Study of the effect of general vehicle powertrain specifications on consumption and CO2 emissions

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Abstract

Currently, a high percentage of vehicles circulating primarily on the roads of Latin America use internal combustion engines as their source of propulsion, still relying on fossil fuels due to their ease of refueling. Although alternative technologies such as hydrogen and electric propulsion exist, implementing these mechanisms still requires widespread technological deployment, which many countries are still working towards. Additionally, these forms of energy generation have environmental impacts that, when combined with the technological implementation, result in a significant environmental footprint that cannot be ignored.

The present study analyzes the effects of specific characteristics of the powertrain, such as engine displacement, number of cylinders, type of transmission, type of fuel, and type of car body, to determine their influence on fuel consumption and carbon dioxide emissions released into the environment. Moreover, the study identifies variables that could be considered to reduce the impact caused by conventional technologies. It is necessary to reconsider the use of internal combustion engines in light of their ease of refueling and high power-to-weight ratio, as they may not be the best long-term solution.

Although electric vehicles have been considered to have zero emissions during their operational phase, thanks in part to larger battery sizes, it is necessary to reevaluate this theory in countries where energy production relies on coal-powered plants, such as hydroelectric plants.

Key words

Internal combustion engine, engine architecture, consumption, emissions.

Introduction

The internal combustion engine since its inception has been conceived in such a way that it manages to convert the greatest amount of chemical energy stored in the fuel into kinetic energy delivered by the crankshaft, however a large amount of this energy is "wasted" in the start-up of the auxiliary systems of the engine such as: cooling system, feeding system, lubrication system among others so only a fraction close to 25% is possible to use [1]. With the passage of time several strategies have been implemented on the internal combustion engine to reduce fuel consumption and with it the pollution generated however its original version and with respect to the most basic aspects have had very few changes. The combustion engine is based on 4 strokes: intake, compression, expansion and exhaust.

- Intake: The piston descends as the intake valve opens, allowing a mixture of air and fuel to enter the combustion chamber.
- Compression: The piston moves upwards, compressing the air-fuel mixture in the combustion chamber. At the same time, the intake and exhaust valves are closed.
- Combustion: When the piston is at the top of its travel, a spark ignites in the spark plug, causing the air-fuel mixture to combust. This generates an explosion that pushes the piston down with force.
- Exhaust: The piston moves upwards again, expelling combustion exhaust gases through the exhaust valve that opens. Then, the cycle repeats [2].

This 4-stroke process (intake, compression, combustion and exhaust) is continuously repeated to generate movement in the piston, which in turn drives the crankshaft and converts the linear motion of the piston into a rotary motion that is transmitted to the wheels of the vehicle, allowing the engine to produce energy and propel the vehicle forward. The physical space where the combustion process takes place is called displacement and clearly has an effect on the consumption of the engine however the arrangement that this volume has or the way in which it is occupied in 1 or several cylinders is an aspect to consider:

A special consideration deserves the compression ratio, as related studies have shown that an increase in the compression ratio from 18 to 20 has increased thermal efficiency by up to 29.5%, in addition it has been demonstrated a decrease in consumption and emissions of carbon monoxide (CO), hydrocarbons (HC), opacity and emissions of nitrogen oxides (NOX) [3][4].

Greater volume of air and fuel: A larger displacement engine has more space in the combustion chambers, which allows a greater amount of air and fuel to be admitted during the intake cycle. This results in a greater amount of fuel being burned during combustion, which in turn leads to higher fuel consumption. Increased internal friction: Larger displacement engines typically have larger, heavier pistons and other components, resulting in greater internal friction. This requires more energy to move engine components and can increase fuel consumption. Lower thermal efficiency: Larger displacement engines may have lower thermal efficiency because they may have a less favorable volume-to-surface ratio compared to smaller engines. This means that a greater proportion of the energy released during combustion is lost as heat rather than being used to produce mechanical work, which can result in higher fuel consumption.

However, it is important to note that the fuel consumption of an engine is not only determined by its displacement, but also by other factors such as combustion technology, compression ratio, fuel injection system, electronic engine management and driving style, among others. Advances in engine technology have made it possible to improve efficiency and reduce fuel consumption in larger displacement engines compared to older engines, so it is important to consider various factors when evaluating the fuel consumption of an internal combustion engine, which is why considering some of the relevant aspects within the power train seeks the existing relationship with fuel consumption and the generation of carbon dioxide[5].

