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STUDY OF EMISSIONS AND FUEL CONSUMPTION UNDER ALTITUDE CONDITIONS ABOVE 3000 M.A.S.L. IN LIGHT GASOLINE VEHICLES USING A REPRESENTATIVE DRIVING CYCLE

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Abstract

This research studies how altitude affects gasoline-powered light-duty vehicles by observing their fuel consumption and emissions through different driving cycles designed to represent different areas of Latin America. To carry out this study, four years of light-duty vehicle operating data were collected over a wide altitudinal range in Ecuador, and the most reliable data were selected. Then, various methodologies were used to construct driving cycles based on micro-trips, which were randomly selected to prioritize the most repetitive operating conditions. These micro-trips were then concatenated to create a representative cycle and the representativeness of each cycle was evaluated by comparison with the initial data. This study is of great importance due to the increasing impact that transportation has on greenhouse gas generation, and the need for representative driving cycles in order to evaluate vehicle performance. In addition, it focused on light vehicles that run on gasoline, which is one of the main fuels used in Latin America. The research also took into account altitude, which is known to affect engine performance and vehicle emissions.

To carry out this study, driving cycles were used that simulate the real behavior of vehicles in different areas of Latin America, which increases the accuracy of the results. Random micro-trips were selected and concatenated to obtain a representative cycle, which was then compared with the initial data to assess its validity. By using representative driving cycles, more accurate results on vehicle fuel consumption and emissions can be obtained, which can help researchers and manufacturers improve performance and reduce the environmental impact of vehicles. This study is important because it provides valuable information on the impact of altitude on gasoline-powered light-duty vehicles in Latin America, and also highlights the importance of representative

driving cycles to accurately assess vehicle performance and reduce the environmental impact of vehicles.

Key words: emissions, fuel consumption, SI Engine, altitude, vehicles

Introduction

The environmental impact of transport, especially land and air traffic, continues to increase despite the commitments made by political and social groups around the world. Since the end of the twentieth century, the transport sector has experienced strong growth due to the market economy and the need to maximize logistics in every area of the economy. This sector is one of the main sources of pollution, emitting the most greenhouse gases and consuming the most oil in the world.

The negative impact on the environment includes damage to atmospheric air, water, noise generation and destruction of the ozone layer. It is important to determine the real impact of the transport sector in high-altitude locations in Latin America, since many urban centers in the region are located above 2000 m.a.s.l.

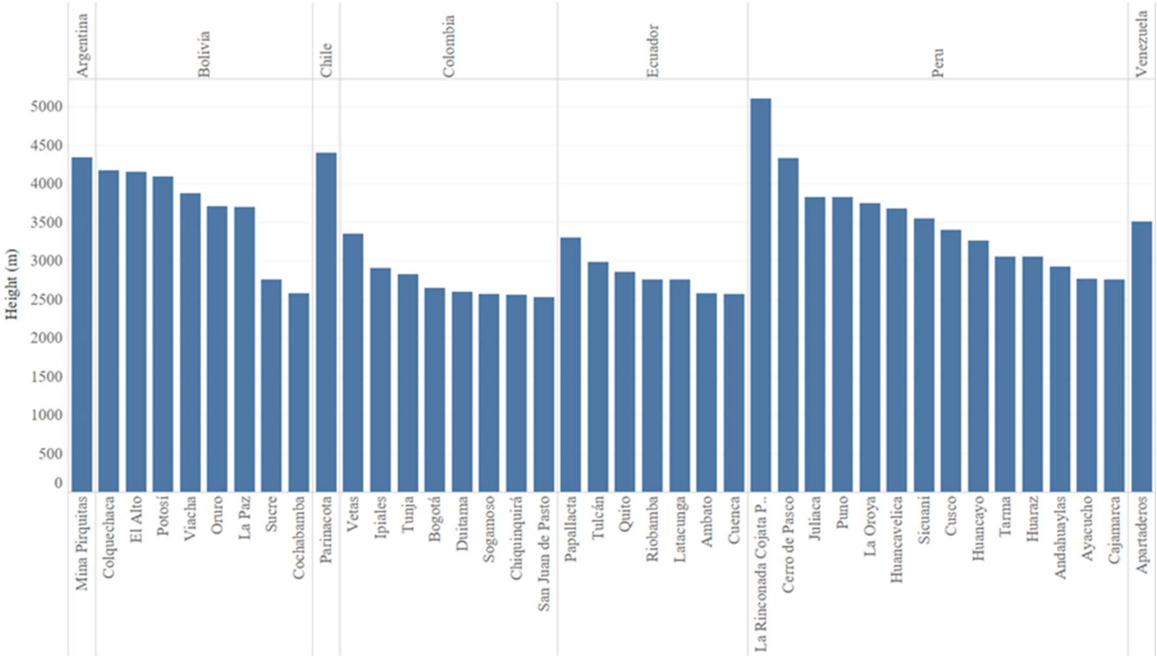

Figure Figure 1 shows the altitudes of some cities in Latin America, such as Ecuador, Peru, Argentina and Bolivia, where several urban centers are above 2000 m.a.s.l. This is relevant when considering the impact of the transport sector, as atmospheric conditions affect the operation of an internal combustion engine due to dependence on the amount of oxygen for its operation. It is important to assess the impact of transport in these localities to have a better understanding of their environmental impact. 30% of the 1400 million cars circulating in the world are in America and for this reason it is necessary to assess the impact generated by the altitude factor on consumption and emissions generated. Quantifying this impact requires a sufficiently representative driving cycle to be able to give credibility to the results obtained in consumption and emissions. However, the cycles used for the verification and homologation processes belong to localities with different operating patterns, which reduces the validity of the results derived from these studies (Hidalgo & Huizenga, 2013).

