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Infrastructure Plan for Charging Stations for Electric Vehicles in Rio de Janeiro

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Abstract

This paper is intended to present a plan for installing a network of electric vehicle charging stations in the city of Rio de Janeiro. It is important to underline the fact that this text results from a research and development project called Planning and Analysis Methodology for the Implementation of Electric Vehicles in Transport Activities in the realm of the Brazilian electric energy regulatory agency, ANEEL, carried out by the distribution power company Light S.E.S.A. in partnership with the Vehicle Propulsion Systems and Electrochemical Sources Laboratory of the Rio de Janeiro State University – UERJ.

Keywords: EV (electric vehicle), charging, infrastructure, smart grid, environment

1 Introduction

The various models of battery powered electric vehicles and hybrids, either currently available in the market or undergoing tests, show that the electric vehicle technology has reached a mature stage and may perfectly meet transport needs in urban areas.

The introduction of EVs offers a series of opportunities for electrical power distributing companies, particularly with the advent of smart grids [1], [2]. For instance, monthly consumption of an EV is equivalent to electrical power consumption levels in a household, so it is easy to see that a massive number of EVs increases the distributing business. Increased demand will be welcomed if it happens in the early hours of the day, a period of low load and, therefore, available capacity to provide the charge without calling for large additional investment in the electrical power grid. However, how much ownership distributing companies will be able to take of these opportunities will depend upon the potential EV market and on how the electrical infrastructure regulation will be made for battery recharge.

Aware of the opportunities and risks involved, in Europe, some electrical sector companies and vehicle manufacturers established partnerships, oftentimes with governmental subsidies, in order to enable EVs [3]. Activities of this sort are somewhat similar in the US and Asian countries.

Figure 1: Electric version of the Fiat Palio Weekend

As of 2006, Brazil's Itaipu Binacional entered into a partnership with Fiat, Kraftwerke Oberhasli AG, and the MES-DEA company to produce, by 2010, 50 units of the electrical Fiat Palio Weekend, an EV equipped with a 15kW (20CV) three-phase induction motor and Sodium-Nickel Chloride battery, commercially know as ZEBRA (Zero Emission Battery Research Activity), shown on Figure 1.

These considerations are indicative of how this technology may be more significant in the Metropolitan Region of Rio de Janeiro, whose touristic activities are a major field for application, since it holds the second largest fleet of automotive vehicles countrywide, and the 2014 FIFA Soccer World Cup and the 2016 Olympic Games are well on their way.

This scene has encourage the Light Serviços de Eletricidade S.A. company to sponsor research efforts that will study the insertion of electric vehicle technology into their fleet as well as their clients' fleets, which will also include the development of charging station standards. This is all a part of Light's Smart Grid Program, which involves five integrated projects: smart measurement of energy, digital certification, electric vehicles, electrical power storage, and distributed generation. This is why this study included the acquisition of an electricity powered Palio Weekend, introduced in the company fleet to perform regular activities that are typically performed by other ordinary fossil fuel vehicles of the fleet.

In its electrical version, this Palio Weekend has an estimated autonomy of 120 km, therefore enough to perform most supervision tasks already performed by the internal combustion vehicle (ICV), since 95% of daily travels involve no more than 100 km [4].

Though electric vehicle batteries may be recharged in user homes, it is crucial to follow introduction of these vehicles in the market with the construction of a charging station infrastructure that may be accessed by the general public.

Basically, in those charging stations, drivers will have electric outlets available with safety and protection requirements according to specific standards. These outlets may be directly fed by a distributor grid, as in consumer residential units, or by a private energy source, as photovoltaic cells, according to regulations to be established. There is also the possibility of relying on robot systems for a quick replacement of a rundown battery with a fully charged one.

Though recharging a battery is somewhat similar to filling up the tank in a fuel station, electric vehicle interaction with energy suppliers is more complex than that between internal combustion motor vehicles and the fuel supplier network. For instance, while the electric vehicle is connected to the grid, it will also be able to contribute its battery to improving electric services provided by the local utility company, thereby increasing activities and benefits of incorporating the so-called smart grid technology.

A charging station network design depends on a number of factors, such as distribution network size, characteristics, level of feeder load, size of EV fleet, the types of EV, the range (km) of the batteries and shape of load curve.