Several studies have suggested that a reduction in consumption is possible using three different modes of combustion: spark ignition by stratified load (SCSI), spark ignition by homogeneous load (HCSI) and compression ignition with homogeneous load (HCCI), these technologies require direct injection, a flexible valve drive and have engine control based on cylinder pressure. As a result of these studies, it has been concluded that a provoked ignition engine (MEP) that uses these improvements can achieve a consumption equivalent to that of a compression ignition engine (MEC)[6]. Another aspect that has a significant effect on consumption and performance is the fuel used, in general, diesel engines tend to have higher fuel efficiency compared to gasoline engines. This is because diesel engines have a higher compression ratio and higher energy content in diesel compared to gasoline, allowing for better thermal efficiency and therefore lower fuel consumption per kilometer driven. Regarding the emissions generated, a compression ignition (MEC) engine tends to generate higher emissions of nitrogen oxides (NOX) and particulate matter (PM) compared to positive ignition (SI) engines due to the high temperatures and pressures that occur in the combustion chamber and the incomplete combustion of diesel [7].

According to this behavior with respect to the type of fuels, one of the widely used standards also reflects this condition in its tolerance values, Board 1

Board 1 Euro standards for MEP and MEC

Provoked ignition engines					
Stage	**CO (g/km)**	**HC (g/km)**	**HC+NOx (g/km)**	**NOx (g/km)**	**PM (g/km)**
Euro 1†	2,72 (3,16)	-	0,97 (1,13)	-	-
Euro 2	2,2	-	0,5	-	-
Euro 3	2,3	0,2	-	0,15	-
Euro 4	1	0,1	-	0,08	-
Euro 5	1	0,1	-	0,06	0,005
Euro 6	1	0,1	-	0,06	0,005
Compression ignition engines					

Euro 1†	2,72 (3,16)	-	0,97 (1,13)	-	0,14 (0,18)
Euro 2, IDI	1	-	0,7	-	0,08
Euro 2, OF	1	-	0,9	-	0,1
Euro 3	0,64	-	0,56	0,5	0,05
Euro 4	0,5	-	0,3	0,25	0,025
Euro 5a	0,5	-	0,23	0,18	0,005
Euro 5b	0,5	-	0,23	0,18	0,005
Euro 6	0,5	-	0,17	0,08	0,005

As can be seen in the Figure 1 CO2 generation has increased exponentially in recent years. Global energy-related CO2 emissions increased by 0.9% in 2022, reaching a new high of more than 36.8 Gt, with slower growth than the 6% increase recorded in 2021, due to the pandemic [8].

