Light vehicle energy efficiency programs and their impact on Brazilian CO_2 emissions

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ARTICLE INFO

ABSTRACT

This paper analyses the impact of an energy efficiency program for light vehicles in Brazil on emissions of carbon dioxide (CO_2), the main greenhouse gas in the atmosphere. Several energy efficiency programs for light vehicles around the world are reviewed. The cases of Japan and Europe were selected for presentation here given their status as current and future world leaders in the control of passenger vehicle fuel consumption. The launching of the National Climate Change Plan and the pressure on the Brazilian car industry due to the world financial crisis make it a good time for the Brazilian government to implement such a program, and its various benefits are highlighted in this study. Three scenarios are established for Brazil covering the 2000–2030 period: the first with no efficiency goals, the second with the Japanese goals applied with a 10 years delay, and the third, with the Japanese goals applied with no delay. The consequences of a vehicular efficiency program and its middle and long-term effects on the consumption of energy and the CO_2 emissions are quantified and discussed. The simulation results indicate that efficiency goals may make an important contribution to reducing vehicular emissions and fuel consumption in Brazil, compared to a baseline scenario.

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0. Introduction

Climate Change is currently a big issue in world discussions. Consumption of fossil fuels around the world has increased the concentration of carbon dioxide (CO_2) in the atmosphere dramatically over the last 150 years. Transport sector emissions are growing fast, sometimes faster than developing countries' GDP (Schipper and Marie-Lilliu, 1999 apud Mattos, 2001).

The use of more efficient vehicles can help reduce fossil-fuel consumption and greenhouse gas emissions. In order to choose between different CO_2 emission mitigation strategies for the light transport sector, it is important to simulate different scenarios.

This study intends to elucidate how an energy efficiency program for light vehicles can produce a significant reduction in CO_2 emissions in Brazil, and assesses some of the more important initiatives that have been taken around the world. It was verified

that now it would be a very good time for Brazil to implement such a program, and its many benefits are highlighted in this article.

Energy efficiency goals were proposed for Brazil, and to quantify the effects on energy consumption and on CO_2 emissions, three scenarios were simulated for the Brazilian light vehicle fleet between 2000 and 2030. With the results obtained from this simulation a more accurate discussion could be undertaken regarding the consequences of an energy efficiency program for light vehicles in Brazil.

Section 1 of this paper presents an overview of international experience in energy efficiency programs for light vehicles and shows recent Brazilian initiatives. Section 2 describes the model framework and scenario formulation. Section 3 presents simulation and results analysis. Section 4 contains the discussion and Section 5 contains the conclusions, with some policy recommendations.

## 1. Energy efficiency programs for light vehicles

Some basic concepts and issues concerning light vehicle energy efficiency programs are presented here, in order to provide an overview of the available information regarding international experience and recent Brazilian efforts.

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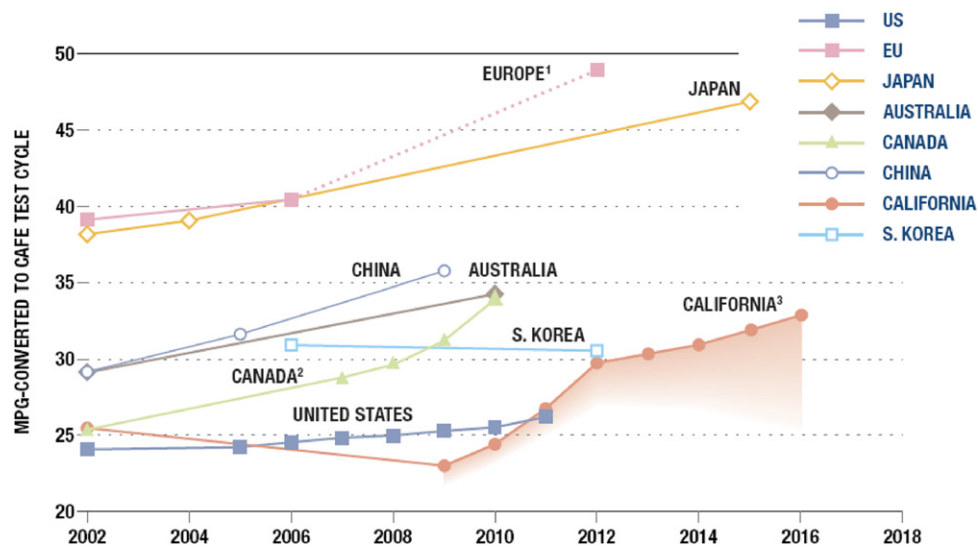
Fig. 1. Comparison of standardized fuel efficiency goals. (1) The apparent discrepancy between European and Japanese performance in emissions and consumption goals due to greater diesel engine fuel efficiency. (2) In Canada the measure also encompasses the existing vehicle fleet. (3) The shaded area under the California curve shows uncertainty related to the manufacturer emissions reduction measures, such as more efficient air conditioners, alternative fuels and hybrid vehicles. *Source*: ICCT (2007).

1.1. International experience

Governments worldwide are struggling with two different but connected issues: how to reduce greenhouse gases emissions and reduce dependence on foreign oil. Light vehicle efficiency targets can contribute to helping these countries attain their objectives. This section compares recent efficiency targets proposed by various countries.

About a decade ago, the European Union entered into a series of voluntary to reduce CO_2 tailpipe emissions. These agreements apply to the new-vehicle fleet, and set an industry-wide target of 140 g CO_2/km by 2008 (2009 for Asian manufacturers). This target was designed to achieve a 25% reduction in CO_2 emissions from passenger cars from 1995. In 2006, manufacturer-fleet average CO_2 emissions ranged from 142 to 238 g/km, with an industry-wide average of 160 g/km. In 2008, the passenger vehicle fleet average CO_2 emissions were projected to reach 155 g/km instead of the 140 g/km target (ICCT, 2007).

