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Evolution of the brazilian passenger car from 2003 to 2018: technology, price, emissions, market, and policy

Evolução do carro de passageiros brasileiro de 2003 a 2018: tecnologia, preço, emissões, mercado e política

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ABSTRACT
This study presents and discusses the evolution of the Brazilian fleet. It is studied the engine and vehicle characteristics (price, registration, engine capacity, maximum power, weight, length, and vehicle segment) from 2003 to 2018, and CO_2 emission, urban and road fuel consumption from 2013 to 2018, highlighting changes and its possible reasons. In general, Brazilian cars became cheaper, heavier, and more powerful. Despite the

increase in weight and power, the CO_2 emission were always inside the government targets. Additionally, it is compared the Brazilian and European average car, and Brazilian cars were cheaper, lighter, shorter, less powerful, and less economical.

Keywords: Brazil, CO2 emission, engine capacity, passenger cars.

RESUMO
Este estudo apresenta e discute a evolução da frota brasileira. Estuda-se as características do motor e do veículo (preço, matrícula, capacidade do motor, potência máxima, peso, comprimento e segmento do veículo) de 2003 a 2018, e emissão de CO2, consumo urbano e rodoviário de combustível de 2013 a 2018, destacando as mudanças e suas possíveis razões. Em geral, os carros brasileiros se tornaram mais baratos, mais pesados e mais potentes. Apesar do aumento de peso e de potência, a emissão de CO2 sempre esteve dentro das metas governamentais. Além disso, é comparado com o carro médio brasileiro e europeu, e os carros brasileiros eram mais baratos, mais leves, mais curtos, menos potentes e menos econômicos.

Palavras-chave: Brasil, emissão de CO2, capacidade do motor, automóveis de passageiros.

1 INTRODUCTION

Brazil has been one of the biggest vehicle markets in the world. From 2009 to 2018, the increase in vehicle sales contributed to increase the energy utilized by the transportation sector, from 28.5% to 32.7%. During those years, gasoline and ethanol consumption increased by 54% and by 32% respectively (1). The registration of passenger cars (PCs) benefits its owners by providing them access to work, study, and leisure; however, the general increase in PC registrations increases fuel consumption and CO_2 emission, as vehicles sold have internal combustion engines (2).

In the last years, several studies have been conducted around the world focusing on the key aspects of the fleet and on CO_2 emission. Fontaras and Dilara (2012) studied the evolution of PCs characteristics in Europe from 2000 to 2010, and Beser Hugosson *et al.*, (2016) analyzed the evolution for the Swedish car fleet along the national policies. Zervas (2010a, 2010b, 2010c) analyzed the influence in emissions from data from European country, from different vehicle segments, and from different brands. The actual fleet characteristics are relevant for technical staff, researchers, and public policy developers' project future scenarios. Several studies have focused on projecting the future modifying parameters, changing policies, verifying impact of hybrid and electric vehicles, along with other technological changes. Kloess and Müller (2011) simulated impact of policy, price and technology in Austrian PC fleet until 2050. Hao *et al.*, (2016) projected the Carbon footprint global scenario through 2050. Hassani and Maleki (2021) performed their study projecting fuel demand and greenhouse gas emission for Iran by 2050, Xue *et al.*, (2020) focused on mitigating pollutants for the Japanese car fleet until 2030, and Mijailović *et al.*, (2019) for the Serbian fleet until 2025.

There is a lack of studies about the fleet key characteristics in Brazil, informing how the key characteristics of engines and vehicles evolved. The most recent study was developed by Posada and Facanha (2015), which presented a report containing relevant information as vehicle fleet characteristics and technology adoption. There are no studies published containing recent data on Brazil, and there is also no study projecting future scenarios for Brazilian PC fleet on literature.

This study objective to analyze the evolution of the key parameters of Brazilian PCs, providing information such as registration, average engine capacity, average maximum power, vehicle length and weight, CO_2 emissions, and fuel consumption. In addition, there is a comparison of the Brazilian and European average car, presenting and discussing relevant aspects of both of them regarding their key parameters and emission. The objective of this study is to provide data to assist technicians, researchers, and policymakers in future analyses and studies regarding the average vehicle.

2 METHODOLOGY

For each year, it was employed official registration data of the 50 most sold PCs in Brazil. The list can be found both in Portuguese (FENABRAVE, 2019) and English (13). Two analyses are performed from this methodology: 1) evaluation of key technical parameters of the average vehicle and engine and; 2) the evolution of the CO_2 emission and fuel consumption in urban and road conditions.

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2.1 VEHICLE AND ENGINE CHARACTERISTICS DATA

Data was compiled from official reports, models' manuals, and technical websites, from 2003 to 2018. The parameters evaluated were: price (in Brazilian Reais, R$), engine capacity ($cm^3$), engine maximum power (hp), length (mm), and weight (kg). The yearly average for every parameter considers the weighted average of all car model sales.

2.2 FUEL CONSUMPTION AND EMISSION DATA

The parameters regarding the fuel consumption and emission gases were: urban fuel consumption, road fuel consumption, and carbon dioxide emission (CO_2). The values for fuel consumption and emissions were obtained from the official test results conducted by the National Institute of Metrology Standardization and Industrial Quality (INMETRO). In this test, the PC is tested on the EPA cycles: FTP-75 for city standard, and HWFET for highway, and adjusted for Brazilian conditions (ABNT NBR 7024 and INMETRO Ordinance nº 377/2011).

2.3 DECISIONS AND LIMITATIONS

The parameters were chosen based on previous studies available in the literature (*e.g*, ICCT, 2018; Zervas, 2010). For vehicle and engine parameters, this study comprises data from 2003 to 2018. This time span was selected because 2003 was the first year containing reliable public data regarding PCs registration, and 2018 was the last year without COVID-19 pandemic effects on sales. To consider an average for each PC, it was selected the cheapest and the most expensive version sold of each vehicle. Each version was considered responsible for 50% of the characteristic studied. This decision was made because the official sales report does not inform the sales of each version

Regarding fuel consumption and emission data, it was considered data from 2013 to 2018, in which 50% or more of the fleet was tested according to the standard procedure informed in the previous section. The yearly average for every parameter (vehicle, engine, or emission) is a weighted average. If a vehicle had no emission or fuel consumption informed for a specified year, its share was not considered.

The average European car was utilized in this study to provide a standard for comparison, and the characteristics are provided by ICCT (2019). Nevertheless, there are several aspects differing Brazil and Europe. For instance, fuel: pure gasoline is not used in Brazil, as is used gasohol: a mix from gasoline and ethanol, established by the government to decrease fossil fuel emission (14). Diesel-engine passenger cars are an irrelevant share of vehicles sold in Brazil. Therefore, parameters such as average and specific power and fuel consumption will be different, even if the same vehicle is tested in both regions. Even if the vehicles were tested with the same fuel, CO_2 emission and fuel consumption would be different, as the type-approval tests differs.