This paper is intended to present criteria used in choosing places of interest to start installing a network of electric vehicle charging stations in the city of Rio de Janeiro, as well as a plan for this purpose. It is important to underline the fact that this text is an outcome of the research and development project called Planning and Analysis Methodology for the Implementation of Electric Vehicles in Transport Activities in the realm of the National Electric Power Agency – ANEEL, carried out by Light Serviços de Eletricidade S.A. in partnership with the Vehicle Propulsion Systems and Electrochemical Sources Laboratory of the Rio de Janeiro State University – UERJ. This plan is inserted in the city's tourist vocation, whose activities in major urban centers are closely connected to electric vehicles.

A brief description of international experiences related with the implementation of charging station networks is provided in section 2 of this paper, as they have been used as reference to develop a similar implementation plan for the city of Rio de Janeiro. The situation of the current vehicle fleet in this city and its projection for 2020, from a conservative viewpoint for the dissemination of the VE, are described in section 3, while in section 4, is established the area of the city of Rio de Janeiro that will be prioritized for the installation of the pioneer charging stations grid. An adequate choice for the recharge station sites in this pioneer grid could perhaps rely on the mathematical programming model described in [5]. The efforts involved in this model included considerations about the geographical per capita income distribution of the population, since Brazil's current legislation does not contemplate incentives for electric vehicles whose tax burden is excessively high, despite the countless advantages offered by the current generation matrix. The dissemination of EVs implies energy efficiency, economical and environmental benefits, by reducing greenhouse gas emissions [4]. An evaluation of these benefits is discussed in sections 5 and 6 of this paper. Finally, in section 7, the main conclusions are presented.

2 The international experience

Lisbon, Madrid, Paris, London and Los Angeles are examples of cities that have already engaged in seeking the energy and environmental benefits resulting from introducing electric vehicles. These cities already have recharge stations grid implementation plans in place that can naturally guide the development of a pilot plan for establishing charging stations in Rio de Janeiro's Metropolitan Region.

In Lisbon, available from parking lots, the charging stations network was inaugurated on September 20, 2008, exclusively for charging electric vehicles. Underlying concepts for the charging stations network considered both vehicle autonomy and access to the electrical grid. The batteries were established as capable to store 24 kWh, requiring maximum charging power of 3.3 kW [5]. The time each vehicle typically uses the charging station depends upon the type of storage: a) standard, slow, corresponding to 100% of total charge in 8 hours, usually occurring during the night, at home or at work; b) opportunity, 50% of the charge in 30 minutes; emergency (20 km) in 10 minutes (slow/fast), made in shopping centers, supermarkets, parking lots and some public roads; c) extended autonomy, fast, 80% of the charge in 10 minutes, in service areas [7].

According to EDP (Eletricidade de Portugal), charging station infrastructure may be either public or private. In the low power private infrastructure, 230 V 16/32 A is used for slow standard charge. In the low power three phase public infrastructure, 400V 100A is used for fast charge in the extended autonomy mode.

Charging stations are no more than 7.8 km apart. The average travel distance in the Lisbon metropolitan area is 20 km, and vehicles average autonomy is around 60 km. As a conclusion, each vehicle may be recharged every 3 days [8].

In Madrid, MOVELE is a pilot project intended to demonstrate the economic, technical and energy feasibility of electric vehicles. [9].

Charging stations are linked to Movele Madrid members, currently the following companies: Gás – Natural Unión Fenosa, Endesa, Iberdrola, and ACS – Cobra. These entities have a total of ten (10) charging stations around the city. The longest distance between them is 16.6 km, and the vehicles have an average autonomy of 60 km [8].

In Paris, DBT (Douaisienne de Basse Tension) in association with EDF (Électricité de France) are the pioneers in Europe, concerning the establishment of a network involving 84 charging stations already.

The greatest travel distance between charging stations is from Porte de Saint Cloud to Villete-Zenith, where a vehicle must cover 15.9 km. again, their typical autonomy is 60 km. [8].

In London, 90% of the journeys involve less than 10 miles (16 km) [10] and electric vehicles have an average autonomy of 60 km. The longest distance before recharge is 9.7 miles (15.5 km), between the charging station located on Wood Green and another one located on Canary Wharf.

In accordance with AltFuelPrices.com the city of Los Angeles has 33 public charging stations in operation.

There are 128 public electric charging stations within 25 miles of Los Angeles and there are 187 electric charging stations within 50 miles of Los Angeles. This site has computed 140 cities with public electric charging stations in California (327 stations total).

