Simulation of the impacts on carbon dioxide emissions from replacement of a conventional Brazilian taxi fleet by electric vehicles

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ABSTRACT

This work evaluates the effects of the replacement of engine-powered vehicles by electric vehicles on carbon dioxide (CO_2) emissions and energy consumption. A case study of a taxi fleet replacement was conducted with the aid of the AVL Cruise software. The simulation was performed under different scenarios of total or partial fleet replacement along a period of 15 years. The scenarios were designed considering favorable and unfavorable conditions for electricity production from a clean source, thus influencing the CO_2 emission factor adopted. The simulations showed that the electric energy consumption by the electric vehicles is about four times lower than fuel energy consumption by the conventional vehicles undergoing a standard test schedule. At the end of the period considered the electric vehicles will produce lower CO_2 emissions than the conventional vehicle fleet by a factor of 10, even considering the most unfavorable scenario of electric power generation. An economic analysis shows that the present value of electric vehicles over the years is lower than that of conventional vehicles, except for the first year after vehicle acquisition.

Keywords: electric vehicle; CO_2 emissions; energy; fuel consumption; sustainable development.

1. INTRODUCTION

To improve air quality, increasingly strict regulation laws require reduced automotive emissions, which has influenced the development of clean technologies [1]. Those technologies include electric vehicles (EVs), hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) [2]. The possible reduction of carbon dioxide (CO_2) emissions with the use of those technologies also contribute to reduce global temperature increase, one of the key factors for climate change [3]. In order to reduce automotive emissions many countries adopt increasingly strict regulating laws [4]. The need to reduce carbon emissions motivates the use of renewable energy sources in the electricity matrix [5]. The demand for sustainable actions inspires the rise of solutions with higher energy efficiency [6]. Those solutions are generally characterized by less oil dependence and reduced fuel consumption [7]. In this sense, there are many studies on EVs as a possible viable alternative, especially in countries with clean electricity matrix [8].

The positive and negative aspects of the replacement of engine-powered vehicles by electrical vehicles are identified for specifics fleets [9]. One of the advantages of EVs is the absence of exhaust emissions [10]. Another advantage is the reduced noise during operation [11]. The reduction of both noise and emissions also help to reduce health risks [12]. In comparison with conventional vehicles, EVs require minimal maintenance [13]. In addition, they have lower operation cost and higher efficiency [14]. The advantages are increased with the possibility of using the EVs in distributed generation [15]. The use of electricity produced from fossil fuels reduces their advantages [16].

One of the disadvantages of EVs is their lower autonomy, in comparison with conventional vehicles [17]. Also, EVs need the development of recharging infrastructure, which already exists for conventional vehicles [18]. Increasing use of EVs demands increased electricity provision [19]. Sustainability aspects of the use of EVs requires adequate battery disposal/recycling [20]. Finally, the main barrier for EVs is their high initial costs [12].

EVs are good alternatives in countries with low emission electricity matrix and cities with small geographic extension, since in this case they can operate all day with a single recharge. According to Tarroja et al. [21], it is preferable to produce the electricity used in EVs from renewable sources, depending on availability and load demand.

The use of EVs may provoke increased emissions from electric power generation. Monteiro et al. [22] point out that the largest CO_2 producers are power plants, responsible by around 40% of the world electricity production. Therefore, for the use of EVs it is desirable low-emission electricity matrices, which is the case of Brazil, for instance, where CO_2 emissions from electricity generation are low (about 135 gCO_2/kWh) in comparison with other countries. In countries such as Poland and Greece, the CO_2 emission factor from electricity generation is around 850 gCO_2/kWh.

A study developed by Varga [23] used the AVL Cruise software to simulate four different types of electric vehicles to determine the energy consumption using the New European Driving Cycle (NEDC). The results for energy consumption ranged from 0.104 to 0.127 kWh/km. This data was used to calculate CO_2 emissions from those vehicles in Romania based on electric power plant emissions during the period from 2004 to 2008, producing values that varied from 84 to 115.9 g/km.

Yuan et al. [24] simulated an electric vehicle using the AVL Cruise software and evaluated CO_2 emissions for different driving cycles (New European Driving Cycle – NEDC, 1975 U.S. Federal Test Procedure – FTP-75, Japanese Modal Cycle – JC-0, and Worldwide Harmonized Light Duty Test Cycle – WLTC) and driving ranges in China. The authors used a high CO_2 emission factor range (736 g/kWh to 1147 g/kWh), taking coal as the main source of power generation in the country. The emission factor used was 855 g/kWh, although the authors recognized that this value varies in the different parts of the country. Simulated results showed electric vehicle energy consumption around 0.16 kWh/km and CO_2 emissions about 105 g/km in the FTP-75 driving cycle. The authors concluded that, for the Chinese energy matrix, the use of EVs could reduce CO_2 emissions only for operation in distances shorter than 250 km, if compared to conventional vehicles.

The objective of this work is to analyze further the impacts of the replacement of conventional vehicles by electric vehicles on energy consumption and CO_2 emissions. The study is performed using the AVL Cruise software to simulate two similar vehicle models, one powered by an internal combustion engine and the other electric. The benefits of replacing conventional vehicles by EVs are verified using as a case study a taxi fleet of a Brazilian city, where hydroelectric power plants account for over 70% of electricity generation. The use of a renewable source of electricity is expected to increase the advantages of EVs in comparison with previous works, where the studies considered electric matrices based on fossil fuels. The extent of the reduction of CO_2 emission from the use of EVs powered by an electric matrix based on renewables is presented using different scenarios of gradual fleet replacement. An economic analysis was performed to verify the costs of replacement.

2. METHODOLOGY

The emissions of CO_2 from two vehicles of similar model were compared, one conventional, powered by an internal combustion engine (vehicle A), and the other electric (vehicle B). Table 1 presents the details of each vehicle. Vehicle A is the model that best represents the average taxi fleet in operation, which, in reality, is composed by different vehicle models. Both vehicles, A and B, were simulated under the Federal Test Procedure 75

(FTP-75) driving cycle using the AVL Cruise software. CO_2 emissions from vehicle A was calculated considering complete combustion [25], as follows:

(1)

The fuel consumption map of vehicle A, available from the manufacturer, was used to evaluate the equivalent energy consumption considering the fuel as a blend of composition 78% gasoline and 22% ethanol (E22), according to:

As no database is available in Brazil for other pollutant gas components emitted from power generation, CO_2 is the only component here evaluated, as it was done in previous studies [26,27]:

(3)

Four scenarios of different replacement rates of a conventional engine powered taxi fleet by electric vehicles were designed as a case study. The conventional fleet is composed by 213 vehicles, and the period of evaluation is 15 years. The fleet replacement rates adopted were 25%, 50%, 75% and 100%, with all vehicles being replaced in the beginning of the period of evaluation. Two scenarios were optimistic and two pessimistic (Tab. 3), and differ from each other according to the adopted CO_2 emission factor and average distance traveled by taxi per day. For each scenario daily travel distances of 200 km and 400 km by each taxi were considered, representing the minimum and the maximum values. In holiday months, the taxis were assumed to travel an additional distance of 100 km per day.

In the first scenario, a low CO_2 emission factor of 30 gCO_2/kWh was considered, corresponding to the use of hydroelectric power to supply over 70% of the electricity demand. In scenario 2, the CO_2 emission factor was slightly higher than in scenario 1 (50 gCO_2/kWh) to consider a small replacement of hydroelectric power by thermoelectric power as a response to dry winter conditions, which reduce the capacity of hydroelectric power plants. In the third and fourth scenarios, the assumption of low rain levels per year means that most of the hydroelectric power is replaced by thermoelectric power, leading to the adoption of higher emission factors.

For the calculations, the EVs electric energy consumption and the fuel consumption of the conventional vehicles were taken as constant parameters. Each month was considered to have an average of 30 days. The EVs batteries were taken as fully charged early in the day. In all scenarios, an annual growth rate of 5% was assumed for the emission factors.

An economic analysis of the cash flow, present value and net present value was performed for both vehicles considering the cost of acquisition, operation and maintenance, and the taxi driver income. The analysis was based on the replacement of a conventional vehicle by an electric one. The acquisition price of the electric vehicle model studied in this work was estimated, because it is still a concept and is not yet available for retail, taking into consideration the price difference of other vehicle models publicly available in conventional and electric versions. Thus, the acquisition prices of US$ 8,780.2611 for vehicle A and US$ 34,382.26 for vehicle B were adopted. The operation costs were based on the fuel used by vehicle A and the electric energy consumed by vehicle B. The inflation rates for fuel and energy consumption were considered 4.00% yr. and 4.86% yr., respectively, which represent the average between 2004 and 2015. The operation costs of vehicle A (C_{Of}) are:

where $C_{Of,i}$ is fuel cost in 2015 (1.046 US$/L), I_{Rf} is the fuel inflation rate (%), t is the period from the initial time (year), η_f is the fuel consumption efficiency of vehicle A (km/L), and d is the annual travel distance (km).