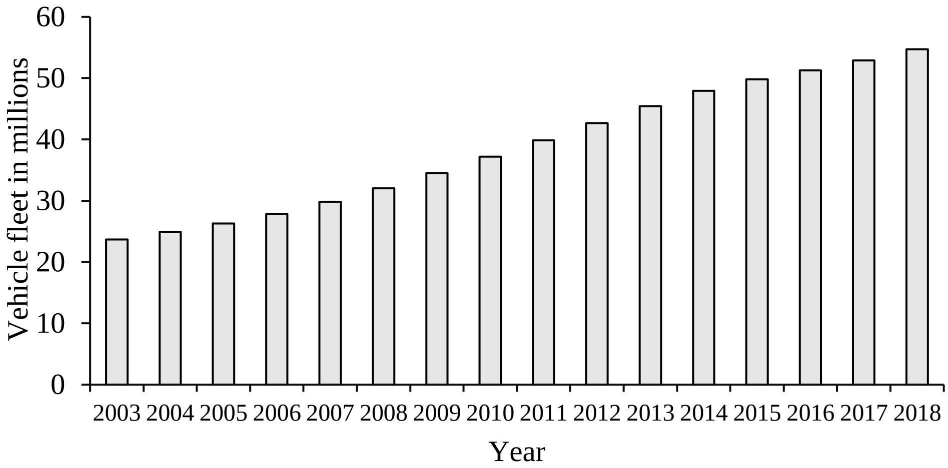
3 RESULTS AND DISCUSSION FOR VEHICLE AND ENGINE CHARACTERISTICS

It was performed an analysis of the Brazilian PC fleet, considering sales and key technical parameters. Finally, it was discussed the variation of the parameters and their effects on the fleet over the years.

3.1 THE EVOLUTION OF BRAZILIAN PC FLEET

Brazil is the sixth most populated country in the world, and its population is estimated at 208 million (15). In the last 15 years, there was an increase of 130% in the PC fleet (Figure 1), from 23.7 million in 2003 to 54.7 million in 2018, being at the time, the fifth largest car fleet in the world.

Figure 1. Brazilian fleet of passenger cars (DENATRAN, 2019)



Even with one of the largest fleets worldwide, Brazil does not present one of the highest proportions of PC per inhabitant. In 2015, Brazil had a proportion of 270 PCs per 1,000 inhabitants. Other developing countries, such as Mexico (193) and Iran (201) present similar values. Wealthier countries, such as the USA (767), Canada (586), Norway (576), France (591), and the UK (522) present higher values in this parameter. Another case consists of the countries with a lower amount of PCs, as in Asian countries in which two- and three-wheeled vehicles are the main transportation modal, such as Cambodia (4.5), Pakistan (17), India (31), and Indonesia (43) (16). From those values, the Brazilian transportation picture is different both from the high-income countries and from Asian countries.

3.2 PCS REGISTRATION OVER THE YEARS

As presented in Figure 1, there was an increase in the Brazilian PC fleet from 2003 to 2018. The increased average income could be the reason for the acquisition of a new individual vehicle. The Gross Domestic Product per capita (GDP) is employed as a measure of a country's economy and as a proxy of the citizens' living standards over time. When comparing the GDP to the number of passenger cars sold yearly (Figure 2), a high Pearson's correlation coefficient was found (r = 0.92).

The selling of new cars may be correlated to the increase of average wage in developing countries, because public transportation does not provide the feeling of freedom, status, and convenience as the individual modal (17). Additionally, in Brazil, public transportation is considered not reliable and is used mainly by those who need it (18,19). This may be considered true in other emerging nations, in which high-income families have car ownership (20).

Figure 2. Yearly registration of passenger cars in Brazil and GDP per capita. Adapted from (FENABRAVE, 2019) and (World Bank, 2019)

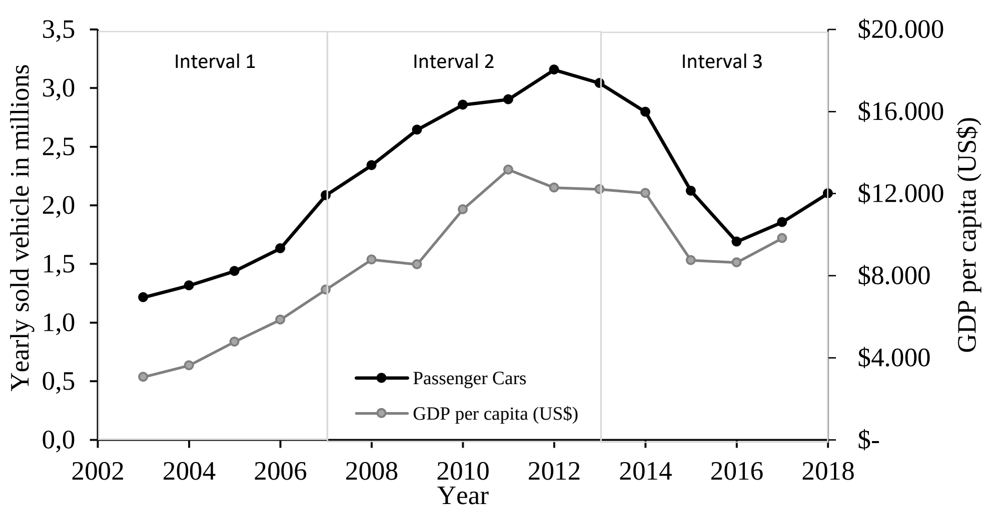


Figure 2 can be analyzed in three-time intervals. In the first interval (2003 to 2007) the individual purchasing power only increased. The economic growth was resultant from an improvement in the domestic economic condition and provided an overall income increment, stimulating the vehicle's acquisition. Other economic factors involved were the lower interest rates, the expansion of vehicle financing, and the worsening of urban mobility. The Brazilian governmental policy has encouraged the automotive industry to boost automotive sales (12), reflecting on economic improvement, and bolstering the supply chain. For citizens, the mobility worsening also stimulated the purchase of a new individual vehicle (19).

The second interval was from 2008 to 2012, and the financial subprime mortgage crisis affected the worldwide market. But even with the global crisis, the Brazilian average income has increased (Figure 2). During the subprime mortgage crisis of 2008, the government fostered the consumer demand with a regime of tax on industrialized products (IPI) tax reduction policy. For 1,000 cm^3 vehicles, the original tax was decreased from 7% to 0% during December 2008 to September 2009 and from May to December 2012. For 1,000 and 2,000 cm^3 vehicles, the tax was halved. Vehicles whose engine capacity was above 2,000 cm^3 had not received tax reduction (21). This tax reduction was not bounded to any kind of efficiency improvement, aiming mainly to increase job positions and sales (22,23). It is estimated that this policy increased the production of automobiles between 4% to 9% per year.

In the third interval (2013 to 2018), several events took place in Brazil, affecting both the population's general income (in US$) and the vehicles' characteristics. First, in 2012 the government presented a new tax policy (Inovar-Auto) incentivizing automakers for improving the energy efficiency of their fleet (Federal Law nº 12.715/2012, Federal Decree nº 7.819/2012). It aimed to promote innovation, stimulate local R&D investments, and increase the manufacturing of more economical, efficient, and safer vehicles (Duarte & Rodrigues, 2017). Second, in 2015 the country committed to the Paris Agreement intending to reduce greenhouse gas emissions by 37% by 2025 – when compared to 2005 levels (14).

