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Master in Business Management

Mass introduction of electric passenger vehicles in Brazil: impact assessment on energy use, climate mitigation and on charging infrastructure needs for several case studies

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"There are no passengers on Spaceship Earth. We are all crew."

Marshall McLuhan

Abstract -

Mobility has proved to be a major challenge for human development, especially in urban centers worldwide, where more displacement is required, since fossil fuels consumption is increasing as well as greenhouse gas (GHG) emissions, causing air quality degradation and global warming. The predicted population increase in cities tends to increase the demand for mobility and to further exacerbate those impacts. Therefore, sustainable transport is key for the future of mobility, and electric vehicle (EV) has emerged as a recognized sustainable option. However, there are many electric vehicle barriers diffusion.

This research aims to contribute to the diffusion of EV in Brazil, by assessing: 1) whether EV is a more sustainable technology when compared with ethanol vehicle; 2) the impacts of the expansion of electric mobility on CO_2 emissions, in Sao Paulo; 3) how to overcome the barriers for the charging infrastructure deployment at the municipality level, in Sao Paulo, Rio de Janeiro and Belo Horizonte; and 4) key challenges and opportunities from the mass adoption of EV in Brazil. A plethora of different methods were used, including scenario analysis, multi-criteria decision methods, geographic information systems and SWOT analysis.

Main results point to EV as the best technology to mitigate passenger transport related CO_2 emissions in Brazil, due to its low carbon footprint. In Sao Paulo, this option could reduce around 11 $MtCO_2$ by 2030 and save 6,200 billion USD in energy with the replacement of 20 percent of gasoline cars with EV. To meet 1 percent of EV's market share, Sao Paulo, Rio de Janeiro and Belo Horizonte together will need around 6,500 charging stations concentrated in around 1/3 of their territories (level 2). Brazil may likely have up to 10 percent of EV penetration by 2030, with the diffusion taking place mostly in southeastern municipality. Ethanol, lack of electric mobility public policy, non-urbanized like subnormal agglomerates, and risk areas, like flood hazard, are major obstacles for EV diffusion in Brazil.

Key-Words: electric vehicle, renewable energy, transport, CO_2 emission, climate change, Brazil

Resumo

A mobilidade provou ser um grande desafio para o desenvolvimento humano, especialmente nos centros urbanos em todo o mundo, onde mais deslocamentos são necessários, o consumo de combustíveis fósseis está aumentando, assim como as emissões de gases de efeito estufa (GEE), causando degradação da qualidade do ar e aquecimento global. O aumento previsto da população nas cidades tende a aumentar a demanda por mobilidade e a agravar ainda mais esses impactos. Portanto, o transporte sustentável é fundamental para o futuro da mobilidade, e o veículo elétrico (VE) surge como uma opção sustentável reconhecida. No entanto, existem muitas barreiras à difusão de veículos elétricos.

Esta pesquisa visa contribuir para a difusão do VE no Brasil, avaliando: 1) se o VE é uma tecnologia mais sustentável quando comparado ao veículo a etanol; 2) os impactos da expansão da mobilidade elétrica nas emissões de CO_2, para o caso de São Paulo; 3) como superar as barreiras para a implantação da infraestrutura de carregamento a nível municipal, para os casos de São Paulo, Rio de Janeiro e Belo Horizonte; e 4) principais desafios e oportunidades da adoção em massa de EV no Brasil. Diferentes métodos foram utilizados, incluindo análise de cenário, métodos de decisão multicritério, sistemas de informação geográfica e análise SWOT.

Os principais resultados apontam para o EV como a melhor tecnologia para mitigar as emissões de CO_2 relacionadas ao transporte de passageiros no Brasil, devido à sua baixa pegada de carbono. Em São Paulo, essa opção poderia reduzir em torno de 11 $MtCO_2$ até 2030 e economizar 6,2 bilhões de dólares em energia com a substituição de 20 porcento dos carros a gasolina por VE. Para atender a 1 por cento da participação de mercado do EV, São Paulo, Rio de Janeiro e Belo Horizonte juntos precisarão de cerca de 6.500 estações de carregamento concentradas em cerca de 1/3 do território (nível 2). O Brasil pode ter até 10 por cento de penetração de veículos elétricos até 2030, com a difusão ocorrendo principalmente no Sudeste. O etanol, a falta de políticas públicas para a mobilidade elétrica, espaços não-urbanizados como aglomerados subnormais, e áreas de risco, como o risco de inundação, são grandes obstáculos para a difusão do VE no Brasil.

Palavras-chave: veículo elétrico, energia renovável, transporte, emissão de CO_2, mudança climática, Brasil

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ACRONYMS

AC – Alternating Current

AHP – Analytical Hierarchy Process

APP – Application (a computer program that is designed for a particular purpose)

AV – Autonomous Vehicle

BEV – Battery Electric Vehicles

BH – Belo Horizonte

BM – Business Model

BYD – Build Your Dreams (EV car manufactory)

