

THE EXPRESSIVENESS OF CO₂ EMISSIONS REDUCTION DUE TO BIOFUEL USE - IN A CONTEXT OF INTENSE CARGO MOVEMENT IN THE STATE OF SÃO PAULO (BRAZIL)

Estevão Brasil Ruas Vernalha, Masters degree in the Energy Systems Planning Program /PSE-FEM-UNICAMP. Administrative Coordinator of the Center for Studies, Research and Extension /CEPE-FAAT. Professor in Electrical Engineering, Civil Engineering, Production Engineering and Logistics courses/FAAT, Phone: +55 11 964197769 , E-mail: estevao.gestao@gmail.com

Sônia Regina da Cal Seixas, Researcher at the Center for Studies and Environmental Research /NEPAM-UNICAMP. Professor of the Doctoral Program in Environment and Society /NEPAM-IFCH-UNICAMP and the Energy Systems Planning Program /PSE-FEM-UNICAMP. Productivity Scholarship CNPq, E-mail: srcal@unicamp.br

Overview

The Brazilian strategy to reduce carbon dioxide (CO₂) emissions from the transportation sector has been biofuel use. However, this strategy presents different results when we compare the passenger segment to the cargo one. There is large penetration of biofuels among passenger cars, while among cargo vehicles their participation is still not very significant. In this sense, the objective of the research was to investigate what has been the result of this emission reduction strategy in a context of intense cargo movement, comparing the avoided emissions due to the use of biofuels to the occurred emissions regarding the use of fossil fuels. The region covered was the State of São Paulo (state with the largest circulating fleet in the country), and the SP-65 highway was used as study object, given its context of intense cargo movement. The size and profile of the circulating fleet in 1996, 2001, 2006, 2011 and 2015 were estimated, just like the fuel used by these fleets and, finally, the total emissions associated with the use of these fuels in these years. It was noted that the reduction strategy started to obtain more significant results as of 2011 and reached substantial relevance in 2015. The main reason was the flex-fuel fleet growth (vehicles that can operate with gasoline C or the biofuel hydrous ethanol - AEHC) of passenger cars. Furthermore, the AEHC/gasoline C price ratio proved to be decisive for this fleet growth to have represented increase of AEHC use. However, the high CO₂ emission rates of cargo transport have been a limiting factor for the results obtained due to the use of biofuels.

Keywords: climate change, biofuels, ethanol, biodiesel, transport

1. Introduction

Human influence on climate systems became evident. This process occurs through the accelerated atmospheric emission of greenhouse gases (GHG), responsible for contributing directly to the occurrence of climate change (NOBRE et al, 2012; IPCC, 2014). About these changes, several aspects associated with their impact on natural and human systems have been pointed out, such as the harmful effect of extreme climatic events on human health, the undermining of food systems, the displacement of populations, the worsening of poverty, among others (WHO, 2015). Roughly, the impacts of climate change on human health can be classified as: 1 - direct, due to changes in temperature and precipitation and in the occurrence of heat waves, floods, droughts and fires; and 2 - indirect, due to ecological disturbances (which include, for example, problems in the cultivation of food and changes in patterns of disease vectors such as *Aedes aegypti* and *Aedes albopictus*) and social responses to climate change, such as displacement of populations due to drought (WOODWARD et al, 2014; CAMPBELL et al, 2015). Some authors dissociate these social responses from indirect impacts, therefore classifying the effects of climate changes on health in 3 categories: 1 - direct effects of extreme climatic events; 2 - changes in the environment that alter the determinants of health; and 3 - effects of climatic events on social processes (SOUZA et al, 2013, CONFALONIERI et al, 2007).

According to the United Nations Framework Convention on Climate Change (UNITED NATIONS, 1992), carbon dioxide (CO₂) is considered the main GHG that has contributed to the occurrence of climate change. In the State of São Paulo, the main source of this gas emission is the transportation sector¹ - treated as a subsector of the energy sector by the Intergovernmental Panel on Climate Change (IPCC, 2006b) for the development of national GHG

¹ At the national level, the most emitting sector is Land Use, Land-Use Change and Forestry (LULUCF).

emission inventories. Within the transportation sector, the road transportation is the largest emitter in the state (SÃO PAULO, 2011a; SÃO PAULO, 2011b). In addition, it must be addressed that this is the state with the largest circulating fleet in the country, whose average increase has been about 660 thousand vehicles per year (SÃO PAULO, 2015).

In this sense, the state strategy to reduce emissions from the transport sector has been the use of biofuels, following the nationally proposed standard (BRASIL, 2008). It is considered that a biofuel can reduce CO₂ emissions because when a vehicle starts to use it, it is being dismissed the use of a fossil fuel - that is, the fossil fuel is being displaced. The fossil fuel burning would be increasing the concentration of CO₂ in the atmosphere, unlike what happens in the case of the biofuel burning. This occurs because it is understood that CO₂ emissions from biofuel burning are in equilibrium with the carbon absorbed from the atmosphere by the biogenic material used for its production, before harvest, at the place where it was grown, through the process of photosynthesis. Thus, the CO₂ emitted in the biofuel burning and the one absorbed by the biogenic material used to produce it result in a net emission equal to zero². Therefore, it is assumed that the displacement of a fossil fuel, due to the use of a biofuel, generates avoided emissions (MACEDO et al, 2004; IPCC, 2006a; IPCC, 2006b).