3 The fleet of vehicles in the city of Rio de Janeiro

The statistics from the Traffic Department of the State of Rio de Janeiro shows that in 2009 the city had an active fleet of circa 2,2 million vehicles, with almost 90% used to transport passengers. These numbers show a high potential for electrification of the fleet by models of cars, motorcycles and electric buses already on the market.

Regarding the type of fuel, gasoline vehicles are still the majority, but their share are declined since the advent of flex-fuel vehicles. This is an important consideration, because if the buyers accepted the proposal of flex fuels, it is expected the will accept EVs.

The forecast for 2020 indicates a fleet of circa 3,6 million vehicles in the city of Rio de Janeiro, so we can expect a significant amount of EVs, even assuming a conservative scenario with a penetration of 2% of electric vehicles in the fleet.

4 Geographical boundaries of the EV market in Rio

The EV is a new technology, so it still has high price for the most drivers in Rio. This conclusion is reinforced by the observation that just half of the active fleet (55%) has over 10 years old. Low fleet renewal rates reflect the scarce availability of resources on the part of individual owners. For them, electric vehicles are not yet affordable, even with likely government subsidies.

Thus, the geographic distribution of income within the urban space, which is information available from the demographic census and from the National Household Sampling Survey (PNAD/IBGE), has proven to be a good indicator for potential places to be visited and roads to be used by the first private electric vehicles in the city of Rio de Janeiro. In other words, the market for electric vehicles in the city or Rio de Janeiro ought to start in the areas of better average income households. Estimates of average household income in local districts have thus indicated the most adequate regions to start building a network of charging stations for electric vehicles, as indicated by the yellow areas in Figure 2.

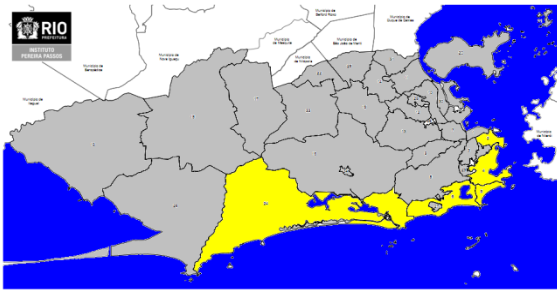

Figure 2: In yellow, the regions with potential market for the installation of the first charging stations in Rio

In 2010, this region contained 446,777 residential consumers (19% of the total residential consumers) which consumed 1,846,338 MWh (31% of the total electric power consumption in households). This region is also the main touristic destination in the city of Rio de Janeiro and is currently the stage for a broad array of civil works in progress as preparation for the World Cup and the Olympic Games. For illustration purposes, the port region in Rio's downtown area is currently being revamped, including 5 million m^2 of construction sites, one of which is an underground parking area for 1,000 cars. Naturally, as electric vehicles experience price reductions and increase their participation in the local fleet, the initial charging stations network will later have to be expanded to other regions of the city (grey areas in Figure 2).

5 Locating recharge points

Another criterion adopted for charging station sites considered the fact that current regulations in Brazil do not allow for the sale of electrical power by third parties.

Thus, in sites that already have parking facilities for vehicles, users will be able to use pre-paid energy cards.

Remarkably, spaces such as shopping malls, supermarkets and parking lots have been prioritized, considering that, in these places, user waiting time is usually diluted amongst other errands. Leaving supermarkets and parking lots aside, in the area of potential markets for electric vehicles (yellow area in Figure 2) ten shopping malls have been identified, totaling 19,227 parking spots.

There is no need, therefore, to create any further parking areas, suffice it to create electric outlets in some of the parking spots, such as in the model shown in Figure 1, displaying an electric Palio Weekend acquired by Light for developing and testing these facilities in the realm of research projects with UERJ's School of Engineering.

In addition to charging stations for electric vehicles, places have also been identified for charging stations to be used by two-wheel electric vehicles: bicycles and scooters. The latter are already being sold at affordable prices in the city of Rio de Janeiro. They are a major potential market as well and their characteristics relate with traffic sector efforts towards low noise and environment friendly mobility. Additionally, charging stations for two-wheel electric vehicles may be set up in the vicinities of subway stations and along the coastal area of the city, providing users with greater mobility.