The operation costs of vehicle B (C_{Oe}) were calculated similarly to vehicle A:

where CO_{ei} is the energy cost in 2015 (0.226 US$/kWh), I_{Re} is the energy inflation rate (%), and η_e is the energy consumption efficiency of vehicle B (kWh/km).

The maintenance costs for vehicle A was based on the study developed by Wang et al [28], taken as 0.215 US$/km in 2015. According to some authors [28,29], the maintenance costs of electric vehicles are half that of conventional vehicles. Hence, the maintenance costs of vehicle B was considered 0.1075 US$/km in 2015. The maintenance costs of vehicle A (C_{MA}) and vehicle B (C_{MB}) in the following years are calculated by:

(6)

(7)

where C_{MAi} and C_{MBi} are the maintenance costs of vehicle A and vehicle B in 2015, respectively, and I_R is the average annual inflation rate.

The revenue of the cash flow was taken as the taxi driver income, considering the taxi fare of 0.83 US$/km. The taxi was considered to travel 200 km per day, with a lifecycle of 5 years, according to the law. The net present value (NPV) was calculated by:

where C_i is the initial cost (US$), F_C is the cash flow (US$) and I_D is the discount rate (%).

3. RESULTS

Results from the simulations of CO_2 emissions and fuel consumption, for vehicle A, and energy consumption, for vehicle B, are presented in Tabs. 3 and 4, respectively. Figure 1 shows the accumulated fuel energy consumption and CO_2 emissions of vehicle A, and the accumulated energy consumption of vehicle B. The accumulated energy consumption of vehicle A is nearly four times higher than that of vehicle B, showing that the use of EVs is highly advantageous in terms of energy consumption. This is a direct effect of the fuel conversion efficiency of the internal combustion engines used in conventional vehicles, which is typically around 25% and is much lower than the energy conversion efficiency of electric vehicles [16]. Figures 2 to 5 show CO_2 emissions that would be avoided with the replacement of the conventional vehicles by EVs in each scenario studied. In all scenarios, different emission factors and travel distances were considered.

Figure 2 shows the reduction of CO_2 emissions for 25% of fleet replacement by EVs. Scenarios 1 and 2 showed low reduction of CO_2 emissions, of around 770 tons of CO_2 by 2030, considering the travel distance of 200 km per day. Both scenarios show close results, since the emissions factors have little difference. In scenarios 3 and 4, for which the emission factors are higher, the reductions reached around 700 tons of CO_2, lower than that of scenarios 1 and 2. This behavior was the same for all vehicle replacement rates, thus expressing a general trend. However, for taxis that operate 400 km a day, these values are higher, reaching 1,040 tons of CO_2 for scenarios 1 and 2, and 960 and 980 tons of CO_2 for scenarios 3 and 4, respectively.

The reduction of CO_2 emissions from the replacement of 50% of the fleet by EVs is presented in Fig. 3. Scenarios 1 and 2 showed a reduction of around 1,520 tons of CO_2 emissions, considering vehicle operation of 200 km per day. In scenarios 3 and 4, the reductions were 1,422 and 1,400 tons of CO_2, respectively. Considering the travel distance of 400 km, these values change to 2080 tons of CO_2 for scenarios 1 and 2, and 1,950 and 1,915 tons of CO_2 for scenarios 3 and 4, respectively.

Figure 4 shows the emissions reduction for replacing 75% of the taxi fleet. For vehicles that travel 200 km a day, scenarios 1 and 2 showed a reduction of around 2,280 tons of CO_2 by 2030. In scenarios 3 and 4, the reductions were 2,135 and 2,101 tons of $CO_{2,}$ respectively. For the distance of 400 km, these values were 3,135 and 3,115 tons of CO_2 for scenarios 1 and 2, and 2,925 and 2,873 tons of CO_2 for scenarios 3 and 4, respectively.

Figure 5 shows the reduction of CO_2 emission if the whole fleet was replaced by EVs. For taxis that travel 200 km a day, scenarios 1 and 2 show that, by 2030, the reduction of CO_2 emissions will be 3,050 and 3,033 tons of CO_2, respectively. In scenarios 3 and 4, the reductions are 2,846 and 2,801 tons of CO_2. For the distance of 400 km, these values are 4,180 and 4,153 tons of CO_2 for scenarios 1 and 2, and 3,900, and 3,830 tons of CO_2 for scenarios 3 and 4, respectively.

It is noticeable that longer daily travel distance by taxi produced higher reduction of CO_2 emissions for all scenarios studied (Figs. 2 to 5). The use of EVs to replace the conventional consistently caused significant reductions in CO_2 emissions, due to the low emissions of the Brazilian electricity sector. This situation is different compared to countries where the electric matrix is coal-based and, consequently, fleet replacement does not generate negative credits and can even increase emissions. In scenarios 1 and 2, for which low emission factors were considered, the reduction on CO_2 emissions from fleet replacement by EVs does not change substantially along the period studied. In scenarios 3 and 4, where the emission factors are high, the benefits on CO_2 emissions from the use of EVs are reduced along the period considered.

Figure 9 compares CO_2 emissions from conventional vehicles and EVs for both travel distances, 200 km and 400 km. For scenarios 1 and 2, where the emission factors are low, CO_2 emissions are around 50 to 64 times lower when EVs are used instead of conventional vehicles. However, this ratio is reduced to around 31 by the year 2030, still making the use of EVs advantageous. For scenarios 3 and 4, the reductions of CO_2 emission from the use of EVs are much lower due to the high emission factors. In the beginning of the period studied, EVs emitted about 20 times less than conventional vehicles with internal combustion engines. However, by 2030, the EVs will emit around 12 to 10 times less than conventional vehicles in scenarios 3 and 4.

Comparing the present results with those obtained by Yuan et al. [27], who simulated different types of electric vehicles in China, the calculated energy consumption was close. However, CO_2 emissions were higher (105 g/km) in that work due to high emission factors adopted for the electric matrix. In the present study, CO_2 emissions varied from 2.85 to 17.79 gCO_2/km, using Brazilian emission factors. These figures are also lower than the results presented by Varga [26], who calculated CO_2 emissions from power generation between 84 and 115.9 gCO_2/km in Romania. Although the study presented by Varga [26] used a different driving cycle, which can lead to some discrepancy in the results, the divergence of values can be mainly attributed to the differences in the electric matrices. While in Brazil hydroelectric power plants generate most of the energy demanded, in the countries considered in those studies [26,27] energy generation is coal-based, thus explaining the lower levels of CO_2 emissions here obtained.

An economic analysis verified if the replacement of conventional taxis by electric taxis is feasible, mainly for scenarios 3 and 4, where the replacements are up to 75%. The results are presented in Tab. 5 and Fig. 7. Table 5 shows the values calculated for the taxi driver income, vehicle acquisition cost, and annual maintenance and operation costs. Only in 2015, the value of vehicle A is higher than vehicle B, because the acquisition price of electric vehicles is higher than conventional vehicles. Over the years, the use of vehicle A is more expensive than vehicle B because of the higher efficiency of electric vehicles in comparison with conventional ones and the lower price of electric energy in Brazil in comparison with the equivalent fuel energy. The net present value in 5 years was US$ 125,362.49 and US$ 141,116.15 for vehicles A and B, respectively.

4. CONCLUSION

This work investigated the replacement of conventional, compact engine-powered vehicles of a taxi fleet by electric vehicles of similar models at the rates of 25%, 50%, 75% and 100%, using two different daily travel distances. The electric power consumed by the EVs was generated under four different scenarios of increasing participation of thermoelectric power in an electric matrix mainly constituted by hydroelectric power, consequently adopting increasing CO_2 emission factors. From the results obtained for both vehicle types undergoing a simulated U.S. FTP-75 test schedule, the following conclusions can be drawn:

- The fuel energy content consumed by the conventional, engine powered vehicles is about four times higher than the electric energy consumed by the electric vehicles;
- A reduction of CO_2 emissions from substitution of conventional vehicles by electric vehicles was observed for all power generation scenarios, travel distances and replacement rates applied;
- The amount of reduced CO_2 emissions is directly proportional to the applied replacement rate of conventional vehicles by EVs;
- The reduction of CO_2 emissions from the use of EVs increased about 37% when the daily travel distance by the taxi fleet was doubled;
- During the 15 years period analyzed, the reduction of CO_2 emissions from the substitution of conventional vehicles by EVs was decreased by around 6.1%, for 25% replacement rate, and about 1.7%, for 100% replacement rate, due to an annual increase of CO_2 emission factors from electricity generation;
- The total replacement of the taxi fleet by EVs would have an immediate impact from 18% to 64% of CO_2 emission reduction, respectively considering the most unfavorable condition of electricity generation, with high substitution of hydroelectric power by thermoelectric power, and the most favorable condition of electricity generation, with over 70% of the electricity being supplied by hydroelectric power;
- At the end of the 15 years period, the total replacement of the taxi fleet by EVs would cause CO_2 emission reduction from 9% to 30%, for the most unfavorable and the most favorable power generation conditions, respectively.
- Although the acquisition cost of an electric vehicle is higher than a conventional vehicle, the EVs have lower operation costs.

– The economic analysis shows that the replacement of conventional vehicles by electric vehicles in a taxi fleet is feasible, being profitable from the second year of utilization under the conditions of this study.