However, the presence of biofuels in the two road transport segments (passenger and cargo) is very different. The use of hydrous ethanol (AEHC) in flex-fuel vehicles and the presence of high concentrations of anhydrous ethanol (AEAC) (both derived from sugarcane) in gasoline C show an expressive penetration of biofuels among passenger vehicles. In the case of cargo transport, the use of biogenic fuels is basically restricted to the presence of 7% of biodiesel (mainly produced with soybean and beef tallow - BRAZIL, 2015) in the commercial diesel blend (OLIVEIRA et al, 2014).

Considering this disparity between the two segments, the objective of this research was to evaluate what has been the result of CO₂ emissions reduction due to the use of biofuels in a situation of intense cargo movement in the State of São Paulo, during 19 years (1996 to 2015). Considering the assumptions pointed out, it was hypothesized that the CO₂ emissions reduction due to the use of biofuels (mainly due to the use of AEHC and AEAC in the passenger transport segment) has presented low expressiveness in situations with intense cargo movement - since the cargo transport is little impacted by the use of biofuels and still strongly dependent on fossil diesel, whose burning is associated with high CO₂ emission rates.

2. Methodology

To support the construction of the research, the SP-65 highway (Dom Pedro I Highway) was approached as a study object. It is a highway that makes up an important cell of the São Paulo transportation system, the Campinas - São Sebastião export corridor. The corridor, composed by SP-65, Carvalho Pinto (SP-70) and Tamoios (SP-99) highways, has as its objective "to transport, through highways, import and export products of Campinas region and the whole State of São Paulo inland "(SÃO PAULO, 2005). This characteristic reveals the SP-65 neuralgic function of supporting cargo movement, setting it up as a suitable sample to represent the universe investigated by the research (context of intense cargo movement in the State of São Paulo).

The evaluation of the emissions reduction results due to the use of biofuels was made comparing the avoided emissions (biofuel use) with the CO₂ occurred emissions (fossil fuel use). In this way, emission estimations for the years 1996, 2001, 2006, 2011 and 2015 were constructed, building an analysis platform with intervals of about five years. This strategy allowed that variations in emission reduction results could be captured throughout the historical series. Another positive point is that events that occurred within each time interval - and that affect emissions - could be seen in the estimation subsequent to the occurrence dates of these events (distance that can not, according to the proposed methodology, exceed five years).

CO₂ emissions can be calculated from two different methodologies. In the first one, Top-down, the estimation is performed from the fuel consumption in a given geographic area. In this case, the emission factors of the vehicle are waived, and the fuel factors are used. In the Bottom-up methodology, the estimation occurs by determining the fleet (size and profile) and the distance traveled, this time using the vehicles emission factors and dismissing fuel consumption (SÃO PAULO, 2013).

In this work, CO₂ emissions estimations used a procedure that linked both methodologies mentioned and can therefore be divided into two stages. Initially, the fleet (size and profile) and distance traveled by the vehicles in

² It is recommended that biofuel life cycle emissions be counted. It includes upstream emissions (also called indirect emissions), which relate to the stages of production, processing, storage, transport and distribution of fuels. Thus, the volume of CO₂ and other fossil origin GHGs emitted during the whole cycle can be estimated. It is also prudent to investigate and measure possible occurrences of land use changes due to the biofuel production. For example, in the case of a forest devastation be made in order to create an area where the sugarcane (used in the production of ethanol) can be cultivated, the benefits of carbon stocking and sequestration that these forested areas was representing would be compromised. In this way, it is even possible to generate a carbon debit, considering the net emissions resulting from the whole process (BORSARI, 2009; MACEDO et al, 2004).

each stretch of SP-65 were estimated (first stage - Bottom-up). However, instead of applying the emission factors to these fleets, following the calculation using the Bottom-up methodology, these numbers were used to determine the volume consumed of each fuel in the SP-65. This step determines the beginning of the second stage of the procedure (Top-down). This second stage is constructed by two different routes, one for the estimation of CO₂ occurred emissions, the other one for the avoided emissions.

For the occurred emissions estimation, the fossil fuel consumed on the highway is multiplied by its CO₂ emission factor (kg/L), resulting in direct occurred emissions. Added to this number are the upstream emissions associated to the life cycle of these fossil fuels in order to obtain the total CO₂ occurred emissions. In the case of avoided emissions, firstly the biofuel consumed is used to calculate the amount of fossil fuel that has been displaced due to its use. This calculation is made considering the energy content of the biofuel that was consumed (in megajoules - MJ), determining the amount of displaced fossil fuel needed to meet this energy demand. Subsequently, this volume of fossil fuel is multiplied by its CO₂ emission factor, resulting in the direct avoided emissions. Finally, the indirect emissions associated with the life cycle of the biofuel consumed are excluded from this figure, and the indirect emissions of the displaced fossil fuel are added, resulting in the total avoided emissions of CO₂.

Figure 1 presents the procedure used to estimate the total CO₂ avoided and occurred emissions in 1996, 2001, 2006, 2011 and 2015:

