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Article

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CO_2 Emissions Avoided Through the use of Biodiesel in the Brazilian Road System

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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, Environmental
JEL Classifications: Q01, Q42, L71

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 employed its many byproducts in his experiments with other fuels and, after altering his project, he 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 an 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 (Ribeiro et al., 2005).

Transportation accounts for more than 50% of the global consumption of oil derivatives (IEA, 2010). 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% is destined exclusively to the transportation of cargo and passengers by road (BEN, 2014), which is the main mode of transportation in Brazil, accounting for more than 61% of all cargo shipment in the country (CNT, 2011).

In 2009, approximately 87% of all passenger trips in collective modes of transportation in Brazil were taken on diesel buses, causing the emission of 27.8 million tons of CO_2 (ANTP, 2009).

Figure 1 presents petrodiesel consumption per economic sector in Brazil:

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 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, 2011).

Industries and transportation are responsible for the highest greenhouse gas emissions, owing to the energy required for industrial production and road transportation of cargo and passengers.

Concerning infrastructure, the main objective is to attain a higher efficiency through intermodal integration. In Brazil, 61.1% 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, 2011).

According to FGV (2010), 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 by road and to 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 15-20 years. Pipeline transportation and air transportation would reach 5% and 1% respectively, and the participation of roads would decrease from 61.1% to 33%.

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

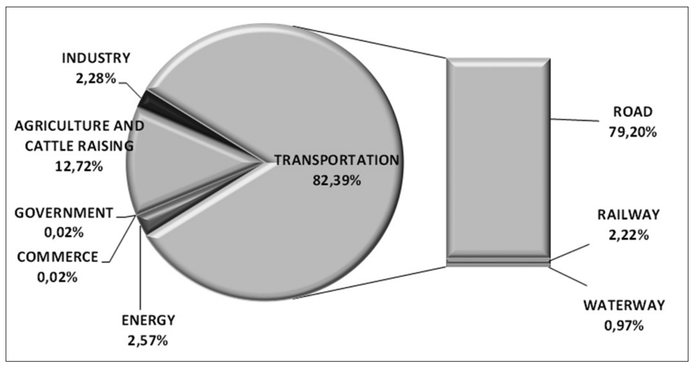
The participation of roads, railroads and waterways in the Brazilian transportation system is significantly different from other countries with continental dimensions. As previously mentioned, the percentage of cargo transported by road is excessively high in Brazil.

Figure 2 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.

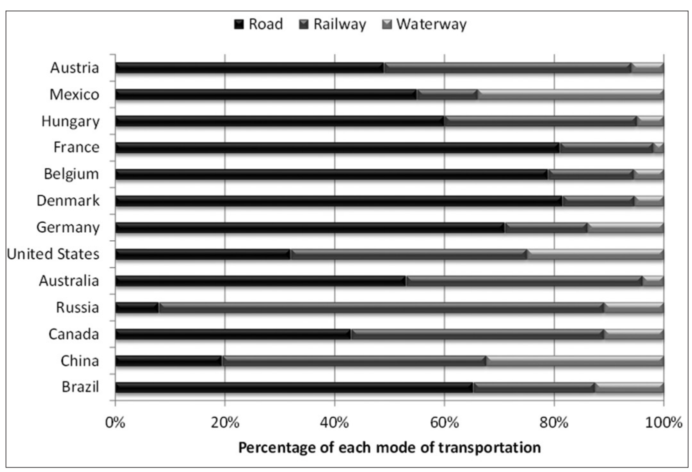
The graph shows as well that countries with smaller territories use mainly roads, and it is surprising to find Brazil in a similar situation as theirs since roads are not the most efficient mode of transportation for a larger country.

Figure 1: Diesel consumption by sector



Source: Adapted from BEN (2014)

Figure 2: Modes of transportation in different countries (tonne × km)



Source: Adapted from COPPEAD/UFRJ (2004) and CNT (2011)

According to ANTT (2006) 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 as the United States, Canada, China and Russia use mainly railways and waterways, Brazil relies excessively on roads, which can be seen in Figure 3.

