Amanda Fernandes Pereira da Silva
(Organizadora)

ENGENHARIAS: Pesquisa, desenvolvimento e inovação 3

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Sabendo que a Atena Editora faz parte do grupo de instituições que incentivam a difusão de inovação científica, a mais nova coleção “Engenharias: Pesquisa, desenvolvimento e inovação 3” engloba pesquisa científica, aplicada, desenvolvimento experimental e inovação tecnológica. Um dos grandes desafios enfrentados atualmente nos mais diversos ramos do conhecimento, é o do saber multidisciplinar, aliando conceitos de diversas áreas.

Atualmente, é necessário que os profissionais saibam discernir e transitar conceitos e práticas levando em consideração o viés humano e técnico. Diante desse contexto, este livro traz capítulos ligados a teoria e prática em um caráter multidisciplinar, apresentando de maneira clara e lógica conceitos pertinentes aos profissionais das mais diversas áreas do saber. Os mais diversos temas estão relacionados às áreas de engenharia, como civil, materiais, mecânica, química, dentre outras, dando um viés onde se faz necessária a melhoria continua em processos, projetos e na gestão geral no setor fabril.

Esta obra se mostra como fundamental, de abordagem objetiva, para todos os âmbitos acadêmicos e pesquisadores que busquem alavancar em conhecimento. Aos autores, agradeço pela confiança e espírito de parceria.

Boa leitura.

Amanda Fernandes Pereira da Silva

SUMÁRIO

CAPÍTULO 14

REPLACEMENT OF CONVENTIONAL VEHICLES WITH ELECTRIC ONES ON THE MACROMETRÓPOLE PAULISTA: ENERGETIC AND ENVIRONMENTAL IMPACTS FOR THE HORIZON OF 2030

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ABSTRACT: This article analyzes impacts resulting from the replacement of conventional cars (CVs) with 100% electric (EVs) in the horizon of 2030 in the region of Macrometrópole Paulista (MMP), located in the State of São Paulo, Brazil. The impacts under analysis are consumption of fuels and electric energy and environmental emissions with a focus on gas CO_2. The vehicle fleets up to 2019 are collected from the licensing statistics of the National Department of Transport (DENATRAN) and the State Department of Transport of the State of São Paulo (DETRAN-SP). The projection of vehicles from 2020 to 2030 is estimated using Linear Regression and BASS methods. The consumption of automotive fuels is available in the Statistical Yearbook of Energy Products by municipalities in the State of São Paulo and electric energy for EVs is estimated by the Authors backed by data from the available bibliography. And, the supply of electricity in Brazil in the horizon of the year 2030 is available in the National Energy Plan 2030 – PNE 2030 - of the Ministry of Mines and Energy (MME/ EPE 2007). The methodological approach of the research is summarized in Figure 2. The case study of this work is limited in terms of region that is the Macrometrópole Paulista (MMP – Figure 1) and to the six analysis scenarios defined, all with a view to the 2030 horizon. The research relies on secondary data collected from governmental institutions, statistical database and academic publications and reports. The sections of the paper are Introduction, Methodological Approach, Objective and Questions to Answer, Case Study, Results, and Conclusions and Comments.

KEYWORDS: Urban transport; Electric Vehicle; Macrometrópole Paulista; Energy consumption; CO_2 emissions.

1 | INTRODUCTION

According to the International Union of Urban Transport (UITP), cities face great challenges to address the process of urban mobility in the face of the increase in the world population that is increasingly urbanized. Currently, 53% of the population $_{\text{lives}}$ in urban areas and, by 2050, this number is expected to reach 67%. In 2014, 64% of trips were made within the urban environment and the total kilometers traveled should increase three times more by 2050 (AUDENHOVE, 2014).

Magalhães (2014) defines transportation as a system. In his model, the researcher defines that the system entries are made up of: people or goods to be transported; energy; equipment and services; and economic, political, cultural and family actions. It defines useful outlets which are the actual transfers of passengers and goods made between points of origin and destinations and other outlets as the waste generated by the equipment and services, including the emissions of greenhouse gases (GHG). Energy, an essential entry in the transport system, is the basis for studies on consumption (energy intensity), energy efficiency and pollutant emissions.

GHG emissions caused by transport systems are directly linked to energy efficiency. GHG emissions in the world in 2013 totaled 49 Giga tons of CO_2 equivalent ($GtCO_2eq$). The total emissions produced by energy consumption, which represent 71% of the overall total, is broken down into: 31% produced by the electricity generation sectors; 31% for heating; 15% for transport systems; 12% for manufacturing and construction; 8% for combustion and other fuels; and 3% for fugitive emissions. As the third party responsible for GHG emissions, the transport sector becomes a target for attentions of society in general and by the governments. As so, it demands incentives to develop innovative solutions to reduce the amount of air pollution. Aligned with this demand, electromobility is one of the promising emerging technologies effective to reduce air pollution generated by transports (DELGADO et. al., 2017).

VUCHIC (2007) stratifies the study of energy consumption and efficiency in urban passenger transportation systems in terms of: vehicles, rolling infrastructure and operational aspects. Analyzing the theme of energy efficiency in passenger transport, SCHILLER (2010) also says that the system is linked to fuels, vehicles and the road scheme of cities. BAEDEKER & HÜGING (2012) ratify SCHILLER's approach (2010), understanding that energy efficiency in transport must be analyzed in terms of vehicle performance, the modes that are used to travel and the performance of the system as a whole. According to these researchers, vehicles can become more efficient through technologies that develop new fuels, reduce engine consumption, reduce weight, improve the aerodynamics of conveyors and reduce friction losses in general system items. As for the system as a whole, the authors state that attention should also be paid to reducing the amount of travel through land use planning actions and interactions between economic and social activities.

Among the opportunities for clean and efficient vehicles, the electric vehicle technologies are receiving more and more attention. The study called “Governance and Public Policies for Electric Vehicles (EV)” analyzes who the stakeholders are, their motivations and how these actors establish and govern actions for the insertion of electromobility in the automotive sector (CONSONI et. al., 2018). The authors researched these elements in the countries that lead this technological trend and also in Brazil. The work states that the fleet of EVs starts to be significant in Norway, Holland, Sweden, France, China, United States, Germany and Japan.

According to CONSONI et. ał., 2018 p.11-12, the country’s leading electrical mobility as Holland, Sweden, France, China, United States, Germany and Japan, it is argued that, “at present, the reduction of greenhouse effect emissions is the main vector. Such concern is the shield for the development and diffusion of EVs, as it places this socio-technical object as a common point for the solution or alleviation of local environmental problems (air quality and public health) and global - less dependence on fossil fuels and reduction of greenhouse gas (GHG) emissions.”

In Brazil, however, there is still no specific motivation since ethanol, as a vehicle fuel, is effective and efficient in reducing GHG. The 100% electric EV will face, in Brazil, competition with conventional vehicles (CVs) powered by this type of fuel. A point to highlight is the cost of EV in Brazil, which today is more than double that of a CV that can provides to families the same passenger transport service. With the exception of Norway, in the leading countries in EV production, the list of stakeholders has in common an active presence of the productive sector. In Brazil, however, the participation of the automotive industry with the intention of technological development of EVs in the country is low, since its low diffusion makes importing and distributing this type of product more viable. In leading countries, actions for the insertion of EV in fleets are governed by public and private actions focusing on regulatory measures to stimulate electromobility. In Brazil, EV’s specific governance actions are aimed at stimulating consumption and reducing vehicle costs. More details the reader can found in Annex I (CONSONI et. ał., 2018).

The 100% electric EV also competes in Brazil and in the world with the hybrid electric that consolidates itself with the recent technology that combines electric motors with a flex-fuel internal combustion engine that works with both fossil fuel and ethanol. Recent examples are the launch of hybrid/flex models by automakers Toyota (Corolla) and Nissan (Leaf) (FONTANA, G. (2019); FORTUNATTI, L., (2020)).

Besides the high acquisition cost compared to a CV equivalent, in Brazil the EV manufacturers should assess the complete EV lifecycle to estimate its environmental benefits, including its entire value chain (like the process of the vehicle manufacturing itself, battery recharging consumption at the electric posts and the lithium batteries, from manufacturing to its disposal).

With regard to cost, it is likely that EVs would currently only be widely accepted by users at the expense of government subsidies for manufacturers and bonuses for buyers. Regarding environmental aggressions, the comparison with the CV cannot be made merely considering the waste that goes out through the exhaust, where, really, the 100% electric types, or even the hybrids, take great advantage because they only use the gasoline propellant occasionally. The comparison should consider the complete vehicle fuel life cycle for the VC (gasoline, or diesel, or ethanol) as well as the electrical energy for the EV. The CV with an ethanol engine reduces CO_2 emissions by more than 70% when compared to a gasoline engine, counting the total fuel product cycle from manufacturing to the exhaust. As for electric energy for EV, for this energy to be effective to reduce emissions and environmental impacts, it must be generated from clean renewable sources (LUCENA, 2018).