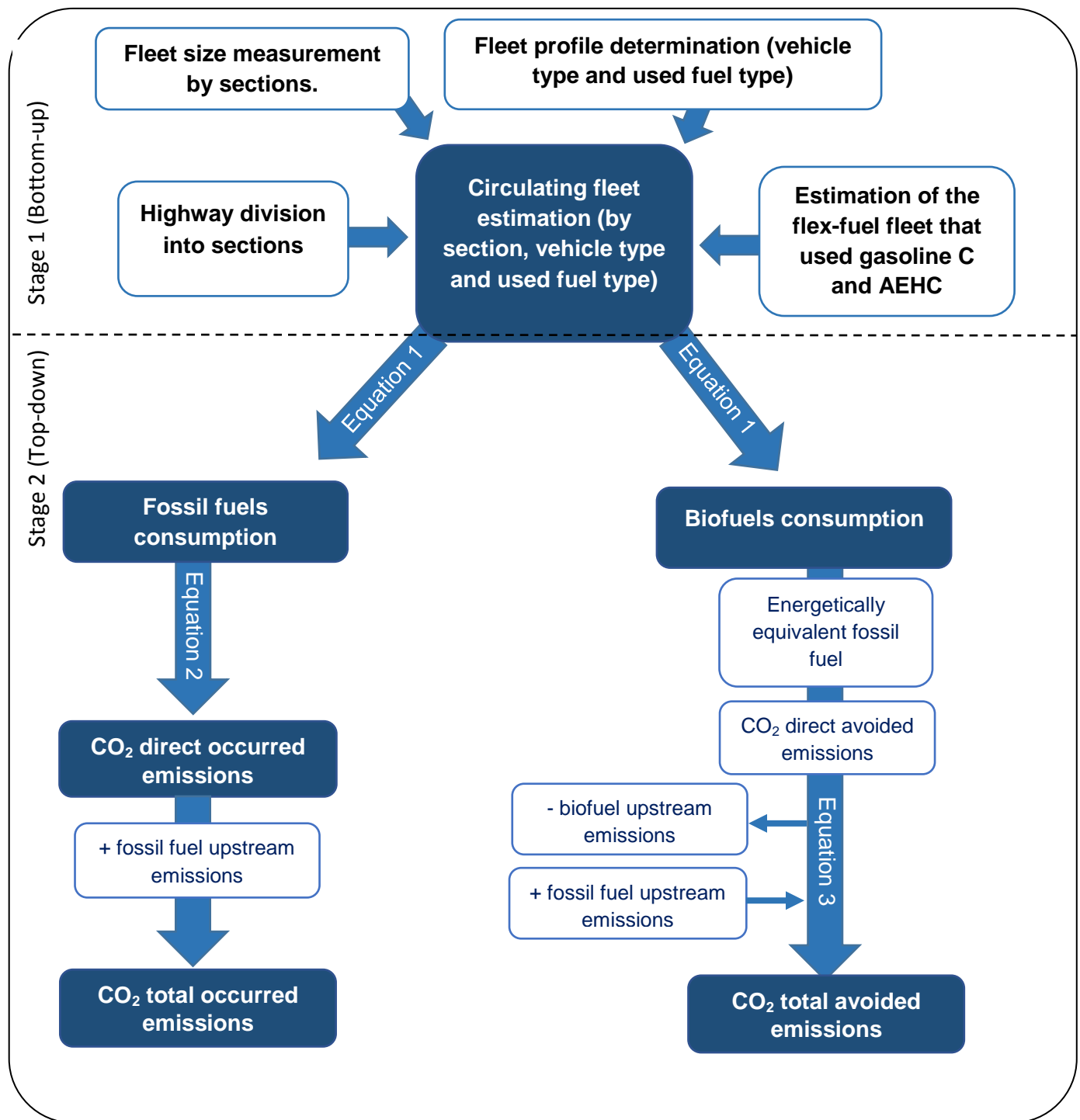


Figure 1 - Methodology for CO₂ emissions estimation in the highway

The highway division into sections occurred considering the points where the vehicles are counted - toll stations. In the same way, the fleet size measurement by sections was also based on the values raised in the tolls. The fleet profile (vehicle type and used fuel type) was made by analogy to the State and country fleets. This procedure is suggested by the IPCC (2006) for situations in which the profile of the fleet whose emissions are being estimated is unknown. In order to estimate the fraction of the flex-fuel fleet that operated with each of the two fuels (AEHC and gasoline C) in each of the years investigated, the study conducted by Goldemberg et al (2008) was used as reference. The analysis shows the flex vehicles fraction operating with AEHC as a function of the average AEHC/gasoline C price ratio recorded in the year.

Equation 1 estimates the fuel consumption of the circulating fleet: $Q(w/z/y) = (Fr(x/y) \times T(z) \times C(w) \times km(y)) / At(z/w)$ ³. Equation 2 estimates the CO₂ direct occurred emissions: $E(dir/w) = Q(w) \times Ft(w)$ ⁴. Finally, equation 3 estimates the CO₂ total avoided emissions: $E(tot.evlt/bw1) = [Q(bw1) \times (PCI(bw1)/PCI(cfw2))] \times Ft(cfw2) - E(ups/bw1) + E(ups/cfw2)$ ⁵.

Thus, in order to evaluate the emissions reduction results due to the use of biofuels in SP-65, the CO₂ total avoided emissions were compared to the total emissions occurred in each one of the five years.

3. Results

Even though SP-65 is a highway with an intensive cargo movement, its passenger vehicles fleet is significantly larger than the cargo fleet. As can be seen in figure 2, the cargo vehicles fleet size represents only about half of the passenger vehicles fleet size throughout the analyzed period.