In December 2008, the European Parliament voted to adopt regulation related to CO_2 car emissions. The long-term goal is to reduce GHG emissions from 160 to 95 g CO_2/km by 2020, a very significant reduction.[3] Unfortunately, this directive was voted after the simulation of the scenarios presented in this paper.

Japan first established fuel economy standards for light-duty passenger and commercial vehicles in 1999 under its "Top Runner" energy efficiency program, based on weight class. In December 2006, the Japanese government revised its fuel economy targets upward. This revision took place before the full implementation of the previous standards, because the majority of vehicles sold in Japan in 2002 already met or exceeded the 2010 standards (ICCT, 2007).

The US adopted its CAFE standards as part of a broad energy policy package in the wake of the 1973 oil crisis. At that time environmental outcomes were not an explicit policy goal; the expressed goal was to reduce the country's dependence on foreign oil. The CAFE standard for passenger cars has remained un-

changed for more than 20 years at 27.5 miles per gallon (ICCT, 2007). Recently, this goal was increased to 35 mpg by 2020.[4]

Other countries can improve their positions, depending on how their efficiency policies will be implemented. China will have to make important decisions regarding the updating of its efficiency programs during the next few years. Some countries with a substantial automotive fleet and increasing sales, such as India, Mexico and South Korea can apply more restrictive targets to assure that their policies objectives will be reached. These decisions will affect both domestic and worldwide markets, forcing automotive industries to produce more efficient cars and reducing the use of fossil fuels (ICCT, 2007; Kågeson, 2007; JAMA, 2007; An, 2006).

In various countries, especially those that are more developed, vehicle fuel efficiency programs have been formulated usually associated with emissions regulation. These programs define minimum fuel efficiency or maximum specific fuel consumption goals that must be followed by the manufacturers. On the other hand, labeling of the vehicles can also act toward reducing consumption by facilitating the comparison of data which is not always accessible, such as the vehicle's specific fuel consumption and the greenhouse gas emissions factor.

The restrictiveness of each goal is strongly influenced by the test used to measure fuel efficiency or emissions. In recent decades, Europe, Japan and the United States have developed tests that reproduce real conditions of vehicle use. As a result, a vehicle tested in Japan might obtain different results when tested in Europe or in the United States. In order to allow a fair comparison, each goal was adjusted to a common reference using the methodology originally developed by An and Sauer (2004).

Fig. 1 shows current and projected goals from 2002 to 2018 for new-vehicles, normalized by means of the Federal Test Procedure (EPA) in miles per gallon. In 2006, Europe and Japan had the most restrictive goals in the world, with an estimated fuel efficiency of 40 miles per gallon (around 17 km/l) for both countries (ICCT, 2007).

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[3] http://ec.europa.eu/environment/air/transport/co2/co2_home.htm#com_2007_19.

[4] http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.43ac99ae fa80569eea57529cdba046a0//.

1.2. The Brazilian context

In 2006, the transport sector accounted for 26.3% of total energy consumption in the country and for half of oil use. This is mainly due to the overwhelming role of roads not only in passenger but also in freight transportation (BRASIL, 2007). This makes the transportation sector the second CO_2 emitter in the country, only behind the industrial sector. On the other hand, CO_2 emissions from transportation are mitigated by the high use of biofuels and natural gas in Brazilian vehicles. Biodiesel has been blended with diesel oil at 2% since 2007, at 3% in 2009 and will reach 4% in 2010. All gasoline sold in the country has been blended with sugar cane ethanol (up to 25%) since 1975 (no pure gasoline, only "gasohol" is available at gas stations). Most new cars sold in the Brazilian market since 2003 may use either gasohol or pure ethanol (the so-called "flex-fuel" cars). Taxi fleets in major Brazilian cities run on natural gas. As a result, the average emission of the Brazilian light car fleet is today less than 150 g CO_2/km, lower than current Japanese and European figures.

An energy efficiency program focusing on light vehicles in Brazil would produce major benefits, such as curbing oil consumption and air pollution in large Brazilian cities. As a co-benefit, it would also allow for further mitigation of the transport sector's CO_2 emissions (Alzuguir and Cordeiro, 2007).

For historical reasons, Brazilian government efforts to implement energy efficiency programs began with the power sector. Created in 1985 by the Ministry of Mines and Energy (MME) and regulated by ELETROBRAS, the Electric Energy Conservation Program (PROCEL) has contributed to increasing the general public's awareness of the concept of energy efficiency. Major appliances such as refrigerators and air conditioners are sold with a label stating their ranking in terms of unit energy consumption compared with other models. After the power shortage in 2001, an energy efficiency law was passed by Congress. The Brazilian government is now authorized to set energy efficiency standards for a list of products including electrical appliances, gas and LPG stoves, and also vehicles. Minimum energy efficiency standards are already in force for electric motors that account for roughly half of power consumption in the industrial sector.

CONPET (the National Petroleum and Natural Gas Conservation Program) was established later, in 1991. This program, run by PETROBRAS, has been very limited in scope, including some small truck driver education programs and encouragement to undertake more frequent truck maintenance. In 1986, the Brazilian Government, with the help of CETESB, launched the Brazilian Motor Vehicle Air Pollution Control Program (PROCONVE) to control vehicle emissions. Its main goal was the reduction of atmospheric contamination by setting emission standards, thereby inducing technological improvements of manufacturing processes and verifying that vehicles and engines meet emission limits in standardized tests with a reference fuel. PROCONVE's target for controlling pollution from Otto Cycle light-duty vehicles is based on the US Programs LEV and CARB, and succeeded in reducing emissions in a relatively short time (Szwarcfiter et al., 2005).