Third, there was the onset of the law obliging vehicles to provide ABS and airbags. Likewise, vehicles were also structurally improved, because clients became more aware of the safety results obtained in crash tests such as Latin NCAP. Fourth, convenience accessories (*e.g.*, touchscreen multimedia, multi-function steering wheels) were provided, as the basic versions of older PCs did not contain any of those features. Fifth, the average price increased considering the inflation over the years, a relevant index for the Brazilian customer. In addition, Brazilian citizens experienced a decrease in the average income (Figure 2), reflected in the increase of unemployment levels, devaluation of their currency, affecting the GDP. This may have affected the possibility of purchasing new vehicles. All those events altogether decreased sales from 3.0 million in 2013 to 2.1 million in 2018 (31% lower).

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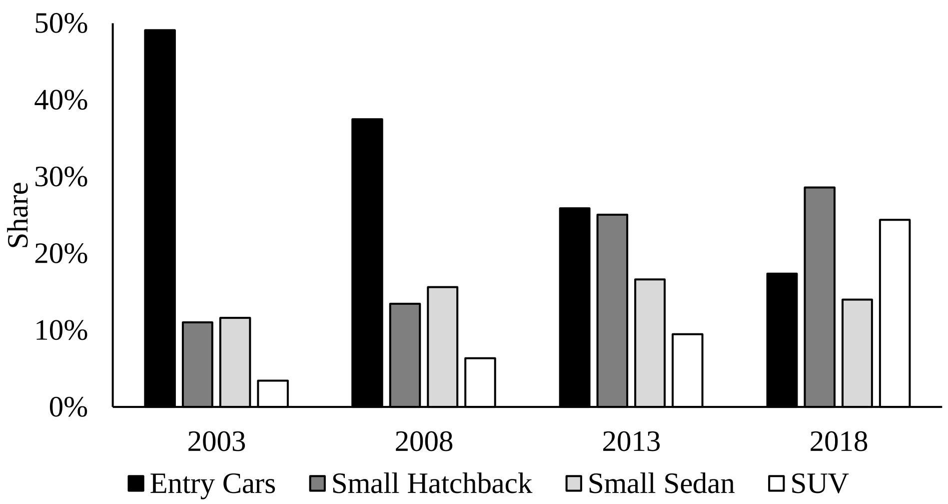
3.3 PASSENGER CARS SEGMENTS REGISTRATION OVER THE YEARS

The preference of the Brazilian consumer has changed from 2003 to 2018 (Figure 3). The entry cars category had their share decreased from 49% to 17%. This category contains the smallest, lightest, cheapest, and least powerful cars in the market. Thus, if the registration in this category decreases, it is expected that the average length, weight, and maximum power of the fleet to increase. In 2018, the compact hatchback segment contained the highest registration number (29%).

The small sedan vehicles category share remained constant over the study, never achieving the top registration position. The most relevant change happened for the SUV vehicles in which their share had increased eight times, from 3% in 2003 to 24% in 2018. SUV vehicles are also responsible for the increase in the average Brazilian length, weight, and maximum power of the fleet. Those four segments corresponded most of the sales over the years, and segments such as medium/large sedans and hatchbacks, sports, and wagons were never representative.

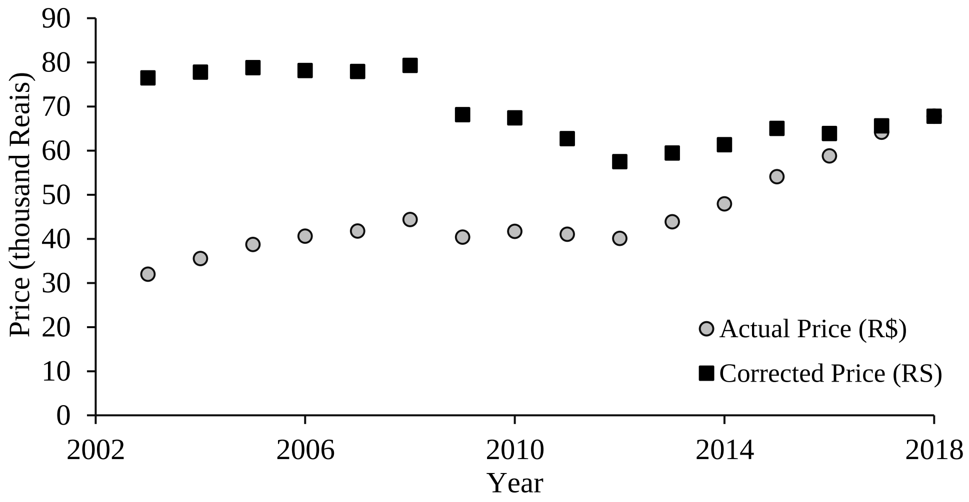
Figure 3. Market share of the Brazilian most sold PC segment



3.4 AVERAGE PRICE

The average selling price (including tax and unadjusted for inflation) is considered in the local currency: Brazilian Reais (R$). The corrected price considers the capital a customer would have in December 2018 if instead of buying the average car in that year, the customer had invested the money (adjusting for the Brazilian customer price index, IPCA, over the period). The average actual price and the average corrected price are presented in Figure 4.

Figure 4. Average price and corrected price of the vehicles sold in Brazil

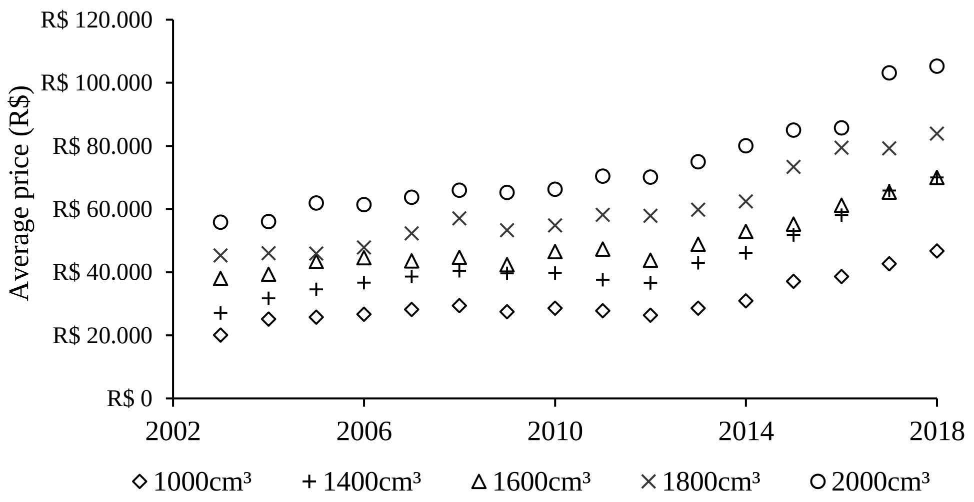


When evaluating Figure 4, the average price increased, although when considering the inflation, the corrected price has actually decreased when comparing 2003 to 2018. Considering the division in time intervals as described in Figure 2, in the first interval (2003 – 2008) the customer paid the most expensive price for a vehicle from the period studied. The customer price index (IPCA) has varied on average by 5.6% per year during the studied years, but presented a maximum 10.7% yearly rate in 2015, as inflation especially affected the price of the older vehicles.

In addition to the annual inflation rate, other aspects contributed to the increase of the average price, already discussed as several changes in the Brazilian PC market in the third time interval (Figure 2) as the imposition of safety equipment as the frontal airbags and ABS (Federal Law nº 11.910/2009). This obligation contributed for the manufacturers to redesign the interior trim and external appearance of the vehicles (face-lifting) aligned with structural changes to allocate the changes, including comfort equipment that was only available on the most expensive versions, such as air conditioning, sound system, and electric car windows in the basic versions.