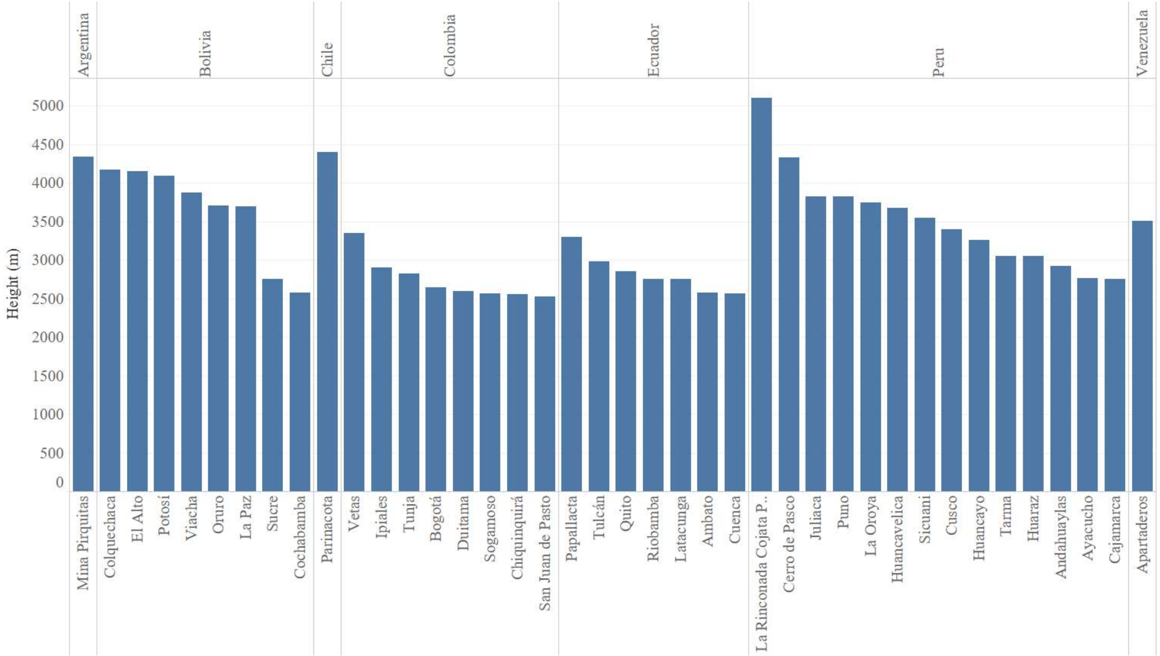

Figure 1 Altitude of the main cities of Latin America

Latin America and the Caribbean is the most urbanized region in the developing world with a rapidly growing fleet of motor vehicles. The number of urban areas with populations greater than 1 million was 43 in 1994 and is expected to increase to 52 by 2010. Air pollutant levels in many urban areas far exceed national, regional or local standards and World Health Organization guidelines. The main source of air pollution in these urban areas is motor vehicles, especially those that are old and poorly maintained. Ozone, particulate matter and carbon monoxide are the pollutants of greatest concern (Bekir & Gautam, 1997).

The challenges facing the design of internal combustion engines in automobiles, which must balance fuel economy and vehicle performance to meet environmental regulations and customer expectations. However, there are gaps in research as to how these engines perform at different altitudes and driving conditions. In particular, ignition of air-fuel mixtures at high altitudes may limit the development of low-emission combustion chambers due to the trend towards lean combustion. In addition, fuel atomization is affected by insufficient aerodynamic force, liquid viscosity and surface tension, which can affect jet generation and flame propagation. It is important to consider these factors when evaluating the performance and efficiency of internal combustion engines under different driving conditions and altitudes (Husaboe et al., 2014).

It is proposed the creation and experimental validation of a methodology to assess the impact of altitude on fuel consumption and emissions generated in a specific locality. In order to obtain reliable and comparable results, a representative driving cycle reflecting the similar geographical conditions of the study area shall be established. To construct the driving cycle, data will be collected from ten vehicles equipped with instruments in a altimetric range from 0 to 4100 meters. This will make it possible to determine the effect of atmospheric conditions on the driving process and the performance of the car. The collection of real-time data on fuel consumption and emissions at different altitudes will provide a better understanding of the relationship between these variables in Latin America and will allow criteria to be established for vehicle homologation processes and engine design for urban centers in the region. Having a baseline regarding fuel consumption in different environmental operating conditions will allow identifying a carbon footprint that has not yet been considered in the higher altitude conditions. Once the methodological model for assessing the effect of altitude on consumption and emissions has been established, zones and driving models that optimise fuel consumption and reduce emissions of polluting gases emitted by vehicles shall be characterised. This proposed solution is important for the region as it will allow the establishment of optimal driving criteria and models to reduce the environmental impact of vehicles in altitude areas. It will also contribute to improving fuel efficiency and reducing greenhouse gas emissions in the region's urban centres.

The environmental impact of transportation is of great importance because it consumes a significant amount of energy and is the main consumer of oil worldwide. This generates air pollution through the emission of nitrous oxides and particulates, and contributes to climate change by emitting large amounts of carbon dioxide into the atmosphere. Within the transport sector, road transport and urban roads are the largest contributors to global warming (Fuglestvedt et al., 2008).

Although consumption has decreased per unit of transport, the final assessment is still negative due to the huge increase in the number of vehicles circulating on the roads of the main cities and that has triggered a massive amount of material and scientific research around the reduction of consumption and the technological trends to achieve it (Johnson, 2015). It has been concluded that since pre-industrial times, transport has been responsible for between 15 and 31% of the total carbon dioxide (CO2) and ozone (O3) produced by human activity. Although global CO2 emissions increased by 13% between 1990 and 2000, CO2 emissions from land transport and aviation increased by 25%. In East Asia, emissions of nitrogen oxides (NOx) and CO2 from land vehicles doubled between 1990 and 2000. In the European Union, most sectors reduced their greenhouse gas (GHG) emissions from 1990 to 2001, but transport emissions increased by almost 21% (Zhai et al., 2008).