CaaS – Car-as-a-Service

CCS – International's Combined Charging System

CE – Circular economy

CO_2 – Carbon Dioxide

CTB – Company Tax Benefits

DC – Direct Current

DER – Distributed Energy Resources

DMS – Demand Management System

DPS – Direct Purchase Subsidies

EM – Electric Mobility

EPA – Environmental Protection Agency

EU – European Union

EURO – European emission standards for vehicles

EV – Electric Vehicles

EVCI – electric vehicle charging infrastructure

EVCS – Electric Vehicle Charging Station

EVIP – Electric Vehicle Initiative Program

EVSE – Electric Vehicle Supply Equipment

FCEV – Fuel Cell Electric Vehicle

GDP – Gross Domestic Product

GHG – Greenhouse Gases Emissions

GIS – Geographic Information Systems

GM – General Motors

HEV – Hybrid Electric Vehicle

HOV – High occupancy vehicle

ICE – Internal Combustion Engine

ICEV – Internal Combustion Engine Vehicle

IEA – International Energy Agency

INI – Infrastructure National Incentives

IoT – Internet of Things

IPCC – Intergovernmental Panel on Climate Change

IVA – Individual Voluntary Arrangement

LCA – Life-Cycle Assessment

LCI – Living City Incentives

LDEV – Light-Duty Electric Vehicles

LDV – Light-Duty Vehicles

LE – Linear economy

LEAP – Long-range Energy Alternatives Planning System

LIDAR – Light Detection and Ranging

MCDM – Multi-criteria Decision Making

OECD – Organization for Economic Co-operation and Development

OHB – Other Benefits

OPEC – Organization of The Petroleum Exporting Countries

OTB – Ownership Tax Benefits

PHEV – Plug-In Electric Vehicle

PPM – Parts Per Million

RD&D – Research, Development and demonstration

REE – Rare Earth Element

RJ – Rio de Janeiro

RTB – Registration Taxes Benefits

SDS – Sustainable Development Scenario

SH – Shanghai

SP – Sao Paulo

SPSS – Statistical Package for the Social Sciences

SUV – Sport Utility Vehicle

SWOT– Strengths, Opportunities, Weaknesses, and Threats Analysis

TCO – Total Cost of Ownership

TPES – Total Primary Energy Supply

TTW – Tank-to- Wheels

USA – United States of America

USC – Union Scientists Concerned

VAT – Value Added Tax

V2B – Vehicle-to-Business

V2G – Vehicle-to-Grid

V2H – Vehicle-to-Home

V2N – Vehicle-to-Neighborhood

V2S – Vehicle-to-Street

V2X – Vehicle-to-Everything

WLC – Weighted Linear Combination

WTT – Well-To-Tank

WTW – Well-to-Wheels

ZEV – Zero Emissions Vehicle

CHAPTER 1 | INTRODUCTION

Human activity has been very carbon intensive, which has resulted in a significant increase in carbon dioxide (CO_2) concentration in the atmosphere. It has increased from about 280 parts per million (ppm) in the pre-industrial period to average concentration of 411 ppm in January 2019, a growth of almost 47 percent (NASA 2019). Santos (2011) quoted Rockstrom saying that the safe limit for the planet's CO_2 concentration in the atmosphere is 350 ppm. Consequently, avoiding the increase of global CO_2 emissions to maintain the global average temperature between 1.5 and 2°C above pre-industrial levels is a major challenge for humankind, in order to support the targets of the Paris Agreement.

Cities account for more than half of the world's population and are great mobility demanders. Also, they constitute a driving force for economic development, holding about 80 percent of global GDP, accounting for two-thirds of all primary energy consumption and for 70 percent of carbon dioxide (CO_2) emissions (Energy & Transformations 2017).

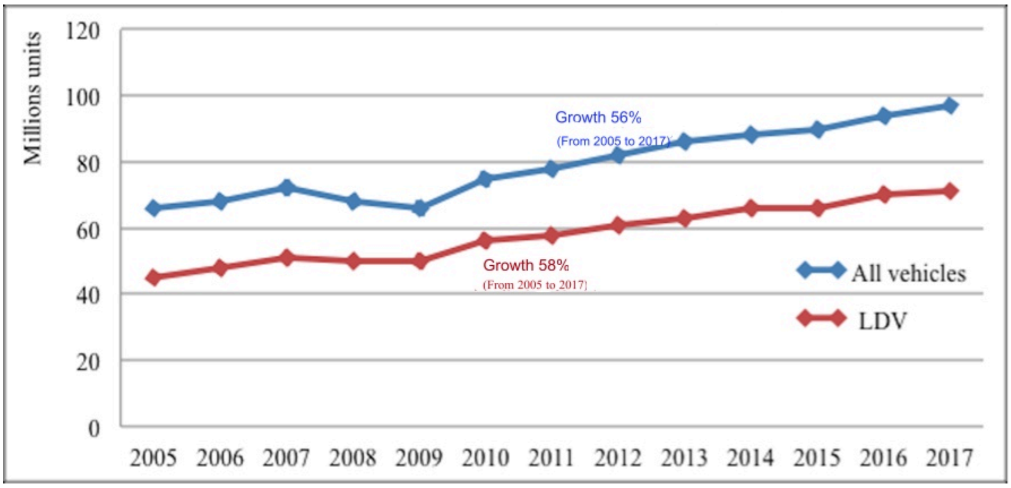

Figure 1.1 – Global vehicle sales from 2005 to 2017 (Adapter from OICA 2018)

Global transport is the second largest sector regarding energy consumption, just after industry. Over the last twelve years, global sales of road vehicles have been growing almost constantly. Between 2005 and 2017 the growth in sales was of around 56 percent, reaching almost 100 million units sold in 2017. Focusing on light-duty vehicles (LDV), in the same period, global sales grew by around 58 percent, reaching around 71 million units in the same year, as show in Figure 1.1 (OICA 2018).

Regarding energy consumption and greenhouse gases (GHG) emissions in 2016, the transport sector was responsible for almost 1/4 of worldwide energy-related emissions and road transportation was responsible for around 1/5 of the fuel consumption (Energy & Transformations 2017). The projections show that without mitigation action, transport emissions could more than double by 2050 (SLoCaT 2018).

In Brazil, the situation is similar, with a rapid growth of the road vehicle market, due to increasing urbanization level and consumers' access to cars. Between 2005 and 2017 there was a growth of around 30 percent in road vehicle sales in Brazil, reaching more than 2 million units licensed in 2017, of which about 81 percent were LDV. In particular LDV sales grew by around 29 percent, in the same period, in the Brazilian market (ANFAVEA 2017). The decline in sales after 2013 was due to the reduction of subsidies for car purchases (2012-2014), economic slowdown and political crisis, as shown on Figure 1.2.