Figure 5 provides the average price per engine capacity segment. In general, segments present distinct prices among themselves, from 2015 on, the price gap was shortened for 1,400 cm³ and 1,600 cm³ segments. In this case, the authors perceived that the segment of 1,400 cm³ is composed of a mix of complete versions of basic vehicles and by entry versions of premium vehicles with turbocharging. Another important aspect of Figure 5 is the sudden increase in the price for PCs in the 2,000 cm³ segment after 2016, due to the entry of luxury cars into this segment.

Figure 5. Average price per engine capacity segment



3.5 ENGINE CAPACITY AND MAXIMUM POWER

Only internal combustion engine PCs were considered, as the sum of electric and hybrid cars sold was always less than 0.1% in the studied period. From 2003 to 2018, there was a slight increase of 2.3% in the average engine capacity, to 1,414 cm³. Figure 6 presents that the average engine capacity had a non-linear pattern. There was an increase of 3.7% in engine capacity from 2003 to 2007, coinciding with the first interval (Figure 2), in which there was a decrease in the registration of the entry category PCs, from 46% to 39%. The average engine capacity decreased by 3,5% from 2008 to 2011, as an effect of the government measures to stimulate the sales of 1,000 cm³ engine vehicles. The 1,000 cm³ engine vehicles are the symbol of the Brazilian automotive (12), known as "popular vehicles", and they are the cheapest automobile that can be acquired (21,23).

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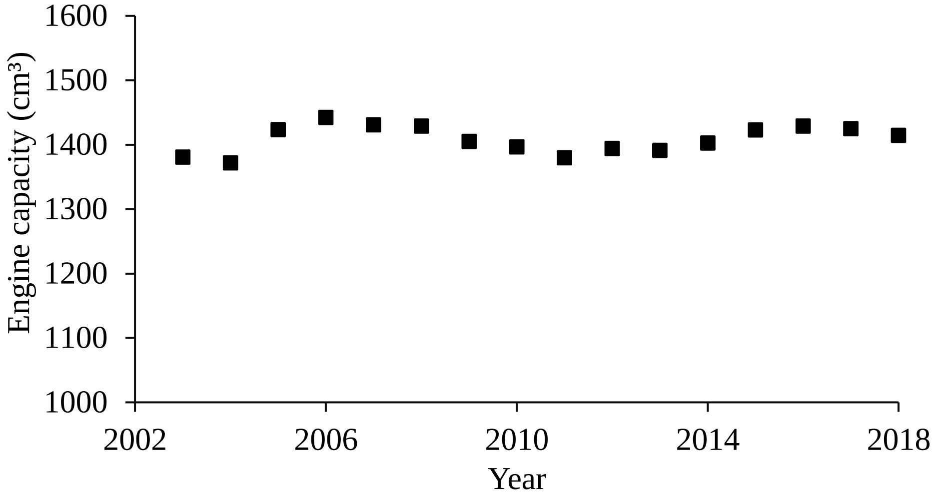
Figure 6. Average Brazilian fleet engine capacity in cm³



There was another cycle of an average increase of 2.5% in engine capacity from 2012 to 2016. The sales of all vehicles in this period had decreased, but the share of the 1,000 cm³ decreased more than the others. Vehicles with larger engines are bought for consumers whose income was not affected in the same proportion as happened those with lower income. After 2017, the decrease in engine capacity can be explained due to the introduction of downsizing in the fleet.

The average maximum power increased by 26% (84.8 hp to 106.9 hp) from 2003 to 2018, Figure 7. All engine capacity segments had their maximum power increased, although this pattern was non-linear. The most common engine, 1,000cm³, had its maximum power increased by 27% (61.1 to 77.7 hp) from 2003 to 2018. Bastin et al. (2010) inform that in the 1990s, 1,000cm³ engines in Brazilian cars had 50 hp as average power, and an average of 70 hp at the end of the 2000s. For 1,400cm³, 1,600cm³, 1,800cm³ and 2,000cm³ segments, the increase was 32% (83.0 to 109.1 hp), 16% (98.5 to 114.4 hp), 21% (107.1 to 129.9 hp) and 19% (127.2 to 151.0 hp) respectively. Understanding the average engine capacity and segment is relevant, for instance, when developing driving cycles to obtain data regarding emission and fuel consumption (24,25).

When evaluating the maximum specific power (i.e., the ratio between the maximum power and engine capacity) increased for all segments. For the average vehicle, the specific power increased by 24% in 15 years, from 0.061 to 0.076 hp/cm³. In the same

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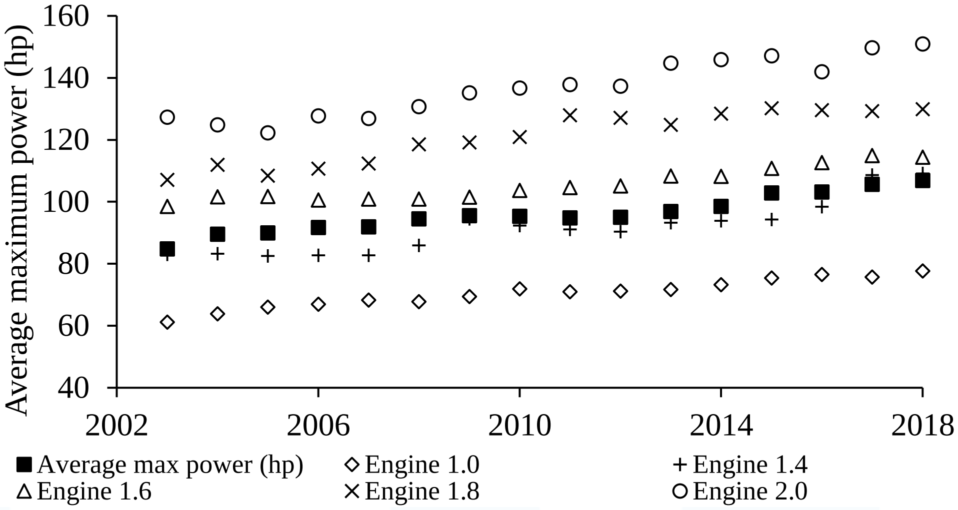
time period, for the 1,000cm³, 1,400cm³, 1,600cm³, 1,800cm³ and 2,000cm³, the maximum specific power increased 27%, 16%, 21%, 19%, and 32%.

Figure 7. Average maximum power for Brazilian cars



Results from Figure 6 and Figure 7 indicate the engine became more powerful for the same capacity. For instance, the 1,000 cm³ engines assembled in the Fiat vehicles, when fueled with gasohol presented the maximum power was 55 hp at 5,500 rpm, in 2003, with a compression ratio of 9.5. The engine was updated in 2004 becoming flex-fuel, producing 64 hp at 6,000 rpm with a compression ratio of 11.65. This engine was modernized in 2010, the maximum power was increased to 72 hp at 6,250 rpm with a compression ratio of 12.3. Finally, in 2016, a new 1,000 cm³ engine has been developed called Firefly. The maximum power decreased to 71 hp at 6,250 rpm, but the compression ratio was higher (13.2). The same pattern has happened for other companies, in which the engine became more efficient over the years, with the adoption and development of newer technologies.