During the 1970s to 1980s, there was a reduction in HC, NOx and CO emissions, and lead, which was one of the main fuel additives, was phased out. Despite the fact that less fuel was used in 1990 than in the early 70s, the process of burning fossil waste will always produce an unwanted end product. One of the mentioned products of combustion are hydrocarbons (HC), which in technologies prior to electronic injection can reach up to 6000 ppm, which is equivalent to 1.5% of the fuel in spark-ignition engines. Of these gases, 40% are original fuel components and the rest are reactionary components that were not found in the original fuel. Figure Figure 2 illustrates how the air-fuel ratio affects the concentration of emissions in the exhaust.

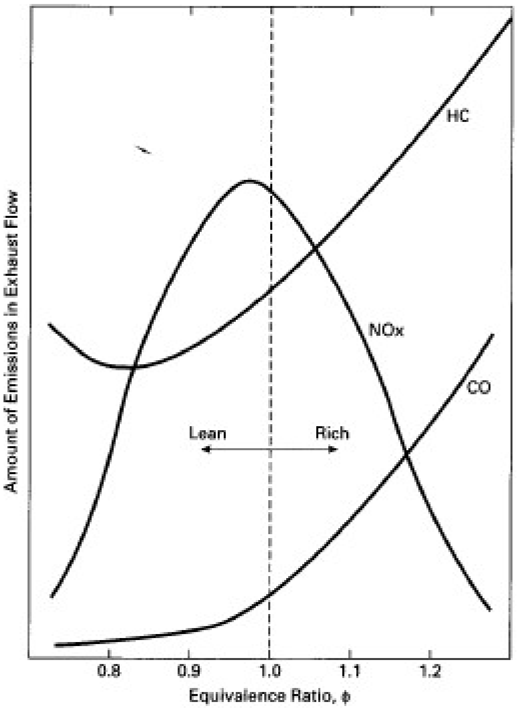

Figure 2 Effect of fuel air composition on environmental emissions produced by the internal combustion engine

The proportion of each component in tailpipe emissions depends on the type of fuel used and the geometry of the combustion chamber. When hydrocarbons are released into the atmosphere, they can act as carcinogens and contribute to the formation of photochemical smog, except for methane. The hydrocarbons in the exhaust are related to rich mixtures that do not have enough oxygen to react with all the carbon, resulting in high concentrations of CO and HC. Similarly, in very poor air-fuel mixture conditions, poor combustion is generated that increases the concentration of hydrocarbons. A flame front out of sync with the piston stroke can cause incomplete combustion that does not consume all the fuel. In addition, exhaust gas recirculation in low-load engines can affect air renewal and NOx reduction. In the valve overlap stage, it is possible for a small amount of fuel to escape without having gone through the combustion process, but this can be minimized with good engine design. At low speeds and at idle, greater amounts of hydrocarbons are emitted. As oil residues accumulate in the combustion chamber, the formation of turbulence is affected, which increases the emission of hydrocarbons (F. payri, n.d.) .

Previous studies have documented the negative impact of emissions in cities located at higher altitudes, such as Mexico City, which is at an altitude of 2200 meters above sea level, and in cities in China where more than 58% of their main localities are at altitudes above 1000 meters and more than 33% of cities are above 2000 meters (Wang et al., 2018). These investigations have shown that the 15 million vehicles that are registered in these locations in China have a significant effect on consumption and environmental emissions. When it comes to diesel engines, rarefied air at low pressures and higher altitude impairs the combustion process (Giechaskiel et al., 2021) It has been shown that the power and efficiency of vehicles decrease at higher altitudes. In addition, it has been observed that vehicles operating at higher altitudes emit more gases and particles compared to those working at lower altitudes. However, there are studies suggesting that CO and hydrocarbon emissions decrease as altitude increases, although the exact correlation between altitude and pollutants is unclear (Wang et al., 2018).

Previous studies have used altimetry test benches to simulate driving conditions in higher altitude areas. In many cases, these studies have shown that vehicle emissions under real driving conditions are higher than the estimated values for European and global driving cycles. A study conducted in China found that vehicles emitted more CO, NOx and hydrocarbons in altitude conditions, which could have implications for vehicle emissions control and management policies. The results of these studies could be useful for the development of emission reduction strategies, fleet inspection programs and maintenance (Lyu et al., 2020).

Methodology

Vehicle selection

Vehicles were chosen that represent the demand and circulation in the national territory and that are also commonly used in Latin American countries. According to a report by the Chamber of the Ecuadorian Automotive Industry, as of June 2022, light vehicles are the second most used means of transport, after motorcycles, with 1.1 million units in circulation. The age of the vehicles is distributed as follows: 27% of the vehicles are less than 5 years old, 24% are between 5 and 10 years old, 18% are between 10 and 15 years old, and 31% are more than 15 years old. On average, the age of vehicles in circulation is 13 years. Figure Figure 3shows the brands that have the highest number of vehicles in circulation, with Chevrolet, Hyundai and Kia occupying the first places in this category (INEC, n.d.) .