2 I METHODOLOGICAL APPROACH

The methodological approach is presented in Figure 2. The case study limits the reserarch, in terms of region, to the Macrometrópole Paulista (MMP – Figure 1) and there are six analysis scenarios under analysis. The research relies on secondary data collected from governmental institutions, statistical database and academic publications and reports.

The MMP is one of the largest urban agglomerations in the southern hemisphere and, according to the United Nations (ONU, 2013), MMP is one of the main metropolises in the world and the largest economic and financial hub in South America.

Inserted in the State of São Paulo, MMP has 174 municipalities. For reference, the State of São Paulo has 645 municipalities with a total of 45.9 million inhabitants. This is one of the 27 Brazilian states that, all together, sum a total of 5,570 municipalities with an estimated population of 210.1 million of inhabitants. Figure 2 shows the geographical view of these urban agglomerations (EMPLASA, 2012; IBGE, 2018).

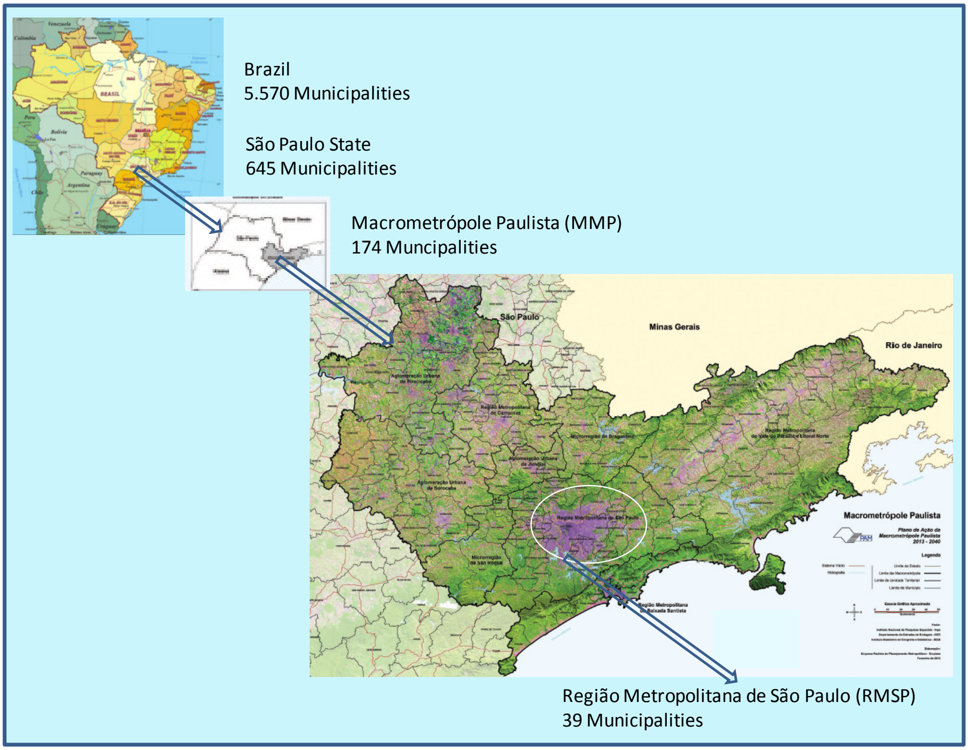

Figure 1. Geographic visions of the São Paulo State, MMP and RMSP.

Source: Authors, based on EMPLASA (2012); IBGE (2018).

The MMP municipalities are grouped into Metropolitan Regions (RMs), Urban Agglomerations (AUs) and Regional Units (UR). The RMs are Baixada Santista, Campinas, Sorocaba and Vale do Paraíba and Litoral Norte (VPLN); the AUs are Jundiaí and Piracicaba; and the only UR is Bragantina. This territory is located in the southeastern region of the State of São Paulo and concentrates high-tech industries, diversified commerce, complex services and the most productive agribusiness in Brazil. The largest port and airport, the best road complex and the largest centers of knowledge and innovation in the country are installed there (EMPLASA, 2012; IBGE, 2018).

The importance of MMP is evidenced by its numbers: 33.7 million inhabitants, representing 74.6% of the population of the State of São Paulo (ESP) and 16% of Brazil; territorial area of 53.4 thousand km^2, 21.5% of the ESP area; 27% of ESP municipalities; 50% of the Urbanized Area (11,700.2 km^2) of the ESP; it houses 20% of the protected natural heritage of ESP; it also houses the Port of Santos, which handled, in 2016, 28.5% of the country's exports and port imports of goods and the Guarulhos International Airport (São Paulo), which served 36.6 million passengers in 2016; the region's GDP was R $ 1.82 trillion in 2018, which is equivalent to 82.8% of ESP's GDP and 25% of the Brazilian GDP

(EMPLASA, 2012; IBGE, 2018).

Among the 174 municipalities of the MMP, 39 of them form the so-called Metropolitan Region of São Paulo (RMSP) which has a population of the order of 22 million inhabitants (IBGE, 2018) and is classified as one of the six largest Metropolitan Regions in the world according to the United Nations Organization (ONU, 2013). The RMSP is divided into four zones: West, Southeast, Southwest and West. The Municipality of São Paulo is the nucleus that integrates all zones (or sub-regions).

The six analysis scenarios under study are all with a view to the 2030 horizon.

In the first three scenarios the analysis focuses on CO_2 emissions: (1) substitution of CV taxis powered with ethanol by EVs in the city of São Paulo (MSP); (2) replacement of CV buses fueled with diesel oil by EVs in the Metropolitan Region of São Paulo (RMSP); (3) replacement of all CVs flex-fuel cars with EVs at the MMP.

In the next scenarios, attention is paid to the electric energy which is consumed from the SIN. Comparison is made between the estimated EV fleets against the strategic reserve of the SIN: scenario (4) considers all EVs estimated to travel on the MMP; scenario (5) considers all EVs estimated to travel in Brazil; and scenario (6) takes all estimated flex-fuel CV cars to travel on the MMP which are converted into EVs.

Six Annexes provide information that complements with details topics presented in this text. They are available for consultation online.

Despite the issue of the lack of a goal for the dissemination of EV at national level, this work employs regional scenarios in which there are technical and economic motivations favorable to the implementation of this technology. The specific objectives of the work are: (i) to select scenarios to assess criteria of energy efficiency, volume of CO_2 emissions and attractiveness to receive incentives via top-down public policies that foster pilot projects to demonstrate feasibility for diffusion on a larger scale; (ii) to estimate the amounts of CVs and EVs in each scenario based on secondary vehicle licensing data made available by Federal and São Paulo State entities and on future estimates prepared by the authors; (iii) to estimate energy consumption and CO_2 emissions for CVs and EVs in each scenario; (iv) to assess the impact of EV electric consumption on the strategic reserve of the Brazilian Electricity Interconnected System (SIN, 2003); (v) to compare the emissions of VCs and EVs in each scenario; (vi) and, finally, to analyze the results and present comments and recommendations.

The demands of vehicle fuels by CVs and electricity by EVs were used as indicators for the analysis of energy impacts. EVs are restricted to 100% electric cars and city buses, both for passenger transport actions.

The estimation of CO_2 emissions by CV vehicles when carrying out a specific transport service is done by multiplying the energy consumed by the engine by the CO_2 emission factor (EF) of the fuel used. In a similar process, for EVs the energy consumed is electrical. When fleet emissions are analyzed over a period of time, it is necessary to know the types and quantities of vehicles in the fleets. The analysis is simple to be done in fleet statistics released by recognized entities. However, as is the case with this research, there is the fact that the analysis has to be done for future fleets, in the horizon of 2030.

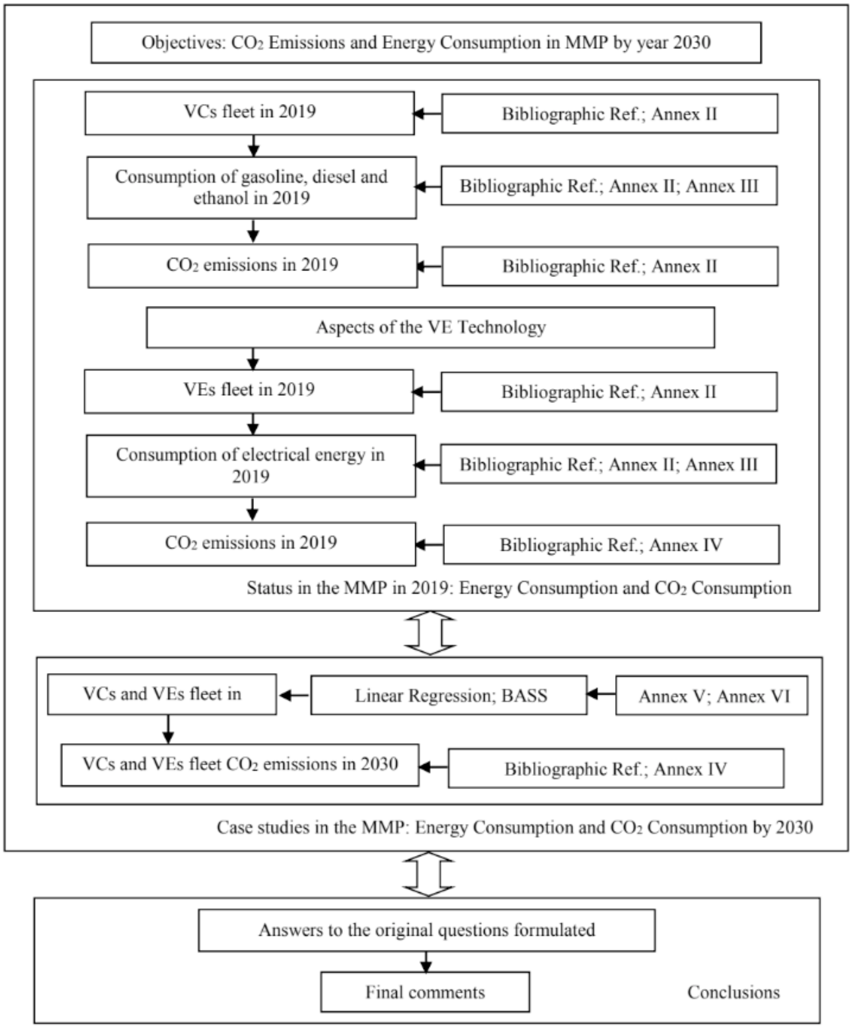

Figure 2. Methodological approach.

