 $KgCO_2$ / 1,000 TKU, what demonstrates a reduction about of 36.66% of emissions.

Already the comparison of the fuels consumption in function of the load transported demonstrates that, for the road system as for the railway system, there was no change in the consumption in liters per TKU. Before and after redistribution of the matrix, the road system presents a consumption value of 28.97 L / 1,000 TKU.

This explains by the fact of that the consumption per capita of fuels does not change in function of the redistribution of load between the modes of transport, but rather in function of technological advances of the transport systems, improvements in the transport infrastructure, greater training to the vehicles operators, development of fuels more efficient, among others.(Murta, 2008).

## 7. Conclusion and recommendations

The consumption of petrodiesel is still expanding globally and in Brazil, increasing greenhouse gas emissions. However, the expansion is unsustainable on the long term due to environmental, social and economic reasons. Nowadays, renewable energy accounts for 12.9% of the world's primary energy supply, while in Brazil this percentage reaches 46%, which shows that the country has been at the forefront of renewable energy for the last few decades (Pereira et al., 2012).

Nevertheless, its transportation system, especially its urban buses, remains highly dependent on petrodiesel. With the constant efforts towards creating awareness regarding greenhouse gas emissions and other forms of environmental degradation, governments are working with corporations to mitigate environmental impacts. Brazil has instituted exemplary public policies which show that it is possible to achieve economic growth and increase the use of renewable sources simultaneously, contributing to issues related to climate change, especially in the field of energy.

One of the aspects this article discusses is precisely the use of a less polluting fuel as a way of lowering greenhouse gas emissions and mitigating the environmental impacts caused by road and rail transportation, complemented by the best redistribution of the freight transport matrix.

Based on the calculations presented in this paper, $CO_2$ emissions decrease approximately 39% when biodiesel is added to petrodiesel in the consumption percentages analyzed.

In the end of 2017, when the Brazilian energy matrix started using a8% biodiesel-diesel blend, Brazil had the highest percentage of biodiesel in biodiesel-diesel blends in the world.

Other important aspect of the study was to demonstrate that the use of biodiesel complemented by the redistribution of the transport matrix can promote a significant reduction of $CO_2$ emissions, can reach 35.94% when compared together and only the portion of the blend concerning biodiesel.There is yet a reduction of total fuel consumption of the order 0.6 trillion liters (35.91%).

The emissions per TKU transported, considering both modes of transport, were also favored once that reduced 36.66%.

On this account, replacing petrodiesel by biodiesel, even to a limited extent, leads to emission cuts which are significant in the context of the greenhouse effect. However, it is not sufficient to lower greenhouse gas emissions to a safe level. Public policies aimed at promoting multimodal transport, restructuring the road network, regulating and inspecting transportation and financing improvements on infrastructure are necessary as well.

Moreover, sustainable transportation policies, a better road planning, higher investments in non-polluting modes of transportation (or modes with low or no greenhouse gas emissions) and a better traffic flow of private or public commercial vehicles would lower the average transportation time, leading to economic gains for corporations (cost-time of transportation) and less energy consumption, which would lessen greenhouse gas emissions.

It is recommended to carry out studies on the other transport systems in Brazil, considering the total redistribution of the transport matrix. In this way, the transport system would be analyzed in its entirety and could present better emission results than those found in this study.

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