5. ACKNOWLEDGEMENTS

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7. NOMENCLATURE

C_F	Fuel carbon content
C_{MAi}	Cost of maintenance of conventional vehicle in the initial year (2015) (US$/year)
C_{MBi}	Cost of maintenance of electrical vehicle in the initial year (2015) (US$/year)
$C_{Oe,i}$	Energy cost in the initial year (2015) (US$/kWh)
$C_{Of,i}$	Fuel cost in the initial year (2015) (US$/L)
CO_2	Carbon dioxide
d	Travel distance in the FTP-75 test schedule or annual traveled distance (km)
E_E	Electric energy consumption (kW.h/km)
E_F	Fuel energy consumption (kW.h/km)
EVs	Electric vehicles
f_{CO2}	Emission factor of CO_2 (t_{CO2}/kWh)
FTP-75	Federal Test Procedure 75

I_D	Discounted rate (%)
ICEVs	Vehicles with internal combustion engine
JC-0	Japanese Modal Cycle
	Fuel consumption (kg/h)
M_{CO2}	Molar mass of CO_2 (kg/kmol)
M_F	Molar mass of fuel (kg/kmol)
NEDC	New European Driving Cycle
NPV	Net Present Value
Q_{LHV}	Low heating value of fuel (kJ/kg)
SIN	Brazilian National Grid System
t	Travel time in the FTP-75 test schedule (h) or time after initial year (year)
I_R	Average annual inflation rate y.y (%)
I_{Re}	Energy inflation rate y.y (%)
I_{Rf}	Fuel (gasoline) inflation rate y.y (%)
WLTC	Worldwide Harmonized Light Duty Test Cycle
η_f	Fuel consumption efficiency of conventional vehicle (km/L)
η_e	Energy consumption efficiency of electric vehicle (kW.h/km)

LIST OF TABLE CAPTIONS

LIST OF FIGURE CAPTIONS

Table 1. Details of vehicles.

PARAMETER	SPECIFICATION	
	VEHICLE A	VEHICLE B
Bore × stroke	70.0 mm × 64.9 mm	-
Compression ratio	12.15:1	-
Volume displacement	1.0 L	-
Rated power	53.7 kW @ 6250 rpm	15 kW
Rated torque	93.2 Nm @ 4500 rpm	50 Nm
Fuel	E22	-
Battery type	-	Sodium-Nickel-Chlorine
Voltage	-	253 V
Energy		19.2 kW.h
Recharge time	-	8 hours

Table 2. Scenarios of vehicle fleet replacement.

SCENARIO	CO_2 EMISSION FACTOR (gCO_2/kWh)	WEATHER CONDITIONS	DISTANCE TRAVELED BY A TAXI FOR A DAY (km)
1	30	Favorable	200 – 400
2	30 – 50		
3	90	Unfavorable	
4	90 – 140		

Table 3. CO_2 emissions, fuel and energy consumption of vehicle A.

VEHICLE A	
CO_2 emissions (g/km)	182.74
Fuel consumption (km/L)	11.91
Energy consumption (kWh/km)	0.6830

Table 4. Accumulated and specific energy consumption of vehicle B.

VEHICLE B	
Accumulated energy consumption (kWh)	2.267
Specific energy consumption (kWh/km)	0.0951

Table 5. Results from the economic analysis.

VEHICLE A							
Year	Revenue	Acquisition Cost	Annual Maintenance	Operation	Cash Flow	Present Value	Net Present Value
2015	$39,988.67	-$8.780,11		-$4,249.78	$26,958.78	$26,958.78	$123,170.22
2016	$39,988.67		-$10,337.21	-$4,419.77	$25,231.69	$23,673.95	
2017	$39,988.67		-$11,742.34	-$4,596.56	$23,649.77	$20,819.75	
2018	$39,988.67		-$12,514.98	-$4,780.42	$22,693.26	18,744.32	
2019	$39,988.67		-$13,338.47	-$4,971.63	$21,678.56	16,800.70	
2020	$39,988.67		-$12,576.79	-$5,170.50	$22,241.37	16,172.71	
VEHICLE B							
Year	Revenue	Acquisition Cost	Annual Maintenance	Operation	Cash Flow	Present Value	Net Present Value
2015	$39,988.67	-$28.090,14		-$1,028.85	$10,869.66	$10,869.66	$141,116.15
2016	$39,988.67		-$5,168.60	-$1,078.86	$33,741.20	$31,658.09	
2017	$39,988.67		-$5,871.16	-$1,131,29	$32,986.20	$29,038.94	
2018	$39,988.67		-$6,257.49	-$1,186.27	$32,544.89	$26,881.64	
2019	$39,988.67		-$6,669.23	-$1,243.92	$32,075.50	$24,858.25	
2020	$39,988.67		-$7,108.07	-$1,304.38	$31,576.21	$22,960.50	

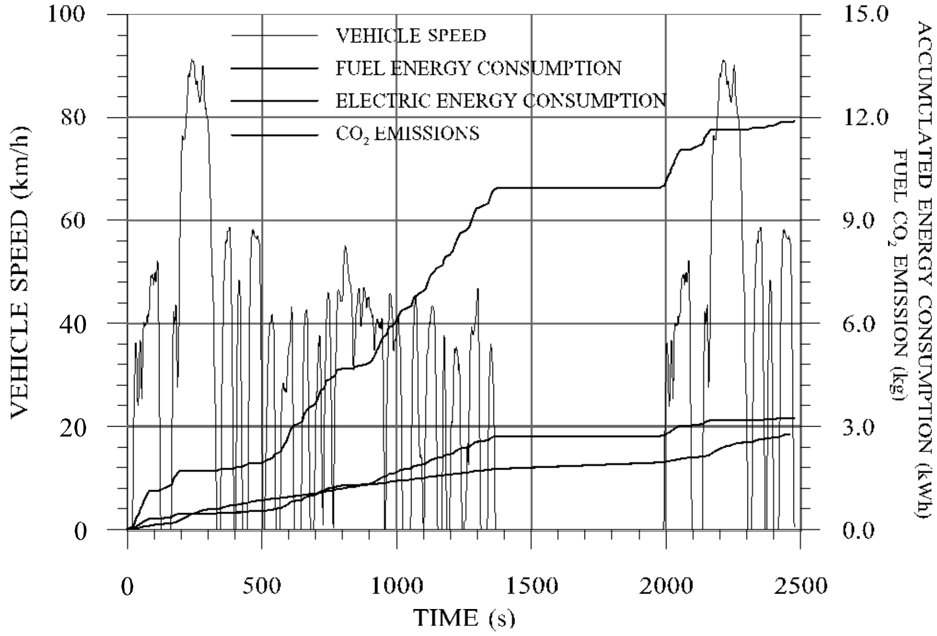

Figure 1. Accumulated fuel energy consumption and CO_2 emissions of vehicle A, and accumulated electric energy consumption of vehicle B.

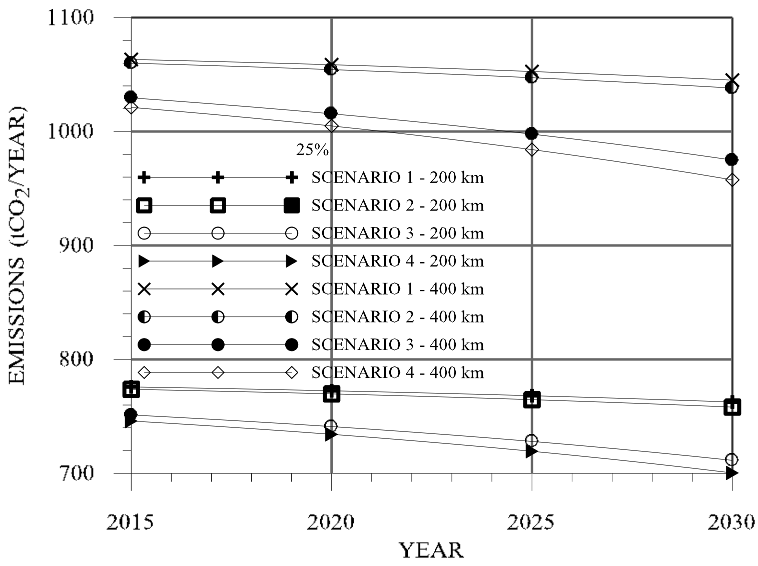

Figure 2. CO_2 reduction for replacement of 25% of the taxi fleet.