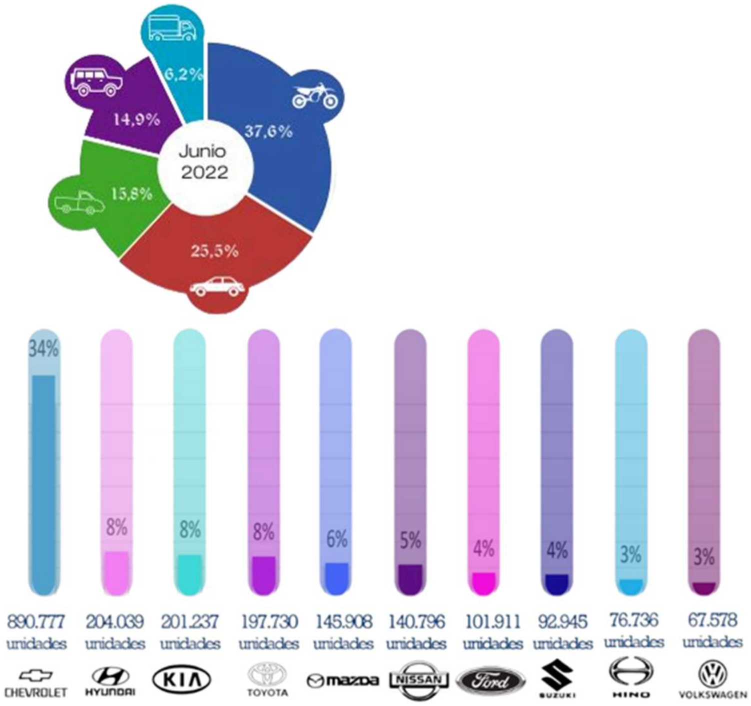

Figure 3 Distribution of car types and brands in the domestic market

Table 1 presents the characteristics of the vehicles used in this study, which include information such as vehicle type, emissions standard, displacement, compression ratio, among others. The vehicles were selected based on the most common brands and models within each car segment, with the aim of obtaining a representative sample of the vehicle fleet in Ecuador, which is similar to that of other Latin American countries. For two years, these vehicles were instrumented and evaluated in different operating conditions by the same drivers, which allowed to isolate the impact of other parameters and focus the study on the rest of the factors.

Table 1 Characteristics of the cars studied

Vehicle	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Guy	*Van*	*Since*	*Hatchback*	*Since*	*Since*	*Since*	*Since*	*Since*	*Suv*	*Truck*
Emissions standard	*EURO III*	*EURO IV*	*EURO V*	*EURO V*	*EURO IV*	*EURO IV*	*EURO IV*	*EURO IV*	*EURO V*	*EURO IV*
Displacement CC.	*1173*	*1399*	*1397*	*1397*	*1498*	*1498*	*1598*	*1799*	*1984*	*2237*
Compression ratio	*10:1*	*10:1*	*10.5:1*	*10.5:1*	*9.5:1*	*9.5:1*	*10.5:1*	*9.8:1*	*9.6:1*	*10:1*

Type of admission	*ON*	*ON*	*ON*	*ON*	*ON*	*ON*	*ON*	*ON*	*Turbocharged*	*ON*
Type of injection	*MPFI*	*MPI CVVT*	*MPI CVVT*	*MPI CVVT*	*MPFI*	*MPFI*	*MPI*	*MPI*	*TFSI*	*MPFI*
Maximum torque Nm-RPM	*106 @ 3500 - 4500*	*136 @ 5000*	*137 @ 5000*	*138 @ 5000*	*128 @ 3000*	*128 @ 3000*	*153 @ 3800*	*165 @ 4000*	*350 @ 1500 - 4500*	*190 @ 2.800*
Maximum power KW-PRM	*59 @ 6000*	*79 @ 6300*	*67 @ 6200*	*68 @ 6200*	*62 @ 5600*	*62 @ 5600*	*77 @ 5600*	*89,55 @ 5800*	*171.5 @ 4700 - 6200*	*79 @ 4600*
Empty weight Kg.	*1230*	*1133*	*1263*	*1074*	*1040*	*1040*	*5*	*1211*	*1830*	*1740*

Instrumentation

Over a period of two years, a set of ten light vehicles of different categories was used to instrument them and measure their operating, consumption and emissions parameters, with a sampling rate of 1 Hz for 2000 hours. The instrumentation was carried out in a altimetric strip from 0 to 4000 meters above sea level. An OBD monitor and a platform built in Python were used to obtain the operating parameters of the vehicles. In addition, the fuel measurement process was experimentally validated by comparing it with other methodologies. Table 2 shows the main parameters obtained, both in terms of operation and emissions generated, of instrumented vehicles that operate with the gasoline Otto cycle.

Table 2 Instrumented parameters in study vehicles

Emissions Analyzer Readings	*Chemical formula*	*Reading of car sensors by OBD II*	*Reference PID (hex)*
Carbon dioxide	CO_2	*Short- and long-term fuel adjustment*	*06 / 07 / 08 / 09*
Carbon monoxide	CO	*Car speed*	*0D*
Total, of hydrocarbons	THC	*Engine load*	*04*
Nitrogen dioxide	NO2	*Instant fuel consumption*	*5E*
Hydrogen monoxide	NO	*Throttle position*	*11*
Oxygen	O_2	*Motor speed*	*0C*
		Coolant temperature	*05*

Table Table 3 shows the specifications of the portable emissions analyzer used, which allowed collecting data on the volumetric percentage emitted by the exhaust of the following gases: Carbon Monoxide, Hydrocarbons, Nitrogen Oxides, Oxygen and Carbon Dioxide. This data collection will allow a temporal analysis of emissions with respect to the dynamics of the car in such a way that it is feasible to perform a cause and effect analysis between the dynamic characteristics of the car and the environmental impact generated.

Table 3. Parameters monitored by the emission analyzer

Gas	*Symbol*	*Range*	*Units*	*Precision*	*Measuring method*
Carbon dioxide	*CO2*	*0 - 20*	*%*	*0.01*	*Infrared Spectrometry*
Carbon monoxide	*CO*	*0 - 15*	*%*	*0.01*	*Infrared Spectrometry*
Total Hydrocarbons	*THC*	*0 - 10K*	*ppm*	*0.01*	*Infrared Spectrometry*
Nitrogen oxide	*NOx*	*0 - 5K*	*ppm*	*20*	*Electrochemical detection*
Oxygen	*O2*	*0 - 25*	*%*	*0.01*	*Electrochemical detection*
Lambda	λ	*0.5 - 10*	-	*0.01*	*Calculated*

The data acquisition equipment is a Raspberry Pi 3, which has a GPS module, bluetooth and network adapter. With this equipment, it was possible to obtain the data that informs about the operation of the vehicle and then upload them to the cloud using a Huawei modem that works with 3G technology. The connection scheme is shown in Figure Figure 1.