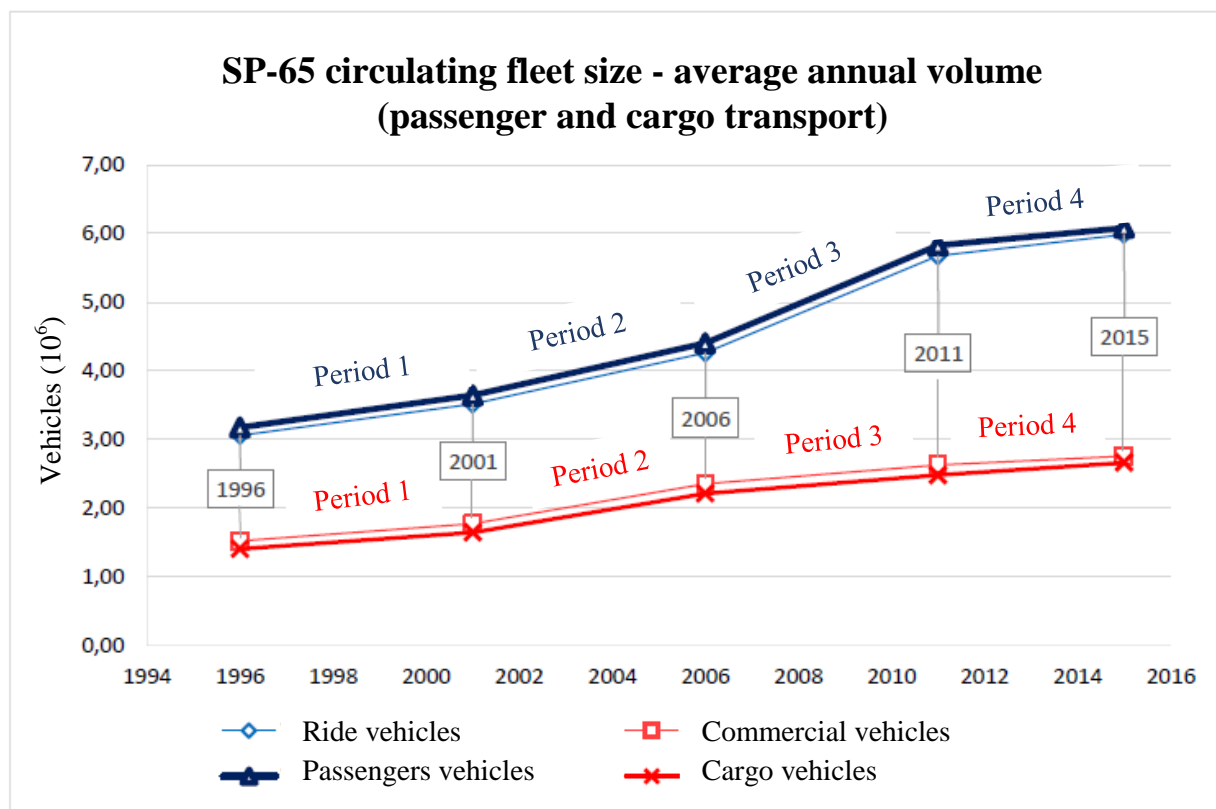


Figure 2 - Circulating fleet annual growth in SP-65 highway - passenger and cargo vehicles⁶

³ $Fr(x/y)$ = Circulating fleet from category x ("R" – Ride, ou "C" - Commercial) in the stretch y ("S1", "S2A", "S2B", "S3" or "S4"); $T(z)$ = Vehicle type z ("c/flex" – car/flex-fuel, "c/gas" – car/gasoline C, etc.), as a percentage of the category fleet to which it belongs (Ride or Commercial); $C(w)$ = Fuel w ("gas" – gasoline, "AEHC" – AEHC, etc.), as a percentage of the flex-fuel fleet that used this type of fuel - in the case of vehicles dedicated to only one type of fuel, this value must be 1, or 100%, naturally; $km(y)$ = Total length of the stretch y , in km; $At(z/w)$ = Autonomy of vehicle type z operating with fuel w , in km/L; $Q(w/z/y)$ = Amount of fuel w consumed, by the vehicle type z , in the section y , in L.

⁴ $Q(w)$ = Total amount of fuel w consumed in SP-65, in a given year, in L; $Ft(w)$ = CO₂ emission factor due to fuel w burning, in kg/L; $E(dir/w)$ = Direct emissions caused by the burning of fuel w consumed in SP-65, in a given year, in kg of CO₂.

⁵ $Q(bw1)$ = Total amount of biofuel $w1$ consumed in SP-65, in a given year, in L; $PCI(bw1)$ = Lower calorific value of biofuel $w1$, in MJ/L; $PCI(cfw2)$ = Lower calorific value of fossil fuel $w2$ (not consumed due to the use of $w1$), in MJ/L; $Ft(cfw2)$ = CO₂ emission factor referring to the burning of the fossil fuel $w2$ (not consumed due to the use of $w1$), in kg/L; $E(ups/bw1)$ = CO₂eq upstream emissions related to the life cycle of biofuel $w1$ consumed in SP-65, in a given year, in kg; $E(ups/cfw2)$ = CO₂eq upstream emissions related to the life cycle of the fossil fuel $w2$ (not consumed due to the use of $w1$) in SP-65, in a given year, in kg; $E(tot.evlt/bw1)$ = Total emissions (direct and upstream) avoided because of biofuel $w1$ consumed in SP-65 in replacement to the fossil fuel $w2$, in a given year, in kg.

⁶ The figure also shows a line relating to "ride" vehicles, which behaves almost identically to that relating to "passenger" vehicles, and one relating to "commercial" vehicles, which behaves almost identically to that relating to "cargo" vehicles. What occurs is that the accounting of tolls categorizes vehicles as "ride" or "commercial", while the specific literature that addresses transport use to segment the sector between "passenger" and "cargo" transportation (POMPERMAYER, 2012). These two categories (ride and commercial) have, in fact, a direct correlation with the passenger and cargo transport segments, respectively. The vehicles classified as "ride" are intended for the passengers transportation and those classified as "commercial" for the cargo transportation. However, there is an exception that required standardization for ride-passenger and

Although this size ratio between the two types of fleet remained practically constant throughout the period, Figure 3 shows that the relevance of the avoided emissions in relation to those occurred increases from 2011 onwards.

