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COMPARISON OF CO_2 EMISSIONS AND ENERGY CONSUMPTION OF AN ELECTRIC VEHICLE AND A VEHICLE WITH AN INTERNAL COMBUSTION ENGINE IN DIFFERENT COUNTRIES

Ana Carolina Rodrigues Teixeira
José Ricardo Sodré
Pontifícia Universidade Católica de Minas Gerais, 500 Dom José Gaspar St., Coração Eucarístico
acrt88@hotmail.com
ricardo@pucminas.br

Abstract. *This paper presents a comparison between an electric vehicle and a vehicle with an internal combustion engine regarding carbon dioxide (CO_2) emissions and energy consumption, whether in electric or chemical form (contained in the fuel). For this analysis, the AVL Cruise software was used to simulate two similar vehicles, one electric and the other with an internal combustion engine. Some parameters adopted in the simulation were: flat, straight road, a 70 kg vehicle driver and driving cycle according to the U.S. FTP-75 standard. The CO_2 emissions from the electric vehicle were calculated using the CO_2 emission factors from electricity generation in Brazil and in other countries in order to compare the use of the electric vehicle in places with different power generation. For this, the CO_2 emission factors used were the average from the values between 2006 up to 2008. With regard to energy consumption, the vehicle with internal combustion engine had a consumption of 0.6830 kWh/km and the electric vehicle 0.0951 kWh/km. The results showed that the electric vehicle emits about 52 times less than a vehicle simulated with an internal combustion engine. In Greece, this value decreases to 2, and for Mexico, US, Turkey, Ireland, UK, the electric vehicle emits 3 times less than the conventional vehicle simulated (182 gCO2/km).*

Keywords: *electric vehicle; emissions; carbon dioxide; energy; fuel consumption.*

1. INTRODUCTION

Concerns about the environment has grown in recent decades and therefore the need to reduce environmental impacts, such as the air pollution faced in large cities. According to Thiel, Perujo and Mercier (2010), the vehicle fleet is one of the responsible for the high levels of pollutants emitted. Thus, Velloso et al (2010) states that the new environmental guidelines have accelerated the evolution of the technological process in several areas, and the electric vehicle have been an alternative to internal combustion vehicles.

Electric vehicles have the beginning of its history in 1834. However, due to the limitations, EVs disappeared from the market until 1930. Only after 1970, the interest in this technology returned (Chan, Boucayrol and Chen, 2010). According to the IEA (2012) electric vehicle sales have increased over the years in many countries, but Brazil still faces many barriers, such as high cost, lack of appropriate and affordable technology and infrastructure recharging required to supply the electric vehicles. However, the electric vehicle offers some advantages, such as zero emissions during the use, no noise and high energy conversion efficiency. In addition, studies have been done about the potential use of this type of vehicle and to assess the impacts of introducing such a product on the market, in addition to technological innovations.

A study developed by Varga (2013) used the AVL Cruise software to simulate four different types of electric vehicles to determine the energy consumption using New European Driving Cycle (NEDC) and this data was used to calculate the CO_2 emissions from these vehicles in Romania based electric power plant emissions during the period of 2004 - 2008. The results for energy consumption ranged from 0.104 to 0.127 kWh/km and CO_2 emissions varied between 84 and 115.9 gCO_2/km.

Monteiro, Gonçalves and Afonso (2011) state that the impact of the use of electric vehicles can be mixed, since the emissions reduction from cars may be accompanied by increased emissions in power generation. The authors also point out that the biggest part of the CO_2 production in the world comes from thermal and 40% of world electricity come from these sources. Thomas (2011) reports that in the US case, such reductions will depend on the number of electric vehicles sold to owners who travel long distances and the emissions from energy sources. In addition, the author also concludes that the simple replacement of combustion vehicles to electric battery-powered vehicles would not be enough to achieve greenhouse gas and fuel reduction targets required in the country, unless almost all the carbon emitted in the US electricity production was eliminated.