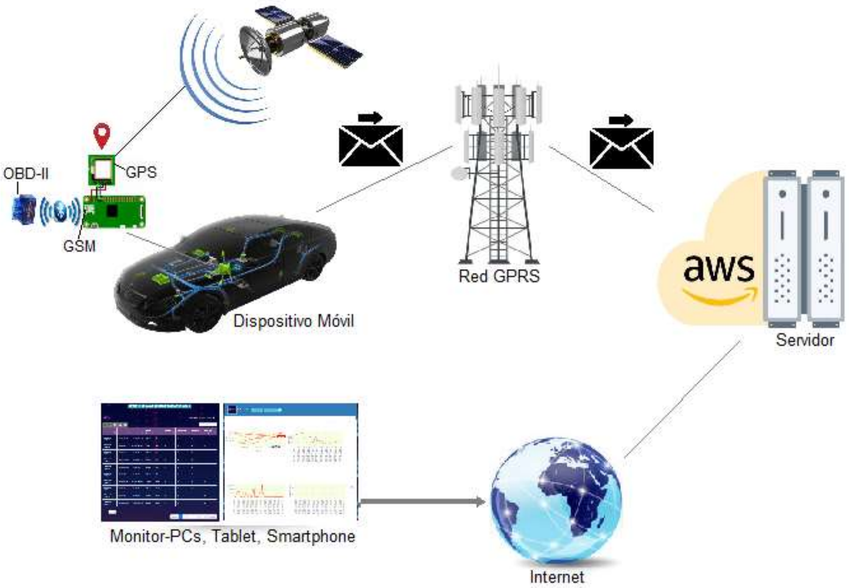

Figure 1. Connection scheme between connection logging components

Data filtering and analysis

The data obtained were filtered considering the particularities of the dynamics of the car, where accelerations out of range or slopes greater than 15% were analyzed to develop a protocol for disabling these data. Another criterion to take into account was the gap between the data obtained by the OBD II monitor and the emissions analyzer, in such a way that it is possible to perform an accurate analysis of events, this because the analyzer for its operation mechanics that requires a lapse of time with respect to the OBD II device, Table Table 4 shows an estimate of the lag times, which may vary with respect to the particularities of each measurement.

The lag between the two measurement instruments mentioned requires a synchronization process based on parameters in which they react with high correlations between the two equipment. The accelerator drive has an immediate response on the generation of hydrocarbons and the increase in CO2, this high existing correlation was used to determine the existing lag through a comparative statistical analysis between several deltas of time between 2 and 10 seconds for the selection of the highest Pearson correlation index.

Table 4. Estimation of the face times between the readings recorded by the OBD II device and the emission analyzer

OBDII		*WITH 6.3*	
Event	*Time[s]*	*Event*	*Time[s]*
Action of pressing the pedal	*1,5000*	*Action of pressing the pedal*	*1,5000*
OBD data logging	*0,0020*	*Action of the electronic butterfly*	*0,0010*
Data Capture App Torque	*1,0000*	*Injection time*	*0,0025*
Log on file	*0,5000*	*Burning time*	*0,0014*
		Gas escape time	*0,0005*
		Measurement time	*2,0000*
		Log on file	*2,3000*
Total	*3,0020*	*Total*	*5,8054*

Results

In order to assess how altitude affects vehicle emissions, measurements were taken at different heights to cover the entire altimetric range in which vehicles circulate in the region. Figure Figure 4shows the number of measurements made for each altitude, which allowed obtaining a sufficient amount of information to analyze each altimetry level with adequate support.

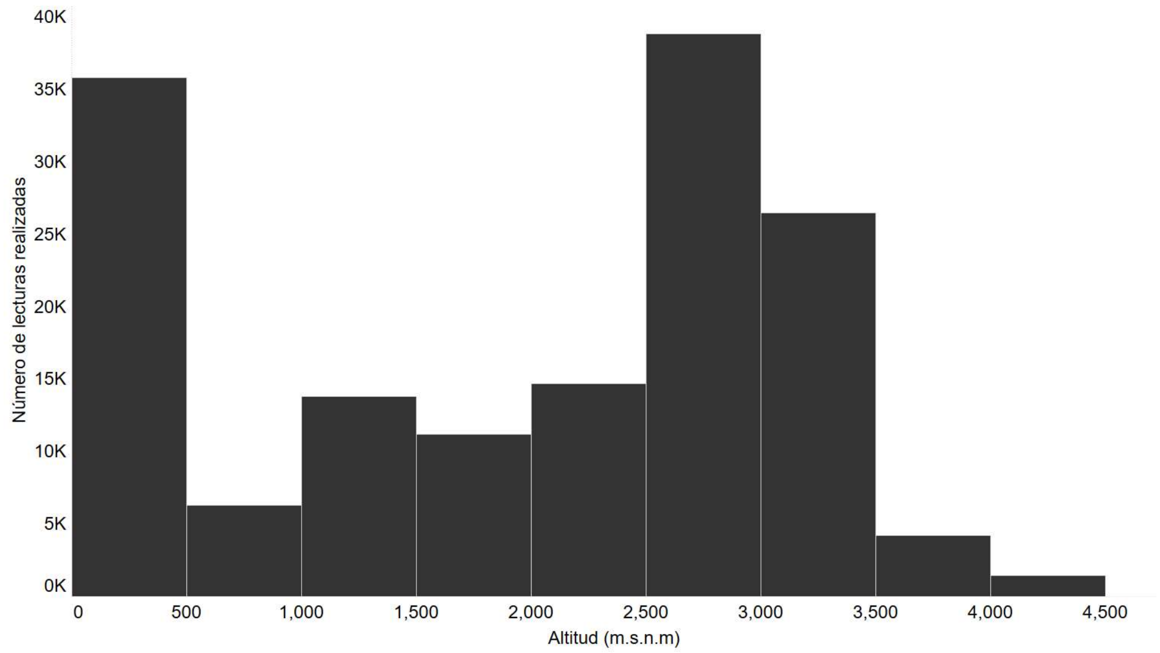

Figure 4 Detail of the altitudes at which the tests were performed

Figure Figure 5shows the range of slopes from which the operating readings of the cars were taken, thus seeking to cover the greatest number of road conditions that have an impact on the performance of the cars. This is in view of the fact that steep slopes cause operating conditions with higher amounts of consumption because these driving conditions demand greater energy delivery to the combustion engine. The same figure also shows the speeds at which it circulates with respect to the slope of the road, using for this purpose the statistical criterion of the median.