Considering only the installation of charging stations in shopping malls located in the yellow area on Figure 2, the longest distance between each station would be around 30 km. Therefore, apart from those shopping malls within the area set aside as the existing potential market (yellow in Figure 2), further sites must be selected for those facilities. This list includes, for instance, parking areas for large supermarkets, gated communities, and regular fossil fuel stations.

For an optimized distribution of charging stations, the proposal is to use a mix with the mathematical programming model described [5], a maximal covering model employed in the location of charging stations in the city of Lisbon. Similar models have been largely proposed and used in optimizing the spatial organization of public service equipment and facilities [6].

The model proposed in [5] is intended to identify the geographical configuration of a network composed of P charging stations that will maximize the demand served within a given limited distance. Additionally, the model proposed herein establishes an optimal number of points of charge (varying between 2 and 10) in every charging station.

Thus, let P be the number of charging stations to be installed in any geographical region, J the number of sites with demands to be fulfilled by those points of charge, and K the number of sites where charging stations can be located (candidate sites). The optimization model looks at identifying P sites among the K candidate sites that will maximize the demand served in the J sites comprising the consumer market. The mathematical formulation of the optimization model is presented as follows:

$$\underset{Q,X,Y}{Max} \quad \sum_{j=1}^{J}\sum_{k=1}^{K} N_n R_{jk} un_j X_{jk} + \sum_{j=1}^{J}\sum_{k=1}^{K} N_d R_{jk} ud_j X_{jk} - 0{,}01 Q_k$$

s.t.

$$\sum_{k=1}^{K} X_{jk} \le 1 \quad \forall j = 1, J$$

Level of demand compliance for site j, X*jk* is the portion of the demand in j served by the charging station located on site k. The j site demand served by charging station k is limited by coverage area (R_{jk}) of charging station *k* on site *j*.

$$X_{jk} \le R_{jk} Y_k \quad \forall j = 1, J \quad \forall k = 1, K$$

The model must select P charging stations between K candidate sites.

$$\sum_{k=1}^{K} Y_k = P$$

The network has P charging stations

$$Z_k = \sum_{j=1}^{J} \left(un_j + ud_j \right) X_{jk} \quad \forall k = 1, K$$

Total of recharges on charging station k, resulting from nightly demands (un_j) and daily demands (udj) on site j.

$$Q_k \ge \frac{Z_k}{N_n + N_d} \quad \forall k = 1, K$$

The number of recharge points in the k^th charging station (Q_k) must be bigger than the recharge demand (Z_k) and the maximum number of nightly recharges from a single point is $N_n + N_d$.

$$2Y_k \le Q_k \le 10 Y_k \quad \forall k = 1, K$$

The number of recharge points per charging stations must be between 2 and 10.

$$X_{jk} \ge 0 \quad \forall j = 1, J \quad \forall k = 1, K$$

Portion of the demand in j served by the charging station located on site k

$$Z_{jk} \ge 0 \quad \forall j = 1, J \quad \forall k = 1, K$$

Demand per recharge at charging station k.

$$Y_k \in \{0,1\} \quad \forall k = 1, K$$

$Y_k = 1$ if charging station is located on site k, and 0 if not.

Q_k is integer $\forall k = 1, K$

Number of recharge points located in the charging station on site k.

The entirely mixed programming model described above produces an indication of the best geographical configuration of the network composed by P charging stations (on selected candidate sites, we have $Y_k=1$), the number of recharge points (between 2 and 10) in each charging station (variable Q_k) and also the level of coverage for each charging station k on each site j (variable X_{jk}).

The result of the model depends on a series of parameters defined on the basis of the assumptions about electric vehicle autonomy, on the average distance covered by the vehicles, and on the battery recharge time. The definition of parameters for the model is described, in short, as follows:

a) Coverage level of charging point k for charging station j (R_{jk}).

$$R_{jk} = 1$$

Site j is covered by charging station k ($d_{jk} < d_{opt}$).

$$R_{jk} = \frac{d_{max} - d_{jk}}{d_{max} - d_{opt}}$$

Site j is partially covered by charging station k ($d_{opt} \le d_{jk} \le d_{max}$).

$$R_{jk} = 0$$

Site j is not covered by charging station k ($d_{jk} > d_{max}$).

where d_{jk} is the distance between the demand point (j) and supply point (k); d_{opt} is the optimal walking distance and d_{max} is the maximal walking distance. These distances are defined previously as a function of the electric vehicle range and the daily average traveling distance

b) Number of charging points per post (P).