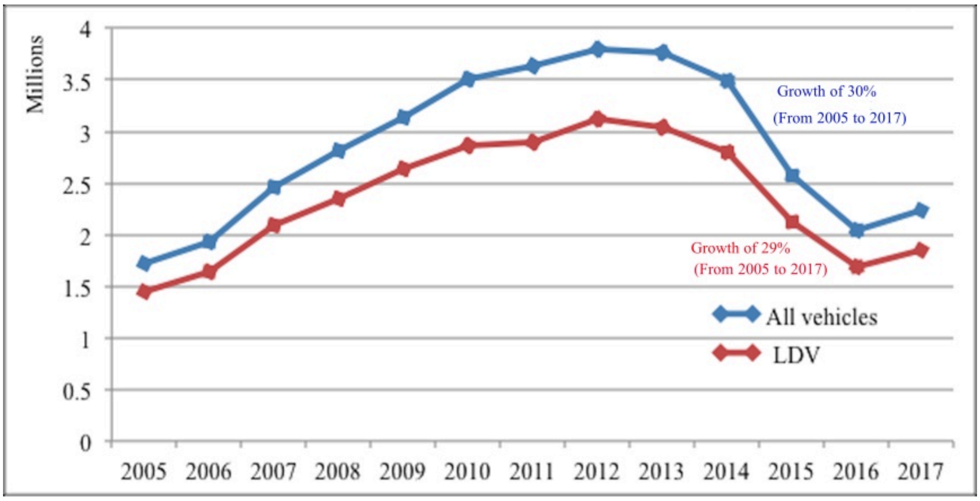

Figure 1.2 – Vehicle sales in Brazil from 2005 to 2017 (Adapted from ANFAVEA 2017)

The growth of penetration of road vehicles in the Brazilian market has contributed to worsening levels of CO_2 emissions, since the country's transport sector consumes around 32 percent of the final energy consumption of which road transport represents 92 percent (EPE 2015).

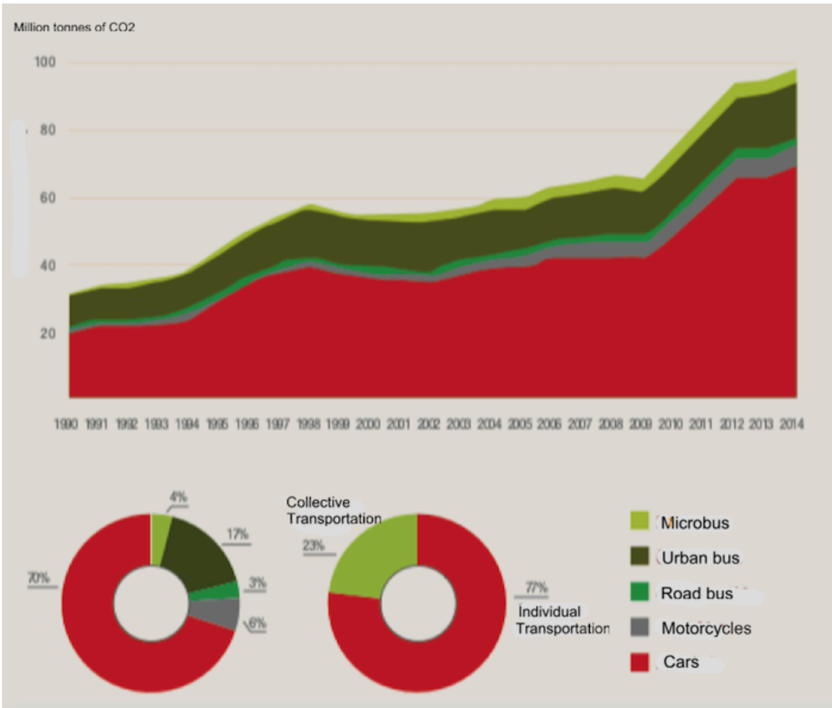

Figure 1.3 – Evolution of CO_2e emissions in road passenger transport in Brazil from 1990 to 2014 (Adapted from SEEG 2016)

The missions of the road passenger transport in Brazil have increased significantly in the last decades. In 1990, CO_2e emissions amounted to around 30 million tons reaching 100 million tons in 2014, representing 46% of CO_2e emissions related to the energy sector (EPE 2015).

Individual transportation (automobiles and motorcycles) emits more than three times in comparison to collective transportation (buses) despite transporting a smaller number of people, as shown in Figure 1.3. In this context, it is important to find new ways to develop alternative transportation solutions linked with resource efficiency under a circular economy collaborative process, aiming to mitigate anthropogenic emissions, including pollutants, and implement them in ways that limit emissions to target levels is a considerable challenge.

1.1 Relevance and Problem statement

The quest for the sustainable development of the global economy has demanded actions from policy makers aimed at limiting CO_2 emissions from the energy and transportation sectors. According to the Intergovernmental Panel On Climate Change (IPCC), about 78 percent of the total GHG emissions increased from 1970 to 2010 were from fossil fuel combustion and industrial processes (IPCC 2014).

In 2010, emissions from energy combustion were around 2/3 of global GHG emissions, and energy demand continues to grow as a result of global economic development. According to IEA (2018) from 1971 to 2014, the global total primary energy supply (TPES) has grown by almost 150 percent and remains dependent on fossil fuels. Since 2014, fossil sources have been responsible for around 82 percent of the global TPES (IEA 2018).

Global energy consumption grew by over 40% between 1990 and 2015, as shown in Figure 1.4, with significant participation of the oil industry. The expected population increase should contribute to the growth of demand for energy. In this context, mitigation actions will be important to avoid the growth of energy consumption in the proportion recorded so far.