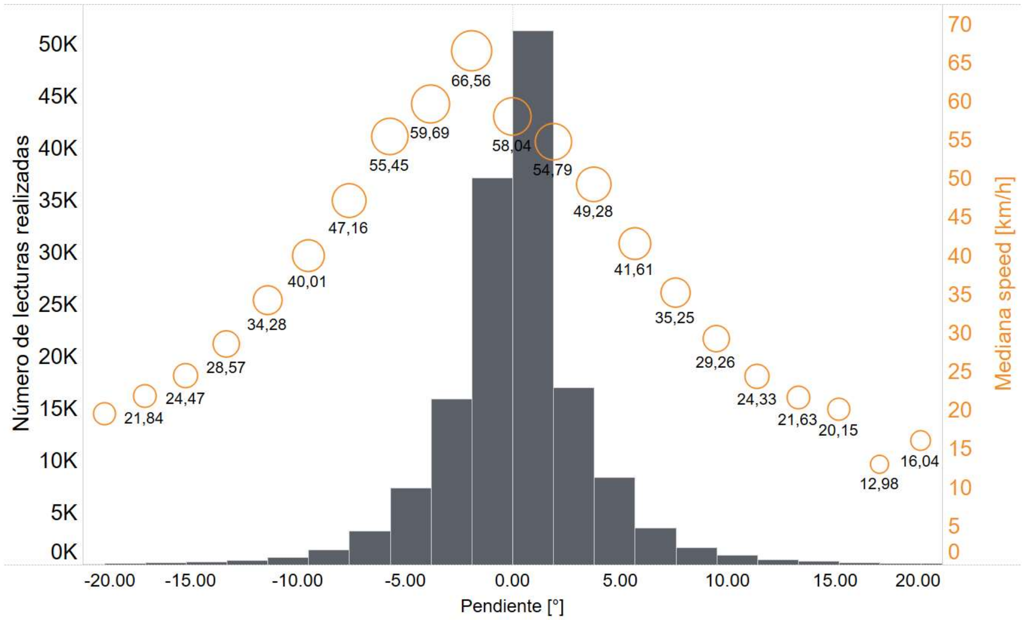

Figure 5 Distribution of data by slope and by speeds obtained

Figure Figure 6presents the data obtained from the speed and acceleration parameters analyzed throughout the study period. It was observed that near-zero accelerations are the most common and that speeds close to 40 km/h and idling conditions are also repetitive. This is because much of the measurements were made during idling periods, which are crucial in fuel consumption, especially in conventional vehicles with internal combustion engines without Star Stop system.

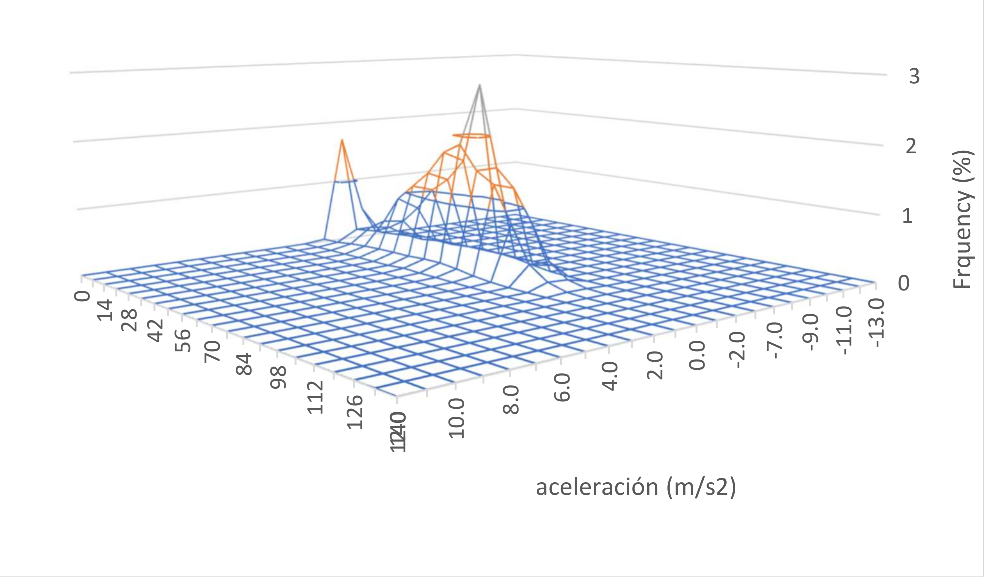

Figure 6 Frequency distribution for the velocity and acceleration data obtained.

Driving cycle

One of the problems with assessing vehicle consumption and emissions using homologation driving cycles such as FTP and WLTC is that they do not describe the local driving pattern. To assess consumption and emissions, two driving cycles were constructed based on different characteristic parameters, such as average positive and negative acceleration, average speed, maximum speed and idling time. One of the cycles was based on fuel consumption, which was previously validated as the most accurate method. The other cycle was based on the criterion of residual vehicular specific power, which demonstrated greater accuracy than the method based on fuel consumption. When analyzing the relative differences between the two methods of cycle construction, it was concluded that the RPSV-based method is more accurate (Montúfar Paz et al., 2017).