c) The nighttime demand (un) and the daytime demand (ud) are dependent of the number of electric cars per household (V_{he}) and the number of electric cars related to work (VE_e):

$$un_j = 0.33V_{he}$$
$$ud_j = 0.33VE_e$$

The coefficient 0.33 is the result of one charging in each 3 days period (0.33 recharges /day). It considers a daily travel distance equal of 20 Km a range of 60 km and a recharging time of 8 hours. Nightly charging occurs from 7:00 PM to 7:00 AM in the residential areas while daily charging starts 7:00 AM until 7:00 PM in the commercial areas.

d) Number of possible charging operations (Daytime N_d and nighttime N_n)

Figure 3 presents shopping malls in the areas with a potential market for electric vehicles (yellow area in Figure 2). Parking areas and buildings are shown in downtown Rio, which are also likely places to install charging stations.

Figure 3: Shopping Malls with large parking areas for the installation of charging stations and Rio de Janeiro's downtown area in detail

6 Economy

The electric motor of the Palio Weekend is fed by a 19.2 kWh Zebra battery. The autonomy is 120 km in an approximate performance of 6 km/kWh. The Palio Weekend version with internal combustion engine performs around 9 km/l in urban rides.
The price of regular gasoline in the city of Rio de Janeiro varies between R$ 2.479 and R$ 2.999, whereas Light's electric power rates for low voltage residential class are presented in Table 1, where one may also observe the effects of taxation.

Based on these numbers, it was established a comparison between recharging costs for the electric model of a Palio Weekend and fueling the internal combustion model of the same vehicle for a daily journey of 100 km. As indicated in Table 2, recharging expenses for an electric model are much lower than those estimated for a conventional model, pointing at a significant margin of savings. It should be observed, however, that the estimated savings depend on the structure of taxes levied on electric power and on gasoline, and that the estimates obtained herein solely reflect the current situation in Rio de Janeiro. Then, on Table 3, consumption levels and monthly expenses are presented, considering working days only. The monthly consumption presented on Table 3 is far superior to the average consumption per consumer unit in Light's residential class, estimated at 190.77 kWh/month in 2008. For daily travels beyond 60 km, electric power consumption is above average consumption of electric power per consumer unit in Light's residential class, suggesting that the dissemination of EVs implies a significant potential market for the distributing company.

Table 1: Rates of the residential class (R$/kWh)

Monthly consumption up to 300 kWh	0.41653
Monthly consumption above 300 kWh	0.49431

Table 2: Fuel expenses (R$/kWh)

Model	Vehicle Efficiency	Consumption for 100 kilometers	Rates	Expenses (R$)
Palio Weekend Elctric	6 km/kWh	16.7 kWh	0.49431 R$/kWh	R$ 8.25
			0.41653 R$/kWh	R$ 6.96
Palio Weekend Iinternal Combustion	9 km/L	11.1 L	2.999 R$/L	R$ 33.29
			2.479 R$/L	R$ 27.52

Table 3: Monthly Expenses (R$)

Model	Vehicle Efficiency	Consumption for 100 kilometers	Rates	Expenses (R$)
Palio Weekend Electric	6 km/kWh	16.67 kWh x 20 days = 333.33 kWh	0.49431 R$/kWh	164.77
Palio Weekend internal combustion	9 km/L	11.1 l x 20 days = 222.22 L	2.999 R$/L	666.44
			2.479 R$/L	550.88

7 Avoided emissions

Calculating road vehicle emissions typically requires a well-to-wheel analysis, particularly when EVs charged by a dirty grid are concerned. Given the vastly predominant hydroelectric share of the power generation mix in Brazil, it is acceptable to assume EV emissions to be negligible. Indeed, in the case of Brazil, neglecting upstream, well-to-tank, emissions actually benefits the ICV since the upstream petroleum processes are very energy, and thus pollution, intensive. Nevertheless, the tank-to-wheel, or tailpipe, analysis greatly simplifies the emissions evaluation while still providing an indicative low-end benchmark result.

It is worth highlighting that tailpipe emissions represent those which a fleet operator has the ability to directly influence, particularly, through a shift in the vehicle technology base. A more detailed description of LDV (light duty vehicles) emissions can be found in [11].