Source: Authors.

3 I OBJECTIVE AND QUESTIONS TO ANSWER

Inserted in the context of the themes discussed above, this article aims to analyze the energetic and environmental effects resulting from the replacement of CVs by 100% electric EVs. The analysis of environmental impacts carried out is restricted to CO_2 emissions. The horizon of the study is the year 2030. And the electrical energy consumed to recharge the

EV batteries are supplied by the National Interconnected energy System (SIN).

Two innovations are present in this research. The first one is the geographical limit to which it is dedicated. The study is restricted to the region called Macrometrópole Paulista (MMP), located in the State of São Paulo, Brazil. In this region there are large concentrations of people who demand high public and individual mobility due to the presence of: important industrial infrastructure; agricultural production; and air, land and naval transport nodes that also demands great mobility of people and goods. The second innovation within this work is the combination of the Linear Regression method with the BASS model to estimate the number of vehicles CVs and EVs on the MMP up to 2030.

The questions that guide the present work are: (1) would the SIN system be prepared to supply battery recharges for all estimated EVs to travel on the MMP ?; (2) what is the maximum number of EV vehicles that could be fueled within the SIN strategic reserve limit ?; (3) which scenarios have the greatest reductions in CO_2 emissions due to the replacement of CVs by EVs ?; and, finally, (4) what are the strategies for installing electro-posts for recharging EV batteries?

4 I CASE STUDY

4.1 Fleet of cars and buses VCs on the MMP in 2019

The surveys that follow reflect the databases of the National Department of Transport (DENATRAN) and the State Department of Transport of the State of São Paulo (DETRAN-SP) with vehicle licenses available from 2012 to 2019.

4.1.1 Licensing

Table 1 shows the quantities of conventional cars and buses licensed in each of MMP's eight urban agglomerations in 2019. (DENATRAN, 2020).

Urban Agglomeration	Car	Bus
AU de Jundiaí	365.990	2.089
RM da Baixada Santista	464.860	3.403
RM de Campinas	1.414.849	12.783
RM de Sorocaba	858.138	5992
RM de SP	9.356.732	76489
RM do VP e LN	948.457	5195
UR da Bragantina	196.094	1.105
AU de Piracicaba	637643	5.532
TOTAL	14.242.763	112.588

Table 1. CVs car and bus licenced in MMP in 2019.

Source: Authors, based on DENATRAN (2020).

As in Brazil there were 56,785,464 car licensing and 648,829 buses in 2019, 25% of cars and 17% of urban buses are concentrated in MMP (DENATRAN 2020).

In the State of São Paulo, in December 2019 19,402,262 automobiles were licensed, 6,334,938 in the city of São Paulo alone, and 170,728 buses, 50,276 of them in the municipality of São Paulo. Thus, the MMP is home to around 73% of automobiles in the State of São Paulo and 66% of urban buses (DENATRAN, 2020). More details can be found in Annex II, which also shows the evolution of these numbers from 2018 to 2019, ratifying these percentages.

4.1.2 Consumption of gasoline, diesel oil and ethanol

According to the Statistical Yearbook of Energy Products by municipalities in the State of São Paulo (GESP/SEM, 2019), consumptions of gasoline, diesel oil and ethanol in MMP occurs aggregated by urban agglomeration, as shown in Table 2.

Urban Region	Vehicular Fuel		
	Gasoline – liters	Diesel Oil – liters	Ethanol – liters
AU de Jundiaí	205.454.786	233.464.692	200.984.055
RM da Baixada Santista	273.226.605	344.547.330	211.556.258
RM de Campinas	700.702.262	958.961.246	831.301.912
RM de Sorocaba	444.303.110	494.595.097	531.550.802
RM de SP	3.871.867.587	3.090.605.375	3.702.150.497
RM do VP e LN	614.667.202	692.519.817	474.076.423
UR da Bragantina	130.259.703	152.994.759	108.976.631
AU de Piracicaba	278.692.199	640.818.888	435.878.295
TOTAL MMP	6.519.173.454	6.608.507.204	6.496.474.873

Table 2. Consumption of vehicular fuel in the MMP in 2019.

Source: Authors, based on GESP/SEM (2019).

As diesel consumption is prohibited for automobiles and light vehicles in Brazil, these modes used, in the MMP in 2019, gasoline and ethanol in the approximate proportion of 50% for each fuel.

The evolution of fuel consumption from 2018 to 2019 is shown in Annex II, in which it can be seen that, from one year to the other, there was a reduction in gasoline consumption, stability in diesel oil and an increase in ethanol.

For information purposes, Annex III shows three maps that individualize the consumption of these three types of fuel for each of the 174 municipalities of MMP in 2017.

4.1.3 CO_2 emissions

The estimation of CO_2 emissions by CVs cars is done in a top-down manner by multiplying the specific CO_2 Emission Factor (EF) for each fuel by the quantity used. Annex IV shows the detailed calculations for these indices. Table 3 shows the EFs for burning gasoline, diesel oil and ethanol in internal combustion engines.

A Flex type of motor can use either: 100% gasoline or 100% ethanol. The motor is automatically adjusted when the type of fuel is identified by an internal controller.

Note that the utilization of gasoline or ethanol in Brazil is not enforced by specific regulation law, but by the availability of each type of fuel in the market as well as by the cost of each one. In terms of cost versus performance (consumption per km) the utilization of ethanol is more effective when it cost is 70% lower than the one for gasoline.

Fuel	Liter	Emission Factor (EF) [tCO_2]
Gasoline	1,0	0,0022942971
Diesel Oil	1,0	0,002696998
Ethanol	1,0	0,000921504

Table 3. Emission Factors to estimate CO_2 emissions.

Source: Authors, based on: Annex III; MELO (2001).

Table 4 shows the estimated emissions of CO_2 by CVs cars at MMP 2019.

Urban Region	tCO_2			
	Gasoline	Diesel Oil	Ethanol	Total
AU Jundiaí	471.374	629.654	185.208	1.286.236
RM Baixada Santista	626.863	929.244	194.950	1.751.057
RM Campinas	1.607.619	2.586.317	766.048	4.959.984
RM de Sorocaba	1.019.363	1.333.922	489.826	2.843.112
RM SP	8.883.215	8.335.358	3.411.546	20.630.118
RM VP e LN	1.410.229	1.867.725	436.863	3.714.817
UR da Bragantina	298.854	412.627	100.422	811.903
AU Piracicaba	639.403	1.728.288	401.664	2.769.354
	14.956.921	17.823.133	5.986.527	38.766.581

Table 4. Estimation of CO_2 emissions by CVs in the MMP in 2019.

Source: Authors, based on: Table 2 x FE.

The evolution of CO_2 emissions from 2018 to 2019 follows the evolution of fuels consumptions (Annex II). The corresponding variations in CO_2 emissions show the same trend: decrease in the case of gasoline consumption, stability in diesel and increase in ethanol. The overall balance for the three fuels shows a reduction of 1,581,250 tCO_2 from

2018 to 2019. Ethanol is an international commodity as is sugar, both produced in Brazil from the same raw material (sugar cane). Producers have the option to produce one or the other product according to international quotations. And the consumers, by their turn, choose the best price either for gasoline or ethanol, a fact that modulates quantities used.

4.2 Aspects of the EV technology

After describing elements that show the socioeconomic importance of the MMP for studies of urban mobility, statistics on CVs vehicles and CO_2 emissions that currently occur due to the burning of vehicular fuel in this region, aspects of electromobility and then their applicability and effects on energy and environmental impacts are now analyzed.