According to CNT (2011), approximately 61.1% of all cargo was transported by road in 2011, totaling 1.2 billion tons, a 5.1% growth compared to 2009.

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 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 (Ballou, 2004).

Consequently, road transportation should be used mainly for high or medium value-added industrial goods of small volume in short distance routes. Nevertheless, due to the low freight rates in Brazil, roads are essential to the transportation of commodities such as 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.

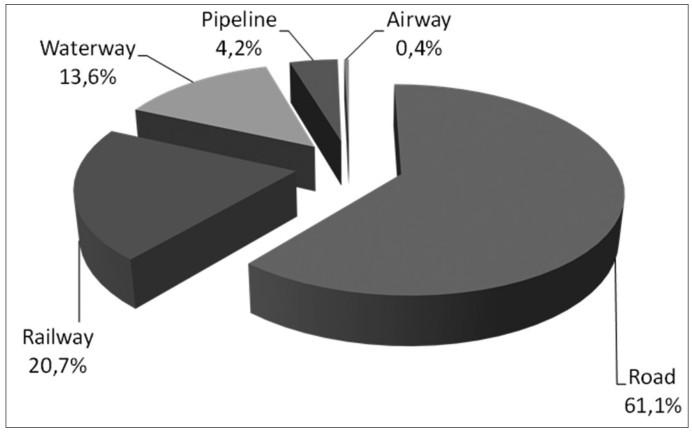
According to Ballou (2004), roads are the second most energy-intensive mode of transportation (airways are the first). As a result, Brazil's preference for roads contributes significantly to the high diesel consumption of the country's transportation system.

2.1. Fuel Consumption

The high demand for new vehicles led to the growth of another branch of the market: Fuels. Figure 4 shows that petrodiesel was the most consumed fuel in the country between 2003 and 2013, reaching an annual consumption of 58.5 billion liters. However, the fuel market started changing its products in 2005 when biodiesel started being added to petrodiesel, its most important product. The consumption of gasoline C (without the anhydrous ethanol blend) increased after December 2009 due to the lower production of hydrous ethanol.

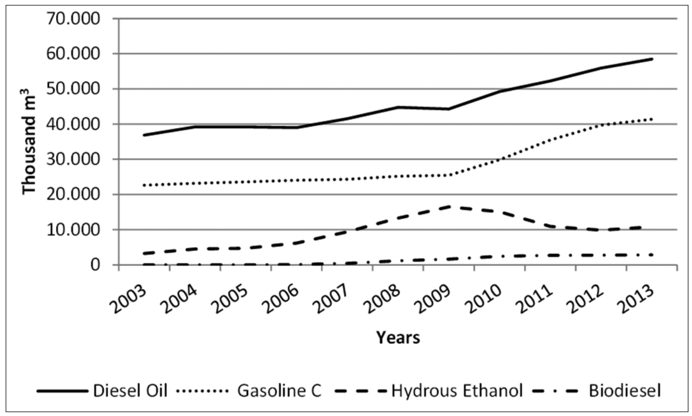
Petrodiesel is most commonly used by trucks, buses and by a small percentage of light commercial or automotive vehicles. The expansion of its consumption started to decrease in

Figure 3: Cargo transportation in Brazil



Source: Adapted from Plano CNT (2011), adapted by the author

Figure 4: Sale of automotive fuels in Brazil



Source: Adapted from ANP (2014a)

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. 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. According to ANP (2014a), fuel consumption in Brazil is expected to grow 4% or 5% in 2014.

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

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. A person born in São Paulo, for instance, has a life expectancy 3.5 years lower than a person who lives in Curitiba, a smaller city in the south of Brazil. In addition, burning fossil fuels causes monetary loss and diminishes interest in future investments in the country (CETESB, 2013).

Brazil's National Inventory on Greenhouse Gas Emissions affirms that deforestation, agriculture and cattle raising are the activities with highest emission levels. Figure 5 shows the emission levels of each productive activity. The automotive sector and transportation are both included in the Industrial Processes category (CETESB, 2013).

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.