Tailpipe emissions from an ICV fleet are proportional to travel distance and to the number of vehicles considered. The following comparative analysis assumes a reference fleet of 100 LDVs, averaging 100 km/day, with five passenger seating capacity, and 1.0 litre (1000 cc) ICE (internal combustion engine). The fleet is assumed to be comprised of new, 2008, ICVs, adhering to all the pollution standards and limits established by the Automotive Air Pollution Control Program (PROCONVE) and the Environmental Sanitation Technology Company of São Paulo (CETESB).

These assumptions reflect the observations available in assessments made along the research effort referred to in this paper, thus allowing that the results obtained herein be easily extrapolated to more numerous fleets.

Concerning the corresponding fleet of EVs, it was considered to be composed of ICV size automobiles, such as the Palio Weekend presented in Figure 1 and whose data were described in the previous item.

Given the predominance of the flex fuel vehicle in the Brazilian market, the study assumes an average annual ethanol-to-gasoline consumption ratio of 78:22. Note that it accounts for the seasonal variations in ethanol prices which makes them less competitive during specific seasons of the year.

Therefore, only 22% of vehicle trips used Type C Gasoline, admitting a 20% content of Anhydrous Ethanol Fuel (AEAC). This hypothesis penalizes EVs in what concerns CO_2 emissions avoided if they use the CDM (Clean Develop Mechanism), as per the Kyoto Convention. For the remaining percentage, plain gasoline was adopted. A fleet thus constituted is composed of new vehicles (model 2008), whose energy and environmental performance evolves every year, according to the same assumptions.

From a conservative point of view, this ongoing work poses the elements for establishing a baseline, should a decision be made in favor of the CDM.

Due to insufficient data, it is not possible to estimate the divergences between urban and rural fuel economy for the vehicles in this study. Estimated average city fuel economy values derived from the works [12] and [13] are used throughout the analysis, presented in Table 4.

Table 4: Fuel efficiency

Fuel	Efficiency (km/L)
Gasoline C (20% of AEAC)	11.30
AEHC (100%)	7.81(*)

(*) AEHC means hydrous ethanol fuel utilized in ethanol vehicles and flex-fuel vehicles in Brazil.

Table 5 presents the average emissions factors (EF) for new vehicles which have been used in this study. In the past few decades, ICVs have enjoyed a considerable reduction in the EFs of regulated pollutants, due to the introduction of catalytic converters and the improved efficiency of combustion processes. By providing a more complete combustion of the fuel, these improvements ensure that carbon monoxide and unburnt hydrocarbon residues react fully, thus forming more CO_2 emissions. Consequently, the CO_2 EF of new vehicles has actually increased over this period.

According to a report by the IPCC (International Panel of Climate Changes), CO_2 is responsible for more than 97% of total greenhouse gas emissions from moving sources.

This leads to the emphasis of this ongoing work upon CO_2 emissions, considering its strict connection with Climate Change and the possibilities of using the CDM proposed by the Kyoto Convention. Concerning contaminating emissions from ICVs, the more influential ones have been considered, that is, CO (carbon monoxide), HC (unburned hydrocarbons), and NOx (nitrogen oxides), as well as CHO (aldehydes), since the remaining substances from new vehicles present relatively low factors, in accordance with the legislation, and lower, in order to reduce their impact.

Table 5: Average emission factor (FE) of new vehicles

Fuel	Combustible Consumption and FE				
	CO	HC	NOx	CHO	CO_2
Gasoline C 20% AEAC	3.73 g/L	0.90 g/L	0.90 g/L	0.023 g/L	2,167 g/L
	0.33 g/km	0.079 g/km	0.079 g/km	0.00204 g/km	191.77 g/km
AEHC (100%)	3.67 g/L	0.86 g/L	0.55 g/L	0.109 g/L	1,382 g/L
	0.47 g/km	0.11 g/km	0.07 g/km	0.014 g/km	179.65 g/km

Based on the results from Table 5 and previously defined assumptions with respect to cumulative travel distances, deterioration factors relative to CO and HC emissions factors were calculated and used to obtain annual adjusted emissions values, as presented in Table 6. It is further assumed that by the sixth year these emissions factors stabilize.