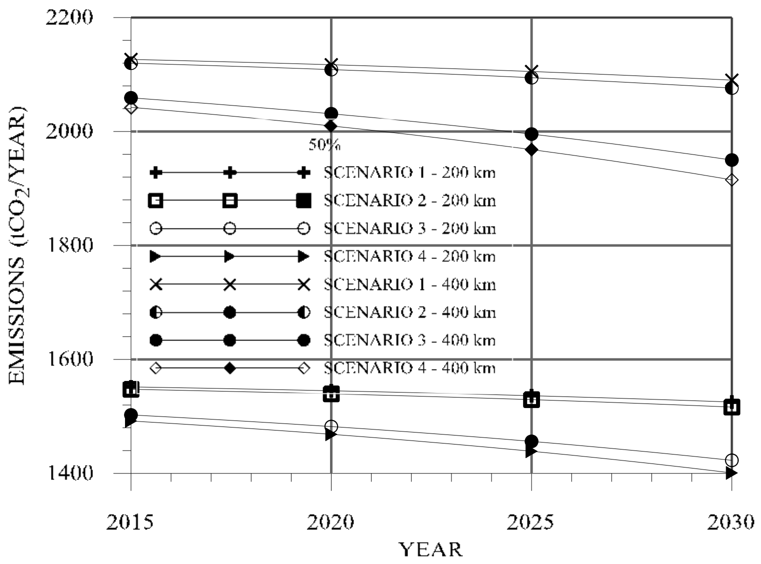

Figure 3. CO_2 reduction for replacement of 50% of the taxi fleet.

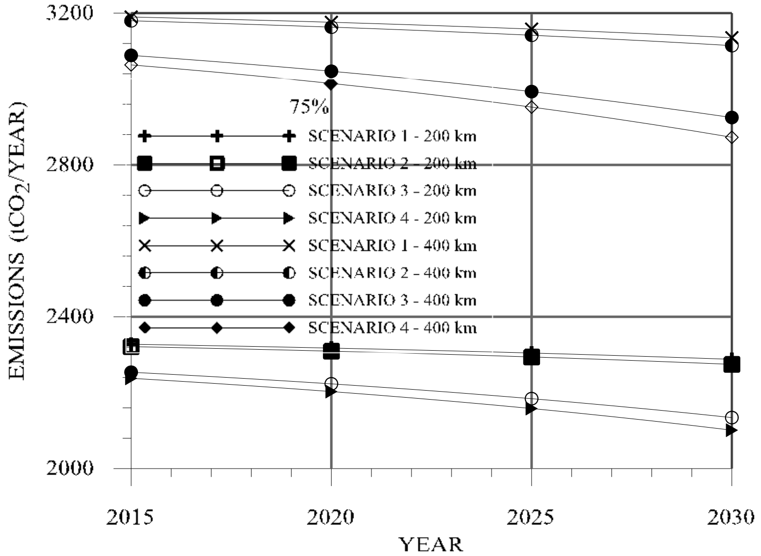

Figure 4. CO_2 reduction for replacement of 75% of the taxi fleet.

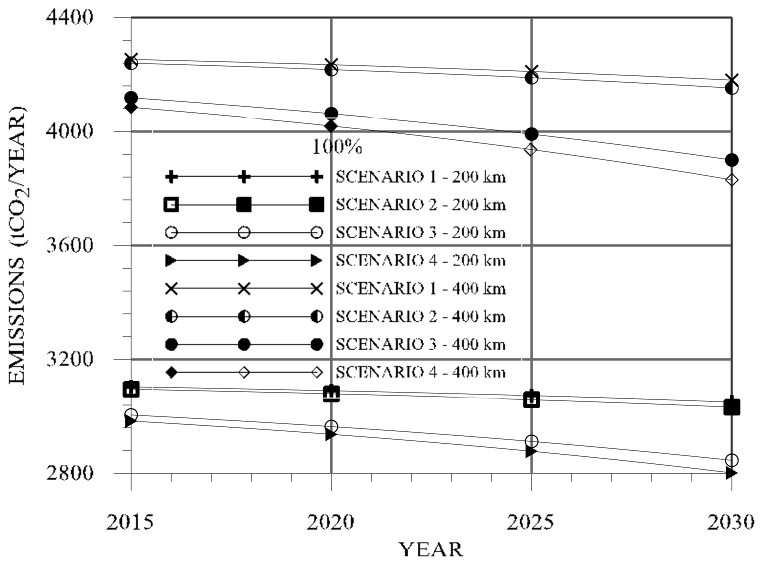

Figure 5. CO_2 reduction for replacement of 100% of the taxi fleet.

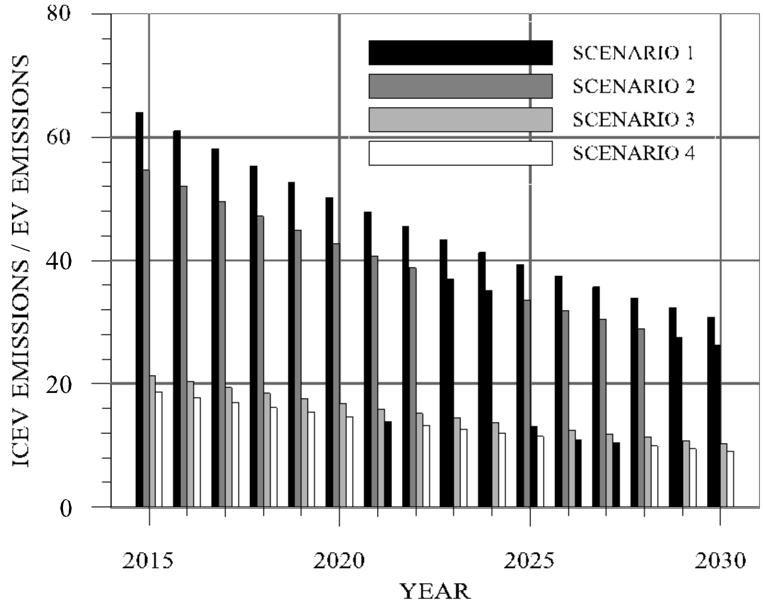

Figure 6. Ratio between CO_2 emissions from the vehicles powered by internal combustion engines (ICEV) and from the electric vehicles (EV).

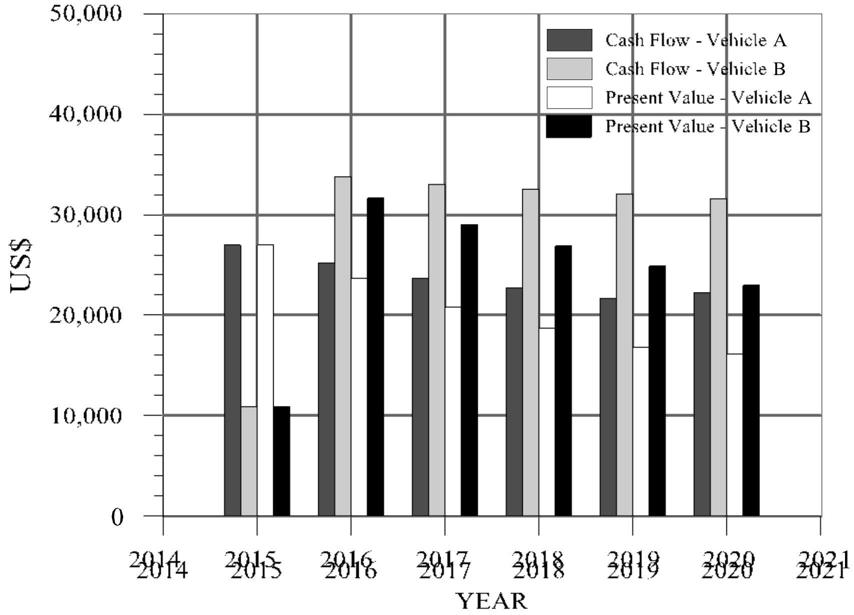

Figure 6. Cash flow and present value over the years.

Simulation of the impacts on carbon dioxide emissions from replacement of a conventional Brazilian taxi fleet by electric vehicles

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ABSTRACT

This work evaluates the effects of the replacement of engine-powered vehicles by electric vehicles on carbon dioxide (CO_2) emissions and energy consumption. A case study of a taxi fleet replacement was conducted with the aid of the AVL Cruise software. The simulation was performed under different scenarios of total or partial fleet replacement along a period of 15 years. The scenarios were designed considering favorable and unfavorable conditions for electricity production from a clean source, thus influencing the CO_2 emission factor adopted. The simulations showed that the electric energy consumption by the electric vehicles is about four times lower than fuel energy consumption by the conventional vehicles undergoing a standard test schedule. At the end of the period considered the electric vehicles will produce lower CO_2 emissions than the conventional vehicle fleet by a factor of 10, even considering the most unfavorable scenario of electric power generation. An economic analysis shows that the present value of electric vehicles over the years is lower than that of conventional vehicles, except for the first year after vehicle acquisition.

Keywords: electric vehicle; CO_2 emissions; energy; fuel consumption; sustainable development.

1. INTRODUCTION

To improve air quality, increasingly strict regulation laws require reduced automotive emissions, which has influenced the development of clean technologies [1]. Those technologies include electric vehicles (EVs), hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) [2]. The possible reduction of carbon dioxide (CO_2) emissions with the use of those technologies also contribute to reduce global temperature increase, one of the key factors for climate change [3]. In order to reduce automotive emissions many countries adopt increasingly strict regulating laws [4]. The need to reduce carbon emissions motivates the use of renewable energy sources in the electricity matrix [5]. The demand for sustainable actions inspires the rise of solutions with higher energy efficiency [6]. Those solutions are generally characterized by less oil dependence and reduced fuel consumption [7]. In this sense, there are many studies on EVs as a possible viable alternative, especially in countries with clean electricity matrix [8].