More recently, in early 2009 a major breakthrough was achieved when a joint group of governmental bodies and ANFAVEA (the car manufacturers association) agreed to establish standard procedures for measurement of light cars energy efficiency. In May 2009, CONPET launched a voluntary energy efficiency label for the sale of new light vehicles in the Brazilian market, which has already been adopted by some leading car manufacturers. Other manufacturers are expected to follow suit. In case of PROCEL labels for electric appliances, manufacturers have adhered to the program to avoid being exposed to negative publicity and in some cases have even discontinued the manufacturing of inefficient equipment models, for the same reason. Programs adopted in other countries for light cars have led to growing awareness on the part of consumers to the point that car marketing strategies now include advertising regarding good performances in terms of g CO_2/km.

These recent developments pave the way for the final step required to launch a Brazilian energy efficiency program targeted at light vehicles: the establishment of minimum energy efficiency standards that may be periodically reviewed to attain stricter standards (Nogueira and Branco, 2005). 2009 seems to constitute the ideal moment for this final step due to the following reasons:

- Brazilian government has launched a National Climate Change Plan including voluntary mitigation goals and is eager to present policies and measures targeted to achieve them for inclusion in the Climate Convention negotiation process.
- Following the world economic and financial crisis, Brazilian markets were also hit and new car sales fell dramatically at the end of 2008. The Brazilian government instituted a 30% reduction in taxes on new cars (IPI—industrial products tax) in the first quarter of 2009, that was eventually extended to 30 June 2009, thus helping sales to recover and achieve the same levels from January to April 2009 seen during 2008s corresponding period. The US administration has requested a commitment from car manufacturers to launch more efficient new models in return for the financial help from the government. In Brazil, only a vague commitment to preserve jobs was required by the government in return for these windfall profits bestowed on the car industry.
- The arrival of new low-cost and low-fuel consumption Chinese cars in the Brazilian market is scheduled for 2009 and will put additional pressure on local manufacturers to include energy efficiency concerns in their product mix and marketing strategies.

2. Model framework and scenario formulation

In Section 2.1, the description of the methodology for estimating fuel consumption and the main parameters used in the model will be presented. Formulation of the scenarios will be presented in Section 2.2.

2.1. Model framework

This methodology adopts a bottom up approach that estimates the total amount of fuel consumed by the fleet by adding the new cars entering the market by fuel type to the existing fleet and applying a scrap rate to the whole fleet, an average travel distance and an average car efficiency rate by fuel type.

The general formula is

$$C_t = \sum (F_{i,t} \times K_{i,t} \times E_i)$$

where, C is the total fuel consumed (gasohol, hydrated alcohol and natural gas) in year t; i the model year; F the number of vehicles of a model year i running in year t on fuel C; K the average distance traveled by a vehicle of model year i in year t, using fuel C; E the average fuel efficiency rate (liters/km) of a model year I, using fuel C.

The parameters used in the model are:

- Fleet
  o Base fleet: the national fleet from 1957 up to 2007, by model year and fuel type.
  o Sales evolution: the socioeconomic scenario used in the simulations is based on the B2 scenario described in La Rovere et al. (2006), which considers a growth rate of new

Table 1
Average travel distance.

Age (years)	Average (km/year)
Up to 1	22,000
2	19,000
3	17,000
4	15,000
5	14,000
6	14,000
7	14,000
8	13,000
9	13,000
10	13,000
+11	9500

Source: CETESB (1999), *apud* Dubeux (2007).

car sales of 5% (GDP rate growth +1%) in the considered period. This choice was made due to the huge increase in light vehicles sales in recent years. In 2007, sales growth was around 13%.

- *Scrap Curve*: the scrap curve function developed by PETRO-BRAS[5] and updated according to a national survey (IBGE/PNAD) carried on in 1988 is used in the model. This function removes scrapped cars from the fleet according to their age (40 years is the maximum vehicle age).

The scrap curve formula is

$$S(t) = \exp[-\exp(a + b(t))]$$

where, $S(t)$ is the share of scrapped cars aged t; t the vehicle age; $a = 1.798$; $b = -0.137$; average travel distance: the average travel distance values from CETESB (1999) were used; they are a function of the fleet's age, as shown in Table 1.

- *Average fuel efficiency*: the average efficiency of the fleet was that obtained in CETESB (2006), and will be explained in detail in Section 2.2.
- *Sales distribution by fuel type*: the flex-fuel new vehicle sales would account for 93% of new sales in 2030. In this study, as in La Rovere et al. (2006), the NGV (natural gas vehicles) would account for 2% of new sales, composed basically of cabs and commercial vehicles, while gasohol vehicles would account for 5% of new sales in 2030, with most of the latter being luxury or imported cars.
- *Consumption distribution by fuel type*: the flex-fuel fleet will use ethanol for about 60% of the miles driven in all scenarios. That market share of ethanol in flex-fuel vehicles was also used by La Rovere et al. (2006), considering a between-sugar-cane-harvests period which elevates the price of the fuel, making gasoline more attractive. It should be noted that this proportion of 60% alcohol and 40% gasoline C in flex-fuel vehicles is a conservative hypothesis when compared to Ribeiro and Abreu (2008), who quantified the economic results of this technology considering that * ethanol is responsible for replacing 95% of gasoline C in the Brazilian flex-fuel light vehicle fleet.
- Percentage of anhydrous alcohol in gasoline: The proportion of anhydrous alcohol present in gasoline C, throughout the simulation period, was 25%.

2.2. Selected scenarios

2.2.1. Scenario assumptions

Scenario A (baseline): projects the natural tendencies of the market as far as type of fleet, fuels, drive distances, etc. are concerned, under the assumption that no specific policies to increase the efficiencies of light vehicles are adopted. However, an increase in new-vehicle fuel efficiency of 0.25% per year was considered to represent autonomous technological progress. The scenarios continue until 2030.