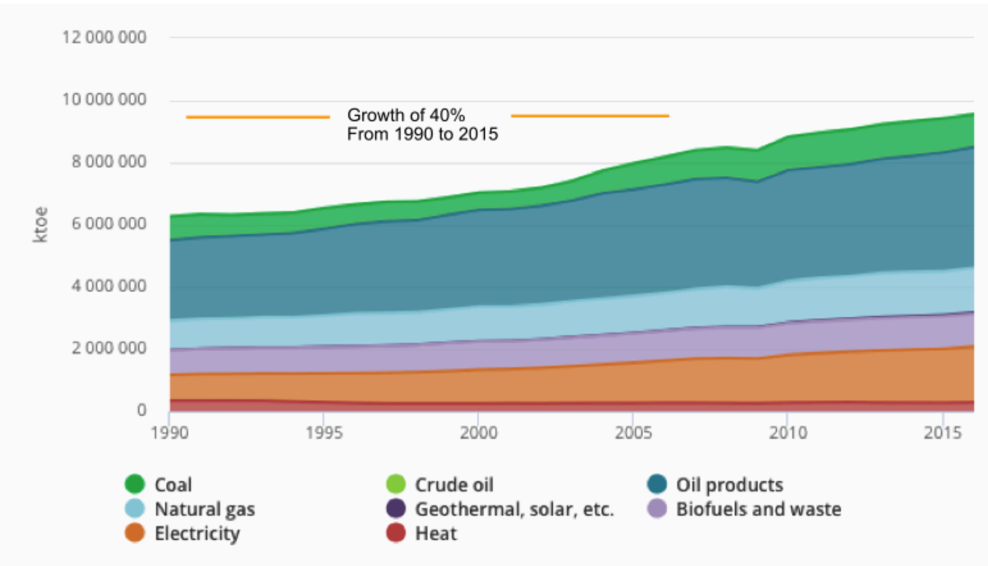

Figure 1.4 – Worldwide evolution of energy consumption from 1990 to 2014 (Adapted from IEA 2018a)

In 2015, road vehicles were responsible for almost 80 percent of the energy consumed in transport, and LDV accounted for 64 percent of this amount (IEA 2019). Globally, CO_2 emissions from the transport sector grew by 71 percent between 1990 and 2014 with road transport accounting for about three quarters of this growth (IEA 2018).

1.1.1 Energy consumption CO_2 emissions from transport in Brazil

In Brazil the status is not so different. In 2014, the transportation sector was responsible for 32 percent of energy consumption and road transportation represented more than 92 percent of that measure. Fossil fuel is responsible for about 50 percent of the energy consumption for transport and it's not greater due to the share of ethanol in the consumption mix (in Figure 1.5, the gasoline line refers to automotive gasoline which includes 27% of ethanol). The growth in the energy consumption of transport has been constant. Between 2008 and 2017 there was an increase of nearly 40 percent, with road transport accounting for more than 90 percent of total transport consumption. The highest energy consumption is diesel, followed by gasoline, as shown in Figure1.5. The gasoline energy consumption dropped from the second half of the 1980s due to ethanol production programs for transportation.

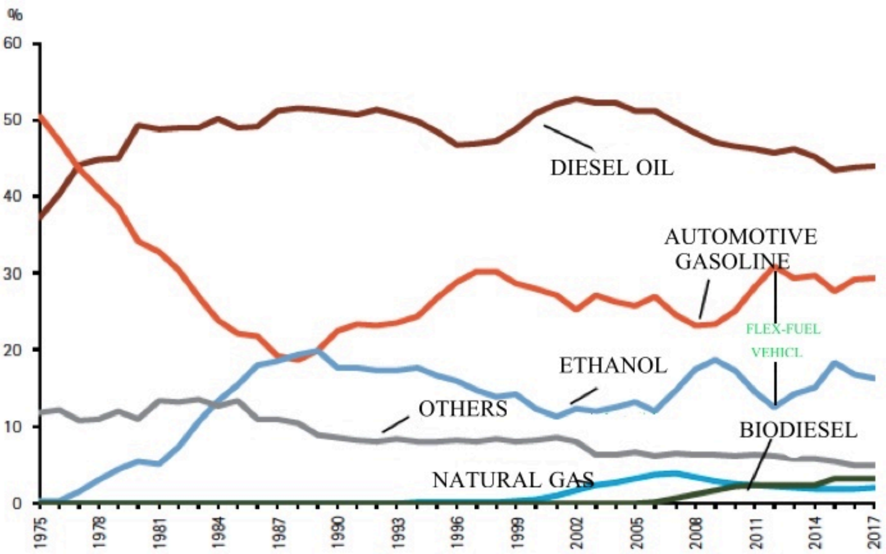

Figure 1.5 – Transportation Sector Energy Consumption - 10 toe (Adapted from EPE 2018)

The growth of the LDV fleet was one of the main factors responsible for the increase in CO_2 emissions in transportation in the country (EPE 2015). In the municipality of Sao Paulo, the highest concentration of road vehicles in Brazil was recorded in 2010, with LDV representing more than 70 percent of the fleet and the transport sector accounting for more than 70 percent of CO_2 emissions related to the energy sector; gasoline and diesel combined accounting for more than 75 percent of CO_2 emissions from road transport. In 2010, the CO_2 emissions from road urban transport in the municipality of Sao Paulo – the largest municipality in Brazil in population, GDP and car fleet – grew 80 percent, compared to 2003 (CETESB 2014). The total fleet of the municipality of Sao Paulo in 2016 was 7.8 million vehicles (about 30 percent of Sao Paulo state fleet).

In Rio de Janeiro's municipality – the second largest municipality in population, GDP and road fleet in Brazil – road passenger transport, in 2013, was responsible for 90% of CO_2e emissions from the transport sector, with individual transport (mostly light duty vehicles) being responsible for 78% of the road transport emissions (SMMA-RJ 2011). In 2013, the total fleet of Rio de Janeiro was around 2.7 million vehicles (about 50 percent of Rio de Janeiro state fleet). In the municipality of Belo Horizonte – the third largest fleet in Southeastern Brazil and the fourth-largest Brazilian city in population and GDP – the road transport sector accounted for around of 90 percent of the CO_2 emission from transport sector of the major municipality of Minas Gerais (Estadual et al. 2008). In 2016, the municipality of Belo Horizonte accounted for 1.7 million vehicles (around 20 percent of Minas Gerais state fleet) of which almost 70 percent are LDV (IBGE 2018).