3.6 AVERAGE WEIGHT AND LENGTH

The average weight increased by 12%, from 1,016 kg in 2003 to 1,138 kg in 2018 (Figure 8). Weight directly affects the power needed to accelerate the vehicle and to overcome tire-rolling resistance, and thus affects fuel consumption (26,27). It is considered that 10% of weight reduction in a vehicle decreases its fuel consumption by 6 – 7% (28). Figure 8 shows that every engine capacity segment had increased the average weight. The 1,000 cm³, 1,400 cm³, 1,600 cm³, 1,800 cm³, and 2,000 cm³ had become heavier in 10%, 25%, 7%, 16%, and 13%, respectively. The increase in vehicle weight is a consequence of several factors, as previously described in the analysis of the Brazilian car registration.

Figure 8. Average weight of Brazilian cars

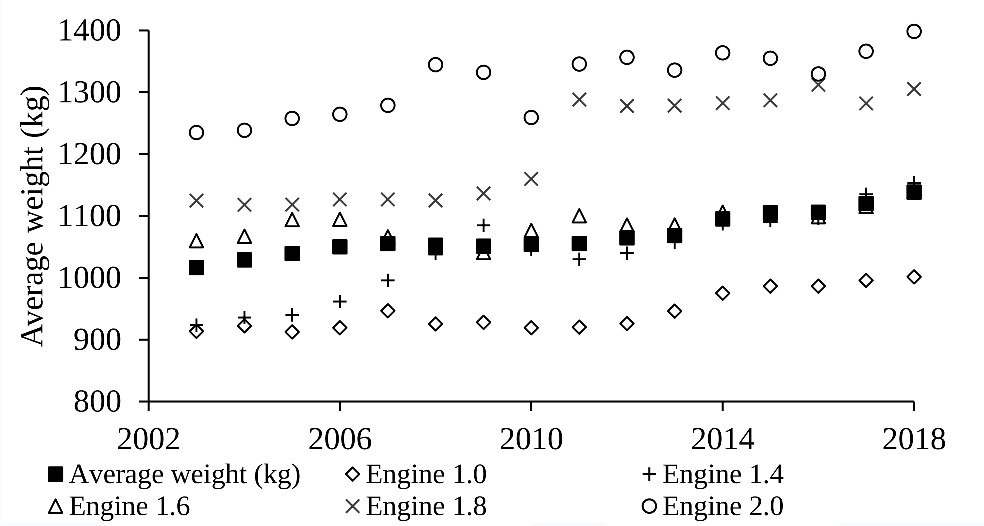


Figure 9 shows the share of new cars sold in different weight intervals. From 2003 to 2018, the share of vehicles weighing less than 1,000 kg has greatly decreased, while the cars between 1,000 kg and 1,250 kg have increased and are now the largest share. Cars with more than 2,000 kg are not representative in the Brazilian market. This trend is found when evaluating the weight of the most sold vehicle yearly from 2003 to 2013, Volkswagen Gol increased its weight from 850 to 960 kg. In 2014, Fiat Palio was the most-sold vehicle in Brazil, weighing 935 kg, and from 2015 to 2018, the most-sold car was the GM Onix, varying from 1,011 to 1,092 kg (29).

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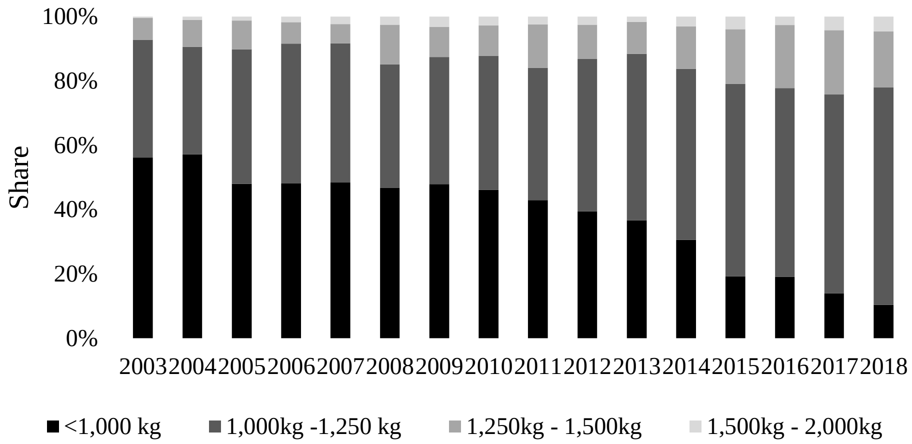
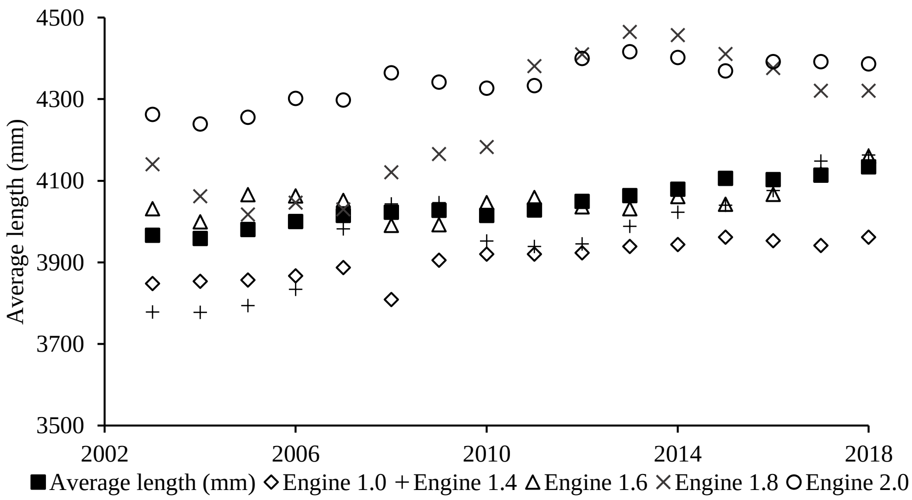
Figure 9. Weight share of the 50 most sold vehicles in Brazil



The average length of the fleet has increased by 4.2% from 2003 to 2018 (from 3,966mm to 4,134 mm). The same pattern happens in every engine segment, as the 1,000 cm³, 1,400 cm³, 1,600 cm³, 1,800 cm³, and 2,000 cm³ had become larger in 3.0%, 3.2%, 4.4%, 2.9%, and 10.2%, respectively. The average length increase confirmed the effects of consumer preference in acquiring SUVs (larger vehicles). Although cars had a length increase in their segment, the most significant increase happened in the 1,400 cm³, dominated by small hatches in 2003 and gradually switched towards SUVs and small sedans in the last years.

Figure 10 - Average Length of Brazilian cars



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4 EMISSION AND FUEL CONSUMPTION

In this section, there are results and discussion for data related to emission and fuel consumption for Brazilian PCs. This time span evaluated comprise from 2013 to 2018. Before 2008, there was not an official program responsible to measure emissions and fuel consumption in Brazil. The enrollment of the automakers was almost null when the PBEV program was launched, and increased yearly following the mandatory enrollment target that also increased. The share of PCs increased every year until all the 50 most sold vehicles had been tested in 2018.