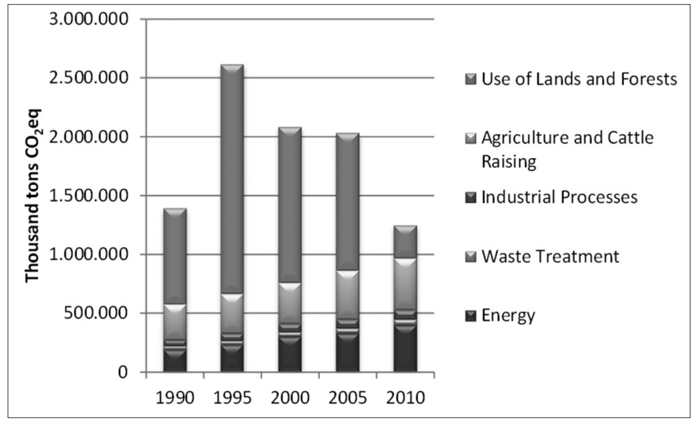
According to SNEA (2011), despite Brazil's low emission of pollutant gases in comparison with other countries, Brazil and China were the only countries which increased their emissions from fuel burning in the last 40 years. However, while Brazilian emissions rose from 91 to 360 Mt CO_2 annually (300%) in 2009, Chinese emissions grew from 809 to approximately 8.000 Mt CO_2 (888%) in the same period.

Two factors influence these differences between both countries. The first is the growth rates of their GDPs in the last decade. In these last 40 years, Brazil maintained an average growth rate of 3.83% annually, while China grew 9.04% each year.

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.

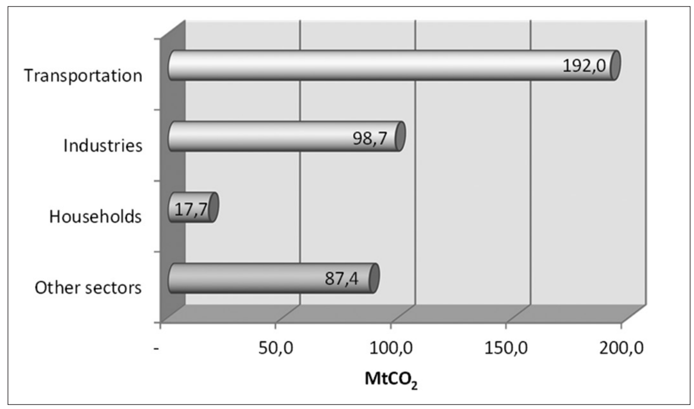
According to BEN (2014), the emissions caused by human activity in Brazil reached 395.8 $MtCO_2eq$ in 2011, with a significant amount of this total (192.0 $MtCO_2eq$) coming from the transportation sector. Despite the growth of its automotive fleet, the carbon intensity in the country's economy was 0.16 kg CO_2/US$ in 2011, which means that the Brazilian economy is in average two times less carbon-intensive than the economy of the United States, 1.4 times less than the European economy and 2.8 less than the Chinese economy. The emissions of each sector in Brazil are presented in Figure 6.

Figure 5: Greenhouse gas emissions in Brazil



Source: Adapted from CETESB (2013)

Figure 6: CO_2 emission total per sector in Brazil (2011)



Source: Adapted from BEN (2014)

The data and information above show that transportation will likely cause an increase in energy demand and emissions owing to the growth of the Brazilian vehicle fleet. 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 to be used for power generation (and other industrial purposes) 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.

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 and 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 (to 3%) and July 2009 (4%) (PNPB, 2003). 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 will reach 6% in July 2014 and 7% in November 2014 (MME, 2014).

As of April 2014, 63 biodiesel production plants had operation licenses granted by the National Agency of Petroleum, with a total capacity of 21,857.79 m^3/day. The construction of two new biodiesel production plants was authorized as well, and four plants were authorized to increase their production capacity. After construction ends and operation is authorized, the total production capacity of biodiesel could increase 1,326.72 m^3/day, a 6% raise from the current capacity (ANP, 2014b). Figure 7 shows the geographical distribution of the biodiesel production plants, which are more concentrated in the Southeast region. The state of São Paulo accounts for 67.7% of Brazilian biodiesel production (ANP, 2014c).