Scenario B (adjusted): This simulation analyzes the effects of a hypothetical case in which new Brazilian vehicles would have to meet minimum fuel efficiency goals. This scenario uses the parameter of the Japanese goals discussed in the previous section, which seek to increase new light vehicle efficiency by 23.5% by 2015, in relation to 2004. Although this scenario assumes that Brazil will only achieve the efficiency improvement percentage 10 years later, that is, in 2025. The annual fuel efficiency increase calculated following the hypothesis used in this scenario, between 2007 and 2030, was 1.12% per year.

Scenario C (optimistic): this simulation uses the same goals as Scenario B, considering in this case that the Japanese goals will be met by Brazil with no delay, that is, in 2015. The annual fuel efficiency increase in this hypothesis and used in this scenario, between 2007 and 2030, was 2.38% per year.

This study, thus, builds three emissions Scenarios: A, B and C. Because this is an exercise, Scenarios B and C will be considered in the simulation as representing an effort by the country to improve average fleet efficiency, beginning in 2007, given that the most recent new-vehicle average fuel efficiency data made available by CETESB in the Air Report are from the year 2006.

Japan was selected as the model to be followed in defining the goals proposed in the scenarios in this study for several reasons:

- the USA had very lenient goals at the time of simulation (EPA, 2004, 2007) and was thus discarded[6];
- California has interesting goals, however, the goals are for CO_2-equivalent emissions (g CO_2 eq./miles) and the model that was used in the scenarios uses the fuel efficiency of vehicles (CARB, 2004a, b);
- the European Union also has interesting goals, but just as in California, the goals are for emissions (g CO_2 eq./km).

A car's emission factor depends heavily on the fuel used by it. Given that in Europe diesel is an important fuel for light vehicles and ethanol use in Brazil is very significant, and also that diesel cycle engines are much more efficient than Otto cycle engines, European emission goals are not appropriate for Brazil, even if they are indirectly used as a measurement of fuel efficiency.

Japan's energy efficiency program was, at the time of simulations, one of the world's strictest. As the simulation model uses a fuel efficiency parameter (km/l), the Japanese program was chosen to guide the scenarios proposed in this article.

2.2.2. Average new-vehicle fuel efficiency

Average new-vehicle fuel efficiency (defined as mileage in km per liter of fuel) is the most important parameter in this study. Through the application of the proposed new-vehicle fuel efficiency targets in each scenario to the simulation model described above, it is possible to quantify the CO_2 emissions of

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[5] This curve is widely used in Brazil, for example, in the Brazilian National Communication MCT, (2004) to the UNFCCC.

[6] http://www.fueleconomy.gov/.

the whole fleet in each year. Fleet average fuel efficiency from years 2002 to 2006 were taken from CETESB Air Report (CETESB, 2006). From 2007 to 2030, the percentage increases in new-vehicle fuel efficiency assumed in Scenarios A, B and C were applied.It is important to realize that car fuel efficiencies vary considerably depending on the driver and vehicle maintenance. We can estimate the margin of error of these values using the American parameter for efficiency labels, which allows for an error of around plus or minus 15% under both city and highway conditions.

In Fig. 2, average new-vehicle fuel efficiency assumptions are shown for Scenario A (baseline). An autonomous energy efficiency improvement of 0.25% per year was assumed.

Fig. 3, shows average new-vehicle fuel efficiency assumptions for Scenario B. This scenario assumes an average new-vehicle fuel efficiency improvement os 1.12% per year, allowing to achieve a 23.5% increase by 2025 (10 years later than the Japanese target).

Fig. 4, shows average new-vehicle fuel efficiency assumptions for Scenario C. This scenario assumes an average new-vehicle fuel efficiency improvement of 2.38% per year, allowing to achieve a 23.5% increase by 2015 (same year as in the Japanese target).

It might seem that the scenarios proposed here have very difficult goals for fuel efficiency. It must be noted that the percentage increases were derived from the Japanese standard, a country already endowed with a technologically advanced light vehicle fleet. In Brazil there is a lot of room for energy efficiency improvement in this segment, while the scenarios described in this study could be deemed conservative.

Table 2 below contains a summary of the parameters used in the simulation.
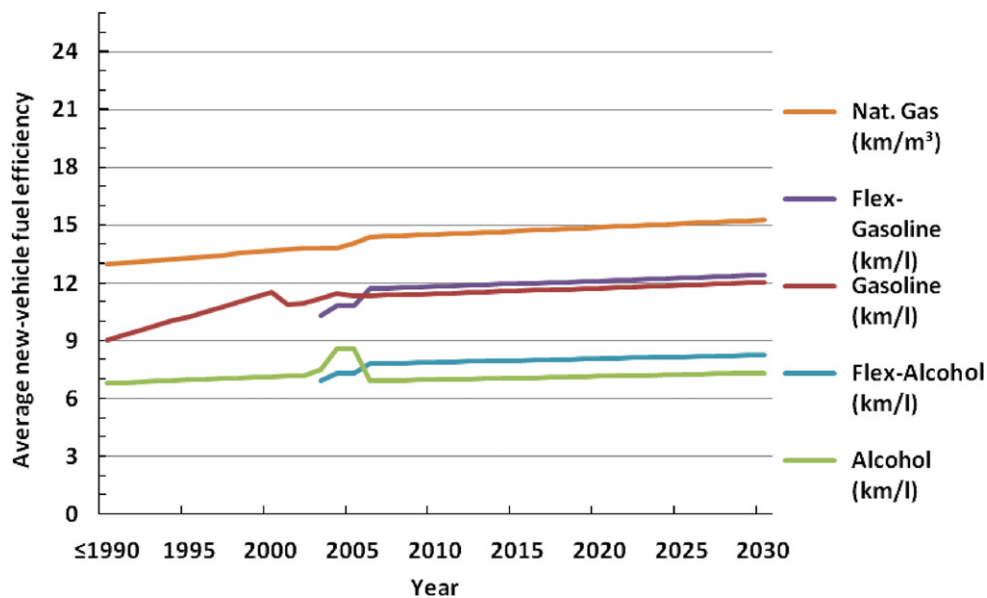