4.1 EMISSION OF CARBON DIOXIDE (CO_2)

The average CO_2 emissions for gasohol as fuel in Brazil decreased from 110.5 to 108.3 g/km from 2013 to 2018 (Table 1). Those values consider only the fossil fuel share present on the gasohol (E22), because the CO_2 emission of the 22% volume of ethanol is considered zero (12). The 108.3 g CO_2/km would be equivalent to 138 g CO_2/km, if considered the CO_2 emitted from the ethanol (30). There was no maximum value defined in law concerning CO_2 emissions for the vehicles in Brazil.

Table 1. Average CO2 emission for the fleet and engine categories

Carbon dioxide - CO_2 emission (g/km)

	Share of cars analysed	Fleet Average	1,000 cm³	1,400 cm³	1,600 cm³	1,800 cm³	2,000 cm³
2013	68%	110.5	101.1		114.4		134.3
2014	65%	110.3	101.7	103.4	111.3		136.6
2015	74%	110.9	100.6	112.6	111.8		132.6
2016	93%	112.7	100.3	113.9	112.5	123.9	136.2
2017	96%	107.9	95.5	107.3	111.3	120.8	135.2
2018	100%	108.3	95.7	108.7	109.9	118.4	129.4

The result for the engine’s categories for the first years (2013 – 2015) should not be considered without further regard, as there were models not tested, and some of the older models were retired or modified because of the requirements applied from 2014, as previously discussed. The CO_2 emission has decreased in all segments except for the 1,400 cm³ engine vehicles. The emission value for 2014 was already less than the fleet average emission in 2018, but several models were not tested at the time. After 2016, in which more than 93% of the fleet was tested, it is possible to verify a consistent decrease in CO_2 emission for all engine classes. Thus, from the results it is possible to imply that during the Inovar-Auto policy (Figure 2, Interval 3) there was a decrease in CO_2 emission.

Inovar-Auto was launched in 2013 as a voluntary program, and to receive a tax reduction, the manufacturer should participate in Brazil's Vehicle Labeling Scheme (PBEV). In PBEV, PC were submitted to a standardized test that recorded the energy efficiency. If their fleet average energy efficiency increased 12% during the program period, the automaker was qualified for the tax incentive. If the improvement were higher than 15.46% or 18.84% there was a further 1% or 2% reduction in the IPI tax, respectively (31–33). The program is still active and provides an official source of information about fuel consumption and emission, encouraging competition among the companies (23).

Voluntary measures are easier to be implemented by the government and to be adopted by the automakers, but is argued that the voluntary measures led to a slower improvement of the overall energy efficiency. If the program was mandatory, automakers would be required to comply with the regulations and reach stricter fuel consumption targets. The European Union and countries in which the emission program was mandatory (*e.g.*, USA, Japan, China, Canada) presented higher improvement when compared to countries in which the program was voluntary (19,34).

4.1.1 Emission of carbon monoxide (CO), non-methane hydrocarbon (NMHC), and nitrogen oxides (NO_x)

The emission of other relevant pollutants, CO, NMHC, and NO_x, are required to be measured under the current law for emissions in Brazil, PROCONVE Phase L-6. The CO emission limit for passenger cars is 1.3 g/km, and the average obtained for the PCs is under the legislation limit. The Euro VI limit for the CO is 1.0 g/km. NMHC emission were steadily decreasing for the average and for every category in the last years, and all results are under the legislation limit: 0.05 g/km. The NMHC emission limit in Europe for passenger cars is 0.068 g/km in Euro VI. The last emission evaluated is nitrogen oxides (NO_X). In this case, all the values decreased in the last years and the value is under the limit of 0.08 g/km for all categories. The NO_x limit in Europe for passenger cars is

0.060 g/km. Finally, the vehicles are complying with the current law in both regions.

Table 2. Average emission of relevant pollutants

CO, NHMC, and NO_x emission in 2018 (g/km)							
	Share of cars analysed	Fleet Average	1,000 cm³	1,400 cm³	1,600 cm³	1,800 cm³	2,000 cm³
CO	100%	0.378	0.370	0.403	0.360	0.442	0.354
NHMC	100%	0.020	0.022	0.019	0.019	0.014	0.020
NO_x	100%	0.019	0.018	0.018	0.017	0.020	0.025

4.2 URBAN AND ROAD FUEL CONSUMPTION

The average urban fuel consumption for the fleet, Table 3, has slightly improved from 2013 to 2018 (-3.4%) while the average road fuel consumption has remained similar (-0.1%). The urban fuel consumption decreases for all vehicle segments, except for the 1,400 cm³ engine, in which this parameter followed a different pattern explained in the CO_2 emission subsection. From 2016 to 2018, the urban and road fuel consumption for all vehicle categories had improved. Considering all vehicles studied, the urban and the road fuel consumption are highly correlated to the CO_2 emission (r = -0.95 and r = -0.94), since the Brazilian vehicles depend on internal combustion engines. As it happened regarding the CO_2 emission, fuel consumption improvement can be also considered a result from the Inovar-Auto program. Overall, PBEV and Inovar-Auto are considered an important step to improve the energy efficiency of Brazilian vehicles, since the program was needed to improve the energy-inefficient fleet. (19,34).

Table 3. Average fuel consumption for urban and road condition

	Urban Fuel Consumption (L/100km)						Road Fuel Consumption (L/100km)					
Year	Fleet avg.	1,000 cm³	1,400 cm³	1,600 cm³	1,800 cm³	2,000 cm³	Fleet avg.	1,000 cm³	1,400 cm³	1,600 cm³	1,800 cm³	2,000 cm³
2013	8,85	8,20		9,17		10,75	7,41	6,90	6,90		7,75	8,55
2014	8,85	8,26	8,33	9,01		10,75	7,41	6,99	6,99	7,04	7,52	8,62
2015	8,77	8,13	8,85	8,93		10,53	7,46	7,46	6,94	7,87	7,63	8,62
2016	8,85	8,06	8,93	9,09	9,90	10,75	7,52	7,52	6,90	7,81	7,58	8,85
2017	8,62	7,63	8,47	8,93	9,62	10,87	7,35	7,35	6,67	7,35	7,58	8,70
2018	8,55	7,63	8,62	8,77	9,52	10,20	7,35	7,35	6,67	7,46	7,52	8,62

4.3 ENGINE AND VEHICLE PARAMETERS AND THEIR INFLUENCE ON EMISSIONS AND FUEL CONSUMPTION

In this section, it was considered data from 2016 to 2018 to evaluate the influence of engine and vehicle on the CO_2 emission and fuel consumption. It was obtained a moderate correlation between CO_2 emission and engine capacity (r = 0.75). The emission disperses within the engine capacities segments existent (there are 68 vehicles equipped with 1,000 cm^3 engine) and their emission varies from 86 g CO_2/km to 117 g CO_2/km. The emission high dispersion pattern also occurs in the 1,600 cm^3 segment, from 91 to 135 g CO_2/km. The elevate dispersion implies that engines in same capacity do not perform and emit similarly, and it is not possible to select only one engine to represent the emission of a category.