4.2.1 Vehicles

There are four basic types of vehicles that incorporate electric motors: (i) The pluggable electric, with electric motor, that uses the energy of batteries charged in the electric grid (SIN); (ii) The hybrid one, whose electric traction energy is generated on board by an internal combustion engine that works with conventional vehicle fuel; (iii) The plug-in hybrid, equipped with batteries that are recharged with energy collected either from the SIN grid or from the embedded generator; (iv) And the one that uses electrical energy generated by an onboard energy cell (SILVA, 2014):

THEOTONIO & TREDINNICK (2018), in turn, define five types of EVs:

Type (i): "Plug in Electric Vehicle" (PEV), an acronym that refers to two categories, "Battery Electric Vehicle" (BEV) and " Plug-In Hybrid Electric Vehicle "(PHEV); in these categories the electricity that recharges the batteries is provided by an electrical outlet connected to the power distribution grid;

Type (ii): "Hybrid Electric Vehicle" (HEV or FHEV), whose vehicle uses both an electric motor and an internal combustion engine and does not use the electrical network for recharging;

Type (iii): The "Plug-In Hybrid Electric Vehicle" (PHEV), a plug-in hybrid electric that uses electricity obtained from the distribution network to power an electric motor, but which also uses an internal combustion engine in parallel to the electric engine, similar to a pure hybrid, to ensure greater travel autonomy;

Type (iv): The "Extended Range Electric Vehicle" (EREV) is a long-range hybrid electric vehicle equipped with an autonomy extender system that allows the change of operation from a battery-powered electric vehicle to a conventional vehicle with an internal combustion engine after full discharge battery after a certain number of kilometers traveled;

And finally a Type (v), the "Fuel Cell Vehicle" (FCV), an electric vehicle equipped with fuel cells that convert the chemical energy of a substance, such as hydrogen gas, into electrical energy.

The main brands that have already filed patent applications in Brazil for their products related to EVs at the Brazilian Institute of Industrial Brands and Patents - IMPI were: Toyota (JP), Nissan Motor (JP), Scania CV AB (SE), Honda Motor CO (JP), Volvo (SE), LG CHEN LTD (KR), General Electric Company (US), Renault SAS (FR), Qualcomm Incorporated (US), and Man Truck & Bus AG (DE). There are also ongoing parent orders for companies from Germany, Brazil, Italy, China, India and England (THEOTONIO & TREDINNICK, 2018).

Based on data from manufacturers available in the bibliography consulted, in the herein study of scenarios there were considered: only 100% electric vehicles equipped with batteries of 60 kWh of energy (average value of the reported products), which can supply to the engines 0.3 kWh/km; motor with power of 60 kW (80 HP); and average travel autonomy in the order of 200 km. For 100% electric EV buses, the following figures were considered: vehicles equipped with 200 kWh of energy batteries, capable of delivering 1.0 kWh/km to engines; two engines of 100 kW (265 HP) each (Authors' estimate, based on BT, 2017); and travel autonomy also of 200 km.

4.2.2 EV charging equipment

There are four basic types of battery chargers (SILVA, 2014):

Type 1: (i) Domestic, single-phase, for slow time charge (~ 8.0h for a 24 kWh battery) with 3.5 kW (16A/220 Vac) power without end of charge control signal (pilot control); (ii) Non-domestic, single-phase, for slow time charge (~ 8.0 h for a 24 kWh battery) with a power of 3.5 kW (16A/220 Vac) with control in compliance with IEC-309-2 standard; (iii) Non-domestic, three-phase, for slow time charge (~ 4.0h to 6.0h for a 24kWh battery) with 11.0 kW power (Vac) with pilot control signal, complying with the IEC-309 standard -2;

Type 2: (i) Non-domestic, for semi-fast time charge (~2.0h for a 24 kWh battery), single-phase, with 7.4 kW power (in Vac at 32A) or single-phase, with 14.5 kW power (in Vac at 63A); (ii) three-phase, with power of 22 kW (in Vac to 32A); all options with pilot control signal complying with SAE 1772 standard;

Type 3: (i) Non-domestic, for semi-fast charge (~2.0h for a 24 kWh battery), single-phase, with 7.4 kW power; (ii) or three-phase, with a power of 22 kW (in Vac, 32A), with pilot control signal in compliance with the SAE 1772 standard;

Type 4: (i) Non-domestic, for quick time charge (~20.0 to 30.0 minutes, for a 24 kWh battery) in Vac (250 Vac at 95A) (ii) or in Vcc (400 Vac at 60A).

The EV charging equipment can be installed in places such as homes, businesses centers, parking lots, highways and shopping centers, among others. The residential ones are for slow time charging, the semi-fast ones for public places and in companies and, the fast ones, for charging stations on streets, highways, shopping centers and parking lots (LEITE, 2017).

In Brazil there are already a number of charging networks in operation and others under installation processes. The BMW manufacturer, in partnership with the local energy concessionaire EDP, installed some charging points on the Dutra highway, which connects São Paulo to Rio de Janeiro. In addition to BMW, EDP, in partnership with the company Findes, is also developing a network of charging points in the Espírito Santo state. Paraná is another state that will have a large network of charging posts on the highway connecting the Port of Paranaguá to the Foz do Iguaçu city (SOUZA, 2019). The "PlugShare" tool is a software application that indicates locations of charging posts and is now available in Brazil (PlugShare, 2019).

The city of São Paulo has around 50 charging points (2018). However, there are initiatives ongoing by EV manufacturers, such as BMW, which began installing about 80 charging posts on commercial points spread across the states of São Paulo, Rio de Janeiro, Paraná, Minas Gerais, Santa Catarina and the Federal District in Brasília (TEIXEIRA, 2018).

Regarding the number of recharging points ZEMOGINSKI (2018) cite an example on what happens in the city of Shenzhen, China, for taxis and electric buses. To make the operation of the fleet of 12,600 taxis in the city feasible, 500 recharging equipment were made available, distributed at the passenger waiting points. For the 17,000 buses, the city created bus garages with more than 5,000 slow chargers, distributed in groups of 510 charging stations (Table 5).

EV (Type)	City/ Region	EV(Units)	Charging point (Units)	Installation Logistic	EV per recharging post
	ZEMOGINSKI (2018)			Hypothesis by Authors; ZEMOGINSKI (2018)	
Taxi	Shenzhen (China)	12.600	500 (type not informed)	Bording waiting points: 400 (Hypothesis) with 31,5 taxis (average) and set of 1,25 (average) charging points in each one waiting point (with time charring strategy to use the charging posts)	25,2 (Note: this number means that it is needed a time charring strategy to use the charging posts)
Urban Bus	Shenzhen (China)	17.000	5.000 (slow charging) distributed in sets of 510 unities	Garages: 10 (Hypothesis), with average of 1700 buses and set of 510 charging points on each one	3,4 (Nota: tem que haver estratégia de compartilha-mento)

Table 5. Logistic of charging points installation for taxis and urban buses - Shenzhen

Source: Authors, based on: Hypothesis taken by the Authors; ZEMOGINSKI, 2018.

4.2.3 Energy efficiency

Energy intensity or energy consumption of a system are generic terms that define the relationship between the energy consumed (system input) and a production unit (useful output). This relationship is also known as the consumption rate. The inverse relationship of energy consumption defines the Energy Efficiency rate with *cet paribus* conditions of capacity to perform work: an increase in the consumption necessary to produce the same useful output (perform the same work) reduces the energy efficiency of the system. (DE LA RUE DU CAN, 2010; ISO 50001: 2011; PATTERSON, 1996; VUCHIC, 2007).

On urban passenger transportation field, energy consumption is usually measured by the relationship between the energy consumed and the number of passengers (p) transported between points of origin and destination. The relationship metrics can be, for example, kWh/p-km, or joules-p-km, or liters (l) of fuel per passenger transported per km (l/p-km). Accurate figures on energy efficiency are difficult to estimate due to the number of factors that affect the calculations. These factors are, for example: the scope of the assessment (the whole system? Only vehicles? Vehicles plus the road infrastructure? Etc.); types of energy; vehicle characteristics; rolling track characteristics (technology and layout); operational aspects (expressways, locations and operating regimes); energy consumed by vehicles outside the normal operating scenario (for example, when they are in maintenance workshops and, then, not transporting passengers); knowledge of the energy consumed per vehicle/km for the different loads and influences due to factors external to the direct operation of vehicles for the transportation of people (for example, energy consumed by maintenance teams with special vehicles) (VUCHIC, 2007).

As an example of the application of this type of metric, data of the São Paulo Metro for 2014 cited that the system: carried an average of 1,110,432,599 passengers on working days in the year; its trains covered the equivalent of 18,065,234 km; and were consumed in the year in the order of 540,000 MWh in the operation of transportation services. Based on these data, the distribution of consumption per passenger in the year was 0.486 kWh/passenger and consumption per km was 29.9 kWh/km (METRÔ, 2014).

The EV vehicle has an energy efficiency around 50% to 70% for the 100% electric configuration, in which the energy losses occur mainly during the process of recharging the batteries. The 100% electric EV has less mechanical friction among components when compared to the CV, since the electric motor is directly coupled to the wheels. Thus, the energy expenditure by distance traveled is lower in the EV compared to the CV. Losses are 30 to 50% in the electric hybrid VE and 35 to 40% in the fuel cell version (NUNES, 2008).