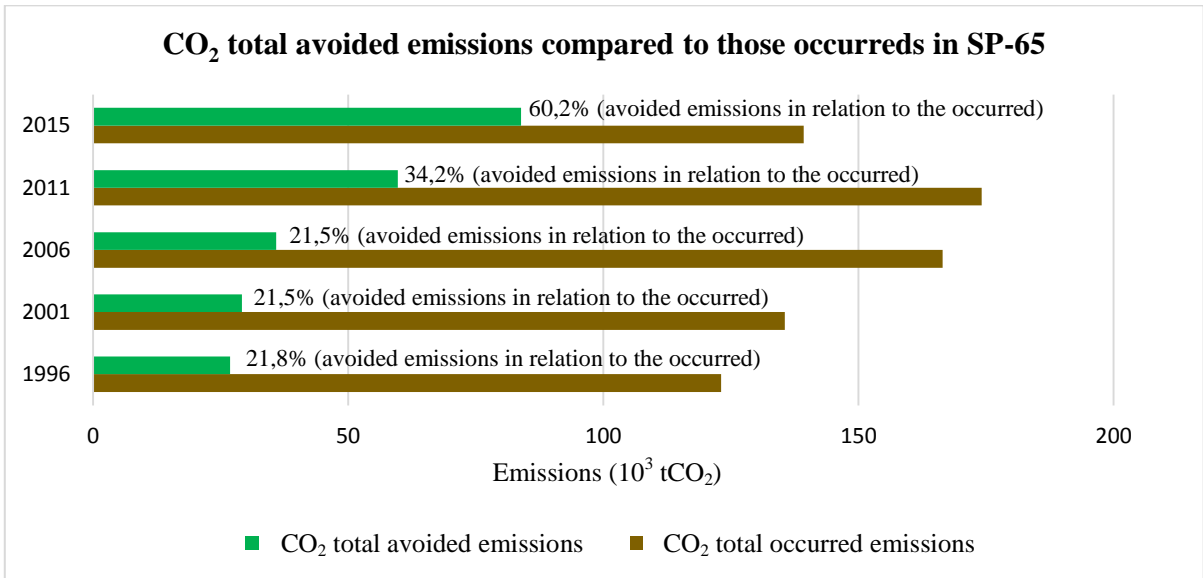


Figure 3 - Evaluation of the CO₂ emission reduction result in the SP-65

This increase in the avoided emissions relevance in relation to those occurred as of 2011 was due mainly to the intensification of the use of AEHC, as can be seen in Figure 4.

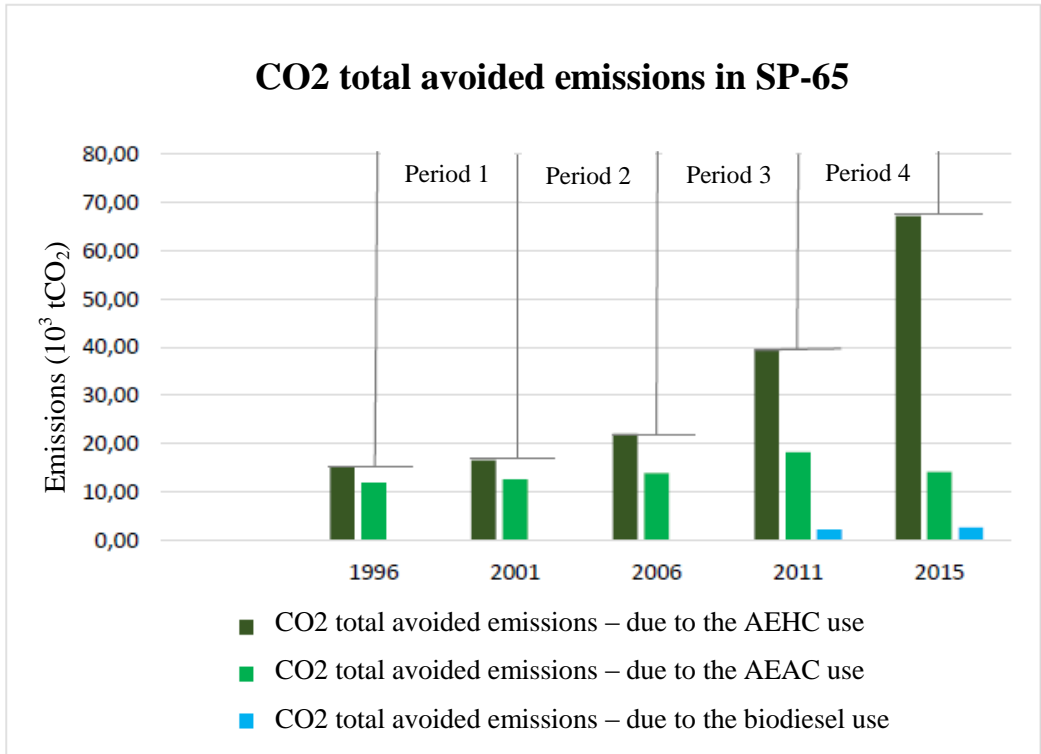


Figure 4 – CO₂ total avoided emissions in SP-65 per biofuels

4. Discussion

Even though SP-65 is a highway with an intense cargo movement, the CO₂ emissions reduction due to the biofuel use has gained expressiveness, given the AEHC use increase in passenger vehicles. About two-thirds of the highway fleet is composed by the passenger transport segment and the increased use of AEHC in these vehicles has generated a significant contribution of avoided emissions. This increase is linked to two main factors: the growth of

commercial-cargo correlations to be true. Buses and minibuses are classified as commercial vehicles in the official accounting of tolls, but are intended for the transport of passengers. In this sense, their fleets were subtracted from the average annual volumes of commercial vehicles of the SP-65 and added to those of ride vehicles, so the results could reflect the segments of passengers and cargo transportation, respectively.

the flex-fuel passenger vehicles fleet and the AEHC/gasoline C price ratio, which determines which percentage of flex-fuel vehicle drivers decide to operate with AEHC.