The maximum power is moderately correlated to the emission (r = 0.75). This probably happen because all the vehicles are evaluated using the same type-approval procedure (standard driving cycle). In general, the vehicle uses as lower power as possible to achieve and/or maintain the required speed during the certification test. The power required during the certification test is considerably lower than the maximum power available in the most vehicles. In addition, according to the Brazilian procedure, if not specified by the automaker, the speed for changing gears is with manual gearbox is fixed (e.g., shifting from the first to the second gear when speed is 25 km/h). Therefore, emission should not be also related to the Brazilian PC average power

Another case of moderate correlation was found between the weight and the emission (r = 0.79). As expected, a heavier vehicle should consume more fuel and emit more CO_2 (Figure 10). However, when evaluating the average CO_2 emission and the average weight (Figure 8 and Table 1), it was found that the average emission of the fleet is decreasing even with the increase of the weight. For instance, in the period (2013 – 2018), the average weight for 1,000 cm^3 vehicles increased from 946 kg to 1,001 kg, while the CO_2 emission decreased from 101 g CO_2/km to 95 g CO_2/km. A similar result happened for 1,600 cm^3; the emission decreased from 114 g/CO_2 to 110 g/CO_2 while the average weight increased from 1,085 kg to 1,138 kg. The improvement of the fuel consumption and emission surpassed the increase in the weight of the car. A higher emission decrease could be expected if the average weight of the vehicles had decreased.

When evaluating NHMC, NO_X, and CO, it was not found any relevant correlation with average weight, average maximum power, engine capacity, or another emission parameter previously evaluated in this study. The absence of a correlation is by some means expected, as it should be considered the complex process of yielding those three by-products in the engine. Aspects such as the angle of valve opening, air/fuel ratio, catalyzer efficiency influence the pollutant result.

Based on all the data and analysis performed in this study, it can be verified that the fuel consumption and emission of Brazilian vehicles have slightly improved over the last years. It may be considered that Inovar-Auto program accomplished success in their intention of capturing the automakers' attention to provide a better fuel economic vehicle, while providing new variables for the consumer to analyze. Despite the improvement of the fuel consumption in the vehicles, little of the most innovative and employed technology regarding improvement of the energy efficiency in the world has been applied in Brazilian vehicles, and therefore it is possible to improve.

In 2018, only eight among the 50 most sold models had the turbocharged technology (Volkswagen TSI engine models: Polo, Virtus, Up, and Tiguan; GM Tracker, and GM Cruze Sedan; the most expensive version of the Honda Civic and Peugeot 208). This technology was more exclusive, available only in premium PCs. In general, PCs equipped with turbocharges present fuel direct injection, another technology accountable to increase the energy efficiency up to 15% (19), while all the ICE models have the cheaper indirect multipoint fuel injection system. Other technologies relevant to improve the energy efficiency as the cylinder deactivation are not available for any one of the models evaluated in this study, from 2003 to 2018. Additionally, little has been done regarding hybrid vehicles (only Ford Fusion Hybrid and Toyota Prius were available in the last 15 years) and nothing regarding electric vehicles.

From the results obtained from the average price and new PC registrations, it may be inferred that purchasing an expensive vehicle is a challenge for the average Brazilian citizen. Brazilian customers are prone to purchase cheaper vehicles, even if the vehicle has less energy efficiency technology or absence of advanced technology on board. Therefore, inserting expensive technologies may refrain the desire and the possibility of acquiring a new PC. Government and automakers need to study the impact of those technologies on the consumer desire and capacity for acquiring a new PC. This may be provided through policies and taxes (3), to provide a national fleet compromised with the actual worldwide emission and fuel consumption regulations and to ensure the companies adequate profit margins for them to motivated to sell in the national market.

5 COMPARING THE BRAZILIAN AND EUROPEAN AVERAGE CAR

In this section, Brazilian and European key technical parameters are compared. As there are significant differences between Brazil and Europe, parameters should not be compared without further considerations. Additionally, the average European is not uniform across the countries. Generally, the northern and richest EU countries have heavier and more powerful cars than the southern ones (6). For all the discussion, it is presented the average European in 2018 (35), comprising diesel and gasoline share, while the Brazilian average car is for 2018.

5.1 CAR FLEET AND REGISTRATION

In 2018, less than 1.4% of the passenger cars sold in Brazil were diesel-fueled engines, while Europe had a large proportion of diesel cars in their fleet (36%). Diesel-engine share in the EU PCs market were higher in 2011 and 2012, 55%. The decline in the Diesel car sales could be related to Dieselgate scandal, as are customers could refrain that their vehicles could suffer ban restrictions in urban areas (35). The share of hybrid and electric in EU was 5.7 %, varying among European countries, as in Norway around 60% of new PCs were electric/hybrid. In Brazil the sum of electric and hybrid cars sold was always less than 0.1% of the total, highlighting that this technology had not arrived and it is far from consolidation. Energy transition to hybrid and electric powered vehicles in Europe and Asia is happening for several factors, as provide a more energy efficiency fleet imply in a lesser dependence on foreign sources (12).

In 2018, five countries were responsible for 75% of the registrations in Europe: Germany (41.4) PCs per 1,000 inhabitants, UK (35.6). France (32.4), Italy (31.7), and Spain (28.2), that are also the countries with more inhabitants. Pcti values across European countries are substantially higher than in Brazil (8.2 PCs per 1,000 inhabitants). Difference in the registration of new cars can be related to the higher purchasing power of the European citizens.

5.2 PRICE

Comparing the price of the Brazilian and European car in December 2016, the unadjusted average price for the Brazilian was R$ 58,794 (US$ 1 = R$ 3.38) or US$ 17,394.67. On the same date, the average European car costed EUR 28,114 (1 EUR = US$ 1.05) or US$ 29,519. Average price also varies in Europe, from EUR 22,442 (Greece) to EUR 42,663 (Norway). The Brazilian car is 41% cheaper than the European, but when considering the purchasing power parity (PPP) per capita, the Brazilian needs 1.22 years of salary to purchase their average car, while for the European the time is 0.72 years (36). Due to the ratio income/car price, if Brazilians car prices are increased, customers are more proportionally affected. It should be highlighted that in every year, the most sold vehicle was a 1,000 cm^3 engine version, indicating that the vehicle price is relevant in the acquisition process. It may be inferred that average Brazilian customer would not be willing or capable to pay more for a vehicle with more technologies, deciding for the cheaper vehicle or purchasing a used vehicle.

5.3 ENGINE CAPACITY AND POWER

In Europe, from 2001 to 2018 there was a decrease of 9% in the average engine capacity, to 1550 cm^3 (35). This happened following the decrease in the cylinder number, as cars with 6-cylinders were replaced by 4- or 3-cylinder, to fulfill stricter emission targets and to decrease costs. Also, improved combustion and presence of turbocharged engines improved engine maximum power. Despite the decrease in the European engine capacity, its average value in 2018 is still higher than the Brazilian (1414 cm^3) that had increased over the last years. Brazil has never had 6-cylinder engines culture, PCs

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contained 4-cylinder engines, although recent 1,000 cm³ are 3-cylinder engine. It may be suggested that the increase in the Brazilian engine capacity is from the sales of more expensive vehicles, that contain larger engines. In the third time interval (Figure 2) the decrease in PC registrations have not affect the richest customers as effected the average.