The positive and negative aspects of the replacement of engine-powered vehicles by electrical vehicles are identified for specifics fleets [9]. One of the advantages of EVs is the absence of exhaust emissions [10]. Another advantage is the reduced noise during operation [11]. The reduction of both noise and emissions also help to reduce health risks [12]. In comparison with conventional vehicles, EVs require minimal maintenance [13]. In addition, they have lower operation cost and higher efficiency [14]. The advantages are increased with the possibility of using the EVs in distributed generation [15]. The use of electricity produced from fossil fuels reduces their advantages [16].

One of the disadvantages of EVs is their lower autonomy, in comparison with conventional vehicles [17]. Also, EVs need the development of recharging infrastructure, which already exists for conventional vehicles [18]. Increasing use of EVs demands increased

electricity provision [19]. Sustainability aspects of the use of EVs requires adequate battery disposal/recycling [20]. Finally, the main barrier for EVs is their high initial costs [12].

EVs are good alternatives in countries with low emission electricity matrix and cities with small geographic extension, since in this case they can operate all day with a single recharge. According to Tarroja et al. [21], it is preferable to produce the electricity used in EVs from renewable sources, depending on availability and load demand.

The use of EVs may provoke increased emissions from electric power generation. Monteiro et al. [22] point out that the largest CO_2 producers are power plants, responsible by around 40% of the world electricity production. Therefore, for the use of EVs it is desirable low-emission electricity matrices, which is the case of Brazil, for instance, where CO_2 emissions from electricity generation are low (about 135 gCO_2/kWh) in comparison with other countries. In countries such as Poland and Greece, the CO_2 emission factor from electricity generation is around 850 gCO_2/kWh.

A study developed by Varga [23] used the AVL Cruise software to simulate four different types of electric vehicles to determine the energy consumption using the New European Driving Cycle (NEDC). The results for energy consumption ranged from 0.104 to 0.127 kWh/km. This data was used to calculate CO_2 emissions from those vehicles in Romania based on electric power plant emissions during the period from 2004 to 2008, producing values that varied from 84 to 115.9 g/km.

Yuan et al. [24] simulated an electric vehicle using the AVL Cruise software and evaluated CO_2 emissions for different driving cycles (New European Driving Cycle – NEDC, 1975 U.S. Federal Test Procedure – FTP-75, Japanese Modal Cycle – JC-0, and Worldwide Harmonized Light Duty Test Cycle – WLTC) and driving ranges in China. The authors used a high CO_2 emission factor range (736 g/kWh to 1147 g/kWh), taking coal as the main source of power generation in the country. The emission factor used was 855 g/kWh, although the

authors recognized that this value varies in the different parts of the country. Simulated results showed electric vehicle energy consumption around 0.16 kWh/km and CO_2 emissions about 105 g/km in the FTP-75 driving cycle. The authors concluded that, for the Chinese energy matrix, the use of EVs could reduce CO_2 emissions only for operation in distances shorter than 250 km, if compared to conventional vehicles.

The objective of this work is to analyze further the impacts of the replacement of conventional vehicles by electric vehicles on energy consumption and CO_2 emissions. The study is performed using the AVL Cruise software to simulate two similar vehicle models, one powered by an internal combustion engine and the other electric. The benefits of replacing conventional vehicles by EVs are verified using as a case study a taxi fleet of a Brazilian city, where hydroelectric power plants account for over 70% of electricity generation. The use of a renewable source of electricity is expected to increase the advantages of EVs in comparison with previous works, where the studies considered electric matrices based on fossil fuels. The extent of the reduction of CO_2 emission from the use of EVs powered by an electric matrix based on renewables is presented using different scenarios of gradual fleet replacement. An economic analysis was performed to verify the costs of replacement.

2. METHODOLOGY

The emissions of CO_2 from two vehicles of similar model were compared, one conventional, powered by an internal combustion engine (vehicle A), and the other electric (vehicle B). Table 1 presents the details of each vehicle. Vehicle A is the model that best represents the average taxi fleet in operation, which, in reality, is composed by different vehicle models. Both vehicles, A and B, were simulated under the Federal Test Procedure 75

(FTP-75) driving cycle using the AVL Cruise software. CO_2 emissions from vehicle A was calculated considering complete combustion [25], as follows:

(1)

The fuel consumption map of vehicle A, available from the manufacturer, was used to evaluate the equivalent energy consumption considering the fuel as a blend of composition 78% gasoline and 22% ethanol (E22), according to:

As no database is available in Brazil for other pollutant gas components emitted from power generation, CO_2 is the only component here evaluated, as it was done in previous studies [26,27]:

(3)

Four scenarios of different replacement rates of a conventional engine powered taxi fleet by electric vehicles were designed as a case study. The conventional fleet is composed by 213 vehicles, and the period of evaluation is 15 years. The fleet replacement rates adopted were 25%, 50%, 75% and 100%, with all vehicles being replaced in the beginning of the period of evaluation. Two scenarios were optimistic and two pessimistic (Tab. 3), and differ from each other according to the adopted CO_2 emission factor and average distance traveled by taxi per day. For each scenario daily travel distances of 200 km and 400 km by each taxi were considered, representing the minimum and the maximum values. In holiday months, the taxis were assumed to travel an additional distance of 100 km per day.

In the first scenario, a low CO_2 emission factor of 30 gCO_2/kWh was considered, corresponding to the use of hydroelectric power to supply over 70% of the electricity demand. In scenario 2, the CO_2 emission factor was slightly higher than in scenario 1 (50 gCO_2/kWh) to consider a small replacement of hydroelectric power by thermoelectric power as a response to dry winter conditions, which reduce the capacity of hydroelectric power plants. In the third and fourth scenarios, the assumption of low rain levels per year means that most of the hydroelectric power is replaced by thermoelectric power, leading to the adoption of higher emission factors.

For the calculations, the EVs electric energy consumption and the fuel consumption of the conventional vehicles were taken as constant parameters. Each month was considered to have an average of 30 days. The EVs batteries were taken as fully charged early in the day. In all scenarios, an annual growth rate of 5% was assumed for the emission factors.

An economic analysis of the cash flow, present value and net present value was performed for both vehicles considering the cost of acquisition, operation and maintenance, and the taxi driver income. The analysis was based on the replacement of a conventional vehicle by an electric one. The acquisition price of the electric vehicle model studied in this work was estimated, because it is still a concept and is not yet available for retail, taking into consideration the price difference of other vehicle models publicly available in conventional and electric versions. Thus, the acquisition prices of US$ 8,780.2611 for vehicle A and US$ 34,382.26 for vehicle B were adopted. The operation costs were based on the fuel used by vehicle A and the electric energy consumed by vehicle B. The inflation rates for fuel and energy consumption were considered 4.00% yr. and 4.86% yr., respectively, which represent the average between 2004 and 2015. The operation costs of vehicle A (C_{Of}) are:

—

where $C_{Of,i}$ is fuel cost in 2015 (1.046 US$/L), I_{Rf} is the fuel inflation rate (%), t is the period from the initial time (year), η_f is the fuel consumption efficiency of vehicle A (km/L), and d is the annual travel distance (km).

The operation costs of vehicle B (C_{Oe}) were calculated similarly to vehicle A:

—

where CO_{ei} is the energy cost in 2015 (0.226 US$/kWh), I_{Re} is the energy inflation rate (%), and η_e is the energy consumption efficiency of vehicle B (kWh/km).

The maintenance costs for vehicle A was based on the study developed by Wang et al [28], taken as 0.215 US$/km in 2015. According to some authors [28,29], the maintenance costs of electric vehicles are half that of conventional vehicles. Hence, the maintenance costs of vehicle B was considered 0.1075 US$/km in 2015. The maintenance costs of vehicle A (C_{MA}) and vehicle B (C_{MB}) in the following years are calculated by:

(6)

(7)

where C_{MAi} and C_{MBi} are the maintenance costs of vehicle A and vehicle B in 2015, respectively, and I_R is the average annual inflation rate.

The revenue of the cash flow was taken as the taxi driver income, considering the taxi fare of 0.83 US$/km. The taxi was considered to travel 200 km per day, with a lifecycle of 5 years, according to the law. The net present value (NPV) was calculated by:

where C_i is the initial cost (US$), F_C is the cash flow (US$) and I_D is the discount rate (%).

3. RESULTS

Results from the simulations of CO_2 emissions and fuel consumption, for vehicle A, and energy consumption, for vehicle B, are presented in Tabs. 3 and 4, respectively. Figure 1 shows the accumulated fuel energy consumption and CO_2 emissions of vehicle A, and the accumulated energy consumption of vehicle B. The accumulated energy consumption of vehicle A is nearly four times higher than that of vehicle B, showing that the use of EVs is highly advantageous in terms of energy consumption. This is a direct effect of the fuel conversion efficiency of the internal combustion engines used in conventional vehicles, which is typically around 25% and is much lower than the energy conversion efficiency of electric vehicles [16]. Figures 2 to 5 show CO_2 emissions that would be avoided with the replacement of the conventional vehicles by EVs in each scenario studied. In all scenarios, different emission factors and travel distances were considered.