Oilseed plantation and biodiesel production are much less energy-demanding than fuel burn, leading to highly positive energy balances. The transformation of biodiesel into energy has a closed carbon cycle, i.e., carbon dioxide emissions from fuel burn are reabsorbed through photosynthesis while the plant grows.

The synergy between the oilseed complex and the ethanol sector intensifies the need for more ethanol production. Biodiesel production involves ethanol consumption through ethyl transesterification, raising ethanol demand. Consequently, the biodiesel market stimulates the development of the sugar-cane alcohol sector and generates new investments, jobs and income (MAPA, 2006).

The byproducts of biodiesel production (such as glycerine, lecithin, press-cake and bran) need to be studied in the future as they are a key factor for improving the economic viability of the fuel (American Biofuels Association, 2006).

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 different regions of the country, as shown in Figure 8. In each region, a particular source prevails. In Brazil, biodiesel is mostly produced from soybean oil (81.36%), beef tallow (13.36%) and cottonseed oil (4.11%).

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, waterway transportation of cargo and passengers, power generators and stationary engines. As for its supply, many oilseed plantations in great extensions of cultivable land are not being used for biodiesel production. Among different feedstocks, palm oil stands out for its high biodiesel yield per hectare (Pereira et al., 2012).

Table 1 shows the potential biodiesel yield per hectare of the main oilseed species found in Brazil. Despite not having the highest output per hectare, soybean oil production is organized and competitive, aiming at exportation, and it currently is the predominant feedstock in the country's biodiesel production.

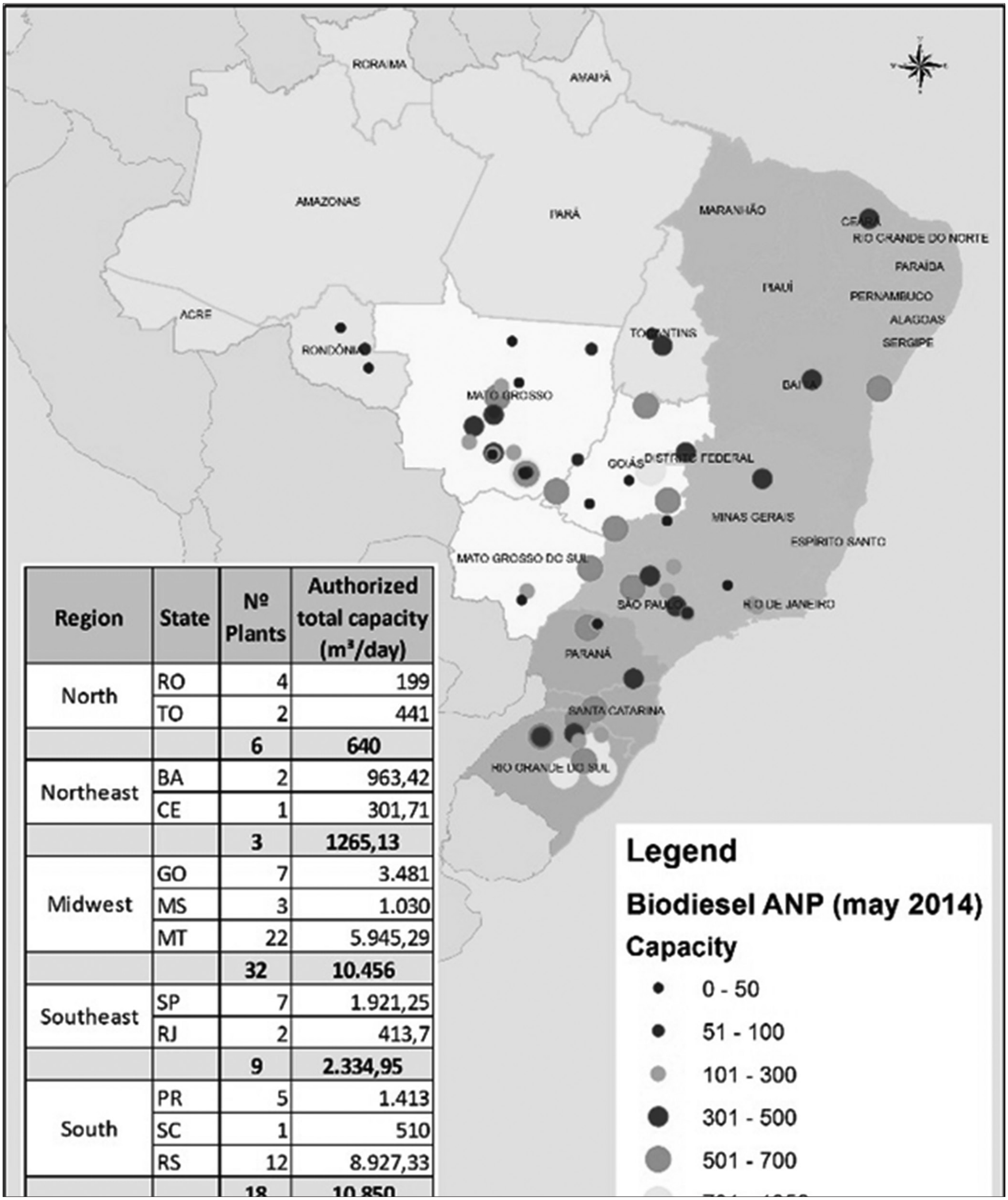
According to ANP (2014c), initiatives such as the National Biodiesel Production and Use Program (PNPB), which focuses on the country's biodiesel supply, stimulate a higher market demand