In Europe, the average power increased by 33% (from 98.6 to 131.4 hp) from 2001 to 2018 considering both the gasohol and diesel power engines in the passenger car fleet (ICCT, 2019). However, there are disparities among average power of European countries, varying from Greece and Italy (<110 hp), Germany and France (~145hp), to Luxembourg, Norway and Switzerland (>165hp). The average power for the Brazilian car increased less, 21% in the same time span, and the average maximum power is lower than every European country: 107 hp. The specific power for the Brazilian vehicle (0.076 hp/cm³) is lower than for the European (0.085 hp/cm³). However, in Europe the specific power varies from 0.074 to 0.098 hp/cm³, in which Italy, Greece and Turkey had the lower values while Switzerland, Germany, Sweden and Netherlands have higher specific power.

5.4 WEIGHT AND LENGTH

Tietge et al. (2017) showed an increase of 10% in weight in European cars from 2001 to 2015 and an average weight (mass in running order) of 1,397 kg in 2018. Average weight varied among European countries from 1227 kg (Greece) to 1607 kg (Norway). All European countries presented heavier cars than the Brazilian average car, 1,138 kg. The absence of diesel, hybrid, and/or electric vehicles could be the main reason for Brazilian vehicles to be lighter. European vehicles presented an average length of 4,320 mm. Length varied between 4,106 mm (Greece) and 4,579 mm (Sweden). Brazilian Vehicles were in average 4,134 mm. PC segments sales in Europe comprise larger vehicles, and nearly 35% of the vehicles sold were SUV. In Europe and in Brazil, SUV sales had increased almost eight times from 2001 to 2018. However, size of vehicle segments differs, as European lower medium is the Brazilian medium hatchback, for instance.

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5.5 CO2 EMISSION

The average value for the European cars on NEDC was 120 g/km. Norway had obtained an emission significant lower than all countries (74 g/km), benefitted by the higher amount of electric/hybrid vehicles in its fleet. Few countries had values higher than the average, but Germany (128 g/km) and UK (127 g/km) influence the overall result due to the higher registration of vehicles. New European Driving Cycle (NEDC) was the type-approval test procedure in Europe until 2018, when it was replaced by the Worldwide harmonized Light Vehicles Test Procedure (WLTP). In general, results from NEDC are lower than WLTP, highlighting that the transition is important for providing accurate data regarding the fleet emission (37,38)

Emission in Brazil was in average 108.3 g/km in 2018, and this value would be 138 g/km if CO_2 emitted from ethanol share in fuel was considered. The type-approval test is performed on the EPA cycles: FTP-75 for city standard, and HWFET for highway, the results are adjusted for Brazilian conditions; therefore, results from Europe and Brazil are measured on distinct basis. Regarding fuel consumption, Brazilian vehicles consumed more fuel compared to Europeans (Table 6). This difference is caused both by the lower energy efficiency and by the different fuels used.

There is less fuel efficiency technologies on Brazilian vehicles when compared to European fleet (absence of: hybrid and electric vehicles, 6-speed transmissions or higher, turbocharging, continuous variable transmission, variable valve technology). The utilization of these technologies can provide energy saving from 20% up to 50%. In 2013, Brazilian average PC consumed about 18% more than the Japanese car. Despite the absence of technologies, the Brazilian lighter vehicle was more efficient than the heavier Chinese, South Korean, and American vehicle (12).

The results in Table 6 summarized the average values for passenger cars in Brazil and Europe. In general, Brazilian cars were cheaper, lighter, shorter, less powerful, and consumes more fuel. The increase in the average engine power, vehicle weight, and length have been similar for Brazil and Europe during the studied period.

Table 4. Summary of parameters for Brazilian and European Passenger cars fleet

	PC Brazil [a]	PC Europe [b]
Price (US$)	$ 17,394	$ 29,519
PPP per capita (US$) [c]	$ 14,256.16	$ 40,553.12
Weight (kg)	1,138	1,397
Length (mm)	4,134	4,320
Engine capacity (cm^3)	1,414	1,550
Maximum power (hp)	107.0	131.4
Maximum torque (kgf.m)	14.7	-
Urban fuel consumption (L/100km)	8.5	6.2
Road fuel consumption (L/100km)	7.3	4.5
CO_2 emission (g/km)	108	120

[a] – Data for Brazil are from 2018 using fuel data related to E22 composition, considering Brazilian driving cycle

[b] – Data for European cars are from 2018 and considers diesel and petrol cars in NEDC cycle.

[c] – Data from 2016 according The World Bank website.

6 CONCLUSION AND POLICY IMPLICATIONS

In this study, it was presented the Brazilian passenger car fleet evolution from 2003 to 2018. The Brazilian vehicle market is different from high-income and motorcycle-oriented countries, therefore any comparison with other car markets should be done carefully. Brazilian vehicles became more expensive over the years, although this fact was not sustained when the customer index price (IPCA) was considered. Vehicle characteristics also considerably changed during the time studied, as engine capacity, maximum power, and average weight have increased. The CO_2 emission decreased for all the fleet and the fact was more pronounceable in the last three years in which the majority of vehicles was tested. CO, NMHC, and NOx emissions were within legislation limits. For the fuel consumption, the vehicles in all segments became slightly more energy efficient in the urban and road tests.

Despite all the modest results obtained during Inovar-Auto program, the program was considered necessary to initiate a local culture about energy efficiency and emissions. Even with the program not being mandatory, all the manufacturers could achieve a reduction in the emission of the fleet. As result, there is a culture about energy efficiency and next targets should be ambitious. In 2018, the government launched an automotive policy program to substitute Inovar-Auto, Rota 2030 (Federal Law nº 13,755/2018). The Rota 2030 program is expected to provide new mandatory energy efficiency goals for

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national and imported vehicles, incentives for R&D, to provide tax reductions for hybrid and electric vehicles, also not violating the regulations from the World Trade Organization. It will be mandatory for all companies to submit their vehicles to PBEV labelling program. After these results, new energy efficiency targets will be set considering the current market situation. Also, the emission control program (PROCONVE) that is actually in the phase L6 (an equivalent of Euro 5), is expected to be updated to phase L7 (towards the Euro 6 regulation) after 2022 (Federal Law nº 492/2018). The modernization of the fleet through the adoption of most advanced technologies should enable Brazilian vehicles to be energy efficient, considering aspects as the financial differences between Brazil and Europe.

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GLOSSARY

ANFAVEA - Brazilian National Association of Vehicle Manufacturers (in Portuguese: Associação Nacional dos Fabricantes de Veículos Automotores)

FENABRAVE – Brazilian National Federation of Distribution of Automotive Vehicles (in Portuguese: Federação Nacional da Distribuição de Veículos Automotores)

FIPE - The Institute of Economic Research Foundation (in Portuguese: Fundação Instituto de Pesquisas Econômicas)

FTP-75 - Federal Test Procedure

HWFET - Highway Fuel Economy Test Cycle

IBGE - The Brazilian Institute of Geography and Statistics (in Portuguese: Instituto Brasileiro de Geografia e Estatística)

IPCA – Customer Price Index (in Portuguese: Índice Nacional de Preços ao Consumidor Amplo)

IPI - Tax on Industrialized Products (in Portuguese: Imposto sobre Produtos Industrializados)

NDC – National Determined Contributions (NDCs)

NEDC - New European Driving Cycle

PBEV – Brazilian Vehicle Labeling Scheme (in Portuguese: Programa Brasileiro de Etiquetagem Veicular)

PROCONVE - Motor Vehicles Air Pollution Control Program (in Portuguese: Programa de Controle da Poluição do Ar por Veículos Automotores)