Sao Paulo, Rio de Janeiro and Belo Horizonte are the three major cities in Southeastern Brazil, being responsible for more than 50 percent of the Brazil's GDP (IBGE 2017a). The Southeast region accounts for a higher level of industrial and urban development, concentrating 68 percent of the industry production, business activity, and services activity, and holding around 96 percent of Brazil Southeast GDP (IBGE 2017).

1.1.2 Electric vehicle potential as massive climate mitigation option

The reduction of anthropogenic greenhouse gas emissions is recognized as imperative to stabilize the Earth's climate. The energy and transport sectors need to significantly reduce their GHG emissions in order to support the targets of the Paris Agreement of limiting the global temperature increase well below 2°C from the pre-industrial level, which requires the decarbonization of the transport by 2050 (Pachauri et al. 2014). Given this scenario, the electric vehicle (EV) has been assumed as an interesting alternative to the internal combustion engine (ICE). In the context of this thesis, the term 'Electric Vehicle' (EV) refers to a vehicle that uses electricity exclusively to propel the vehicle, and receives electricity by plugging into the electric system and storing the energy in batteries. It is synonymous with BEV, as detailed in Chapter II - State of the art in electric mobility. The EV engine is around 90 percent efficient and ICE engine around 20 percent (Eaves 2004). Therefore, EV reduces GHG emissions (cleaner at the same proportion of the renewables share in the power mix), and improves urban air quality, providing significant lower impact on climate change. EV is also pointed to as a case to support the transition for a circular economy specially when using renewable enegy (Sperling & Gordon 2010; Messagie 2014; IEA 2018a).

The GHG emission, by the LCA method, shows that EV emits less than the equivalent ICE model using the LCA method. EV reduces the overall emissions by 51 percent over the lifetime of the vehicle (Nealer et al. 2015). In 2018, in USA, China and United Kingdom all electric cars models emit less carbon dioxide per kilometer than the best-selling petrol vehicles (Gambhir et al. 2018). Besides that, the electric propulsion seems to be a better option specially in urban centers, because of their zero tailpipe emissions (Van Mierlo et al. 2017). More information about GHG emission by LCA principle is in topic 2.3.3 in this thesis. Although EV has potential to mitigate GHG emissions, EV shows slow and restricted diffusion in a small number of developed economies around the world. In 2006, only twenty metropolitan areas accounted for about 40 percent of the global EV stock and 43 percent of EV sales (Hall et al. 2017). To become mainstream, EV must overcome the barriers that prevent its massive diffusion.

Among the main challenges to overcome is the implementation of electric vehicle supply equipment (EVSE) in appropriate volume by level[1], type[2] and suitable locations. This subject is even more critical in most developing countries because of the limited resources for research investments. The creation or expansion of an EVSE network requires research to identify the main variables and attributes typical, and often unique to each region (Costa et al. 2018).

For EV mass-market deployment to take place, barriers from socio-economic transition involving socio-technical factors, environmental-political elements and innovations aspects (Steinhilber et al. 2013) must be overcome. The most common EV mass-market barriers are those of low range perception, lack of charging infrastructure, long time to recharge the batteries, and higher EV price acquisition than the fossil fuel equivalent model. However, there are several other types of barriers that can affect the mass diffusion of EV, as revealed in topic 2.4 of this thesis.

On the other hand, the transportation sector in Brazil offers other low emission vehicles, such as ethanol, which can also contribute to mitigate GHG emissions. However, research is needed to identify the most appropriate technology, the main challenges and opportunities associated with the mass penetration of low emission cars, and the impacts of the expansion in energy system and CO_2 emissions.

1.2 Research questions

The main objective of the research presented in this thesis is to provide knowledge to support the possibility of electric vehicles becoming an alternative for the Brazilian market, as an effective climate mitigation option, while delivering the mobility service needed for the country's development. For that purpose, the following specific research questions (RQ) were undertaken, for the case of Brazil.

RQ#1: What is the most appropriate technology for the purpose of climate mitigation and energy consumption reduction in the case of Sao Paulo: electric or ethanol vehicle?

RQ#2: What will be the expected impacts of the likely expansion of electric mobility in Sao Paulo municipality, in terms of CO_2 emissions and energy consumption and how effective are current public policies in place to promote such expansion?

RQ#3: How to overcome the barriers regarding the deployment of the charging infrastructure at the municipality level, in the case of Sao Paulo, Rio de Janeiro and Belo Horizonte?

RQ#4: What are the main perceived challenges and opportunities from the mass penetration of electric mobility in Brazil?

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[1] In Society of Automotive Engineers (SAE) terminology, 'Level' charging refers to use of a standard of charging equipment capacity to charge the battery of the electric vehicle (BEV). The International Electro-Technical Commission adopts the terminology MODE. In this document we adopt the SEA terminology.

[2] The term 'type' refers the type of connector to connect electric vehicle to the charging station.

1.3 Research strategy

To answer the research questions listed in the previous section, a careful and comprehensive research strategy was adopted, supported by extensive literature review on the modeling methodologies available for each one. It was sought not only to identify the tools, but also to understand their efficiency and the critical factors in each application. The same principle was used to determine the methods of execution as well as the techniques of analysis. Figure 1.6 presents an overview of the methods adopted throughout the research to provide the answers to the research questions, which includes three main phases as explained below.