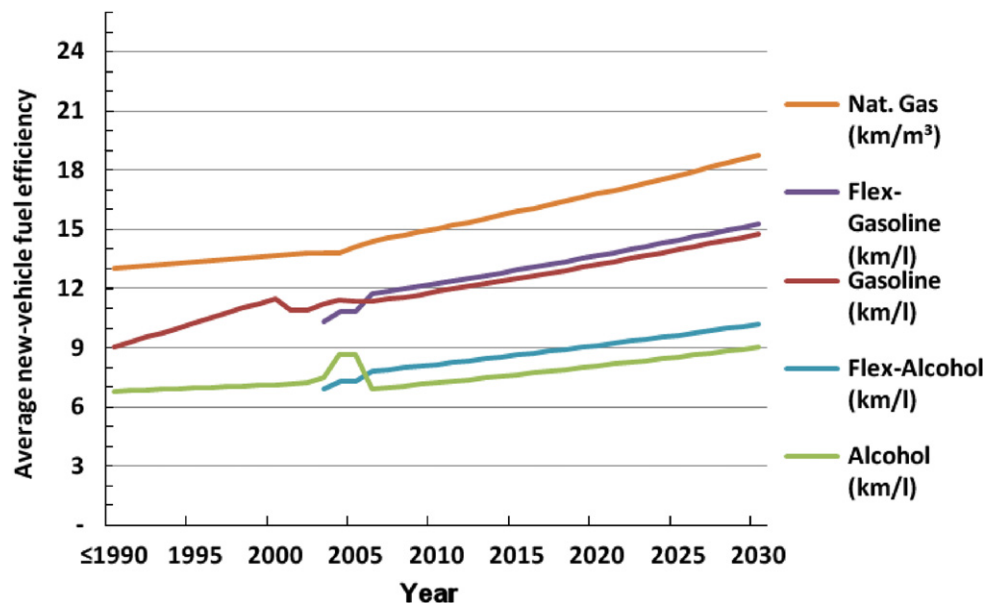Fig. 2. Average new-vehicle fuel efficiency in Scenario A. Source: developed for this study.

Fig. 3. Average new-vehicle fuel efficiency in Scenario B. Source: developed for this study.
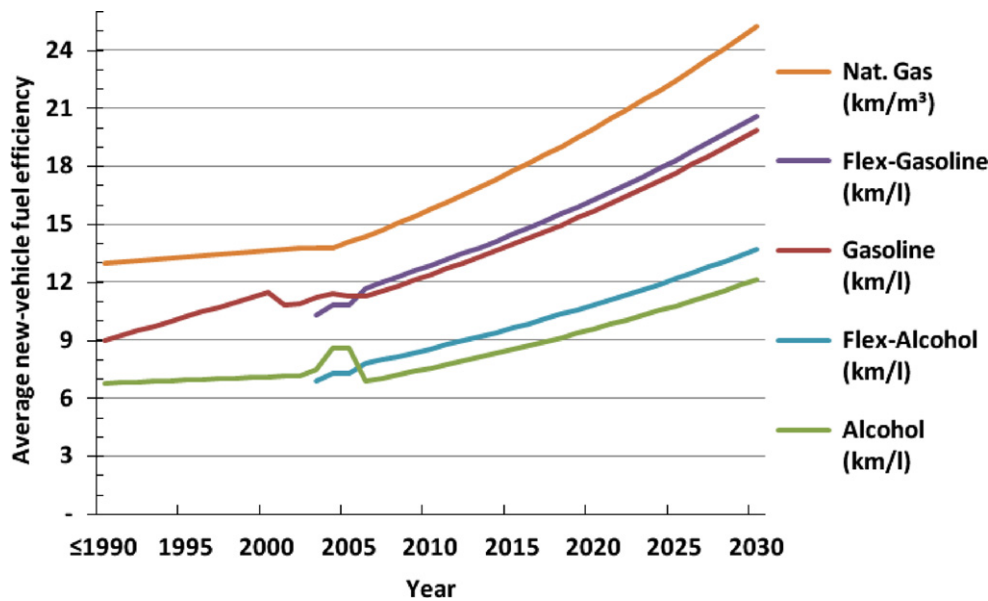
Fig. 4. Average new-vehicle fuel efficiency in Scenario C. *Source*: developed for this study.

Table 2
Summary of the parameters used in the model.

Targets		Scenario A		Scenario B		Scenario C	
Year		2000	2030	2000	2030	2000	2030
Sales growth		Growth of 5% per year (equal to growth in GNP+1%)					
New sales by fuel type	OBS	No. FF cars	Almost all vehicles use FF, taxis use natural gas and only luxury and imported cars use gasohol	No. FF cars	Almost all vehicles use FF, taxis use natural gas and only luxury and imported cars use gasohol	No. FF cars	Almost all vehicles use FF, taxis use natural gas and only luxury and imported cars use gasohol
	Gasohol (%)	98.2	5	98.2	5	98.2	5
	Alcohol (%)	0.8	0	0.8	0	0.8	0
	Flex-fuel (FF) (%)	0	93	0	93	0	93
	Natural gas (%)	1	2	1	2	1	2
Scrap rate	All cars	$S(t) = \exp[-\exp(a+b(t))]$; $a = 1.798$; $b = -0.137$					
Average new-vehicle efficiency by fuel type (km/l or km/m³ for natural gas)		Current data	Natural development	Current data	Japanese goals for 2015 reached in 2025 and maintained up to 2030	Current data	Japanese goals for 2015 reached in 2015 and maintained up to 2030
	Gasohol	11.47	12.00	11.47	14.76	11.47	19.85
	Alcohol	7.13	7.33	7.13	9.01	7.13	12.12
	Flex-gas	10.30	12.42	10.30	15.28	10.30	20.56
	Flex-alc	6.90	8.28	6.90	10.19	6.90	13.70
	GNV	13.66	15.26	13.66	18.77	13.66	25.25

Source: developed for this study.