Table 1: Oilseeds and their potential biodiesel production in Brazil

CROP		Oil content (%)	Agricultural yield (ton/ha)	Oil Yeld (L/ha)
Common name	Scientific Name			
Sesame	*S. indicus*	38-40	0.8	1200-620
Sunflower	*H. annus*	39-48	1.5-2.0	2510-2100
Castor	*R. comunis*	42-45	0.6-2.5	450-270
Peanut	*A. hipogaea*	39-48	1.4-2.5	1680-950
Palm	*E. guineensis*	18-26	10.0-22.0	5900-3000
Soybean	*G. max*	17-20	1.5-3.0	1000-700
Rapeseed	*B. napus*	37-46	1.7-2.0	1100-690
Cottonseed	*G. hirsutum*	16-18	1.7-3.0	700-490
Jatropha	*J. curcas*	24-26	1.0-5.0	520-350
Coconut	*C. nucifera*	52-60	1.0-5.0	1100-700

Source: Nogueira (2011). *S. indicus: Sesamum indicus, H. annus: Heltantus annus, R. comunis: Ricinus comunis, A. hipogaea: Arachis hipogaea, E. guineensis: Elaets guineensis, G. max: Glyctne max, B. napus: Brassica napus, G. hirsutum: Gossyptum hirsutum, J. curcas: Jatropha curcas, C. nucifera: Cocos nucifera,*

Figure 7: Biodiesel production units in Brazil (2014)