In the CV vehicle there are energy losses in the exhaust system (heat loss), in the engine cooling system and in all the frictions that occur between the mechanical parts in the path from the engine down to the movement of the wheels. In this whole path, the effective energy that reaches the CV wheels is about 22% of the energy that is generated in the burning of the energy source in the combustion chamber. (NUNES, 2008).

It should be noted that the technology present in EVs allows configuring options to save energy, for example, turning off the engines whenever the vehicle is stopped in traffic (technology already available in some CVs and recovering kinetic energy in the form of electrical energy during braking, process called regenerative braking. This is possible because an electric motor can be reconfigured to operate as an electricity generator and then be able to self-recharge the onboard batteries while braking occurs. The EV, therefore, can return energy to the embedded system itself (THEOTONIO & TREDINNICK, 2018).

4.2.4 Brazilian plan for electricity generation and consumption by 2030

The offer of electricity in Brazil in the 2030 horizon is known (planned) in the documents "National Energy Balance and National Energy Plan 2030" provided by the Ministry of Mines and Energy of 2018 (MME/EPE, 2018,a,b – Balanço Energético Nacional 2018 base 2017; MME/EPE, 2007 – Plano Energético Nacional 2030).

As the 100% electric EV needs to use electric energy (EE) to recharge its batteries, this consumption will demand energy mainly from the National Interconnected System (SIN), although there are initiatives of alternative sources for distributed generation. It is therefore important that the introduction of EV fleets in cities in Brazil is analyzed together with the energy provided by the SIN.

The National Energy Plan projects in the supply pole the production plus importation of EE in the order of 1,194.9 TWh in the year 2030. In the consumption pole, the projection is for 1,030.1 TWh. This scenario shows then a strategic reserve of electrical energy in the order of 164.8 TWh for that year.

4.3 Impacts of the 100% electric EV fleet of cars on the MMP in 2019

The following items inform the vehicle fleet of EV cars on the MMP in 2019 and the corresponding electricity consumption and CO_2 emissions.

4.3.1 Licencings

Figure 3 shows the historical series of 100% electric cars licensed in Brazil between January 2012 and April 2019. This data is published by ANFAVEA - National Association of Vehicle Manufacturers, made with data from DENATRAN - National Department of Transport (ANFAVEA, 2019; DENATRAN, 2020).

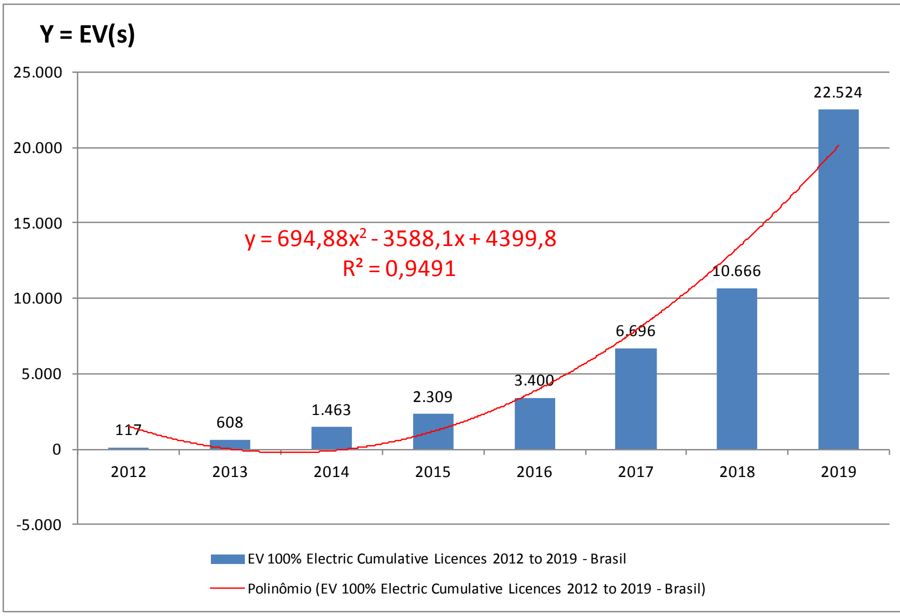

Figure 3. Car 100% Electrical Licensed in Brasil in 2019.

Source: Authors, based on ANFAVEA (2019); DENATRAN (2020).

Adopting the assumption that the MMP has a fleet of cars in the order of 25% of the cars of Brazil, then around 5,631 EVs (22,524 x 0.25) were licensed in this region in 2019.

4.3.2 Electric power consumption

Through a bottom-up approach and with the assumptions that each EV runs an average of 20,000 km/year (Authors) and that EVs typically consume between 0.1 to 0.23 kWh per kilometer according to THEOTONIO & TREDINNICK (2018), the consumption of electric power by EVs running at the MMP in 2019 was in the order of:

Electrical consumption = 5,631 EVs x 20,000 km x year/VE x 0,23 kWh/km = 25,902,600 kWh

4.3.3 Emissions of CO_2

The CO_2 emission for electricity consumption from the SIN is calculated by multiplying the total energy involved by the Emission Factor (EF) by 0.0750 tCO2/MWh, an index that is monthly published by the Ministry of Science, Technology, Innovation and Telecommunication (MCTIC, 2019).

Based on the following equation, it is possible to estimate the emissions produced by EVs that traveled through the MMP in 2019 in the order of 1,950 tCO_2.

Emissions = 5,631 (EVs) x 20,000 km ano/VE x 0,23 kWh /km/EV x 0.0750 tCO_2/MWh = 1,950 tCO_2

4.4 Impacts of the 100% electric EV fleet of buses on the MMP in 2019

As done for cars, the following items inform the fleet of EV buses at the MMP in 2019 and the corresponding electricity consumption and CO_2 emissions.

The fleet of 100% electric buses present at the MMP in 2019 is concentrated in the cities of São Paulo and Campinas.

In São Paulo there are fifteen units equipped with on-board batteries (AB, 2019) and 201 trolleybuses powered with energy captured outside the vehicle through the SIN grid with pantographs (SPTrans, 2018). Campinas, in turn, has thirteen units equipped with on-board batteries (Diário do Transporte, 2018) and the local City Hall has plans to expand the fleet to 400 units in the near future (Diário do Transporte, 2019).

As the numbers in 2018 and 2019 of electric buses present in the MMP are modest, the studies of energy consumption and CO_2 emissions for this modality of EV will be made for the specific scenarios described in the next item.

4.5 Analysis of impacts in scenarios for the MMP in the horizon of 2030

The analysis of EV impacts in the 2030 horizon implies firstly estimating vehicle fleets in future periods. Next, electricity consumption and CO_2 emissions are calculated.

4.5.1 Diffusion of EVs in Brazil and in the MMP

The International Energy Agency (IEA) estimates that, in 2030, the global stock of electric cars should reach 140 million units, which represents 10% of the total light passenger vehicle fleet. The "Paris Declaration on Electro-Mobility and Climate Change and Call to Action" sets a global goal for the deployment of 100 million electric cars and 400 million of two and three-wheel vehicles (electric bikes and tricycles) in 2030 (DELGADO et. al., 2017).

A recent study carried out in Brazil by FGV Energia shows that the world fleet of vehicles for passengers (excluding buses and motorcycles) was 2 million in 2016. The number is expected to reach 13 million in 2020 and, in 2030, the study corroborates the estimated 140 million, or 10% of the total car fleet. In Brazil, from 2011 to 2016, only 5.9 thousand electric and hybrid cars were sold (combining combustion and electric engines), only 0.3% of the world fleet. Of the total sold in the country, 2,079 were sold in 2016 and the Toyota Prius hybrid model accounted for almost 80% of sales, with 1,635 units sold. (FGV Energia, 2017; 2018).

In 2017, the licensed electric or hybrid electric vehicles in Brazil represented 0.2% of the nearly 2.2 million of the licensed cars. The Brazilian Association of Electric Vehicles

(ABVE) informs, with data from 2018, that there are about 10,000 electric or hybrid vehicles running in the country. This number is less than 0.03% of the 36 million car fleet. (TEIXEIRA, 2018).

4.5.2 Estimated fleets of EVs in Brazil and MMP by 2030

The methods used by the Authors to estimate EV fleets between 2020 and 2030 are those of Linear Regression and BASS.

Linear Regression is a statistical procedure that has become a widespread tool for the development of future product sales trends to allow business managers to plan actions, among others, the acquisition of raw materials, expansion of companies in hiring staff and estimating profits (McFEDRIES, 2007; MEDEIROS et. al., 2013).

In general, Linear Regression analysis is used to determine the relationship between a phenomenon that depends on another. For example: the sales volume of a product (y) can be dependent on the sales price (x); the sale price of the product can be mainly dependent on the amount of assembly hours it requires; or mainly dependent on the cost of the necessary raw material. The phenomena are studied by analyzing the interaction between the dependent (y) and independent (x) variables.

After defining the variables for a given case, the regression method allows the analyst to: (i) visualize the future general trend of the relationship between "x" and "y" from known values of the relationship between these variables in a given period of time; (ii) expand the known trend to other "y" values.