Figure 2 shows the reduction of CO_2 emissions for 25% of fleet replacement by EVs. Scenarios 1 and 2 showed low reduction of CO_2 emissions, of around 770 tons of CO_2 by 2030, considering the travel distance of 200 km per day. Both scenarios show close results, since the emissions factors have little difference. In scenarios 3 and 4, for which the emission factors are higher, the reductions reached around 700 tons of CO_2, lower than that of scenarios 1 and 2. This behavior was the same for all vehicle replacement rates, thus expressing a general trend. However, for taxis that operate 400 km a day, these values are higher, reaching 1,040 tons of CO_2 for scenarios 1 and 2, and 960 and 980 tons of CO_2 for scenarios 3 and 4, respectively.

The reduction of CO_2 emissions from the replacement of 50% of the fleet by EVs is presented in Fig. 3. Scenarios 1 and 2 showed a reduction of around 1,520 tons of CO_2 emissions, considering vehicle operation of 200 km per day. In scenarios 3 and 4, the reductions were 1,422 and 1,400 tons of CO_2, respectively. Considering the travel distance of 400 km, these values change to 2080 tons of CO_2 for scenarios 1 and 2, and 1,950 and 1,915 tons of CO_2 for scenarios 3 and 4, respectively.

Figure 4 shows the emissions reduction for replacing 75% of the taxi fleet. For vehicles that travel 200 km a day, scenarios 1 and 2 showed a reduction of around 2,280 tons of CO_2 by 2030. In scenarios 3 and 4, the reductions were 2,135 and 2,101 tons of $CO_{2,}$ respectively. For the distance of 400 km, these values were 3,135 and 3,115 tons of CO_2 for scenarios 1 and 2, and 2,925 and 2,873 tons of CO_2 for scenarios 3 and 4, respectively.

Figure 5 shows the reduction of CO_2 emission if the whole fleet was replaced by EVs. For taxis that travel 200 km a day, scenarios 1 and 2 show that, by 2030, the reduction of CO_2 emissions will be 3,050 and 3,033 tons of CO_2, respectively. In scenarios 3 and 4, the reductions are 2,846 and 2,801 tons of CO_2. For the distance of 400 km, these values are 4,180 and 4,153 tons of CO_2 for scenarios 1 and 2, and 3,900, and 3,830 tons of CO_2 for scenarios 3 and 4, respectively.

It is noticeable that longer daily travel distance by taxi produced higher reduction of CO_2 emissions for all scenarios studied (Figs. 2 to 5). The use of EVs to replace the conventional consistently caused significant reductions in CO_2 emissions, due to the low emissions of the Brazilian electricity sector. This situation is different compared to countries where the electric matrix is coal-based and, consequently, fleet replacement does not generate negative credits and can even increase emissions. In scenarios 1 and 2, for which low emission factors were considered, the reduction on CO_2 emissions from fleet replacement by EVs does not change substantially along the period studied. In scenarios 3 and 4, where the emission factors are high, the benefits on CO_2 emissions from the use of EVs are reduced along the period considered.

Figure 9 compares CO_2 emissions from conventional vehicles and EVs for both travel distances, 200 km and 400 km. For scenarios 1 and 2, where the emission factors are low, CO_2 emissions are around 50 to 64 times lower when EVs are used instead of conventional vehicles. However, this ratio is reduced to around 31 by the year 2030, still making the use of EVs advantageous. For scenarios 3 and 4, the reductions of CO_2 emission from the use of EVs are much lower due to the high emission factors. In the beginning of the period studied, EVs emitted about 20 times less than conventional vehicles with internal combustion engines. However, by 2030, the EVs will emit around 12 to 10 times less than conventional vehicles in scenarios 3 and 4.

Comparing the present results with those obtained by Yuan et al. [27], who simulated different types of electric vehicles in China, the calculated energy consumption was close. However, CO_2 emissions were higher (105 g/km) in that work due to high emission factors adopted for the electric matrix. In the present study, CO_2 emissions varied from 2.85 to 17.79 gCO_2/km, using Brazilian emission factors. These figures are also lower than the results presented by Varga [26], who calculated CO_2 emissions from power generation between 84 and 115.9 gCO_2/km in Romania. Although the study presented by Varga [26] used a different driving cycle, which can lead to some discrepancy in the results, the divergence of values can be mainly attributed to the differences in the electric matrices. While in Brazil hydroelectric power plants generate most of the energy demanded, in the countries considered in those studies [26,27] energy generation is coal-based, thus explaining the lower levels of CO_2 emissions here obtained.

An economic analysis verified if the replacement of conventional taxis by electric taxis is feasible, mainly for scenarios 3 and 4, where the replacements are up to 75%. The results are presented in Tab. 5 and Fig. 7. Table 5 shows the values calculated for the taxi driver income, vehicle acquisition cost, and annual maintenance and operation costs. Only in 2015, the value of vehicle A is higher than vehicle B, because the acquisition price of electric vehicles is higher than conventional vehicles. Over the years, the use of vehicle A is more expensive than vehicle B because of the higher efficiency of electric vehicles in comparison with conventional ones and the lower price of electric energy in Brazil in comparison with the equivalent fuel energy. The net present value in 5 years was US$ 125,362.49 and US$ 141,116.15 for vehicles A and B, respectively.

4. CONCLUSION

This work investigated the replacement of conventional, compact engine-powered vehicles of a taxi fleet by electric vehicles of similar models at the rates of 25%, 50%, 75% and 100%, using two different daily travel distances. The electric power consumed by the EVs was generated under four different scenarios of increasing participation of thermoelectric power in an electric matrix mainly constituted by hydroelectric power, consequently adopting increasing CO_2 emission factors. From the results obtained for both vehicle types undergoing a simulated U.S. FTP-75 test schedule, the following conclusions can be drawn:

- The fuel energy content consumed by the conventional, engine powered vehicles is about four times higher than the electric energy consumed by the electric vehicles;
- A reduction of CO_2 emissions from substitution of conventional vehicles by electric vehicles was observed for all power generation scenarios, travel distances and replacement rates applied;
- The amount of reduced CO_2 emissions is directly proportional to the applied replacement rate of conventional vehicles by EVs;
- The reduction of CO_2 emissions from the use of EVs increased about 37% when the daily travel distance by the taxi fleet was doubled;
- During the 15 years period analyzed, the reduction of CO_2 emissions from the substitution of conventional vehicles by EVs was decreased by around 6.1%, for 25% replacement rate, and about 1.7%, for 100% replacement rate, due to an annual increase of CO_2 emission factors from electricity generation;
- The total replacement of the taxi fleet by EVs would have an immediate impact from 18% to 64% of CO_2 emission reduction, respectively considering the most unfavorable condition of electricity generation, with high substitution of hydroelectric power by thermoelectric power, and the most favorable condition of electricity generation, with over 70% of the electricity being supplied by hydroelectric power;
- At the end of the 15 years period, the total replacement of the taxi fleet by EVs would cause CO_2 emission reduction from 9% to 30%, for the most unfavorable and the most favorable power generation conditions, respectively.
- Although the acquisition cost of an electric vehicle is higher than a conventional vehicle, the EVs have lower operation costs.

– The economic analysis shows that the replacement of conventional vehicles by electric vehicles in a taxi fleet is feasible, being profitable from the second year of utilization under the conditions of this study.

5. ACKNOWLEDGEMENTS

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7. NOMENCLATURE

C_F	Fuel carbon content
C_{MAi}	Cost of maintenance of conventional vehicle in the initial year (2015) (US$/year)
C_{MBi}	Cost of maintenance of electrical vehicle in the initial year (2015) (US$/year)
$C_{Oe,i}$	Energy cost in the initial year (2015) (US$/kWh)
$C_{Of,i}$	Fuel cost in the initial year (2015) (US$/L)
CO_2	Carbon dioxide
d	Travel distance in the FTP-75 test schedule or annual traveled distance (km)
E_E	Electric energy consumption (kW.h/km)
E_F	Fuel energy consumption (kW.h/km)
EVs	Electric vehicles
f_{CO2}	Emission factor of CO_2 (t_{CO2}/kWh)
FTP-75	Federal Test Procedure 75

I_D	Discounted rate (%)
ICEVs	Vehicles with internal combustion engine
JC-0	Japanese Modal Cycle
	Fuel consumption (kg/h)
M_{CO2}	Molar mass of CO_2 (kg/kmol)
M_F	Molar mass of fuel (kg/kmol)
NEDC	New European Driving Cycle
NPV	Net Present Value
Q_{LHV}	Low heating value of fuel (kJ/kg)
SIN	Brazilian National Grid System
t	Travel time in the FTP-75 test schedule (h) or time after initial year (year)
I_R	Average annual inflation rate y.y (%)
I_{Re}	Energy inflation rate y.y (%)
I_{Rf}	Fuel (gasoline) inflation rate y.y (%)
WLTC	Worldwide Harmonized Light Duty Test Cycle
η_f	Fuel consumption efficiency of conventional vehicle (km/L)
η_e	Energy consumption efficiency of electric vehicle (kW.h/km)

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LIST OF FIGURE CAPTIONS

Figure 1. Accumulated fuel energy consumption and CO_2 emissions of vehicle A, and accumulated electric energy consumption of vehicle B.