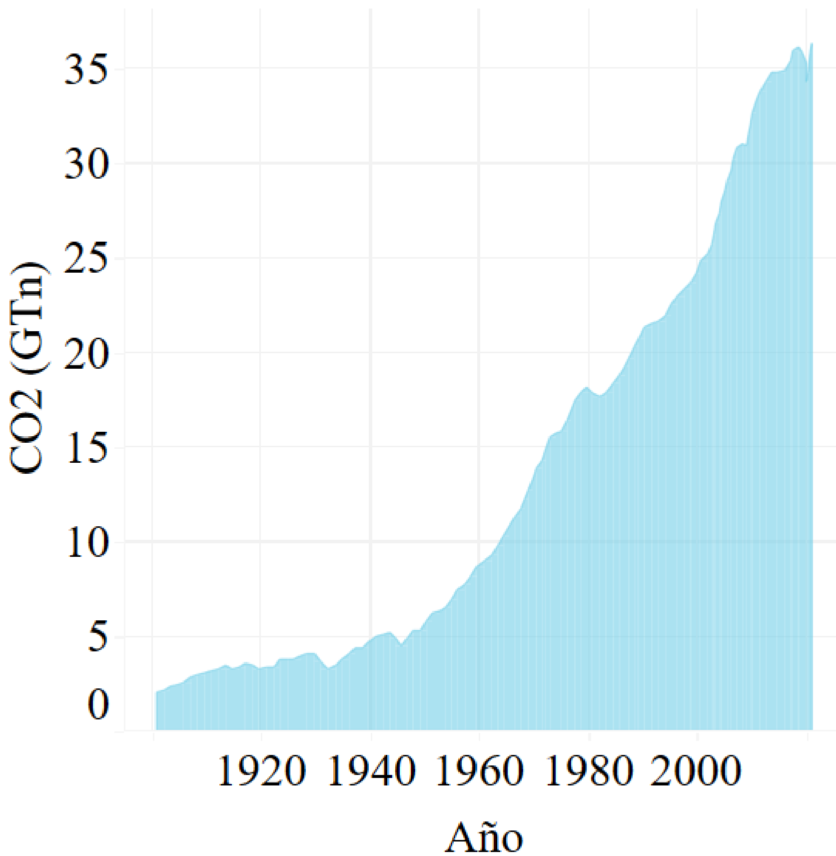

Figure 1 Amount of carbon dioxide emitted into the environment in recent years

The transport sector, one of the main consumers of energy with almost 30% of the total energy produced, has undergone certain changes within the fuels used. In the case of light transport, 92.6% of gasoline was used in 2000 to 82.6% in 2019, increasing the use of diesel from 6.2% to 16% in this same time gap. For cargo vehicles in 2000, 82.6% used diesel and in 2019, 89.5% of vehicles as shown in the Figure 2[8].

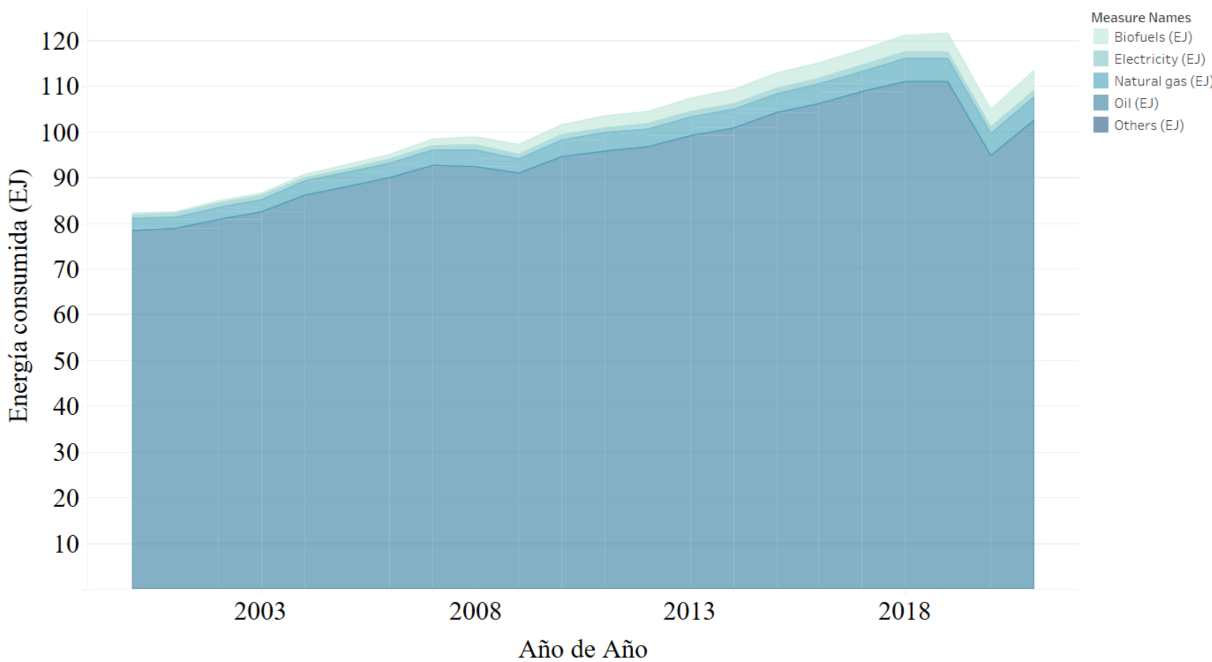

Figure 2 Consumption of different fuels according to the year and type of vehicles

From the data shown, it is interesting to know the effect of aspects related to the power train such as displacement, number of cylinders, type of transmission and fuel used on fuel consumption, so that these criteria can provide a starting line of the state of the art and indicate possible aspects that have been proven to be decisive in fuel consumption.

The design and construction of internal combustion engines and the power train of cars still have a series of challenges to meet, since their original version made by Nicolaus Otto and Rudolf Diesel, in view of their progress managed to mitigate the generation of exhaust emissions and consumption, while electric and hybrid vehicles manage to position themselves as an appropriate transport system. [9]. On the way to a wide use of this type of hybrid propulsion has also worked on alternatives that under the fundamental concepts of the internal combustion engine achieve with certain variants to offer a more appropriate design within the environmental point of view in such a way that internal combustion engines can still offer viable transport solutions.