In the case of the article in this paper (y) refers to the number of vehicles that are licensed and (x) the time periods in which licensing takes place until the year 2030.

The steps for applying the Linear Regression model are: (i) collect historical (known) data for (y) over a given period of time; (ii) determine the linear equation that describes the behavior of (y) as a function of (x); (iii) apply the equation in the future periods of specific cases.

Based on the historical evolution of EVs shown in Figure 3, the Authors' estimate for the amount of 100% electric EVs to be licensed in Brazil in 2030 is 598,262 (Figure 4).

Adopting the 25% national fleet index for MMP, the estimate of EVs to be licensed in this region in 2030 is around 150,000 units.

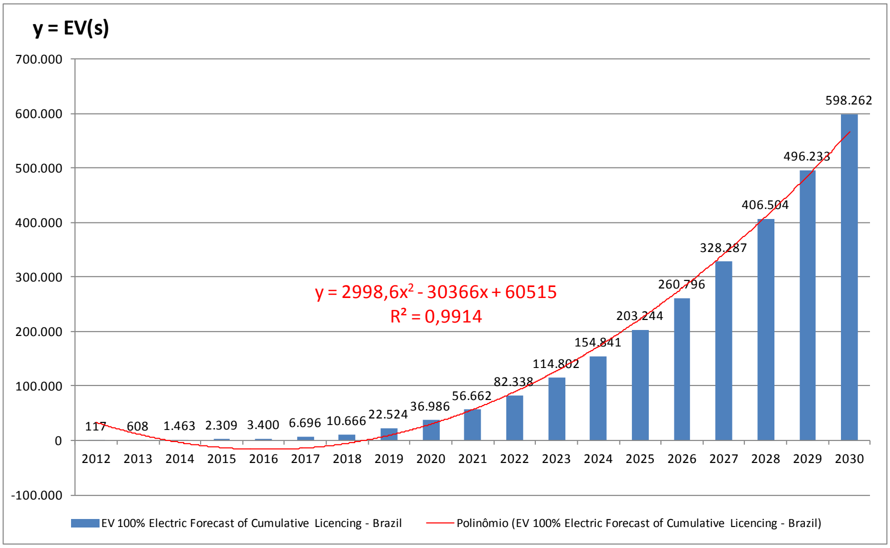

Figure 4. Forecast for 100% electrical cars to be licensed in Brazil up to 2030.

Source: Authors, with Linear Regression method considering the evolution from 2012 to 2019.

The BASS diffusion model (BASS, 1969) is used to determine the number of sales at a certain time based on the coefficients of innovation (*p*) and imitation (*q*). They focus on the growth (adoption) and spread (diffusion) of new products.

This model gives a good baseline forecast of long-term sales patterns of new products and technologies based on data for: (i) recently launched product that has few periods of historical sales data is available; (ii) product were not yet produced, but it is similar to existing ones whose sales history is well known.

In the BASS diffusion model buyers are separated into two groups: innovators and imitators. Innovators are buyers who are more receptive to new products and are the first ones to buy them, while imitators are buyers who purchase new products based on the influence and interaction with others who have already adopted such new technology.

The mathematical model, known as the BASS Model Principle, is presented in Equation (1).The behavioral rationale that supports such equation are (BASS, 1969, p. 217):

a) Initial purchases of the product are made by both “innovators” and “imitators” and the distinction between them is the buying influence. Innovators are not influenced in the timing of their initial purchase by the number of people who have already bought the product, while imitators are influenced by the number of previous buyers. Imitators “learn,” in some sense, from those who have already bought and used the new technology;

b) The importance of innovators will be greater at first but will diminish monotonically along the time;

c) “p” refers to the coefficient of innovation and “q” the coefficient of imitation.”

The model allows the forecaster to determine the probability of a purchase at time t given that the individual has not yet previously purchased the product.

$$n(t) = pm + (q – p) N(t) – q/p (N(t))^2 \quad (1)$$

Where
n(t) = Sales in period (t)
N(t) = Cumulative sales in period (t)
m = Total number of buyers in the market
p = Coefficient of innovation
q = Coefficient of imitation

Over the years, the BASS Model Principle has been extended in order to model different situations.

Applied to the case of this study, the BASS model projects the number of "sales" of 179,297 EVs in 2030 in the MMP, which is an amount very close to that estimated with the Linear Regression model.

Annexes V and VI show more details of these two models and the fleets of EVs on forecast in the 2030 horizon.

4.5.3 Energy and environmental impacts

The total energy consumption by EV cars is first estimated by the authors to later obtain CO_2 emissions. The assumptions for calculating total electricity consumption and emissions are, respectively:

(i) Electrical consumption for EVs:

$$\text{Electrical consumption} = \text{number of EVs x 20,000 kWh/km-EV} \quad (2)$$

(ii) EVs Emissions

$$\text{Emissões} = \text{Electrical consumption x EF (Emission Factor of } CO_2\text{)} \quad (3)$$

Adopted EF: 0,0750 tCO_2/MWh

The power adopted for automobiles is 0.23 kWh/km (THEOTONIO & TREDINNICK, 2018). As VE buses use more powerful electric motors, it is herein considered double the consumption adopted for cars, that is 0.46 kWh/km. Applying these values in equations (2) and (3) in different possible situations for the future, six scenarios were analyzed and the results are shown in next section.

5 I RESULTS

Six scenarios are analyzed. Scenarios 1, 2 and 3 analyzed emissions in cases ordered from the smallest to the largest territory, that is, the city of São Paulo, Metropolitan Region of São Paulo and MMP. Emission balances resulted out of the replacement of vehicular fuels with electric energy.

In the other scenarios, 4, 5 and 6, the analysis focused on electricity consumption and its impacts on the SIN's strategic reserve of energy.

The results are presented in five items. The first one has the conventional car and bus fleets (CVs) licensed at the MMP in 2019 and corresponding fuel consumptions and CO_2 emissions. The second shows aspects of electric vehicles (EVs) technology and figures of the Brazilian electricity plan for generation and consumption by 2030. The third show impacts of the 100% electric EV vehicles licensed at the MMP in 2019. The fourth shows impacts of the fleet of 100% electric buses licensed at the MMP in 2019. Finally, the fifth shows the analysis of scenarios.

Just reminding, the questions that guide the present work are: (1) would the SIN system be prepared to supply battery recharges for all estimated EVs to travel on the MMP ?; (2) what is the maximum number of EV vehicles that could be fueled within the SIN strategic reserve limit ?; (3) which scenarios have the greatest reductions in CO_2 emissions due to the replacement of CVs by EVs ?; and, finally, (4) what are the strategies for installing electro-posts for recharging EV batteries?

Following are the analyzes of impacts on total electricity consumption and CO_2 emissions for EVs in the six scenarios selected for EVs to penetrate in the MMP by 2030.

<u>Scenarios</u>

<u>Scenario 1</u>: Replacement of CV taxis fueled with ethanol by EVs in the city (municipality) of São Paulo (MSP) in 2030.

This scenario was selected because there is data available in the consulted bibliography (ADETAX, 2019; SMT/DTP, 2017) on the number of taxis (34,000 in 2018), type of fuel used (ethanol) and average daily mileage that these vehicles travel in the city of São Paulo (200 km). In addition, the taxi driver class is covered by public policies to reduce the cost of its vehicles for fleet renewal. The State of São Paulo also has regulations that reduce taxes for EVs.

The São Paulo City Hall (MSP) has a database that accounts for the evolution of the taxi fleet between 2000 and 2017 (SMT/DTP, 2017). Applying the Linear Regression and BASS methods, the fleet in 2030 is estimated at 36,000 units (details in Annexes V and VI).

The electric energy consumption of EVs and the reduction of emissions by replacing VC taxis with EVs in the MSP are shown in Table 6.

Scenario Year 2018				
	Vehicles (Taxis)	Ethanol Consumption (liter)	Electrical Energy Consumption (MWh/year)	CO_2 Emissions (t)
CV	34.000	244.500.000	NA	225.308,00
Scenario Year 2030				
EV	36.000	NA	165.600	12.420
		CO_2 balance in the year 2030		212.888,00

Table 6. CO_2 effects of replacing CV ethanol taxis with EVs in the city of São Paulo in 2030.

Source: Authors, based on: ADETAX (2019); MELO (2001); MCTIC (2019); SMT/DTP (2017).

Note that the reduction in CO_2 emissions (212,888.00 t) is significant, because the electricity consumption from the SIN has a much lower FE, compared to the ethanol consumption index.

Scenario 2: Replacement of CV buses fueled with diesel oil by EVs in the Metropolitan Region of São Paulo (RMSP).

This scenario, like the first one, also has known data regarding: vehicle fleet and type and consumption of vehicle fuel used; and it is likely to receive specific attention from the government to receive public policies to encourage substitution by EVs, mainly because the urban bus system is highly criticized due to the use of diesel oil in large quantities.

The National Traffic Department (DENATRAN, 2020) has the evolution of the bus fleet between 2000 and 2015. Applying the Linear Regression and BASS methods, a fleet with 185,226 units is estimated in 2030 (details in Annexes V and VI).