Figure 2. CO_2 reduction for replacement of 25% of the taxi fleet.

Figure 3. CO_2 reduction for replacement of 50% of the taxi fleet.

Figure 4. CO_2 reduction for replacement of 75% of the taxi fleet.

Figure 5. CO_2 reduction for replacement of 100% of the taxi fleet.

Figure 6. Ratio between CO_2 emissions from the vehicles powered by internal combustion engines (ICEV) and from the electric vehicles (EV).

Figure 6. Cash flow and present value over the years.

Table 1. Details of vehicles.

PARAMETER	SPECIFICATION	
	VEHICLE A	VEHICLE B
Bore × stroke	70.0 mm × 64.9 mm	-
Compression ratio	12.15:1	-
Volume displacement	1.0 L	-
Rated power	53.7 kW @ 6250 rpm	15 kW
Rated torque	93.2 Nm @ 4500 rpm	50 Nm
Fuel	E22	-
Battery type	-	Sodium-Nickel-Chlorine
Voltage	-	253 V
Energy		19.2 kW.h
Recharge time	-	8 hours

Table 2. Scenarios of vehicle fleet replacement.

SCENARIO	CO_2 EMISSION FACTOR (gCO_2/kWh)	WEATHER CONDITIONS	DISTANCE TRAVELED BY A TAXI FOR A DAY (km)
1	30	Favorable	200 – 400
2	30 – 50		
3	90	Unfavorable	
4	90 – 140		

Table 3. CO_2 emissions, fuel and energy consumption of vehicle A.

VEHICLE A	
CO_2 emissions (g/km)	182.74
Fuel consumption (km/L)	11.91
Energy consumption (kWh/km)	0.6830

Table 4. Accumulated and specific energy consumption of vehicle B.

VEHICLE B	
Accumulated energy consumption (kWh)	2.267
Specific energy consumption (kWh/km)	0.0951

Table 5. Results from the economic analysis.

VEHICLE A							
Year	Revenue	Acquisition Cost	Annual Maintenance	Operation	Cash Flow	Present Value	Net Present Value
2015	$39,988.67	-$8.780,11		-$4,249.78	$26,958.78	$26,958.78	$123,170.22
2016	$39,988.67		-$10,337.21	-$4,419.77	$25,231.69	$23,673.95	
2017	$39,988.67		-$11,742.34	-$4,596.56	$23,649.77	$20,819.75	
2018	$39,988.67		-$12,514.98	-$4,780.42	$22,693.26	18,744.32	
2019	$39,988.67		-$13,338.47	-$4,971.63	$21,678.56	16,800.70	
2020	$39,988.67		-$12,576.79	-$5,170.50	$22,241.37	16,172.71	
VEHICLE B							
Year	Revenue	Acquisition Cost	Annual Maintenance	Operation	Cash Flow	Present Value	Net Present Value
2015	$39,988.67	-$28.090,14		-$1,028.85	$10,869.66	$10,869.66	$141,116.15
2016	$39,988.67		-$5,168.60	-$1,078.86	$33,741.20	$31,658.09	
2017	$39,988.67		-$5,871.16	-$1,131,29	$32,986.20	$29,038.94	
2018	$39,988.67		-$6,257.49	-$1,186.27	$32,544.89	$26,881.64	
2019	$39,988.67		-$6,669.23	-$1,243.92	$32,075.50	$24,858.25	
2020	$39,988.67		-$7,108.07	-$1,304.38	$31,576.21	$22,960.50	

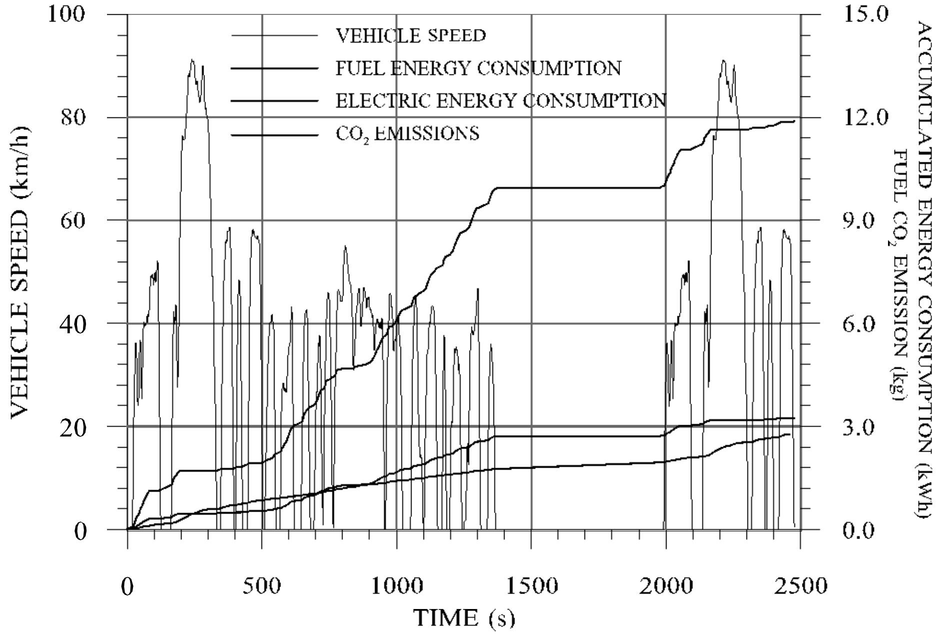

Figure 1. Accumulated fuel energy consumption and CO_2 emissions of vehicle A, and accumulated electric energy consumption of vehicle B.

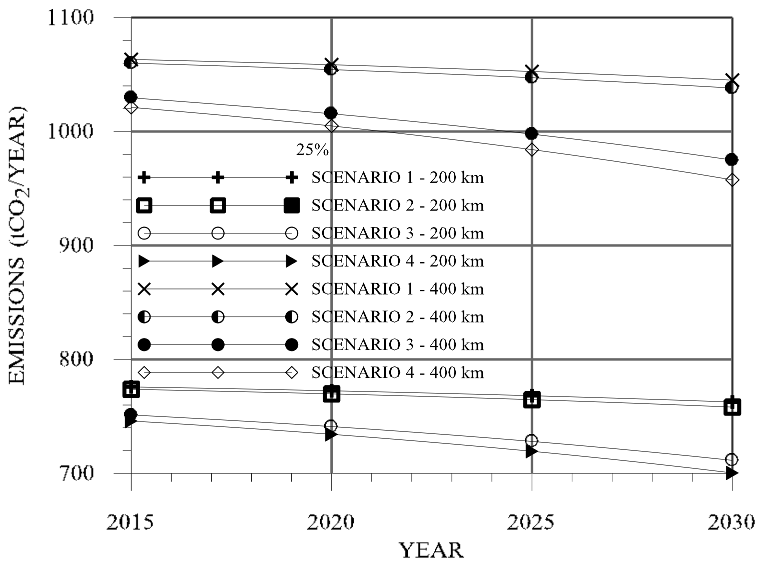

Figure 2. CO_2 reduction for replacement of 25% of the taxi fleet.

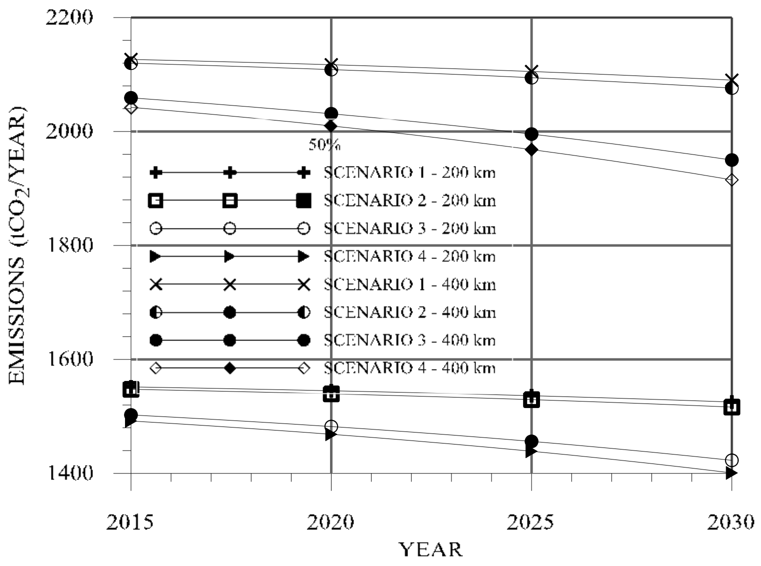

Figure 3. CO_2 reduction for replacement of 50% of the taxi fleet.