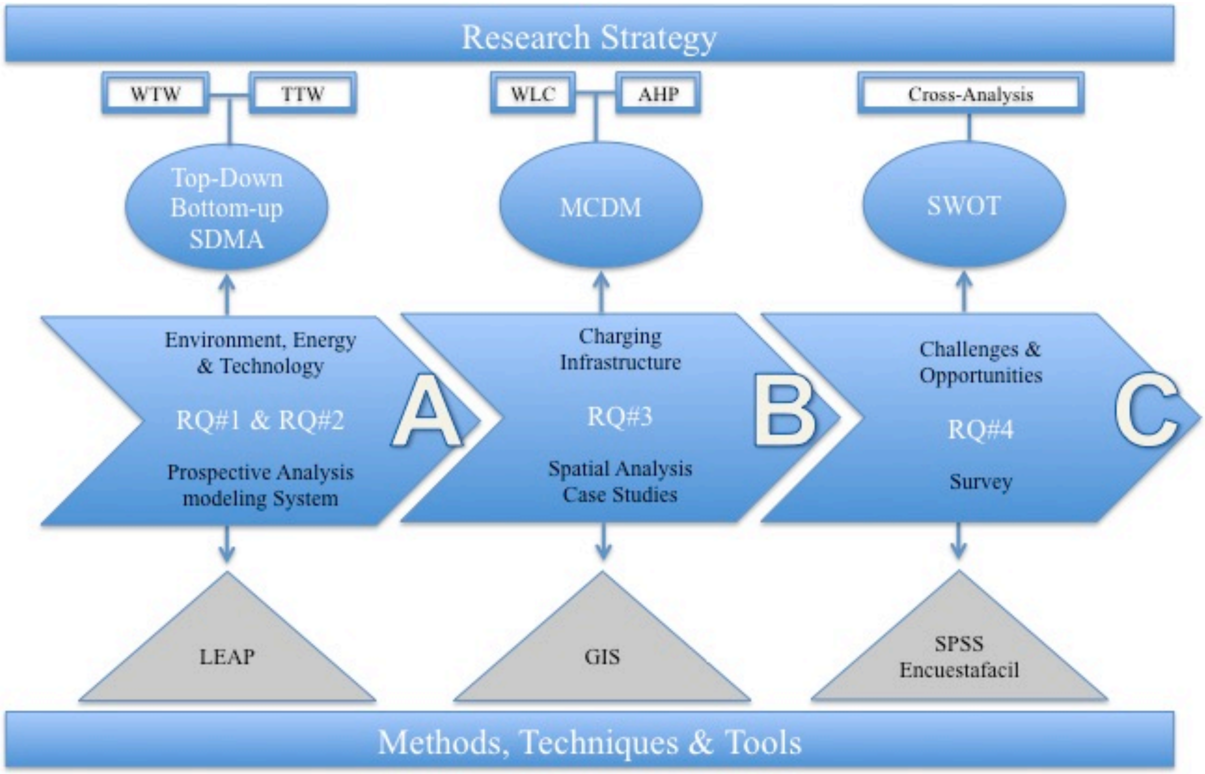

Figure 1.6 – Research scheme

Phase "A" –Climate mitigation and energy, energy consumption and appropriate technology

This phase was carried out to answer questions RQ#1 – What is the most appropriate technology for the purpose of climate mitigation and energy consumption reduction in the case of Sao Paulo: electric or ethanol vehicle? And RQ#2 – What will be the expected impacts of the likely expansion of mobility in Sao Paulo municipality, in terms of CO_2 emissions and energy consumption and how effective are current public policies in place to promote such expansion?

Prospective analysis (GODET, 1993) was used to construct scenarios that may influence the decisions regarding the expansion of EV in Brazil. Scenarios were built to tackle the uncertainty behind technical and optional aspects involving uncertain and complex scenarios for the mass diffusion of electric mobility in Brazil. Indeed, the expansion of EV depends on the performance of new and different technologies and on how they impact environmental and energy issues. Using prospective analysis allowed identifying what would likely be the best technology for light duty vehicles (LDV) in Sao Paulo.

Regarding the environmental issues involving the CO_2 emissions of the LVD, as well as the energy issues aiming to understand the impacts on the generation of energy for diffusion of EV, a modeling system was used with elaboration of future scenarios capable of pointing out the environmental and energy impacts with EV mass-market.

The research focused on two major aspects. Firstly, the goal was to assess the energy and environmental impacts caused by scenarios of EV adoption instead of gasoline or ethanol. The replacement of fossil fuel and ethanol-powered passenger cars by EV was assessed. Regarding energy consumption, the study aimed to identify and quantify the increase in the electricity demand, as well as the saving of fossil fuels through a balance of energy consumption. The environmental issue focused on the elaboration of the CO_2 emissions inventory (it was contemplated by the indirect emission from the increase of the electricity demand to attend EV penetration). In summary, the study aimed to identify the impacts of EV expansion considering the CO_2 emissions and the energy aspects.

Secondly, the research aimed to identify if the diffusion of EV is suitable when compared with ethanol, since Brazil is the world's leading producer of sugarcane ethanol (Filoso 2015) and has a broad ethanol support program. Ethanol is considered a fuel with less GHG emissions, when compared with fossil fuels (Florez 2015). In addition, Brazil is a major oil producer with vast oil reserves and incentive programs for its extraction. Therefore, the research aimed to identify, from the environmental and energy perspective, which technology can provide better benefits: EV, fossil fuel or ethanol cars. The following methods, techniques and tools were used.

i) The Top-Down and Bottom-up methods were used (in two different analyses) to organize information and process ordered data to meet a particular demand. The two methods usually required processing tools for their implementation and are widely used in various fields of knowledge, especially in the transport sector to determine fuel consumption and GHG emissions (Peng et al. 2015; Chavez-Baeza & Sheinbaum-Pardo 2014; Hong et al. 2016; Ruzzenenti & Basosi 2009).

The essence of the Top-Down method is to fragment processes, always from the largest to the smallest (or the upper-level to to the lower-level) of the studied subject. Through this method one can obtain a broad understanding of the studied subject. In the case of transport – the object of the study – the method was adopted to estimate emissions of pollutants from fuel consumption by road transport in the demarcated geographical area. (Peng et al. 2015; Chavez-Baeza & Sheinbaum-Pardo 2014; Hong et al. 2016; Ruzzenenti & Basosi 2009). The method uses fuel emission factors (not the vehicle).