Electricity consumption and emission reductions by replacing CV buses with EVs are shown in Table 7.

Scenario Year 2018				
	Vehicles (Buses)	Diesel Consumption (liter)	Electrical Energy Consumption (MWh/year)	CO_2 Emissions (t)
CV	73.400	3.140.380.199	-	8.469.599,12
Scenario Year 2030				
EV	185.226	-	127.805,94	715.513,4
		CO_2 balance in the year 2030		8.341.793,40

Table 7. Replacement of diesel buses with EVs in the RMSP.

Source: Authors, based on: DENATRAN (2020); MELO (2001); MCTIC (2019).

Comparing with Scenario 1, note the much greater reduction (8,341,793.40 t) of CO_2 emissions because it is contemplated with the low FE of electric energy replacing the high FE of the diesel oil.

Scenario 3: Replacement of all flex-fuel vehicles estimated for the MMP by electric ones.

This is a scenario in which all flex-fuel CVs estimated for the MMP in 2030 are converted to electric along the period 2021 to 2030.

The estimate of the Brazilian fleet of this type of CV in 2030 is made by the Authors with the application of the Linear Regression method to the total vehicle licenses in the national territory (details in Annex IV, Figure AIV-6). Licenses are estimated for 86,880,351 units. Applying the consideration that 25% of them will be in the MMP, this fleet is 21,720,088 units.

Gasoline and ethanol consumption is estimated by keeping the relationship between vehicles and consumption in 2019 (Tables 1 and 2). Maintaining that ratio, 21,720,088 CVs will be consuming 9,941,482,039 liters of gasoline and 9,907,066,903 liters of ethanol. The FEs for gasoline and ethanol are the ones in Table 3. The reduction of emissions by conversions to VEs is shown in Table 8. In summary, the case compares two situations in 2030: that of flex-fuel vehicles fueled with gasoline and ethanol and that of all of them converted into electric vehicles.

		Scenario Year 2018			
	Vehicles	Gasoline Consumption (liters/ year)	Ethanol Consumption (liters/year)	Electric Consumption (MWh/year)	CO_2 Emissions (t)
VC	21.720.088	9.941.482.039	-	-	26.812.157
		-	9.907.066.903	-	26.719.339
Total 1					53.531.496
		Scenario Year 2030			
VE	21.720.088	-	-	99.912.405	7.493.430
Total 2					7.493.430
		Balance in Year 2030 (Total 1 - Total 2)			46.038.066

Table 8. Replacement of the VC flex-fuel car fleet with VEs on MMP in 2030.

Source: Authors, based on: DETRAN SP (2018); GESP/SEM (2017).

This scenario also shows a significant reduction in CO_2 emissions (46,038,066 t) if the entire car fleet at the MMP would to be electric ones in 2030.

Scenario 4: Energy consumption of the estimated EVs to travel on the MMP.

The number of private EV vehicles that will be licensed in Brazil by 2030 is estimated by the authors at 598,262 units, applying to the historical series of 100% electric vehicles licensed in Brazil between January 2012 and April 2019 the Linear Regression and BASS methods (details in Annexes IV and V). With the assumptions that 25% of these EVs will be circulating in the MMP (150,000 units), traveling 20,000 km per year and consuming 0.23 kWh per kilometer, the energy consumption will be 690 MWh or 0.69 TWh per year. This consumption does not affect the energy reserve of the SIN, which is in the order of 164.8

TWh in the year 2030 (MME/EPE, 2007).

Scenario 5: Energy consumption of all estimated EVs for Brazil.

Like in Scenario 4, the SIN's strategic reserve is easily preserved. The 598,262 units that, traveling an average of 20,000 km per year and consuming 0.23 kWh per kilometer, the energy consumption will be about 2.7 TWh a year, far below 164.8 TWh.

Scenario 6: Energy consumption if all flex-fuel CVs estimated for MMP in 2030 is converted to EVs.

This case is like Scenario 3 in terms of quantity of vehicles (21,720,088), but here with attention to electricity consumption.

Electrical consumption = 21,720,088 (EVs) * 20,000 (km year/VE) x 0.23 kWh /km-VE
= 99,91 TWh (4)

Here, again, the amount of electricity that would to be consumed does not affect the SIN reserve.

After all, the question that still remains open is about the maximum number of EVs in Brazil that could compromise the SIN's energy reserve. Within the assumptions established for the calculation of the number of EVs, the limit would be a fleet of approximately 35.6 million units (equation (5)).

Electrical consumption = 36,000,000(EVs) x 20.000 (km year/VE) x 0.23 kWh /km/VE
= 165,60 TWh (5)

Electric Recharging equipment

Scenarios 1and 2

Electro recharging units are estimated for scenarios 1 and 2, the conversion of 36,000 taxis in the Municipality of São Paulo (MSP) and 185,226 buses in the Metropolitan Region of São Paulo (RMSP), always in the 2030 horizon.

For taxis there are about 2,000 passenger pick-up points in the City of São Paulo (ADETAX, 2019) which gives an average of 18 vehicles parked in each point. Considering the hypothesis that nine of them are parked and the others in service and also that there is a sharing of a charger for every two cars, then each point would have three recharging posts (Authors' Hypothesis). In total there would be 6,000 recharging posts distributed among the 2,000 points. The recharging equipment can be, for example, of the semi-fast type. Table 9 summarizes these figures.

The fleets of buses in the RMSP are headquartered in garages in the 39 municipalities. Establishing the hypothesis that up to 300 vehicles are accommodated in each garage, the city of São Paulo will need 159 garages (to accommodate the biggest fleet) and the other cities from one to 14, totaling 620 garages (Authors). If all buses would to be recharging at the same time, 186,000 recharging points would be necessarily. However, considering that the fleets would have 100% of units circulating during peak transport periods and 50% in valley periods and that there are also units under maintenance, the number of recharging points may be lower. It is estimated that half of the points, 93,000, can be installed in banks of 150 units in each of the 620 garages (Authors). The recharging equipment can be, for example, of the slow type, fueling the buses parked at night or when parked in the garages along the day outside the transport peak intervals (Table 9).

EV (Type)	City/ Region	Vehicles	Recharging units	Installation logistics	Recharging units per vehicle
	Source: ADETAX 2019; DETRAN SP 2019; Authors estimation			Authors' estimation	
Taxi	São Paulo City (MSP)	36.000	6.000 (slow to medium time charging)	Passenger waiting point: 2.000 (with an average of 18 taxis each and a bank of 3 recharging unit in each one – semi-fast charging time)	6 (Note: there must be a time sharing strategy)
Urban Bus	São Paulo Metropolitan Area (RMSP)	185.226	93.000 (slow time charging)	Garages: 620 (estimated), with an average of 300 buses and a bank of 150 recharging unit in each one- slow charging time)	2 (Note: there must be a time sharing strategy)

Table 9. Logistics for recharging facilities for taxis and city buses - MSP and RMSP.

Source: Authors, based on: ADETAX (2019); DETRAN SP (2019).

<u>Scenarios 3 and 6</u>

In Scenarios 3 and 6 there are large quantities of 100% electric EV vehicles: 21,720,088 and 36,000,000 of units. In the view of the Authors, the recharging equipment for these high quantities of EVs will have to be installed in different locations, for example, in homes, shopping centers, condominium garages, existing filling stations for CVs and in parking lots, among others.

<u>Scenarios 4 and 5</u>

Scenarios 4 and 5 will deal with small quantities of 100% electric EV vehicles, respectively 150,000 and 598,262. These quantities of EVs could have their batteries easily recharged with recharging points installed in different locations of the MMP (Authors).

<u>Energy efficiency</u>

According to THEOTONIO & TREDINNICK (2018) electric vehicles typically consume between 0.1 to 0.23 kWh per kilometer. The same authors report that the average consumption for a vehicle equivalent consuming gasoline is 0.98 kWh per kilometer. According to these figures, when comparing two equivalent CV and EV vehicles developing the same transport service, the EV "stops losing" 0.75 kWh per kilometer traveled.

5.1 Comments

CO$_2$ emissions – Reductions due to the substitution of CV by EV

Figure 5 shows the emission reductions (millions of tons) in ascending order provided by the conversions of CV vehicles by EVs described in Scenarios 1, 2 and 3.