The first flex-fuel vehicles were introduced in Brazil in 2003 (RODRIGUES, 2012). In 2006, 9% of the passenger vehicle fleet was flex, with 90% of these cars operating with AEHC (8.1% of passenger vehicles using AEHC). In 2011, the fraction of the flex-fuel fleet rose to 36% and the percentage of this fleet operating with AEHC dropped to 50% (18% of the passenger vehicles operating with AEHC). Finally, in 2015, the flex-fuel vehicles fleet reached 51%, with 70% of these cars operating with ethanol (35.7% of the passenger vehicles operating with AEHC). Therefore, these numbers explain the improvement of the emission reduction results that begins to occur after 2006 (both in absolute values - figure 4 - and relative values - figure 3). In 2011, the fraction of passenger vehicles operating with AEHC rose to 18%, and this share reached 35.7% in 2015.

Even so, it can be seen that the low penetration of biofuels between cargo vehicles has prevented emission reduction strategy results from being even better. The amount of emissions from cargo transport are similar to those related to the passenger transport (figure 5), even though cargo vehicles fleet size is only about half of passenger vehicles fleet size on the highway.

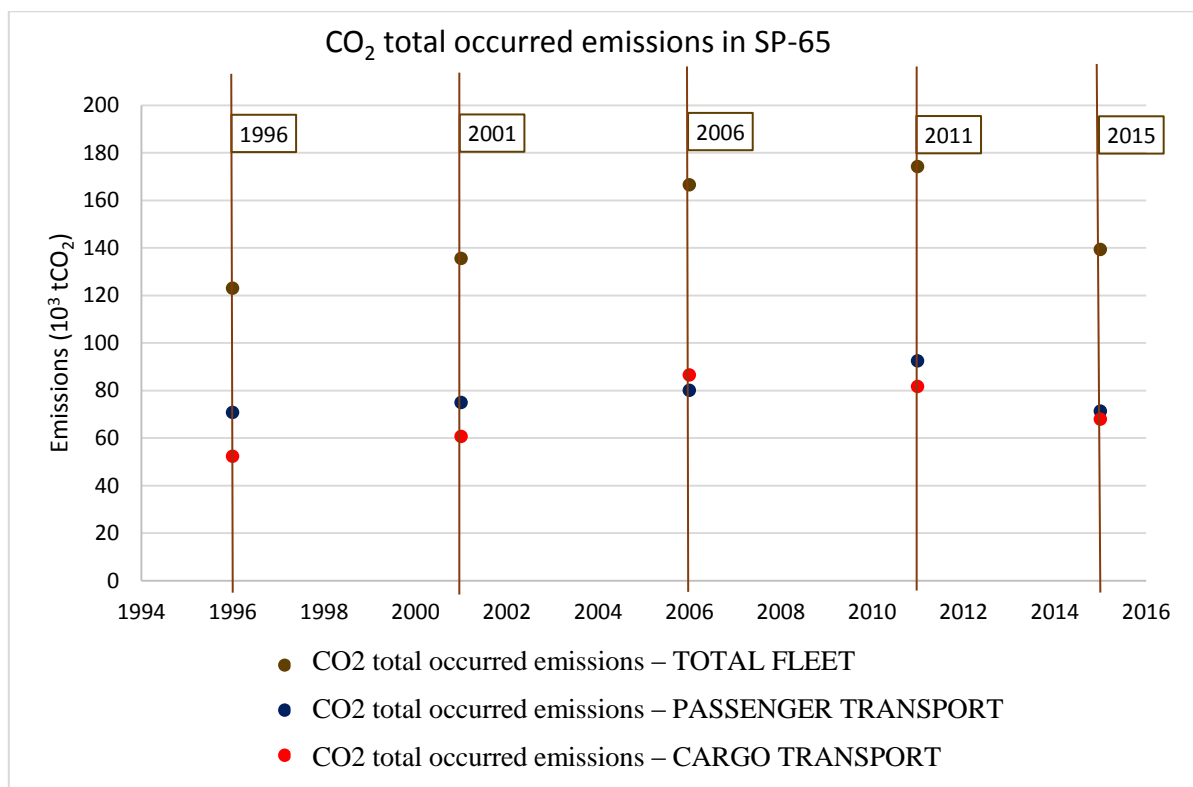


Figure 5 - CO₂ total occurred emissions evolution in SP-65 per transport segment

The amount of avoided emissions due to the use of biofuels in the cargo transport (biodiesel) is still not very significant, as can be seen in Figure 4. In 2011, biodiesel was present in the commercial diesel mixture in the order of 5% (the so called diesel B5), displacing a still small volume of fossil diesel. In 2015, this concentration increased to 7% (B7), expanding the contribution of avoided emissions in this transport segment.

In this sense, the biodiesel use expansion is linked to issues that merit attention. It should be noted that there is a large variation between the indirect emissions associated with the life cycle of different inputs that can be used in biodiesel production. For example, the amount of equivalent carbon dioxide (CO₂eq) emissions associated with the biodiesel production stage, when developed from soybeans, is more than twice as high as when produced with beef tallow. When biodiesel is made from castor bean, these emissions are six times higher than when it is produced from beef tallow - and three times higher than when soybean is used as the input. In the case of using palm oil in the production, indirect emissions are similar to those when soybeans are used⁷ (GAZZONI, 2012).