The Bottom-up approach basically consists of performing information analysis that uses the understanding of fractional parts of the studied objects, aiming at obtaining a detailed perception of the parts that form the whole, that is, it analyzes and describes the most basic elements to form a result of the greater part. In the case of transport, the method was used to determine the emission of pollutants from the fleet, the distance traveled and the emission factors of the vehicles.

ii) Well-to-Wheel (WTW) and Tank-to-Wheels (TTW) are used to evaluate energy efficiency and GHG emissions. The well-to-wheel analysis is commonly used to assess total energy consumption, or the energy conversion efficiency and emissions of motor vehicles, including their carbon footprint, and the fuels used in each of these transport modes. The WTW analysis "refers to specific lifecycle analysis applied to transportation fuels and their use in vehicles. The WTW stage includes resource extraction, fuel production, delivery of the fuel to vehicle, and end use of fuel in vehicle operations. Although feedstock for alternative fuels do not necessarily come from a well, the WTW terminology is adopted for transportation fuel analysis" (Verbruggen et al. 2011).

TTW is used to determine the efficiency of the vehicle based on fuel consumption. The TTW analysis considers the manufacturer's information about fuel consumption and emissions coefficients. Although widely used the techniques present approximate results, as there are several aspects that are difficult to be measure; i.e. conditions of use of the vehicle, driving style, conditions of maintenance of the vehicle. The WTW techniques differ from the LCA method because they do not consider energy and emissions involved in building facilities and the vehicles, or end of life aspects.

iii) In order to identify the most appropriate technology, indicators and coefficients from the life cycle assessment (LCA) method, available in the literature and adopted by the Brazilian government were used. The LCA method is widely used in transport (Nealer et al. 2015) to identify benefits for EV compared to ICEV (Ellingsen et al. 2016); to identify how clean they are EV (Hooftman et al. 2016) compared to the measure GHG emissions from fossil fuel vehicles (Anair & Mahmassani 2012; Van Mierlo et al. 2017); to EV charged using coal-based electricity (Ellingsen et al. 2016); to the analysis of ethanol and hydrous ethanol emissions (Florez 2015; Ometto et al. 2009) or to clarify the differences presented in several LCA studies (Nordelöf et al. 2014). For the Brazilian case, the method was adopted to compare the environmental impacts between cars using ethanol and EV.

iv) Secondary data methodology analysis (SDMA) is all the data collected and made available by the respective sources, including census data, data collected from reports or government databases, organizational records. Secondary data analysis is well-known and a well-established methodology for re-using quantitative data in social research (Dale et al. 1988; Hakim 1982). The recourse to secondary data was essential for this research, as it is the natural way to properly capture past changes and / or developments. Among the main advantages of using secondary data are (Heaton 2008).

i. It makes the study possible (it is often not possible to complete a study without recourse to secondary data),

ii. It is faster to get than primary data,

iii. It is more affordable to obtain,

iv. It specifies the primary data (with the help of secondary data, we can identify gaps and deficiencies and what additional information needs to be collected).

Among the disadvantages are cited bellow.

i. It is not always available in the desired format,

ii. It has limitation of access to clarify divergences

The analysis of secondary data was adequate to compare CO_2 emissions and public policies adopted by the largest Brazilian city and the city of Shanghai in China in relation to the first decade of 2000 (Costa et al. 2018). Both these Brazilian and Chinese cities seek to reduce emissions from road transport and are the gateways to new technologies in their respective countries. The method of analysis of secondary data allowed the evaluation of the emissions and public policies adopted by two cities.

v) Long-range Energy Alternatives Planning (LEAP) is an integrated modeling tool used to track energy consumption, production and resource extraction in various sectors of the economy. LEAP is able to evaluate GHG emissions from the production chain involving the extraction of raw material, processing, distribution and combustion, which can provide a more efficient use of energy. In addition, LEAP can be used to assess emissions of local and regional air pollutants and short-lived climate pollutants (SLCPs), which makes it suitable for studies to assess the climate benefits derived from the reduction of local air pollution.

LEAP is a widely-used software tool for energy policy analysis and climate change mitigation assessment (SEI 2018). Developed by the Stockholm Environment Institute, LEAP is generally used to analyze national energy systems. Around 190 countries – including government agencies, academics, NGOs, consulting firms and energy companies – use the LEAP modeling tool (SEI 2018).

LEAP has become an interesting option for the Brazilian study because it is an adequate tool to evaluate applications in energy (Gajjar, H. & Mondol 2016; Gil. 2011), environment (HAO 2015), and in the transport sector (MVX 2014). For the present study, LEAP was used to simulate scenarios of energy consumption and CO_2 emissions from urban road transport.

Phase "B" – Charging infrastructure

This phase was carried out to answer question RQ#3 – How to overcome the barriers regarding the deployment of the charging infrastructure at the municipality level, in the case of Sao Paulo, Rio de Janeiro and Belo Horizonte? A set of case studies and spatial analysis were performed. As the investigation required the application of in-depth qualitative and quantitative methods involving groups of specialists in electrical mobility and consequent analysis and evaluation of the information collected, the case study was timely. The case study proved to be a valuable resource in view of the need to reveal the complexity of the optimized construction of a charging network for EV in three large Brazilian municipalities.

The spatial analysis became an essential resource since the studies required the characterization and modeling of random variables in special structure format from the samples and demanding interpretation of the special correlation of the samples as well as their quantification of the spatial variability. In this context, using complementary technical tools such as Geographic Information

Systems (GIS) and Analytical Hierarchy Process (AHP), it was possible to determine the best location within the delimited areas for the different levels of EV charging equipment, thus indicating the opportunities and the critical factors for the creation of a network of EVSE in three large Brazilian municipalities. This phase also included a modeling and prospective analysis system, as shown in Figure 1.7.

In order to evaluate the infrastructure to support the diffusion of EV in the studied region, three case studies were assessed. One specific study for the municipality of Sao Paulo was based on geographic data of 96 districts, and two complementary case studies: one for the municipality of Rio de Janeiro carried out based on 33 districts, and a second for the municipality of Belo Horizonte considering 487 neighborhoods (one preliminary study was carried out to consider nine administrative regions).