3. Analysis of simulation results

Fleet composition follows the methodology used in the previous section. It was considered that gasoline vehicles would diminish their market share due to the wide acceptance of flex-fuel vehicles. Vehicles powered by natural gas would have a small market share.

Note that the size of the fleet increases fourfold during the simulation period. A 5% annual sales growth rate was considered throughout the period as described earlier. Also note that flex-fuel vehicles' market share increases significantly while other types of vehicles declines or remains stagnant. One must remember that the size and composition of the fleet are the same in all of the scenarios simulated as can be seen in Fig. 5. This is also true for total kilometers driven.

Flex-fuel vehicles predominate at the end of the period, and around 2010 the kilometers driven by this type of vehicle already exceeds the kilometers driven by vehicles that run only on gasoline.

In Fig. 5, total energy consumption is compared in Scenarios A, B and C. It can be observed that the fuel efficiency goals proposed for Scenarios B and C provide consistent results. Until 2006, the scenarios are absolutely equal. Beginning in 2007, with the differentiation of the goals in the scenarios, the differences in energy consumption begin to appear.

In Scenario B, energy consumption was significantly reduced at the end of the period (14.2% reduction) when compared to

Scenario A. Meanwhile, in Scenario C, due to more restrictive goals, there was an energy consumption reduction of 30.7% in 2030, compared to Scenario A. Comparing Scenarios B and C, consumption in the latter was 19.3% lower than in Scenario B in 2030, Fig. 6 compares emissions in the scenarios described above.

Emissions values are identical in all of the scenarios until 2006, becoming increasingly significant at the end of the period. These values and the reductions referred to in each scenario are shown in Table 3.

Table 3 shows that the reduction in CO_2 emission levels was very significant, even in the adjusted scenario, attaining 15% in 2030. In the most optimistic Scenario C—,emissions were reduced by 30.9% in relation to the baseline scenario, and 18.9% compared to the adjusted scenario.

Fig. 7 shows the accumulated avoided emissions values in the period compared with the baseline Scenario A in a bar graph. This reduction was obtained by implementing the vehicle efficiency goals in the scenarios.

As was observed in this item, the Brazilian vehicle efficiency program could significantly reduce emissions in the transportation sector if efficiency goals were adopted. Even in Scenario B, the reduction in emissions was very large, attaining almost 15% in 2030. In absolute values, total CO_2 emissions in the Scenario A in the end of the period would be 1,264,886 Gg of CO_2. For Scenario B, this value would be 1,187,493 Gg of CO_2, which represents a 6.1% reduction during the period. Meanwhile, for Scenario C, total emissions during the period would be 1,101,516 Gg of CO_2, which represents a total reduction of 12.9%.

Fig. 8 below shows the average emission factors of the circulating fleet for each year in Brazil, in gCO_2/km. The approximate values for Japan and the European Union were also plotted to facilitate comparison. As expected, Scenario C had the lowest fleet average emission factor, while Scenario A had the highest emission factor beginning in 2007, when the differentiated emissions goals began to be put into practice.
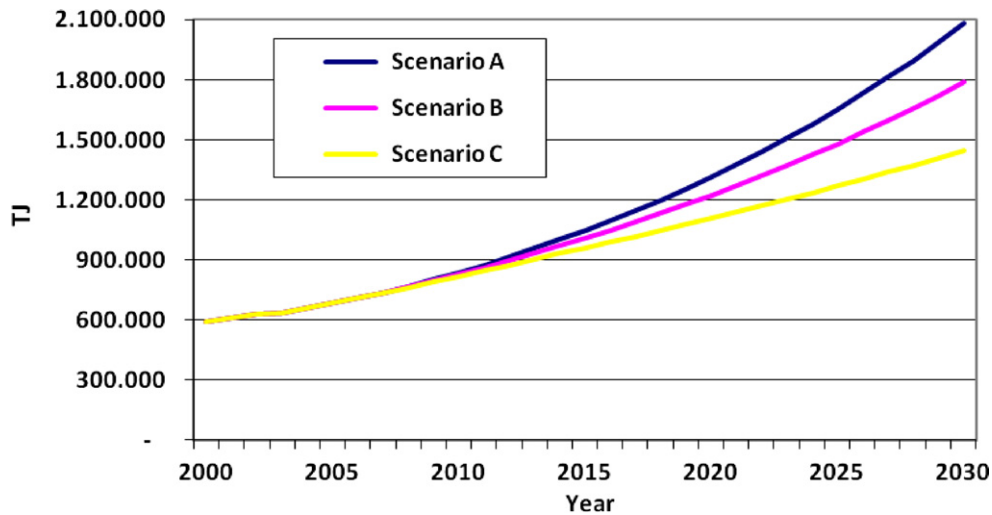