Table 6: Deterioration factors (FD) and emission (FE) adjusted for CO and HC

Deterioration factors considering a average annual distance of 24,000 km (100 km/day x 12 months x 20 weekdays)						
Períod Years	0 -1	1-2	2-3	3-4	4-5	5-6
FD (CO)	1	1.07	1.13	1.20	1.27	1.28
FD (HC)	1	1.08	1.17	1.25	1.34	1.35
Emission factors adjusted for gasoline C						
FE(CO) x FD(CO)	0.330	0.352	0.375	0.397	0.419	0.424
FE(HC) x FD(HC)	0.080	0.086	0.093	0.100	0.106	0.108
Emission factors adjusted for AEHC						
FE(CO) x FD(CO)	0.470	0.508	0.550	0.588	0.630	0.635
FE(HC) x FD(HC)	0.110	0.119	0.129	0.138	0.147	0.149

Combining the corresponding values from Tables 5 and 6, annual CO and HC emissions estimates were calculated and their results are presented in Table 7.

Table 7: Annual emissions of CO and HC for the typical fleet with 100 vehicles

Year	22% of ICVs with Gasoline C (fleet with 100 vehicles)		78% of ICVs Flex with AEHC (fleet with 100 vehicles)		Total emissions	
	CO	HC	CO	HC	CO	HC
0-1	0.174	0.042	0.880	0.206	1.054	0.248
1-2	0.186	0.046	0.939	0.223	1.125	0.269
2-3	0.196	0.049	0.998	0.241	1.194	0.290
3-4	0.210	0.053	1.058	0.258	1.268	0.311
4-5	0.221	0.056	1.117	0.275	1.338	0.331
5-6	0.224	0.057	1.129	0.279	1.353	0.336

Emissions for the remaining pollutants - that is, NOx, CHO and CO_2 - are not expected to deteriorate over time and their annual estimates are presented in Table 8.

Table 8: Yearly emissions of NOx, CHO and CO_2

Fuel	NOx (t)	CHO (t)	CO_2 (t)
Gasoline C (20% AEAC)	0.042	0.001	101.255
AEHC (100%)	0.132	0.026	331.250
Total emissions	0.174	0.027	432.250

Tables 7 and account for all the tailpipe emissions resulting from the ICV fleet operations. Given EVs present zero tailpipe emissions, it is assumed that these tailpipe emissions would be fully mitigated if the fleet were converted to electric. Concerning an assessment of how much non-renewable CO_2, the portion of CO_2 coming from Anhydrous Ethanol Fuel (AEAC) contained in gasoline when dual-fuel vehicles run solely on C type gasoline is disregarded. This portion is not entitled to using any CDM, just as in operation with only AEHC(100%). Table 9 presents the total CO, HC, NOX and CO_2 emissions caused by 100 ICV over a 10 year period.

Table 9: Avoided emissions with a fleet of 100 electric vehicle in 10 years (t)

CO	HC	NOx	CHO	CO_2
12.75	3.13	1.74	0.27	4,325.10

Taking the group of one hundred 1,000 cc size engine vehicles running on C type gasoline, in 22% of their travels under consideration here, the total CO_2 emissions must be distinguished between those from fossil fuels and others subject to a CDM. Analyses of this sort are presented in [13] and the amount of non-renewable CO_2 found was calculated in accordance with expression (1) derived in [14], considering densities equal to 0.740 and 0.791 kg/liter for the stoichiometric burn of automotive gasoline (C_8H_{18}) and of the AEAC (C_2H_5OH) respectively, which results in the C type of gasoline adopted:

$$p(CO_2 \mid G) = \frac{3,0877 m_G}{m(CO_2 \mid G) + m(CO_2 \mid A)} \cdot 100\% \qquad (1)$$

where:

- $p(CO_2 \mid G)$ is the percentage of CO_2 in Gasoline (C_8H_{18}).
- m_G is the quantity of mass of gasoline in the fuel mix in kg / liter.
- m_A is the quantity of mass of ethanol in the mixed fuel, in kg / liter.
- $m(CO_2 \mid G) = 3.0877 m_G$.
- $m(CO_2 \mid A) = 1.9130 m_A$.

In these conditions, 85.79% of the total CO_2 emissions when vehicles run on C type gasoline may be considered to be non-renewable, totaling 868.67 tons in a period of 10 years for each group of 100 dual fuel vehicles. Thus, for Light's 823 vehicle fleet it is possible to apply CDM in accordance of Kyoto Convention.