On the other hand, Christensena, Wells and Cipcigan (2012) and Van Vilet et al (2011) argue that the implementation of EVs is an efficient way to reduce CO_2 emissions due to several factors: EV is more efficient than the ICEV and its adoption may reduce emissions of greenhouse gases, depending on the energy matrix and the recharge conditions; the

BEV recharges from the electric power transfer CO_2 emissions from the transport sector to the energy sector, which is not bad, since the energy companies have emission limits to be reach. Thus, the energy sector is forced to use more renewable sources and promote greater energy savings, and BEVs can improve the efficiency of the power system.

Soimakallio and Saikku (2012) calculated the production-based and consumption-based of CO_2 emission intensities of electricity for the OECD (Organization for Economic Co-operation and Development) countries during the period 1990 - 2008. Among other results, they determined the CO_2 emission factors from power generation and the absolute value accounted for more than 5% of the overall national CO_2 emissions in, at least, 13 European countries were studied.

In this context, the aim of this study was to compare CO_2 emissions and energy consumption of an electric vehicle and a vehicle with internal combustion simulated in the AVL Cruise and show the difference between the use of the electric vehicle in different countries from the emissions point of view.

2. METHODOLOGY

Initially, a simulation using the AVL Cruise software was performed to determine the fuel energy consumption and CO_2 emissions from the engine powered vehicle (A) and the energy consumption electric vehicle (B). Then, CO_2 emissions related to electric power generation in the Brazilian national grid to supply the electric vehicle demand was calculated. Some input data about the vehicle A, B and battery characteristics are shown in Tab. 1, 2 and 3, respectively.

Table 1. Some vehicle A input data.

PARAMETER	SPECIFICATION
Bore × stroke	70.0 mm × 64.9 mm
Compression ratio	12.15:1
Volume displacement	1.0 L
Rated power @ 6250 rpm	53.7 kW
Rated torque @ 4500 rpm	93.2 Nm
Fuel	E22

Table 2. Some vehicle B input data.

PARAMETER	SPECIFICATION
Nominal power	15 kW
Maximum power	28 kW
Nominal torque	50 Nm
Maximum torque	124 Nm
Battery	Sodium-Nickel-Chlorine
Voltage	253 V
Energy	19.2 kWh
Recharge time	8 hours

Table 3. Battery data.

PARAMETER	SPECIFICATION
Units	1
Capacity/ Efficiency	76 Ah
Weight	165 kg
Energy	21.2 kWh
Nominal Tension	278 V
Max. Tension	355 V
Min. Tension	186 V
Useful Life	1000 cycles

Both vehicle were simulated using the software AVL Cruise which provide specific tasks to evaluate emissions and fuel consumption of vehicles with Otto and Diesel cycle, hybrids, battery electric and others. For this, in this simulation the Cycle Run routine was used, which fixes a driving profile for the vehicle. The driving cycle Federal Test Procedure 75 (FTP-75) was used, which is set by Environmental Protect Agency and it is used in Brazil (NBR 6601). The cycle represents the urban reality where the stop and go is constant. The cycle characteristics are distance of 17.880 km, length of 1.876 seconds and average speed of 34.1 km/h. The first phase includes the engine cold and lasts about 505 s; the second phase lasts 866 s; there is an interval of 10 min between the second and third phase, and the third phase takes place with the hot motor and has the same duration as the first stage. This cycle is adopted by the Pollution Control Program by Motor Vehicles (PROCONVE) in Brazil.

Some characteristics considered in the simulations were flat road with no curves, cold engine start, one occupant of 70 kg and driving profile according to the chosen cycle. To perform the simulations it was necessary data from all parts of the vehicle. The model consists in many blocks which are connected by an algorithm and each block needs different input data and has a calculation routine. It is important to note that the software allows more input data to be entered in addition to those mentioned above for each block. However, they depend on the purpose of calculation and need the results, which in this case are CO_2 emissions and energy consumption.

As noted previously, the AVL Cruise software offers specific tools for the calculation of emissions and energy consumption. The main inputs used for this purpose, such as fuel consumption map, are inserted in a three dimensional form (x-axis: engine speed, y-axis: engine torque and z-axis: fuel volumetric flow). The characteristic data of the vehicle (characteristic curves, shifting, torque curve, etc.) and other basic specifications (gross weight, gear ratio, tire radius, etc.) were also defined in the dynamic vehicle based program database. The adoption of high-quality data in the process is important to improve the accuracy of simulation results.