EBMT is a newly created method for representing driving patterns in a specific location with the aim of reproducing consumption and emissions. To develop this method, data on energy consumption, speed and idling time were used, and a database containing information on speed, fuel consumption and exhaust emissions was used. This database was collected through the monitoring of 15 heavy vehicles in different traffic conditions for eight months. Speed and time data from this database defined the local driving pattern. To assess the representativeness of the method, mean relative differences and interquartile range were calculated (Giraldo & Huertas, 2019). On the other hand, PSV is another method that considers drag forces, downforce, rolling force and the degree of road inclination to estimate emissions. The degree of road inclination was collected using GPS and was shown to significantly affect emissions estimation. The impact of the slope on emissions has been studied by several authors and it has been found that a 3.76% increase in the slope generates an increase factor of 2 in emissions. Emission values increase when the vehicle increases in weight and when the slope is greater (Xu et al., 2021).

The calculation of these forces is dimensioned as follows:

$$F_a = 0.5 * \rho * A * C_d * {V_r}^2 \qquad \text{Equation 1}$$

Where:

- $F_a \rightarrow$ Aerodynamic force
- $\rho \rightarrow densidad\ del\ aire$
- $A \rightarrow área\ frontal\ del\ vehículo$
- $C_d \rightarrow Coeficiente\ aerodinámico$
- $V_r \rightarrow\ Resultante\ de\ la\ suma\ algebraica\ de\ la\ velocidad$
- $del\ automovil\ y\ la\ velocidad\ del\ viento$

$$R_x = f_r * M * g * \cos(\emptyset) \qquad \text{Equation 2}$$

Where:

- $R_x \rightarrow$ Gradient force
- $f_r \rightarrow Coeficiente\ de\ fricción\ del\ vehículo\ con\ la\ calzada$
- $M \rightarrow Masa\ total\ del\ automovil$
- $g \rightarrow Gravedad$
- $\emptyset \rightarrow Ángulo\ de\ pendiente\ de\ la\ vía$

$$W = M * g * sen(\emptyset) \qquad \text{Equation 3}$$

- $W \rightarrow$ Force generated by the weight of the car

$$F_T = F_a + R_x + W + M * a \qquad \text{Equation 4}$$

Where:

- $F_T \rightarrow$ Tensile force
- $a \rightarrow$ Normalized acceleration of the car (mathematical model of 4th. Degree)

$$PSV_{inst} = \frac{F_T * V}{M} \qquad \text{Equation 5}$$

Where:

- PSV_{inst} → Instantaneous specific vehicular power
- V → Car speed

The calculation of the vehicle-specific power value involves the sum of different drag forces, such as aerodynamic force, rolling force and the force generated by the weight of the car, together with the internal force of the vehicle. This result is then multiplied by the ratio of speed to mass of the car. Figure Figure 7illustrates the interaction of these forces and how they can demand or deliver energy to the vehicle at different times, depending on factors such as speed, slope and acceleration. For electric vehicles, these moments can be opportunities for energy recovery.

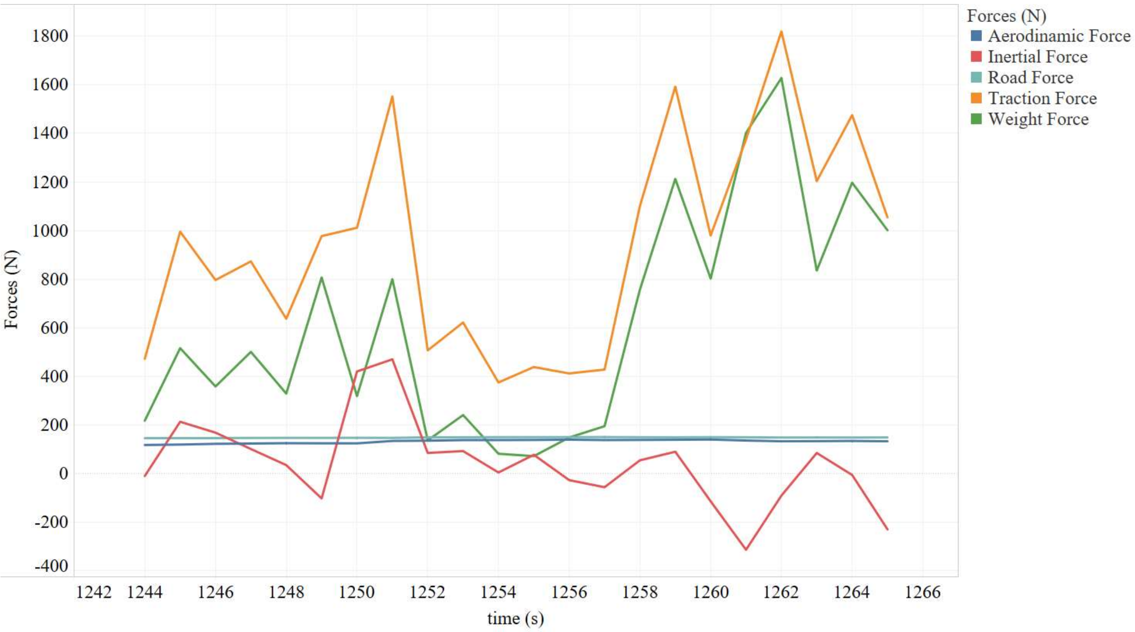

Figure 7 Interaction of drag forces in a random driving time lapse

From the data obtained, a driving cycle based on consumption is constructed and selected because it is the one that demonstrated the greatest representativeness and the following characteristic data were obtained.

Using the data obtained during two years of monitoring on 10 light vehicles, the cycle was built based on energy consumption, under the methodology of micro trips where 10 driving cycles were obtained.