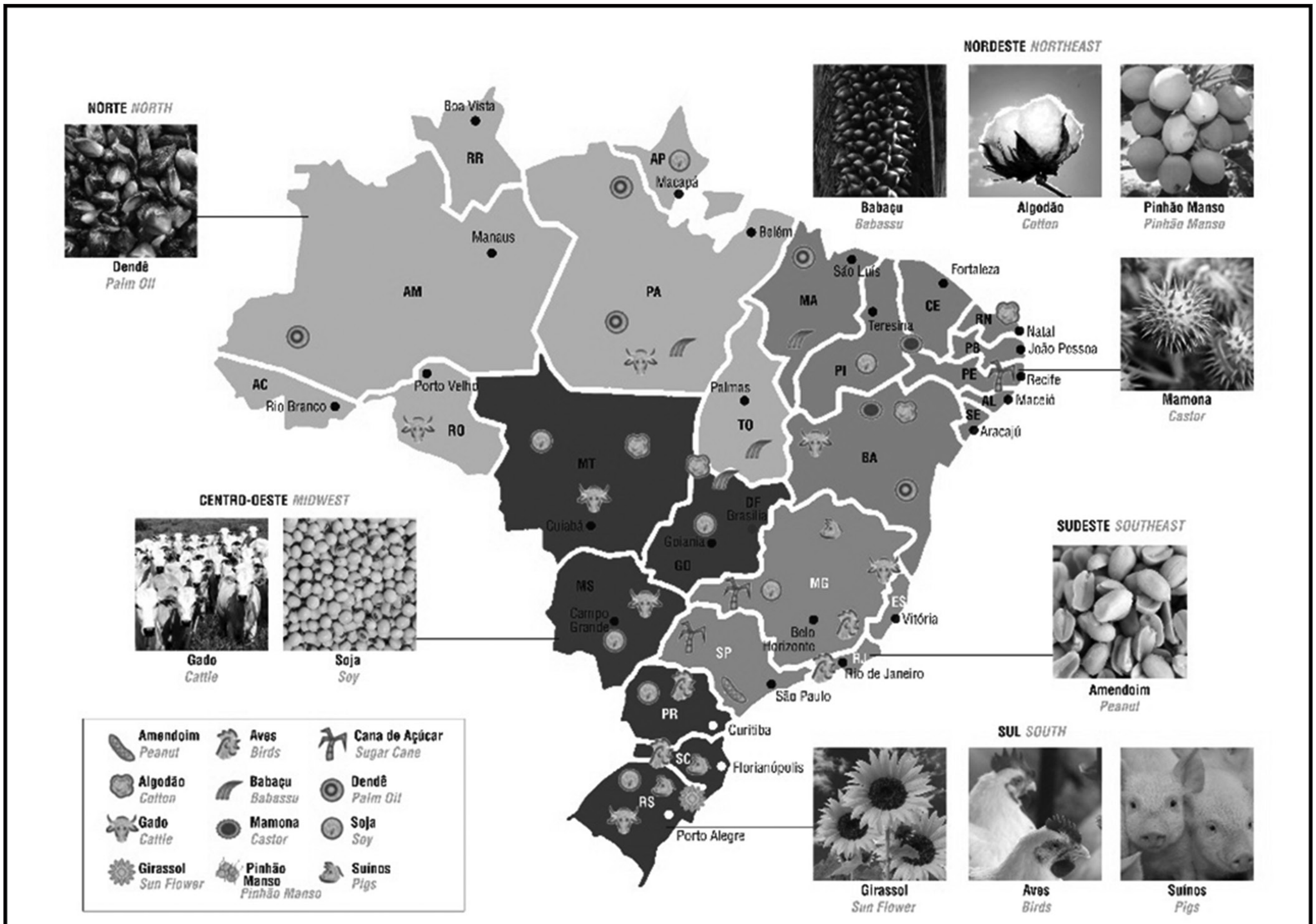


Region	State	Nº Plants	Authorized total capacity (m³/day)
North	RO	4	199
	TO	2	441
		6	**640**
Northeast	BA	2	963,42
	CE	1	301,71
		3	**1265,13**
Midwest	GO	7	3.481
	MS	3	1.030
	MT	22	5.945,29
		32	**10.456**
Southeast	SP	7	1.921,25
	RJ	2	413,7
		9	**2.334,95**
South	PR	5	1.413
	SC	1	510
	RS	12	8.927,33
		18	**10.850**

Source: Adapted from ANP (2014b)

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 2.

Figure 8: Biodiesel feedstock production per Brazilian region (2014)



Source: Adapted from ANP (2014b)

Table 2: Biodiesel production in the world

Production of biodiesel and share of the world market			
Position	**Countries**	**TEP (Milion)**	**%**
1	Germany	3.698	49.9
2	USA	1.597	32.5
3	France	1.194	5.7
4	Brazil	0.301	3.2
5	The Netherlands	0.276	2.5
6	Spain	0.271	1.2
7	United Kingdom	0.269	1.0
8	China	0.264	0.5
9	Austria	0.212	0.5
10	Italy	0.180	0.5
11	Portugal	0.134	0.4
12	Sweden	0.102	0.3
13	Belgium	0.087	0.3
14	Greece	0.086	0.3
15	South Korea	0.084	0.3
	Others	0.529	0.8
	World	9.285	100.0

Source: MME (2014)

5. METHODOLOGY FOR CALCULATING AVOIDED CO_2 EMISSIONS

For calculating the CO_2 emissions avoided 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 road transportation described in the National Energy Balance (BEN, 2014).