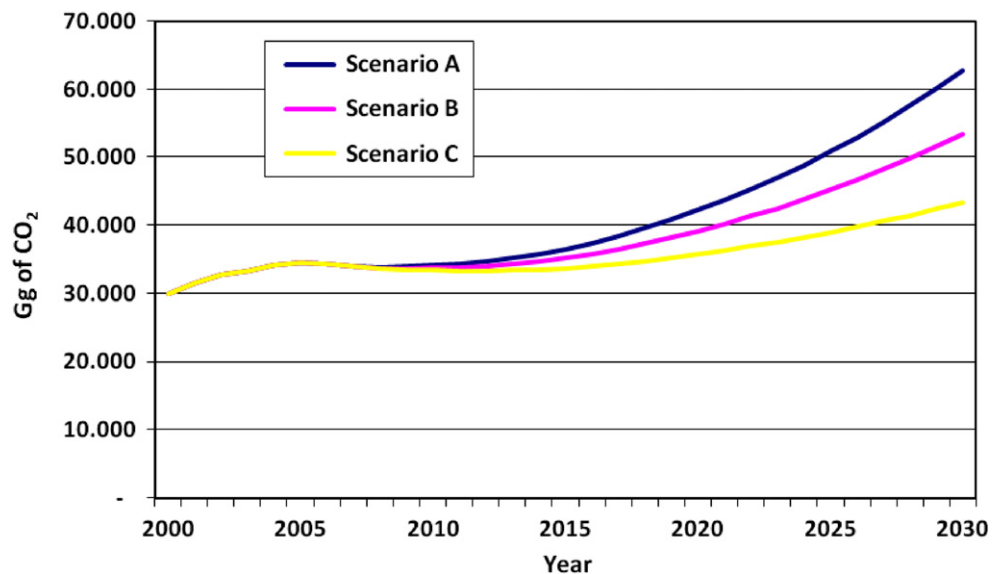**Fig. 5.** Energy consumption in Scenarios A, B and C (TJ). *Source*: developed for this study.

Fig. 6. Comparison of CO_2 emissions in Scenarios A, B and C. *Source*: developed for this study.

Table 3
Comparison of emissions in Scenarios A, B and C.

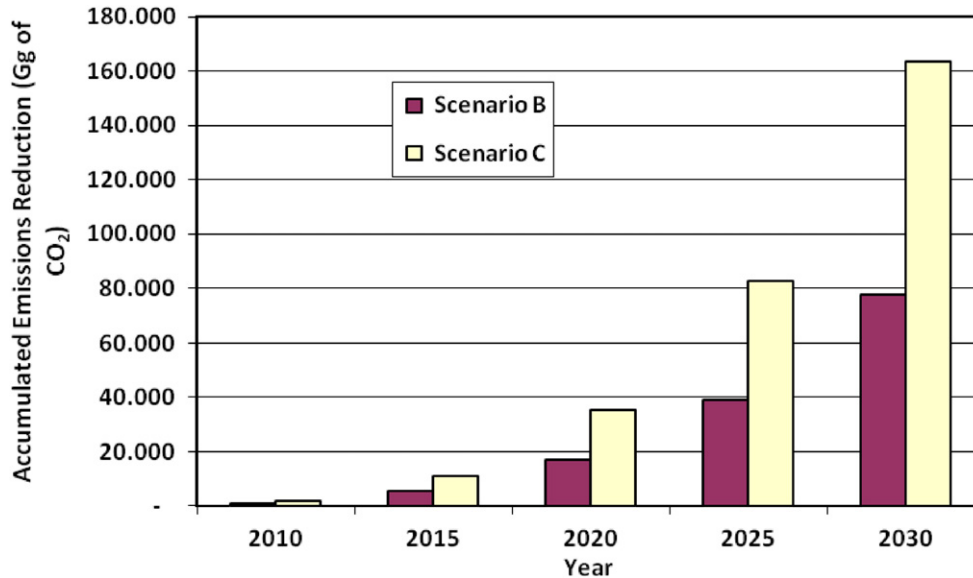| Year	Scenario A (Gg CO$_2$)	Scenario B (Gg CO$_2$)	Scenario C (Gg CO$_2$)	Reduction B/A (%)	Reduction C/A (%)	Reduction C/B (%)
2000	29,910	29,910	29,910	0.0	0.0	0.0
2005	34,536	34,536	34,536	0.0	0.0	0.0
2010	34,149	33,765	33,427	1.1	2.1	1.0
2015	36,468	35,133	33,666	3.7	7.7	4.2
2020	42,164	39,158	35,736	7.1	15.2	8.7
2025	50,798	45,245	38,988	10.9	23.2	13.8
2030	62,687	53,454	43,334	14.7	30.9	18.9

Source: developed for this study.

Fig. 7. Accumulated avoided emissions (compared to Scenario A). *Source*: developed for this study.
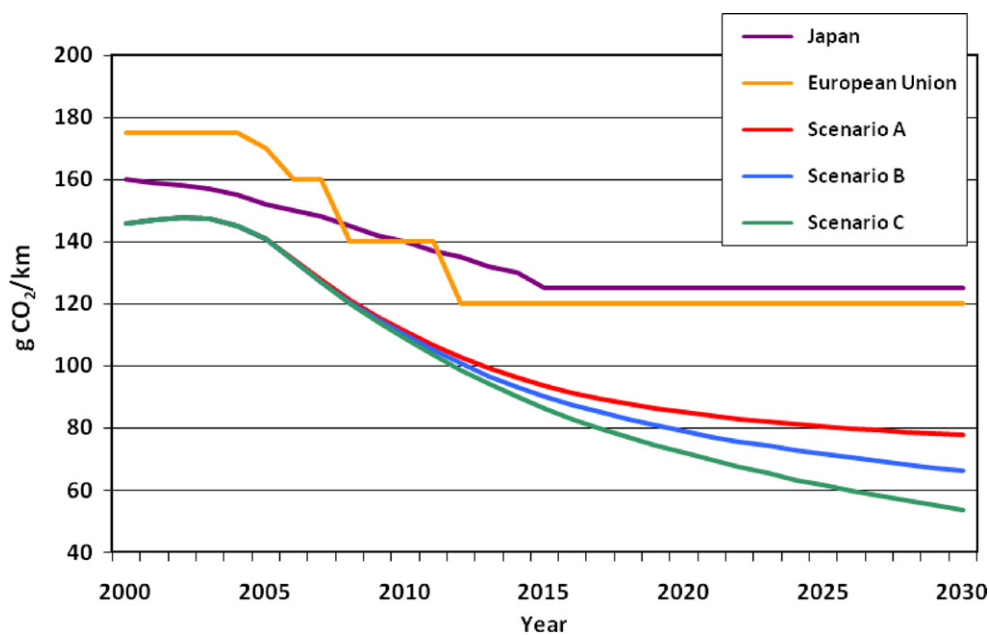

Fig. 8. Fleet average emission factors. *Source*: developed for this study.