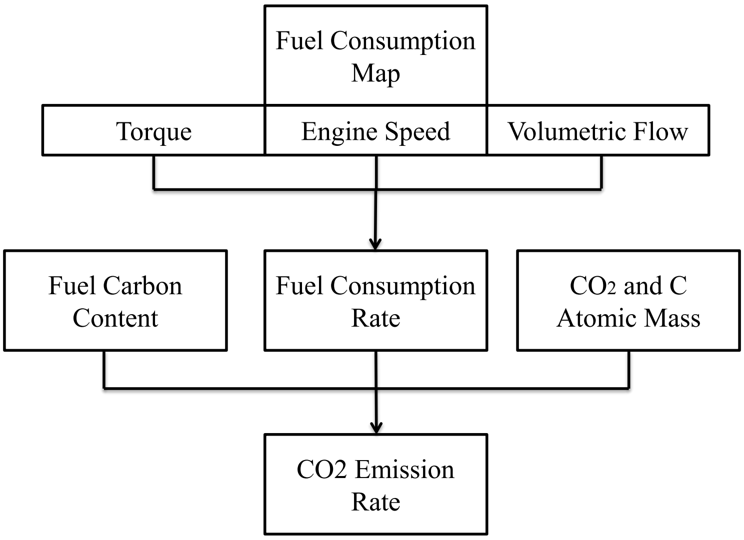

Figure 1. Calculation guidelines.

The calculation of CO_2 emissions from the vehicle B was based in the emissions factor from the Brazilian electricity matrix obtained from the Brazilian National Grid System (SIN), available from the Ministry of Science, Technology and Innovation. Thus, it is possible to quantify the pollutant concentration emitted according to the distance traveled as can be observed in the Eq. 1 prepared by IPCC (2006):

$$\mathbf{E_{pol}} = \mathbf{FE_{pol}} \times \mathbf{C} \tag{1}$$

Where:
E_{pol}: Pollutant emissions (t_{pol}/km);
FE_{pol}: Pollutant emission factor (t_{pol}/MWh);
C: Electricity consumption per kilometer (MWh/km).

Finally, since the results of energy consumption from the vehicle B and the CO_2 emission factor from different countries, it was possible to calculate the CO_2 emission from vehicle B in each country. The CO_2 emission factor data from power generation for different countries was obtained from a previous study developed by Soimakallio and Saikku (2012). The analyzed period was 2006 to 2008. It was considered that the emission factor was the average of these three years (2006, 2007 and 2008).

3. RESULTS

The results of the simulations found the values of CO_2 emissions and fuel energy consumption for the vehicle A, and the energy consumption for the vehicle B, which can be verified in Tab. 4.

Table 4. Results for vehicle A.

Vehicle A	Vehicle A	Vehicle B
CO_2 emissions (g/km)	182.74	-
Accumulated energy consumption (kWh)	11.89	2.267
Electric energy consumption (kWh/km)	0.6830	0.0951

The fuel consumption of the vehicle A is close to that found in datasheet (Tab. 1). Regarding CO_2 emissions, the value found in the simulation was higher than the datasheet (172.54 g/km). This difference occurred because the simulation was performed considering the complete combustion, which makes raise the amount of CO_2 emitted. If the incomplete combustion was considered, other pollutants such as CO and HC are appeared, thereby reducing the amount of carbon dioxide. Due to the availability of input data required for the software, combustion had to be considered complete.

The accumulated fuel energy consumption of the vehicle A was 11.89 kWh (Fig. 2), and the accumulated CO_2 emission at the end of the cycle was 3.2473 kg (Fig. 3). It is worth noting that the curve of cumulative emissions exhibits the same behavior of the fuel consumption curve, which is predictable, since the formation of CO_2 emissions is directly linked to fuel consumption. Moreover, the interval that occurs during the FTP-75 cycle, both consumption and emissions remain constant, since it is a graph that shows the accumulated values. Thus, the vehicle is in the resting phase, not consuming energy and emitting pollutants.