Table 5 Characteristic parameters of the cycle with greater representativeness

VALUES	**Volume Global**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**Average**
V. Max (m/s)	28.5	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	**30.3**
V. prom (m/s)	15.1	16.1	16.2	16.1	15.8	16.1	15.8	15.8	16.1	16.1	16.2	**16.0**
Sd_Velocidad	5.4	6.3	6.3	6.3	6.4	6.3	6.4	6.4	6.3	6.3	6.3	**6.3**
A. Max + (m/s²)	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	**3.6**
A. prom. + (m/s²)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**
Sd_A +	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	**0.4**
A. Max – (m/s²)	-6.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-7.6	-3.6	**-4.0**
A. prom – (m/s²)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	**-0.5**
Sd_A -	0.5	0.4	0.4	0.4	0.5	0.4	0.5	0.5	0.5	0.5	0.4	**0.5**
Idle time (%)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	**0.3**
Time to. + (%)	34.7	43.3	43.5	43.2	43.0	43.4	43.0	43.0	42.9	43.6	43.4	**43.2**
Time a. – (%)	33.4	23.9	23.8	24.3	24.3	23.8	24.3	24.3	24.3	23.9	23.8	**24.1**
Cruise time (%)	31.1	32.5	32.4	32.2	32.4	32.5	32.4	32.4	32.4	32.3	32.4	**32.4**
Accelerations per km	10.4	10.8	10.7	10.8	11.0	10.7	11.0	11.0	10.7	10.7	10.7	**10.8**

Table 6 Relative errors of the cycle

ERRORS	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**Average**
V. Max (m/s)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	**0.06**
V. prom (m/s)	0.07	0.07	0.06	0.05	0.07	0.05	0.05	0.07	0.07	0.07	**0.06**
Sd_Velocidad	0.18	0.17	0.17	0.20	0.18	0.20	0.19	0.18	0.17	0.17	**0.18**
A. Max + (m/s²)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	**0.05**

A. prom. + (m/s²)	0.05	0.05	0.04	0.03	0.05	0.03	0.03	0.05	0.04	0.05	**0.04**
Sd_A +	0.06	0.06	0.05	0.04	0.06	0.05	0.04	0.06	0.05	0.06	**0.05**
A. Max – (m/s²)	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.16	0.45	**0.42**
A. prom – (m/s²)	0.04	0.04	0.03	0.03	0.04	0.02	0.03	0.01	0.02	0.04	**0.03**
Sd_A -	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.03	0.11	0.01	**0.02**
Idle time (%)	0.04	0.04	0.01	0.00	0.04	0.01	0.00	0.03	0.05	0.04	**0.03**
Time to. + (%)	0.25	0.25	0.25	0.24	0.25	0.24	0.24	0.24	0.25	0.25	**0.24**
Time a. – (%)	0.28	0.29	0.27	0.27	0.29	0.27	0.27	0.27	0.28	0.29	**0.28**
Cruise time (%)	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	**0.04**
Accelerations per km	0.03	0.03	0.04	0.06	0.03	0.06	0.05	0.03	0.03	0.03	**0.04**
Average/cycle	0.11	0.11	0.10	0.10	0.11	0.10	0.10	0.10	0.09	0.11	

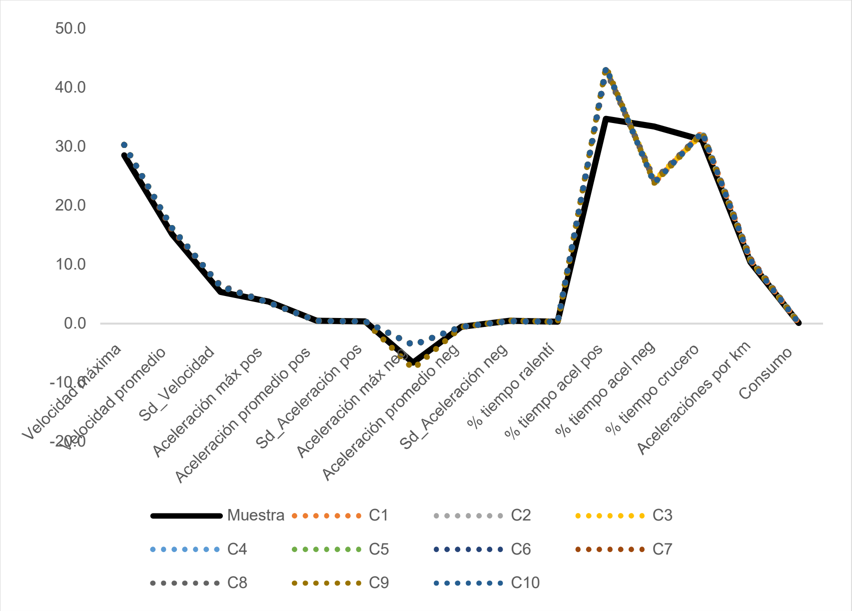

Figure 8 10 driving cycles built on the basis of micro trips taking Consumption as one of the priority selection parameters

Conclusions

In the study of consumption and emissions of light vehicles, two different methodologies were used for the analysis. The first involved using the driving cycle obtained from micro-trips to determine the impact of altitude on fuel efficiency and emissions. In the second methodology, the consumption and emissions generated to obtain a specific specific power, expressed in liters per 100 kilometers, were considered.

The results show that, as altitude increases, the fuel efficiency of light vehicles improves, going from 12 km/litre to 0 m to 13 km/l at altitudes above 3000 m. However, carbon monoxide emissions remain constant at values close to 19 g/km, regardless of altitude. On the other hand, hydrocarbon and NOx emissions show an increase when subjected to altitude conditions.

Regarding the analysis of consumption expressed in liters per 100 kilometers required to generate a necessary amount of power, it was found that consumption decreases with altitude. At altitudes of 2000 meters above sea level, consumption was 7.3 liters / (100 km) and at altitudes of 4000 meters above sea level it was 8.9 liters / (100 km) to obtain between 0 and 100 Kw / Tn. However, an unexpected effect was observed when vehicles operate with a specific power between -50 and -150 Kw/Tn, as consumption increases with altitude. At sea level, consumption was 16 litres/(100 km), while at 2000 masl it was 20.4 litres/(100 km) and at 4000 masl it was 21 litres/(100 km), suggesting that vehicles require more fuel to operate at high altitudes when low specific power is required.

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