Despite the high emission rates of cargo transport, it can be noted that, as of 2011, there was reduction of emissions in this segment in relation to previous years (figure 5 - red circles). However, as mentioned before, it is known that

⁷ Currently, soybean oil is the most used raw material for biodiesel production in the country, and in the Southeast beef tallow has rivaled this leadership - 46% share in biodiesel production, against 47.5% of soybean oil (BRAZIL, 2015b; BRAZIL, 2015d; BRAZIL, 2015e).

the contribution of biodiesel to the avoided emissions in 2011 and 2015 was still low. Thus, other factors contributed more decisively to the emissions occurred reduction in this segment that began in 2011.

Firstly, it was verified the efficiency increase of several categories of cargo vehicles (better autonomy⁸), reducing fuel consumption (fossil diesel, mainly) per traveled kilometer. Then, some changes in the profile of a specific niche in this segment also contributed to the reduction of fossil fuel consumption. Within the category of "light commercial vehicles", from 2011 onwards was observed the reduction of gasoline and diesel dedicated vehicles (which only operate with one fuel type) and the accelerated growth of those that can use both gasoline and AEHC, the flex-fuel. In this way, the use of AEHC in cargo transport also contributed to increase the expressiveness of avoided emissions, due to the penetration of this biofuel among light commercial vehicles.

Accordingly, it can be seen that the emissions of the cargo transport segment started to be relatively controlled after the year 2006, as it can be seen in Figure 5. In other words, they stopped growing and underwent a soft reduction - even with the number of cargo vehicles continuing to grow. However, this segment emission rates are very high compared to the passenger transport segment throughout the analyzed period. It is therefore concluded that the emissions stabilization from the cargo transport, or even soft reductions of these emissions, must not be seen as fully satisfactory results. However they can be understood as an indicative of the emission reduction leveraging feasibility of this segment to more significant levels, at least similar to those identified in the passenger transport segment.

5. Final Considerations

The procedure used to evaluate the emissions reducing result due to the use of biofuels, comparing the avoided emissions to the occurred emissions, generated an analysis that integrated the emission scenarios of the two different transportation sector segments - passengers and cargo. Even in a context of intense cargo movement, avoided emissions in passenger transport have contributed decisively to containment of total occurred emissions in the highway, especially after 2006, given the high biofuels volume used in this segment (AEHC and AEAC).

In addition, despite the fact that cargo transport has high emission rates (which keep the emissions of this segment at high levels), as mentioned previously, some factors that have contributed to contain CO₂ emissions from cargo transport in the analyzed period were identified. The main factors are the improvement of the efficiency (in km/L) of certain categories of trucks (mainly heavy trucks) and the increase of the light commercial vehicles fraction that is flex-fuel and can operate with AEHC.

These positive effects gain significant expressiveness in 2015. This year, for the first time CO₂ total occurred emissions fall in relation to the year investigated previously, considering the entire period analyzed. In addition, the emissions occurred in 2015 fall back to a level close to that identified 14 years earlier, in 2001. This expressive result can also be identified in the comparison between avoided and occurred emissions. In 2011, the avoided emissions represented still little more than 34% of the occurred emissions in the highway. In 2015, this ratio has risen to 60%, indicating that in a short to medium term the amount of avoided emissions may surpass that of occurred emissions, even in a context of intense cargo movement.

These elements provide evidence that the strategy of using biofuels to reduce CO₂ emissions has the potential to achieve satisfactory results. However, it is known that this GHG reducing alternative regarding the transport sector is associated to a series of other socio-environmental problems, such as the possibility of biofuel production affect the production and the price of the food, contribute to the increase of the deforestation (which would reduce the benefits in terms of reducing GHG emissions), aggravate the problem of water security, among others.

One of the socio-environmental problems directly related to the use of biofuels is the emission of atmospheric pollutants. Despite contributing to the reduction of GHG emissions, the burning of biofuels in motor vehicles is also linked to the emission of gases considered to be harmful to human health (that is, they have a local impact). In the case of AEHC, for example, the emission of aldehydes at high levels, as well as carbon monoxide can be highlighted (although in this last case the rates are lower than those presented by gasoline and diesel).

In view of these issues, there is a worldwide trend towards the vehicle fleet electrification as the ultimate goal to be achieved regarding GHG emissions reduction. This is an alternative that also contributes to the mitigation of other socio-environmental problems, such as the atmospheric pollutants emission. In case of opting for the expansion of the electric vehicles fleet, besides the possibility of using batteries in vehicles, there is a technological route that has worked with the production of electricity in the vehicle from the hydrogen, through an electrochemical reaction in the so called fuel cells. To obtain this hydrogen, one of the considered possibilities has been the use of ethanol, subjecting it to the process called steam reforming. In the case of Brazil, this possibility reveals convenience, since the country has already consolidated a large production infrastructure for ethanol.

⁸ The concept of autonomy used by CETESB is been considered: "distance that the vehicle travels using a certain volume of fuel - usually (...) expressed in the km/L unit" (SÃO PAULO, 2015). This concept also receives, under different circumstances, other definitions, such as in the National Inventory of Atmospheric Emissions by Road Automotive Vehicles, headed by the Brazilian Environment Ministry. In it, the term "mileage per liter" is used (BRAZIL, 2014).