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 by the country.

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 of the studied years.

Once consumption was discovered, the methodology was employed in six steps: 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. These steps are described below, and the results will be discussed in the next section.

5.1. 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 1.

$$FC\ (fuel) = AC\ (fuel) \times F_{conv} \times 41.841 \times 10^{-3} \quad (1)$$

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];

41.841×10^{-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 (2014) and DOE (1998).

5.2. 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 2.

$$CQ\ (fuel) = FC\ (fuel) \times F_{emission} \times 10^{-3} \quad (2)$$

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).

5.3. 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.

5.4. 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.

5.5. 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.

5.6. 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.

6. RESULTS

Based on the consumption data gathered by the Ministry of Mines and Energy, published annually in its National Energy Balance (BEN), a projection of petrodiesel consumption was elaborated for the years 2013-2025 (future emissions) using real consumption levels from 1990 to 2012 (past emissions). A second-order polynomial regression was used to obtain the growth trend shown in Figure 9:

Based on the values provided by the regression, the biodiesel and diesel consumption levels 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% and 7% (for the periods of 2005-2008, 2009-2012 and 2013-2025) of the total petrodiesel consumption, the results shown in Tables 3 and 4 were obtained by applying the methodology for calculating CO_2 emissions.

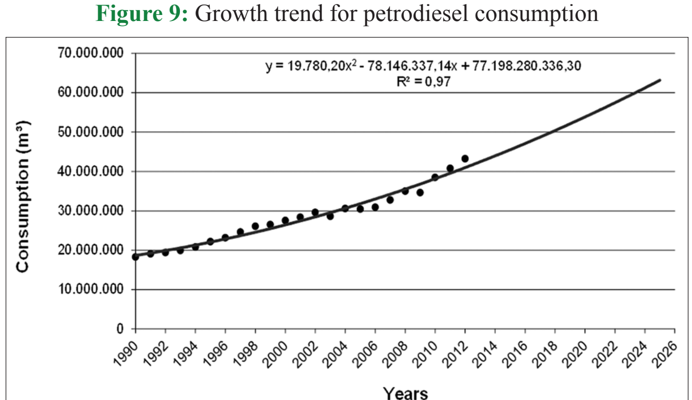
From the calculations above, a total result of 97,638,668 tons of emitted CO_2 was obtained for petrodiesel consumption and 59,821,185 tons for biodiesel consumption, as shown in Table 5:

As a result, assuming the entire fleet of road vehicles will gradually increase their biodiesel consumption, a total of 37,817,483 tons of emitted CO_2 would be avoided, i.e. the initial diesel emissions would decrease 39%.

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

Figure 9: Growth trend for petrodiesel consumption



Source: Adapted from BEN (2014)