Concerning the energy performance, the data on Table 4 referring to specific consumption of the fleet under study, have allowed to calculate annual consumption of fuels, as indicated on Table 10.

Table 10: Annual fuel consumption

Fuel	Consumption (L)
Gasoline C	46,725.66
AEHC	239,692.70

In order to underline energy performance of the fleet under study, data about the lower heating values and fuel densities were considered, as published by Brazil's Ministry of Mines and Energy, which have enabled to build Table 11.

Table 11: Energy density fuel (kWh/L)

Fuel	PCI (*) (kcal/kg)	Density (kg/L)	kWh/L
Gasoline	10,400	0.740	9.241
C type gasoline (20% de AEAC)	9,670	0.750	8.433
AEAC	6,750	0.791	6.208
AEHC	6,300	0.809	5.926

Note(*): PCI – lower heating power

Table 12 expresses the values found, indicating a comparison between the energy expended by the 100 EVs in relation to the periods when the VCI run on C type gasoline and AEHC, exclusively.

Table 12: Fleet performance in 10 years

Energy	VE	ICVS with Gasoline C	EV	ICV with AEHC
MWh	879	4,181	3,117	14,204

In a period of 10 years, the 100 ICV consume 467,257 liters of C type gasoline and 2,396,927 liters of AEHC, whereas a group of 100 EVs would use 3,996 MWh. This enables us to obtain the amount MWh in energy consumption equivalent. Indeed, internal combustion engine vehicles running on C type gasoline consume 4,181 MWh and, running on AEHC, they consume a total amount of 14,204 MWh, totaling 18,485 MWh.

These results point at a ICV performance, in terms of consumption of energy equivalent, four times greater than a similar EV to cover the same distance, which is compatible with the results found for the simulation model that has already been developed and validated in [15] as well in measurements carried out with the Electric Palio Weekend considered in this work [16].

8 Conclusions

The electric vehicle is by no means a recent invention, and interest in them has come and gone several times without triumph. The present day renewal of interest and resurgence in EVs is supported by an unprecedented technological, economic, political and social context, with innovative solutions emerging to address the needs of niche market segments.

The present statistical analysis of Light's maintenance fleet travel patterns indicates that these transportation requirements can be met by EV technology. The switch to an EV fleet would reduce its annual energy expenditure to a third of that faced by the present ICV fleet. As for the relative energy efficiency gains, an EV fleet would have an equivalent energy consumption rate which is 3.6 to 4.9 times lower than the existent fleet [4, 16]. On the environmental front, for every 100 vehicles considered over a 10 year period, tailpipe emissions would be reduced by 12.34 tCO, 3.13 tHC, 1.74 tNOx, 0.27 tCHO and 4.43 with a greatly improving local air quality, particularly in densely populated metropolitan areas. Non-renewable CO_2 emissions have been estimated, in this period, at 7,000 tons.

The geographic pioneer market space for electric vehicles in the city of Rio de Janeiro has been determined. As established, the zone comprises the higher income regions in the city. This choice was exclusively due to the fact that at present moment only people with a higher per capita income can afford this kind of investment. This is therefore the most appropriate region for the installation of a recharge network for electric vehicles in the city of Rio de Janeiro. However, as the price of electric vehicles becomes more affordable, the proposed network may be expanded to the other regions of the city.

It is recommended that the first recharge points be located in areas of greater circulation of people and cars, for instance, shopping mall and supermarket parking areas as well as garage buildings in the region with the greatest potential market for electric vehicles. Such choices come from the fact that drivers in those areas are already used to parking in appropriate lots and no further parking facilities will need to be offered, sufficing to provide the recharge equipment that will be needed. In order to optimize recharge points within those areas established for the potential market, the same mathematical programming model supporting Lisbon's plan for the network of charging stations may be used, including the element of geographic distribution of per capita income.

While the deployment of EVs into the utility's fleet ensures significant operational cost savings it is desirable that commercial charge stations offer more attractive electricity tariffs, notably through a reduction in ICMS (state tax for goods). Furthermore, business-to-vehicle data communication solutions combined with smart grid capabilities would allow for discounted electricity tariffs during off-peak hours. However, the predominant obstacle hampering EV deployment is its elevated battery capital cost, which in the case of Brazil is aggravated by harsh federal and state taxes. Indeed, legislation in various countries has been modified in favor of energy efficiency and environmental benefits, making use of diverse financial incentives to accelerate EV penetration.

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