In this way, different possibilities are presented involving the use of biofuels. Considering its potential to reduce GHG emissions, relativized by the fact that its use is associated with the cause of other important socio-environmental problems (such as local air pollutants emissions), it is reasonable to consider its use as a transition alternative to a reality of electric vehicles. Thus, during the maturation of technological alternatives that could consolidate this reality of vehicles electrification, the use of biofuels can ensure that the levels of GHG emissions in the transport sector remain low.

In the case of Brazil, the option for vehicles electrification through the use of hydrogen obtained from the ethanol reforming makes the idea of biofuels transient use even more coherent. In this case, the expansion of biofuels production to meet the demand of the transition period has the perspective that a large part of these biogenic fuels will continue to be used later, when the electric vehicles fleet will need ethanol for the production of hydrogen. If the option is for battery-powered vehicles, the transitional use strategy of biofuels, even if reasonable, becomes less convenient, considering that any increase in the production capacity of these biogenic fuels, made during the transition period, will lose usefulness in a long term.

Regarding this issue, it is recommended for future work the investigation of a scenario that considers, in the short and medium term, a period of biofuels use expansion in Brazil, and in the long term the electrification of the fleets through the use of hydrogen obtained from the ethanol reforming. It is suggested that the work can address economic, social and environmental indicators associated with this scenario, in order to verify its potential as an option to strengthen sustainability.

As for the emissions analyzed specifically in the area of the cargo transport segment, we have identified another effect that has also worked to reduce its emission rates and deserves attention. The participation of vehicles with intermediate cargo capacity (light, medium and semi-heavy trucks) in this segment is being reduced, while the participation of those with low cargo capacity (light commercial vehicles) and high cargo capacity (heavy trucks) are being raised.

The light commercial vehicles increased from 66% in 1996 to 78% of the commercial vehicles fleet in 2015. Heavy trucks moved from 2.8% of the fleet (1996) to 4.6% (2015). This increase of vehicles with low and high cargo capacity occurs concurrently with the reduction of vehicles with intermediate cargo capacity (light, medium and semi-heavy trucks). This contributes to the reduction of emissions because, in the first case, the type of light commercial vehicle that has become predominant in the fleet is flex-fuel, which can operate with AEHC - while all trucks with intermediate cargo capacity only operate with diesel. Therefore, the increase of light commercial vehicles operating with AEHC and the reduction of trucks with intermediate cargo capacity operating with diesel reduces emissions.

In the second case, heavy trucks can carry a greater amount of cargo than trucks with intermediate cargo capacity, but the emission rates of these two types of trucks are similar, since they have similar autonomy and both operate on diesel. For example, according to CETESB (SÃO PAULO, 2015), the average autonomy of a heavy truck is about 3.6 km/L, just like a semi-heavy truck - so, to travel the same distance, both would consume the same amount of diesel. However, the heavy truck could carry a higher cargo amount than the semi-heavy would support. Therefore, in order to be able to carry the same cargo amount carried by the heavy vehicle, several semi-heavy ones would be necessary, resulting in a higher diesel consumption. Thus, the increase of vehicles with high cargo capacity (heavy trucks) and the reduction of those with intermediate capacity (light, medium and semi-heavy) also reduce emissions, once it turns the cargo transport more efficient and reduces diesel consumption per transported cargo unit.

As for the phenomenon that has stimulated the reduction of vehicles with intermediate cargo capacity and the growth of those with low capacity and high capacity, a main hypothesis is suggested. The growth of electronic commerce (e-commerce) has altered the logic of the supply chain management from most of the companies that operate in the retail market. Increasingly, the experience of consumption has been materialized through electronic operations, within the internet. Therefore, one of the main challenges for companies that sell through the internet has been the creation of logistics systems capable of meeting demands that are very specific and distributed in a widely decentralized manner.

In this sense, it is raised the hypothesis that the increase of light commercial vehicles and heavy trucks fractions, as well as the reduction of the trucks with intermediate cargo capacity, are symptoms associated to the e-commerce growth phenomenon. It is understood that the increase in the participation of light commercial vehicles in the fleet has to do, in part, with the need to meet a growing demand for delivery of products in small quantities, directly to the final customer. They are more suitable vehicles to penetrate the urban area and promote the cargo movement in narrow roads.

Regarding the heavy trucks increase, it is considered that there is a relation with the increasing need of the companies to count on the services of large distribution centers, located in strategic regions. With the growth of e-commerce, the challenge of several companies has been to respond quickly, safely and cheaply a large volume of orders made in several different locations. In this sense, the distribution centers contribute directly, since they are

installed in strategic places, near the regions that concentrate the greater number of orders. When an electronic purchase is made, the distribution center enables the merchandise to be delivered from a point relatively close to the place where the order was made. It is precisely due to the need to feed these large distribution centers that the increased participation of heavy trucks in the cargo fleet is credited. Trucks with intermediate cargo capacity are suited to the volumes demanded by physical stores, but in the case of distribution centers, inventories are destined to meet substantially larger demands, distributed in several cities.

Thus, the use of heavy trucks with high cargo capacity can optimize each trip to supply the distribution center, reducing the cost per transported cargo unit and justifying its use instead of trucks with intermediate cargo capacity. In this sense, for future work, it is suggested to investigate the correlation between the e-commerce growth and the profile transformation of cargo road transport - reduction of trucks with intermediate cargo capacity (light, medium and semi-heavy) and increase in the number of vehicles with low (light commercial) and high (heavy trucks) capacity. It is therefore recommended that the analysis be continued in order to verify the possibility that the phenomenon of e-commerce growth is contributing to the containment of CO₂ emissions from cargo transport.

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