Table 3: Results of applying the methodology for petrodiesel CO_2 emissions

Year	Petrodiesel consumption (m^3)	Energy consumption (TJ)	Quantity of carbon (GgC)	Quantity of fixed carbon (GgC)	Net carbon emissions (GgC)	Real carbon emissions (GgC)	Real CO_2 Emissions (GgC)
2005	608.575	21.608	436	0.00	436	432	1.584
2006	617.971	21.942	443	0.00	443	439	1.609
2007	654.280	23.231	469	0.00	469	465	1.703
2008	1.748.850	62.094	1.254	0.00	1.254	1.242	4.553
2009	1.731.362	61.473	1.242	0.00	1.242	1.229	4.508
2010	1.924.459	68.329	1.380	0.00	1.380	1.366	5.010
2011	2.039.392	72.410	1.463	0.00	1.463	1.448	5.310
2012	2.161.095	76.731	1.550	0.00	1.550	1.534	5.626
2013	2.120.846	75.302	1.521	0.00	1.521	1.506	5.522
2014	3.074.782	109.172	2.205	0.00	2.205	2.183	8.005
2015	3.183.148	113.020	2.283	0.00	2.283	2.260	8.287
2016	3.294.284	116.966	2.363	0.00	2.363	2.339	8.577
2017	3.408.188	121.010	2.444	0.00	2.444	2.420	8.873
2018	3.524.862	125.153	2.528	0.00	2.528	2.503	9.177
2019	3.644.305	129.394	2.614	0.00	2.614	2.588	9.488
2020	3.766.518	133.733	2.701	0.00	2.701	2.674	9.806
2021	3.891.499	138.171	2.791	1.00	2.790	2.762	10.128
2022	4.019.250	142.707	2.883	2.00	2.881	2.852	10.457
2023	4.149.770	147.341	2.976	3.00	2.973	2.944	10.793
2024	4.283.059	152.073	3.072	4.00	3.068	3.037	11.136
2025	4.419.118	156.904	3.169	5.00	3.164	3.133	11.487

Source: Prepared by author (2015)

Table 4: Results of applying the methodology for biodiesel CO_2 emissions

Year	Biodiesel consumption (m^3)	Energy consumption (TJ)	Quantity of carbon (GgC)	Quantity of fixed carbon (GgC)	Net carbon emissions (GgC)	Real carbon emissions (GgC)	Real CO_2 Emissions (GgC)
2005	676.195	22.423	446	178	267	265	971
2006	686.635	22.770	453	181	272	269	986
2007	726.978	24.107	479	192	288	285	1.044
2008	1.943.167	64.437	1.281	512	768	761	2.790
2009	1.923.735	63.793	1.268	507	761	753	2.762
2010	2.138.288	70.908	1.409	564	846	837	3.070
2011	2.265.991	75.143	1.494	597	896	887	3.253
2012	2.401.216	79.627	1.583	633	950	940	3.447
2013	2.356.496	78.144	1.553	621	932	923	3.383
2014	3.416.424	113.292	2.252	901	1.351	1.338	4.905
2015	3.536.831	117.285	2.331	933	1.399	1.385	5.077
2016	3.660.315	121.380	2.413	965	1.448	1.433	5.255
2017	3.786.876	125.577	2.496	998	1.498	1.483	5.436
2018	3.916.513	129.876	2.582	1.033	1.549	1.533	5.623
2019	4.049.228	134.277	2.669	1.068	1.601	1.585	5.813
2020	4.185.019	138.780	2.758	1.103	1.655	1.639	6.008
2021	4.323.888	143.385	2.850	1.140	1.710	1.693	6.207
2022	4.465.833	148.092	2.944	1.177	1.766	1.748	6.411
2023	4.610.856	152.901	3.039	1.216	1.824	1.805	6.619
2024	4.758.955	157.812	3.137	1.255	1.882	1.863	6.832
2025	4.910.131	162.825	3.236	1.295	1.942	1.922	7.049

Source: Prepared by author (2015)

country has been at the forefront of renewable energy for the last few decades (Pereira et al., 2012).

Nevertheless, its transportation system, especially its roads, 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 transportation.

Table 5: Emissions avoided through the use of biodiesel

Years	Ton. CO_2		
	Petrodiesel emissions	Biodiesel emissions	Avoided emissions
2005-2012	29.903.704	18.321.379	11.582.325
2013-2025	67.734.964	41.499.807	26.235.157
2005-2025	97.638.668	59.821.185	37.817.483

Source: Prepared by author (2015)

Based on the calculations presented in this paper, CO2 emissions decrease approximately 39% when biodiesel is added to petrodiesel in the consumption percentages analyzed.

In the end of 2014, when the Brazilian energy matrix started using a 7% biodiesel-diesel blend, Brazil have the highest percentage of biodiesel in biodiesel-diesel blends in the world.

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 perform calculations on the types of biodiesel produced from the different oilseeds found in Brazil, as they may present different emission levels. In addition, the transportation system should be analyzed in its entirety.

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