Near-term advances in spark-ignition (SI) gasoline direct injection (GDI), cylinder deactivation, turbo size reduction) engine technology for passenger vehicles promise to generate significant fuel savings for vehicles of the immediate future. future. Similarly, trends in transmissions indicate higher gear numbers (8-speed, 9-speed), higher intervals, and a focus on speed reduction to improve engine efficiency. Dual-clutch transmissions, which show greater efficiency in lower gears than traditional automatics, are being introduced in the light-duty vehicle segment worldwide. Another development that requires low investment and provides immediate benefits has been the adaptation of start-stop technology (micro-hybrids or idle engine stop technology) in current vehicles. [10].

Methodology

The present study collects a sample of 7385 vehicles of a period of time of 7 years using the specifications provided by the factory of the vehicles, it is necessary to consider that obtaining experimental data of this group of cars is a very complicated task is for this reason why values provided by the brand for the elaboration of this study have been considered.

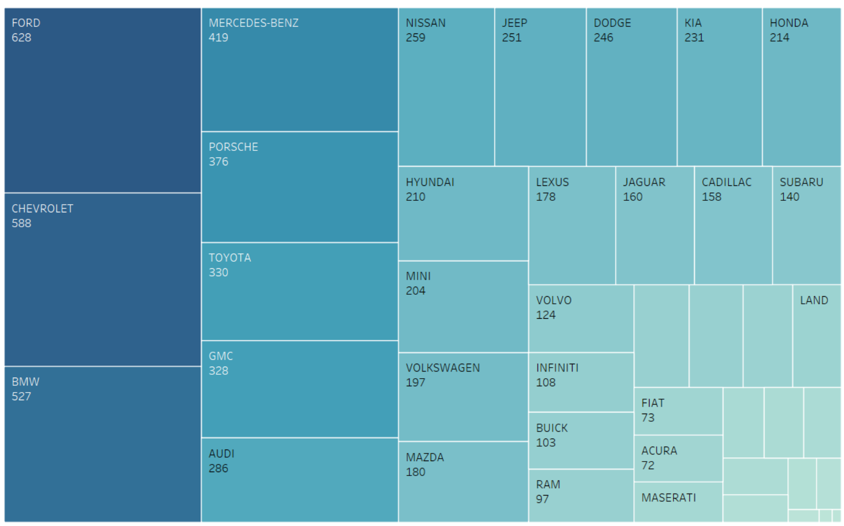

Figure 3 Brands and number of units studied

The Figure 4 shows the EnerGuide label of the Government of Canada the same one that was used to obtain the informative data of the vehicles studied.

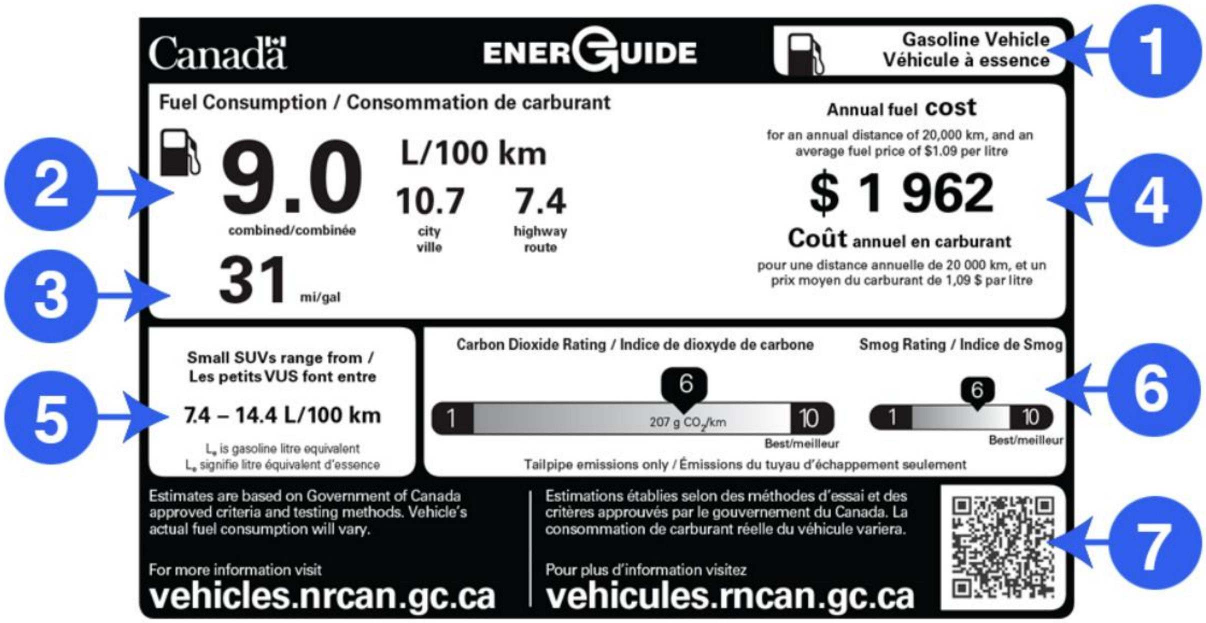

Figure 4 EnerGuide consumption measurement parameter label

The information recorded for each car is described under the following criteria.