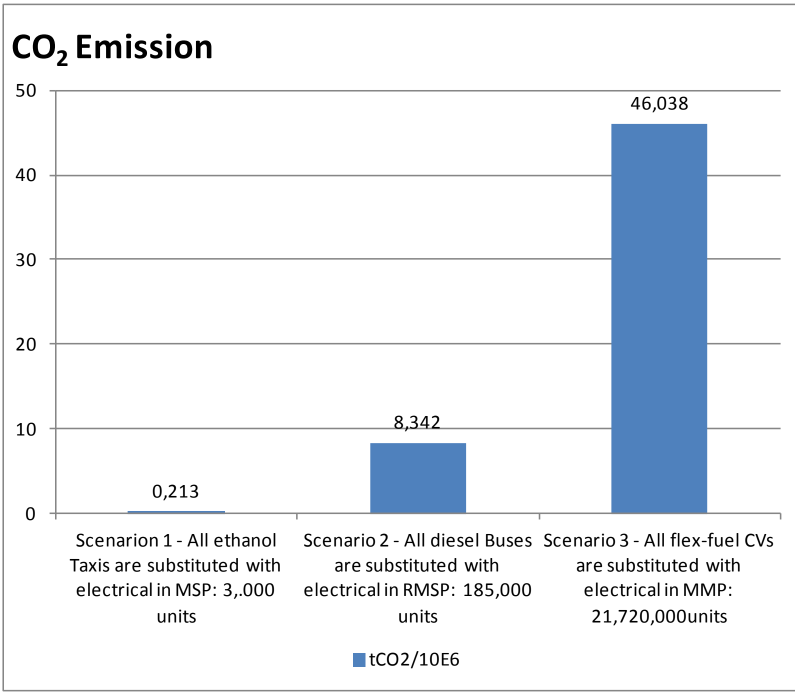

Figure 5. Reductions on CO$_2$ Emissions per Scenarios.

Souce: Authors.

Electricity consumption from SIN

In the scenarios 4, 5 and 6 analyzed, the electricity consumption does not exceed the strategic reserve of the SIN planned for 2030. As discussed above, to exceed this reserve, figures of the order of 36.0 million EV vehicles would be necessary (Figure 6)

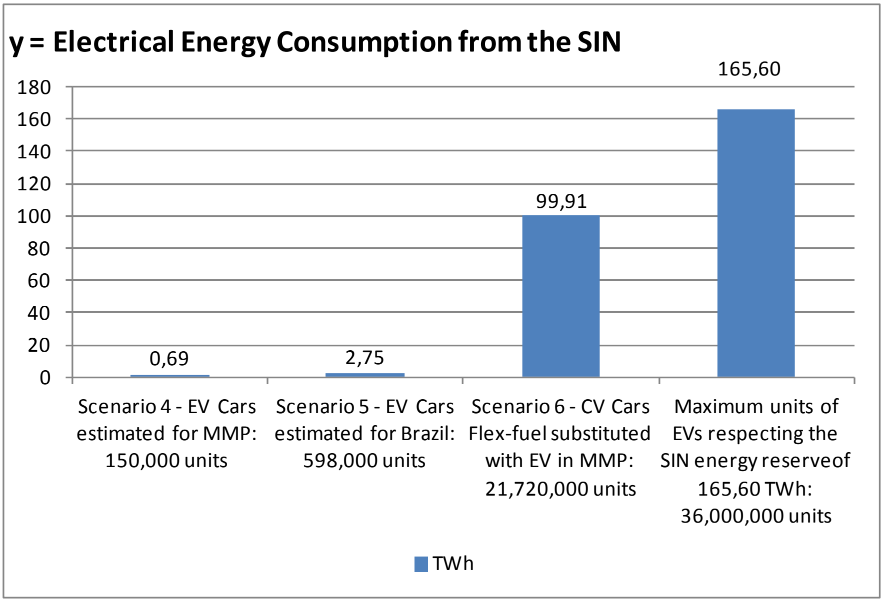

Figure 6. Electrical Energy Consumption per Scenario and Limit for SIN.

Source: Authors.

6 I CONCLUSIONS AND COMMENTS

6.1 Answers to questions

Regarding the impacts on the offer of electrical energy supplied by the SIN, in all the scenarios surveyed the limits of electricity consumption are below the strategic reserve of the 2030 energy planning. Within the assumptions and limits of this study the offer available by the SIN would be compromised only in the case of a national fleet of EVs above 36 million vehicles.

EVs have lower CO_2 emissions than CVs, as shown in Scenarios 1 to 3. Scenarios 1 and 2 show significant emission reductions, especially scenario 2. Scenarios 1 and 2 can be promoted by Public Authorities, which have the power to implement policies for the conversions of conventional taxis and buses to EV types. Scenario 3 is a bold hypothesis, which in addition to demanding public incentive policies to engage the owners of private VC cars to opt for the electric models also faces the need of a large infrastructure of battery recharging equipment.

In relation to the best types and locations of equipment for recharging batteries, these equipment can be of the types of slow recharging (8.0 h), medium or semi-fast recharging (2.0 to 4.0 h) and fast recharging (in the order of 20.0 to 40.0 minutes) and can be installed in different locations, according to specific cases.

In terms of energy consumption and CO_2 emissions, the EV: first, it is more efficient than CV due to its specific characteristics, mainly due to the high efficiency of electric motors; and it takes the benefit that the Brazilian electric supply is generated substantially (in the order of 70%) by “clean” hydroelectric and wind power plants. Efficiency is related to the entire motor and traction set, which, due to its fewer mechanical components, provides a system with low thermal loss due to mechanical frictions. As the electric motor can be mounted directly on the wheels and has instant torque, the system does not require a gearbox. There is also the ability to convert and store kinetic energy into electrical, since the electric motor can act as a generator, which allows it to participate with electric braking when necessary and also recharge the onboard batteries. With proper electronics on board, battery consumption can be even optimized, for example, with automatic power off when the vehicle is stopped in traffic.

6.2 Final comments and next steps

Reminding, the purpose of this article was to analyze energy and environmental impacts related to the introduction of electric vehicles in MMP in the horizon of 2030.

Relevant observations:

(i) in Scenario 1, the reduction in CO_2 emissions in the year 2030 would be of the order of 213,000 t, in Scenario 2 of 8,342,000 t and, in Scenario 3, of 46,038,000 t. Scenario 2, in particular, shows that the conversion of diesel CV buses to 100% electric EVs is a very interesting case. In it, all CV buses powered by diesel oil are replaced by electric vehicles in the Metropolitan Region of São Paulo (RMSP), comprising 39 municipalities.

(ii) in all scenarios, there is no electricity consumption that compromises the national strategic reserve planned in the SIN for the year 2030. The 164.8 TWh reserve projected for the year 2030 in the National Energy Plan 2030 would be compromised in the hypothesis (theoretical) of an amount of EVs in the order of 36.0 million units. This hypothesis, however, is seen by the Authors as far from the diffusion trend identified for EVs in the 2030 horizon. It is not the case of the electrical intensity (consumption) observed in the analyzed cases, but, for future cases that exceed the 36,0 million EVs, in order not to overload the SIN system during vehicle recharging periods, regulatory policies could be put in place, such as: applying differentiated taxes on kWh to direct recharges outside peak consumption hours for various other social services; there is also the possibility of recharging equipment to be powered outside the SIN system, such as, for example, the use of alternative energies generated by photovoltaic cells or wind powered generators.

Next steps:

Improve EV related estimates

(i) Improve the calculations of CO_2 consumption and emissions, seeking to make a more elaborated time synchronization between the data related to estimating the vehicle fleets, electricity consumption and CO_2 emissions;

(ii) Follow up on the strategic reserve of the SIN that is currently under review within the ongoing national energy plan forecasting 2050 (MME/EPE);

(iii) Follow up on vehicle fleet data made available by DENATRAN; the improvement of the historical series of cars and buses fleets will make future estimates more robust, improving the estimates herein done with Linear Regression and BASS methods;

Keep improving the estimating fleet model

(i) The EV dissemination models (Annexes V and VI) must be updated periodically according to the evolution of the historical series and any EV parameters that modify the innovation and imitation coefficients of the BASS model (e.g. any public incentive policy can change the trend of EV adoption); it is also recommended that a market research be carried out to investigate the real intentions for people to purchasing and or using electric vehicles for the next coming decades and to consider investigating any changes in consumer behavior in the automotive market; these are perceptions that can reduce or increase consumption, therefore the coefficient of imitation of the BASS model.

Keep following the EF figures

(i) The EF provided by the national Electric System Operator is variable and published monthly. This electric energy grid (SIN) system considers a mix of renewable and fossil energy generation sources to calculate the electrical EF. As most of the electricity generated in Brazil comes from hydroelectric plants, good periods of rain are essential. In periods of drought, the thermoelectric plants are activated, which impacts (increases) the EF.

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SUPPLEMENTARY INFORMATION

Supplementary information associated with this article can be found in Annexes available online at: https://drive.google.com/drive/folders/1DFMrITLdWOEu1ve4Gp3zS3Z2eejuAVvz

Annex I - Topics on Governance and Public Policies for Electric Vehicles (EV).

Annex II - Evolution of the CV fleet, vehicle fuel consumption and CO_2 emissions between 2018 and 2019 at MMP.

Annex III - Consumption of gasoline, diesel oil and ethanol in each of MMP's 174 municipalities.

Annex IV - CO_2 emission factor (EF) for gasoline, ethanol, diesel oil and electricity.

Annex V - Diffusion of 100% Electric and Hybrid EVs with Linear Regression Model.

Annex VI - Diffusion of 100% Electric and flex-fuel EVs with BASS Model.

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ÍNDICE REMISSIVO

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ENGENHARIAS: Pesquisa, desenvolvimento e inovação 3

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