Table 4 highlights these emission factors every five years. When comparing these values with the goals for various countries shown in this study note that Brazil finds itself in a very favorable position. Even in Scenario A, without efficiency goals, the emission factors of the Brazilian fleet are smaller than the emissions goals of any country analyzed. This is

Table 4
Emission factors of Brazil's active fleet.

Year	Scenario A (g CO_2/km)	Scenario B (g CO_2/km)	Scenario C (g CO_2/km)
2000	145.89	145.89	145.89
2005	140.77	140.77	140.77
2010	111.16	109.91	108.81
2015	93.47	90.05	86.29
2020	84.96	78.91	72.01
2025	80.31	71.53	61.64
2030	77.69	66.24	53.70

Source: developed for this study.

not due to the Brazilian fleet's great efficiency, but due to the growing use of ethanol as a fuel, which has low carbon content (ethanol emission factor from Macedo et al., 2008, which does not consider direct or indirect emissions from land-use change). Because of this the Brazilian fleet has probably the world's lowest CO_2 emission factor, and should maintain this position for several years.

4. Discussion

Improvements in the transportation system may increase the population's mobility and accessibility. Vehicle traffic can cause traffic jams, accidents, loss of life, health problems and changes in land use and occupation. In addition, vehicle pollution causes environmental degradation such as local and regional air pollution and contributes to increasing the greenhouse effect.

Considering the environmental impacts and effects that are produced by motor vehicles, nations around the world have reacted by trying to reduce the impacts of local pollutant gas emissions and GHGs that result from fuel burned by light vehicles, through the implementation of vehicle energy efficiency programs.

Technological improvements in motor vehicles, fuel efficiency and the establishment of more rigorous fuel economy or emissions limits will all help to reduce GHG emissions. A factor favoring the implementation of an energy efficiency program is its alignment with national public policies, its contribution to improving environmental conditions and its role in consolidating oil supply self-sufficiency.

The increase in the participation of public transport in Brazil is very important for diminishing fuel consumption and consequently reducing GHG emissions. For this reason, the goals proposed in this study should be just one component of a wider transportation policy.

The flex-fuel technology, associated with high oil prices, was the major responsible for the recent increment in ethanol consumption in Brazil. However, raising ethanol production at fast rates shown in all scenarios depends not only on huge available areas, but on important investments in infrastructure, to permit the transportation of the ethanol to regional markets. In order to avoid increasing deforestation in Brazil and competition with food production, adequate land-use planning and environmental certification of ethanol production expansion will be required (La Rovere et al., 2008).

5. Conclusions and policy recommendations

Thus, based on the scenarios proposed and the model described in Sections 2 and 3, interesting results were obtained relating to the implementation of light vehicle efficiency goals in Brazil. Flex-fuel vehicles account today for almost 90% of total sales (87% in 2008). As a consequence, by 2012, they will probably outnumber vehicles that are solely gasoline powered and in 2030 they will make up around 91% of the total fleet, leading to an exponential growth in the expected consumption of anhydrous alcohol until the end of the simulation period in all of the scenarios evaluated.

Through the implementation of the Japanese goals in 2025 instead of 2015 (Scenario B) and in 2015 (Scenario C), it was possible to verify the energy consumption savings for Brazil's light vehicle fleet. Scenario B reduced the consumption of energy from 2 to 1.8 million TJ in 2030, a saving of 14.2%, whereas in Scenario C, due to earlier implementation of the goals, the reduction was greater, with consumption falling from 2 to 1.4 million TJ in 2030, a saving of 30.7%. As was expected, CO_2 emissions were also substantially cut in the proposed scenarios, compared to Scenario A.

The emission factors of the Brazilian light vehicles fleet are lower than the emission goals of any of the countries analyzed, even in Scenario A, without efficiency goals. This is due to the use of ethanol as a fuel. So, the fleet in circulation in Brazil has probably the world's smallest CO_2 emission factor in the world. In Scenario C, with efficiency goals, the Brazilian average emission factor of the light vehicle fleet would be 50% lower than the current European or Japanese goals.

Without applying efficiency goals, Scenario A shows that the transportation sector's CO_2 emissions could increase by up to 110% between 2000 and 2030. In Scenario C, this increase would be limited to 45% despite the fourfold increase in the fleet. This shows the importance of implementing a vehicle efficiency program in Brazil. However, implementation depends on the government's skills and political will.

At first sight, the scenarios proposed seem very optimistic, but it should be noted that the increase in energy efficiency proposed was based on Japanese goals, whose fleet has a technological advantage over the Brazilian fleet. This leads to the belief that there is a lot of room for improvement in fuel efficiency in the light vehicle segment in Brazil, hence the scenarios proposed here could be considered conservative.

As a policy recommendation, the update of general data about the Brazilian light vehicles fleet, in particular the fleet running on natural gas would be very important to perform more accurate calculations. An updated scrap rate is also needed with urgency.

The voluntary labeling program that exists today in Brazil should turn into an obligatory program. Today only a few models are labeled. Another great advance in this area would be the creation of a federal program following the international best practices discussed in Section 1, with the establishment of fuel efficiency or GHG emissions goals.

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