1. Vehicle technology and fuel: The text and related icon identify the type of fuel used by the vehicle.

2. Fuel consumption: This is a featured classification of combined fuel consumption and separate city and highway fuel consumption ratings in liters per 100 kilometers (L/100 km). The combined rating reflects 55% city driving and 45% highway driving.

3. Fuel Economy: Here, the combined rating is expressed in miles per imperial gallon (mi/gal).

4. Annual fuel cost: This is an estimate based on the combined fuel consumption rating, 20,000 km driven and the indicated fuel price.

5. Vehicle Class Range: Shows the combined best and worst fuel consumption ratings of vehicles in the same class.

6. CO2 and smog ratings: These are vehicle tailpipe emissions of carbon dioxide (CO2) and smog-forming pollutants rated on a scale of 1 (worst) to 10 (best). CO2 emissions, in grams per kilometre travelled, are shown on the CO2 bar.

7. QR Code: The quick response code links smartphone users to Natural Resources Canada's fuel consumption index lookup tool.

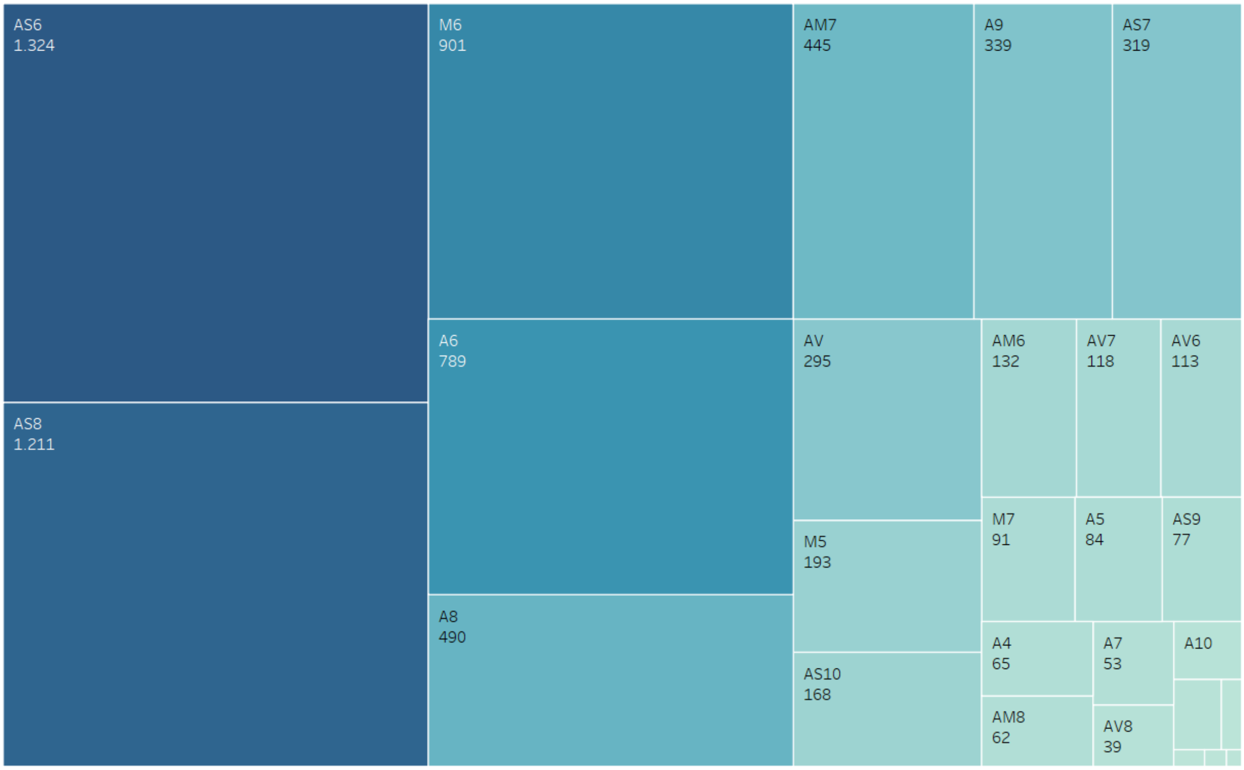

Figure 5 Types of transmissions present in the study

The Figure 5 shows the different types of transmissions present in the study under the following meaning of the acronyms: A Automatic, AM Robotic box, AS Tryptonic box, AV Continuous variable, M Manual, # Number of gears.