Fig. 4 shows the speed of the vehicle B (km/h) and the accumulated power consumption (kWh) for the FTP-75 cycle (2.267 kWh). Comparing the power consumption values of the vehicle A and B, it can be seen that the first one has a consumption of approximately five times greater than the second. This can be explained due to the electric engine has higher efficiency, reaching almost 90%, different from vehicle with an internal combustion engine, which efficiency is around 20%.

According to data results from the simulation of the vehicle B which have had an energy consumption around 0.0951 kWh/km, which is less than the results obtained by Varga (2013). It was possible to calculate the indirectly emissions from electric vehicle in many countries with different characteristics such as power generation, geographic extension, economics and others. The only value used to find the emissions from electric vehicle (vehicle B) was the CO_2 emission factor for each country. Thus, it is important to point out that the emissions factor was took account only the emissions from the power generation. Fig. 5 shows the CO_2 emissions per kilometer for each one. Considering the values, Greece was the country with the high emissions, which are around 87 gCO2/km. Mexico and US had close values: 63 and 60 gCO2/km, respectively. The countries with low emissions were Norway, Sweden, Switzerland and Brazil, whereas all these around 0.7 to 3.5 gCO2/km.

It is worth mentioned that the countries have different geographic extensions, thus if the electric vehicle owner wants to drive for long distances in a country such as Brazil, the vehicle will probably have more emissions than a country such as Belgium which has a smaller geographic extension. Hence, it is important to develop a study which covers all the variables. In this study, only the emission factor was analyzed.

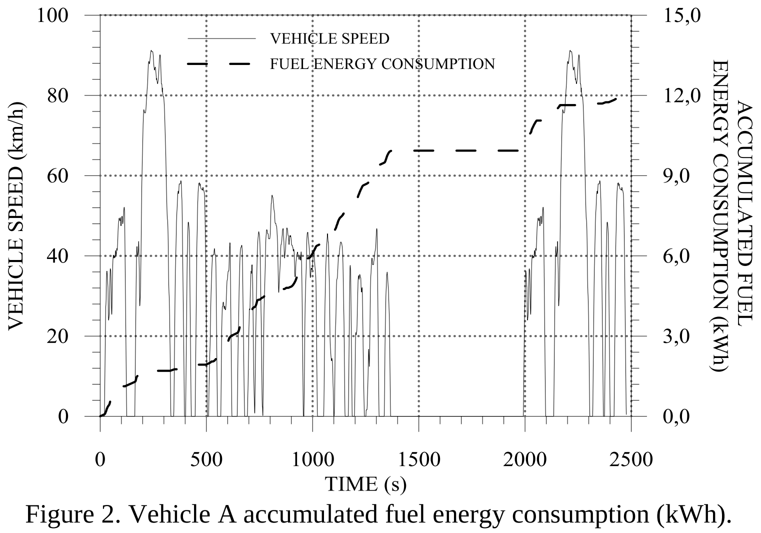

Figure 2. Vehicle A accumulated fuel energy consumption (kWh).

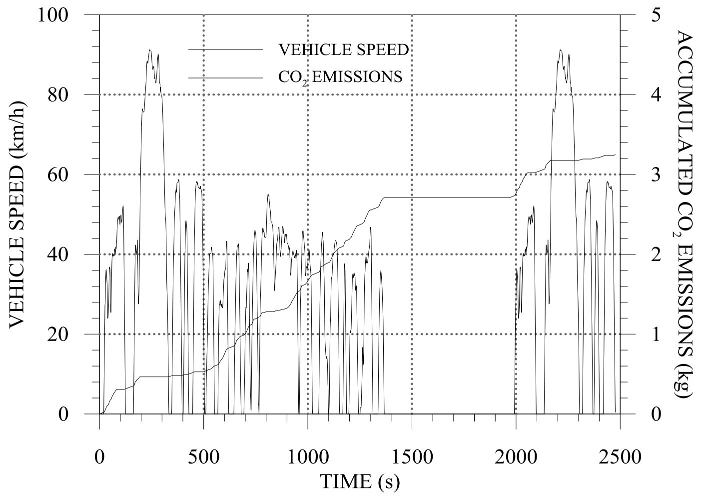

Figure 3. Vehicle A accumulated CO_2 emissions.