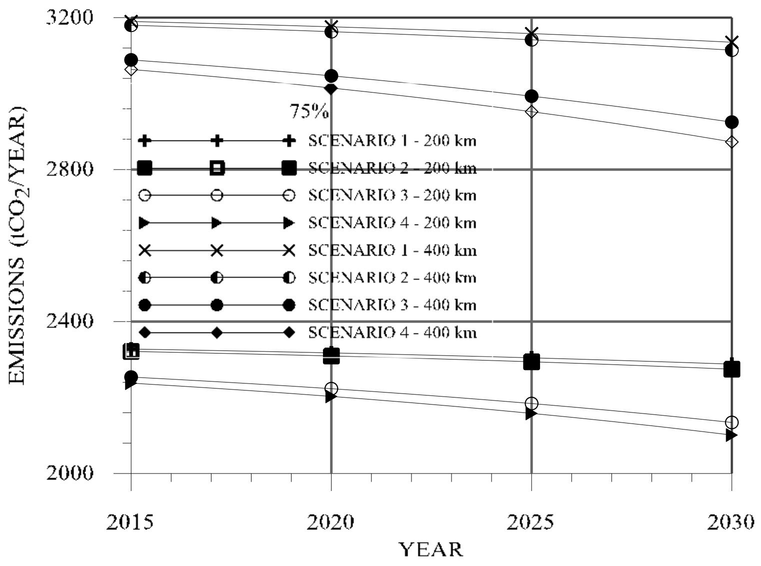

Figure 4. CO_2 reduction for replacement of 75% of the taxi fleet.

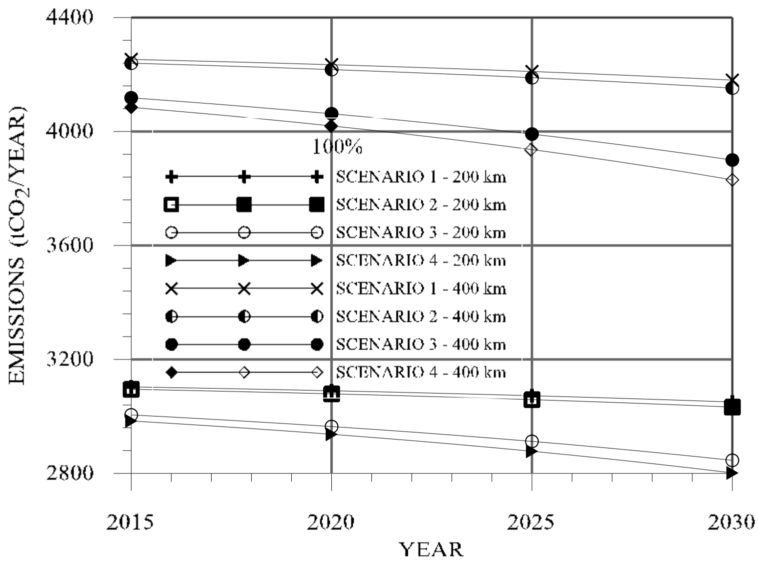

Figure 5. CO_2 reduction for replacement of 100% of the taxi fleet.

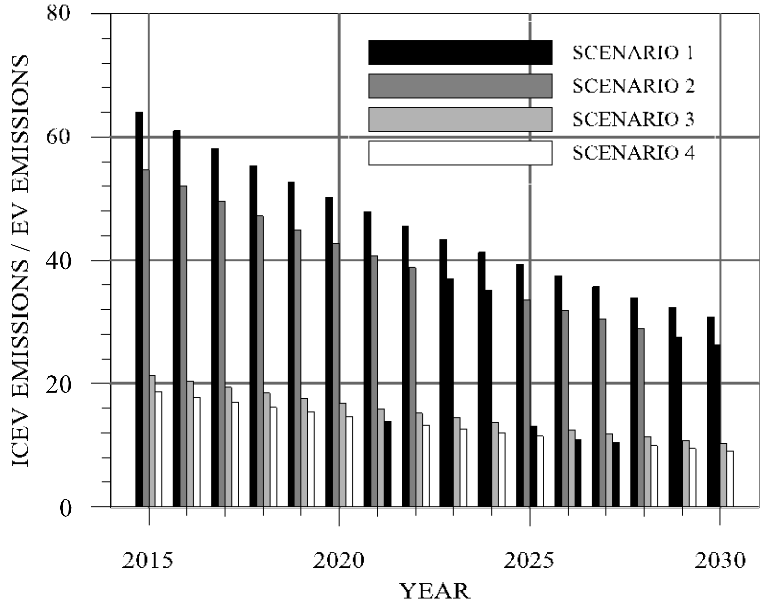

Figure 6. Ratio between CO_2 emissions from the vehicles powered by internal combustion engines (ICEV) and from the electric vehicles (EV).

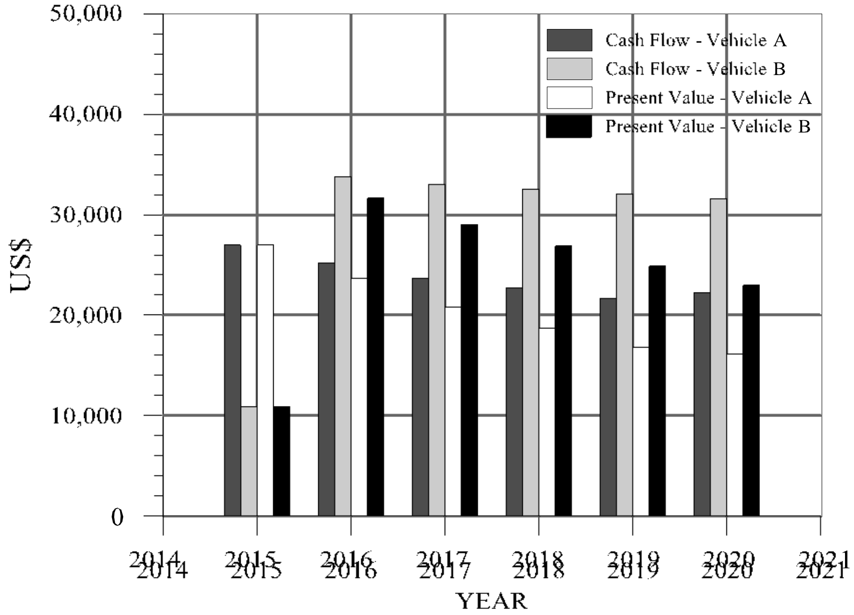

Figure 6. Cash flow and present value over the years.

*Table

LIST OF TABLE CAPTIONS

Table 1. Details of vehicles.

PARAMETER	SPECIFICATION	
	VEHICLE A	VEHICLE B
Bore × stroke	70.0 mm × 64.9 mm	-
Compression ratio	12.15:1	-
Volume displacement	1.0 L	-
Rated power	53.7 kW @ 6250 rpm	15 kW
Rated torque	93.2 Nm @ 4500 rpm	50 Nm
Fuel	E22	-
Battery type	-	Sodium-Nickel-Chlorine
Voltage	-	253 V
Energy		19.2 kW.h
Recharge time	-	8 hours

Table 2. Scenarios of vehicle fleet replacement.

SCENARIO	CO_2 EMISSION FACTOR (gCO_2/kWh)	WEATHER CONDITIONS	DISTANCE TRAVELED BY A TAXI FOR A DAY (km)
1	30	Favorable	200 – 400
2	30 – 50		
3	90	Unfavorable	
4	90 – 140		

Table 3. CO_2 emissions, fuel and energy consumption of vehicle A.

VEHICLE A	
CO_2 emissions (g/km)	182.74
Fuel consumption (km/L)	11.91
Energy consumption (kWh/km)	0.6830

Table 4. Accumulated and specific energy consumption of vehicle B.

VEHICLE B	
Accumulated energy consumption (kWh)	2.267
Specific energy consumption (kWh/km)	0.0951

Table 5. Results from the economic analysis.

Year	Revenue	Acquisition Cost	Annual Maintenance	Operation	Cash Flow	Present Value	Net Present Value
VEHICLE A							
2015	$39,988.67	-$8.780,11		-$4,249.78	$26,958.78	$26,958.78	$123,170.22
2016	$39,988.67		-$10,337.21	-$4,419.77	$25,231.69	$23,673.95	
2017	$39,988.67		-$11,742.34	-$4,596.56	$23,649.77	$20,819.75	
2018	$39,988.67		-$12,514.98	-$4,780.42	$22,693.26	18,744.32	
2019	$39,988.67		-$13,338.47	-$4,971.63	$21,678.56	16,800.70	
2020	$39,988.67		-$12,576.79	-$5,170.50	$22,241.37	16,172.71	
VEHICLE B							
Year	Revenue	Acquisition Cost	Annual Maintenance	Operation	Cash Flow	Present Value	Net Present Value
2015	$39,988.67	-$28.090,14		-$1,028.85	$10,869.66	$10,869.66	$141,116.15
2016	$39,988.67		-$5,168.60	-$1,078.86	$33,741.20	$31,658.09	
2017	$39,988.67		-$5,871.16	-$1,131,29	$32,986.20	$29,038.94	
2018	$39,988.67		-$6,257.49	-$1,186.27	$32,544.89	$26,881.64	
2019	$39,988.67		-$6,669.23	-$1,243.92	$32,075.50	$24,858.25	
2020	$39,988.67		-$7,108.07	-$1,304.38	$31,576.21	$22,960.50	