Results

This section presents some of the data obtained by tabulating the information collected.

In the Board 2 The efficiency in fuel handling for the different types of fuel used for the present study is shown, verifying the better efficiency of diesel, the main reason why many of the work vehicles mainly use this fuel. In addition, the amount of carbon dioxide, CO_2, emitted to the environment for each kilometer traveled is verified, demonstrating that natural gas, CH_4, has a lower affectation and on the contrary Ethanol (E85) the one that emits the most amount of CO_2 to the environment.

Board 2 Fuel efficiency expressed in litres/100km

Type of fuel	Consumption COMBINADO (L/100km)	Consumption Road (l/100km)	Consumption City(l/100km)	F CO2 (g/km)
Diesel	8,84	7,8	10,2	237,55
Ethanol (E85)	16,86	12	17,5	243,72
Gas Natural	12,70	9,5	15,2	213

Premium gasoline	11,42	8,4	11,5	236,94
Regular gasoline	10,08	7,8	10,6	220,39

In the Figure 6 The values of consumption and emissions of carbon dioxide generated according to the different brands studied are shown, to perform this analysis an average was made on all the values of the different models of vehicles produced, for this reason it is necessary to consider that there are brands that have historically built engines of larger dimensions reason why the amount of consumption and emissions is also deduced, The values of the average displacement of each maraca are shown in orange number on the Figure 6.

An additional analysis is made from the type of vehicle in the Figure 7, where Van types are the most widely consumed and

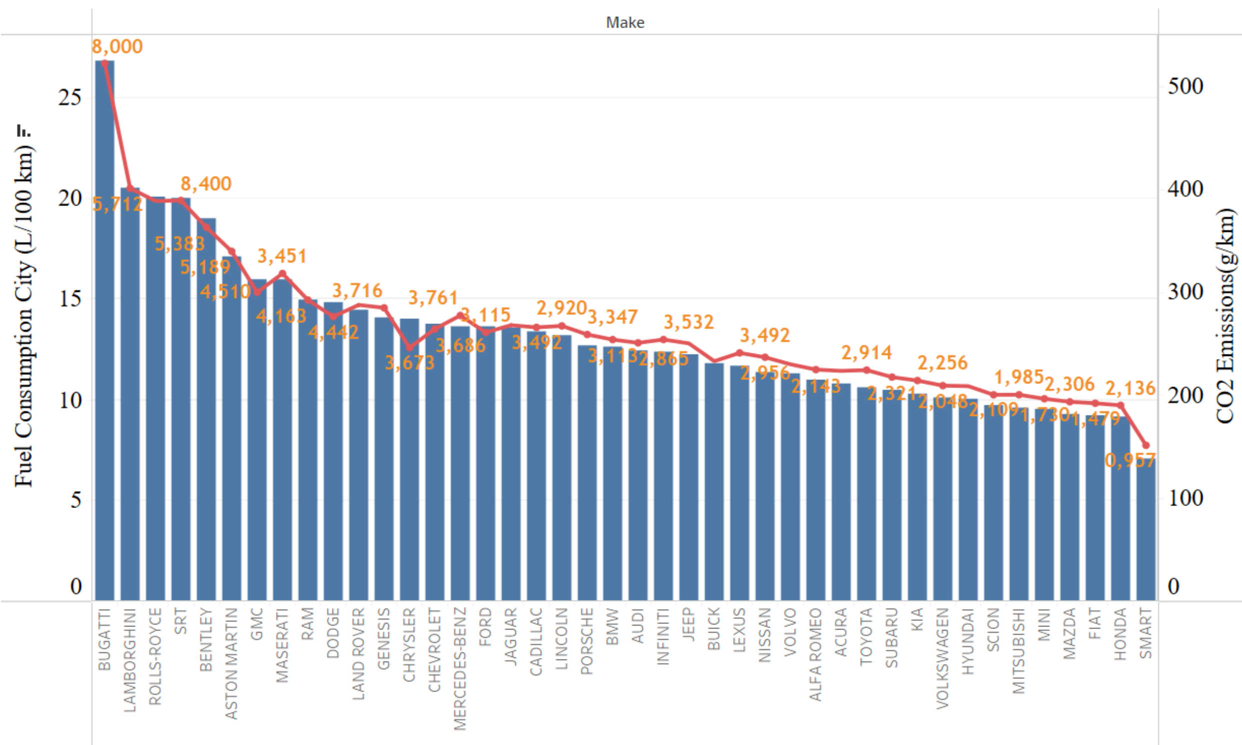

Figure 6 Consumption and CO2 emissions generated with respect to the different brands studied.