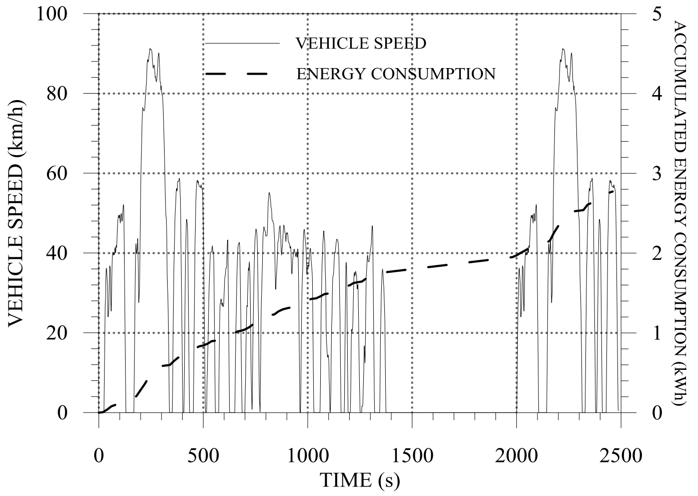

Figure 4. Vehicle B accumulated energy consumption (kWh).

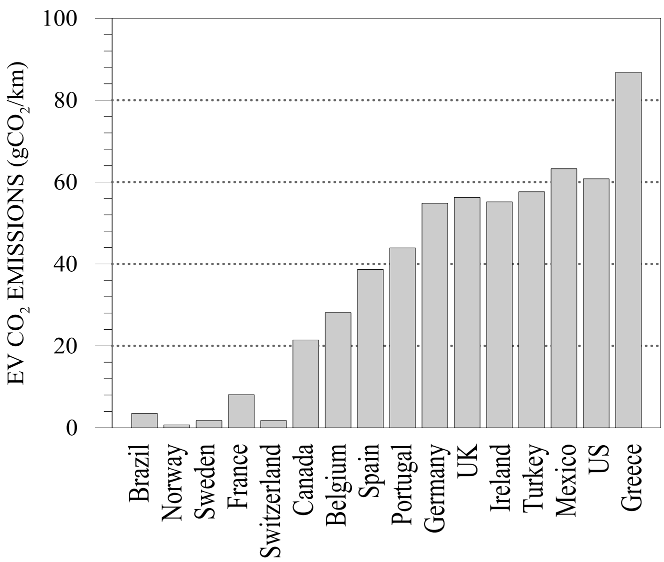

Figure 5. CO_2 emissions from vehicle B studied.

4. CONCLUSIONS

According to the simulations it was possible to find results for the energy consumption and CO_2 emissions for two types of vehicle: conventional with internal combustion engine and battery electric vehicle. From the point of view of energy consumption, the consumption from vehicle B was around five times less the vehicle A. The simulation results have compared to CO_2 emission factors from electricity generation in Brazil and in other countries for the period 2006 to 2008 in order to find the emissions that an electric vehicle would emit indirectly. Thus, the analysis results showed that an electric vehicle emits about 52 times less CO_2 than a vehicle with an internal combustion engine in the period studied in Brazil, since the conventional vehicle simulated emit around 182 gCO2/km. In Greece, the electric vehicle emits 2 times less CO2 than a conventional vehicle, and in Mexico, US, Turkey, Ireland, UK around 3 times less. It is worthy to note that the study was done for only two types of the same size vehicle. Furthermore, the emission calculation was done for a vehicle. It is therefore necessary to make a study of the all fleet and verify the impact of the introduction of the electric vehicle in terms of emissions, energy consumption, geographic extension and other.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.

8. ABBREVIATIONS

CO2	Carbon dioxide
EVs	Electric vehicles
BEVs	Battery electric vehicles
ICEV	Internal combustion engine vehicles
NEDC	New European Driving Cycle
FTP-75	Federal Test Procedure - 75