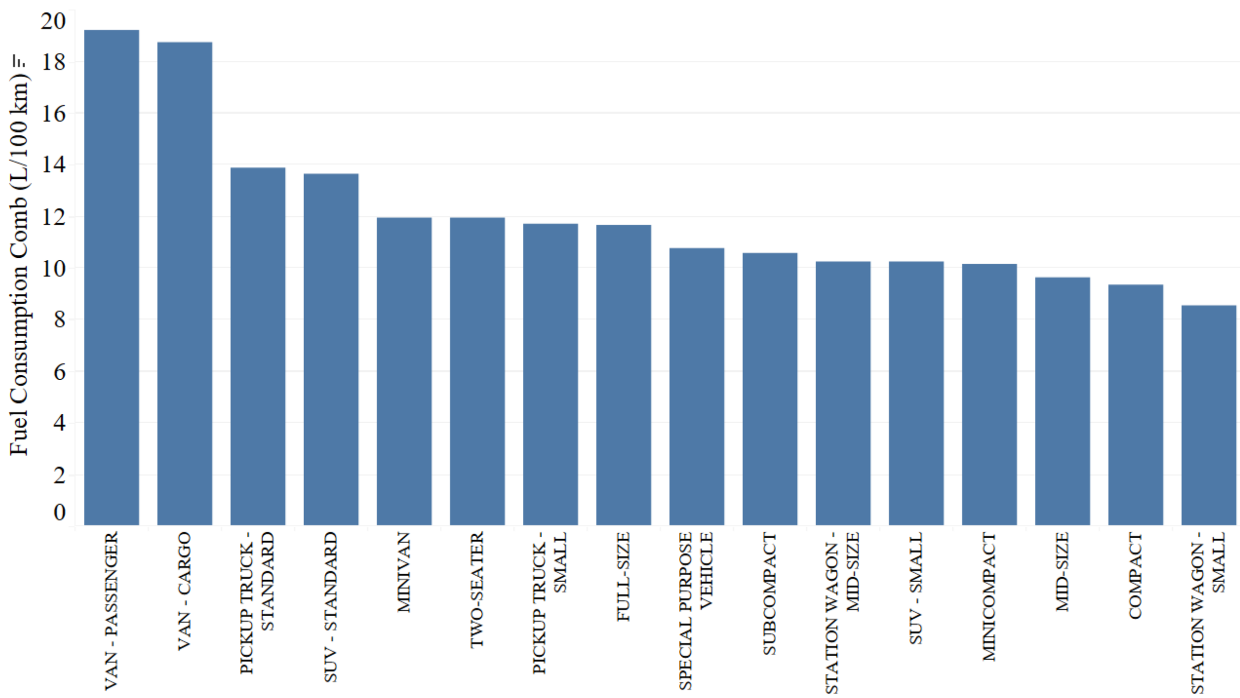

Figure 7 Consumption with respect to the type of vehicle

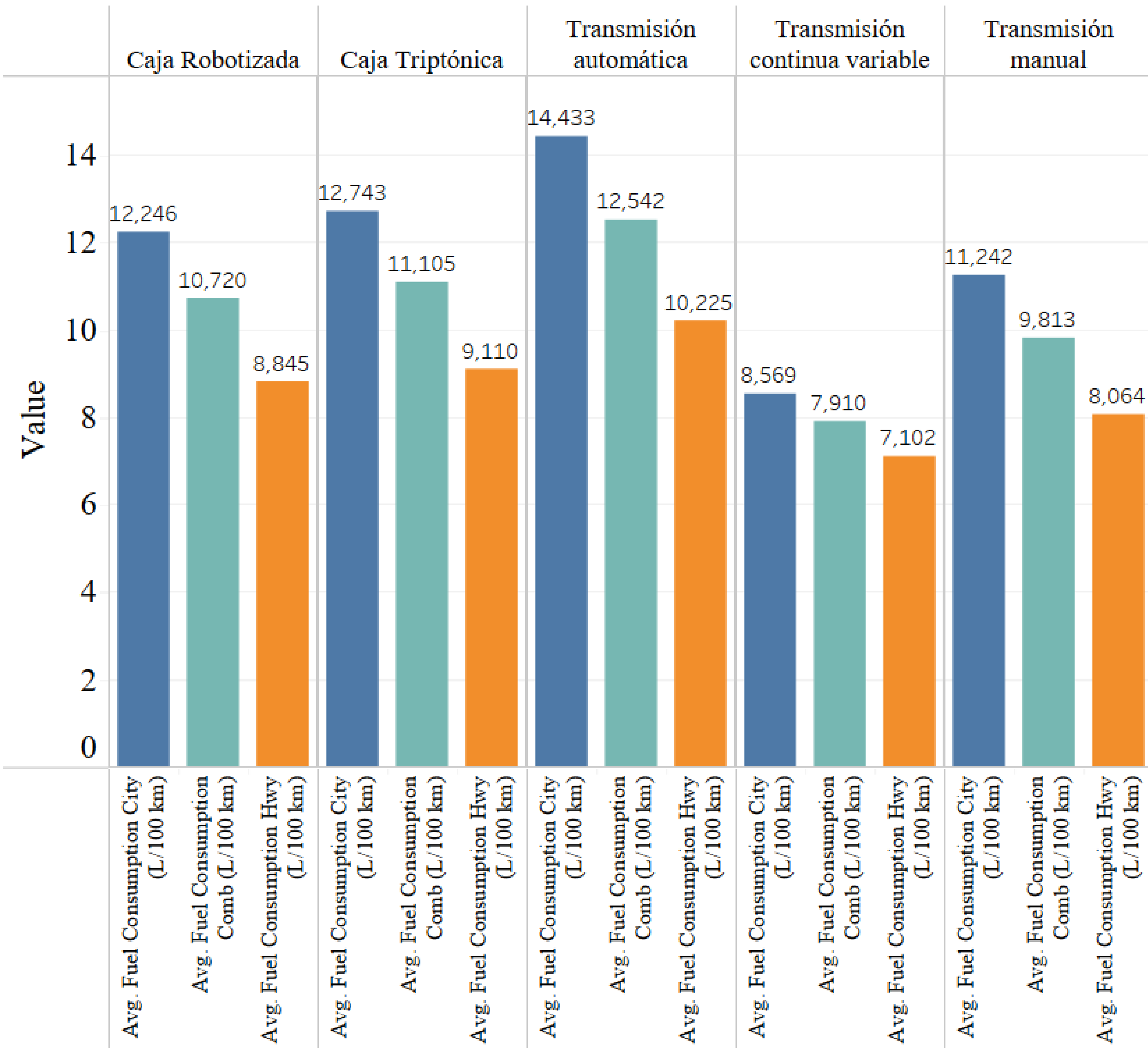

Figure 8 City, highway and combined performance of different transmission types

The Figure 8 It shows the consumption with the different types of transmission used, obtained from the vehicles analyzed, determining the clear dependence of the type of transmission, since it is this component of the power train that is responsible for adapting the characteristics of the engine to the geographical and road conditions of the locality.

Conclusions

The type of fuel that achieves the highest efficiency per kilometer traveled is diesel with 8.8 liters to reach 100 km, while premium and regular gasoline has values close to 10.5 liters to achieve the same distance.

The fuel that generates the lowest amount of mass of carbon dioxide is Natural Gas with 213 grams for each kilometer traveled and diesel produces 237 grams for each kilometer traveled and value very similar to premium gasoline and regular gasoline emits less carbon dioxide (220 grams) for each kilometer traveled.

Volumetrically, diesel is the one with the lowest consumption in the city and on the road with values of 10.2 and 7.8 liters per 100 km, in the case of gasoline it is slightly higher and ethanol with values of 17.5 and 12 liters per 100 km for city and road conditions respectively is the fuel with the highest consumption.

Luxury brands such as Bugatti, Lamborghini and Rolls' Royce are those that have on average higher fuel consumption and greater amount of emissions generated to the environment, presumably this is due to their large size of engines between 5 and 8 liters on average. On the contrary, Maza, Fiat, Honda and Smart are the ones with the lowest consumption and emissions, the latter with a consumption of 7 L / 100km and 150 grams of CO2 for each kilometer traveled.

The type of transmission also has an effect on fuel consumption, with the continuously variable transmission being the most consumed with 7.9 litres/100 km and the conventional automatic transmission the most consumed with 12.5 l/100km.

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