The accomplishment of the two complementary case studies' analysis was important to evaluate possible similarities and differences in the ideal location of an EVSE network, since they are the three largest municipalities (in GDP, fleet of vehicles and population) of the Brazilian Southeast. These are responsible for more than 50 percent of the Brazilian GDP (IBGE 2015) and can be considered as leading markets for penetration of new technologies in Brazil. The analysis of the three Brazilian large municipalities may give policymakers and stakeholders feasible information for future projects and investments in the diffusion of electric mobility in Brazil. The development for the analysis was supported in the following methodologies, technique and tools of modeling.

i) Multi-criteria Decision Making (MCDM) is a method used to explicitly evaluate several conflicting criteria in decision making; i.e. in a car purchase process cost, comfort, safety, and fuel economy may be some of the main criteria to be considered. The method aims to reduce the risks in decision making of complex issues involving multiple criteria. Attempts to find the best trade-off decisions have been around for a long time. The first attempts to create a method to deal with the trade-off in important decisions came with Benjamin Franklin (Köksalan et al. 2011) who addressed the issue of multiple objective mathematical programming.

However, MCDM emerged as a method in the 1950s with the publication of "The Theory of Decision Making" by Ward Edward and the book "The Behavior Model of Rational Choice" published in 1955 by Herbert A. Simon. From the 1970s the MCDM method became popular with Simon (won the Nobel Prize in Economics in 1978) and he published a series of studies on MCDM (Köksalan et al. 2011).

The MCDM method provides the consistent analysis of distinct qualitative and quantitative variables giving more consistency to the choice process, thus becoming widely used in various disciplines such as the environment, energy (Kylili et al. 2016) and transport (Costa et al. 2017; Costa et al. 2018). The MCDM method becomes even more important in incipient issues and as with little information available, such as the infrastructure for EV, thus requiring maximum assertiveness (Coelho et al. 2012). The method relies on a wide variety of software to support its implementation, such as the

Geographic Information System GIS, which was adapted to the development of the Brazilians' case studies.

ii) Weighted Linear Combination (WLC) is an analytical technique commonly used to assist in decision-making involving multi-attribute problem processes in which more than one attribute should be evaluated. After attributes are treated according to their importance (through weight assignment) the results are generated with spatial characteristics. The results obtained after generation of the respective weights (AHP for the Brazilian study) will be used for the WLC processing in the modulation tool (GIS for the Brazilian study). The WLC technique applied in the GIS tool must follow the following steps: 1) definition of the attributes; 2) identification of possible alternatives; 3) alignment of the maps considering the attributes; 4) definition of criteria (attribute importance); 5) perform the processing according to the scoring of each cell; and 6) order according to the total score of each attribute (Malczewski 2000).

The WLC approach is widely used in decision rules in the GIS environment (Hopkins 1977, Tomlin 1990, Eastman et al. 1993). One of its most common applications is land use analysis, site adequacy and selection, as well as resource assessment problems (Hobbs 1980; Han 1988), geographic analysis and land use (Duc 2006; Aruldoss et al. 2013) and transport and infrastructure (Abbasi & Seyedhoseini 2011; Terh & Cao 2018). The WLC technique (adopted in the Brazilian study) was implemented in the GIS environment (ArcGIS for Desktop 10.3 software) with the support of map reclassification and algebra tools (AHP provided attribute weights). The weighted linear combination allowed for the performance of the processing considering the weights assigned in relation to the selected variables and in a geo-referenced form.

iii) Analytical Hierarchy Process (AHP) is a technique that involves organizing data in a structured way to provide analysis clarity for complex and group decision-making. The AHP technique is based on mathematical and psychological foundations (Saaty 2008). The AHP technique selected criteria or alternatives respecting a certain criterion, in a natural, pairwise mode. AHP uses a range of absolute numbers to capture individual preferences over attributes that can be quantitative and qualitative to facilitate the solution of complex problems (Forman & Gass 2001).

In summary, the AHP converts the individual preferences into weights of reason scale and can be used to compare and classify the alternatives, thus facilitating the process of choice. The AHP consists of three basic functions: structuring complexity, measuring a ratio scale, and synthesizing. If processed in a structured way it is able to help simple people make complex decisions (Forman & Gass 2001). The AHP technique assigns attributes to attribute weights taking into account three basic steps (Lin et al. 2014): creating a hierarchical structure of factors influence; structuring a judgment matrix consisting of the application of comparative notes between attributes (from 1 to 9); and creating uniformity of the matrix.

As a multi-objective decision-making technique for complex subjects, AHP can combine quantitative analysis and qualitative analysis with the attribution of weights to attributes. Attributes are compared on a peer-by-peer basis, ranked according to the example of Saaty (1990). The AHP technique was developed by Thomas L. Saaty who worked since the 1970s to find a way to facilitate decisions involving complex problems, but it was in the 1990s when Saaty lectured at Wharton School that he found the form he considered ideal giving it the name Analytical Hierarchy Process (Forman & Gass 2001). The AHP technique is widely used by various organizations such as universities, companies and governments. In the Brazilian study the AHP was adopted combined with the MCDM methodology to facilitate the decision process about the choice of the best location for the implementation of an EVSE network (Costa et al. 2018).

iv) The Geographic Information System (GIS) is a software tool developed to treat spatial information with the goal of collecting, storing, retrieving, manipulating, visualizing and analyzing spatially referenced data in a known coordinate system in order to facilitate the generation of geographic information (maps) and facilitate the process of analysis, management or representation of space and the phenomena that occur in it (Clarke 1986; Maliene et al. 2011). The emergence of the GIS system began in the 1960s with the contribution of English geographer Roger F. Tomlinson[3] considered the first to use computerized mapping in studies conducted in Canada. Later the system became known as ARDA Data Coordinate System, assuming a few years later the current name Geographic Information System (GIS). For his contributions, Tomlinson is considered the "father of GIS" and received several awards (Rura et al. 2014).

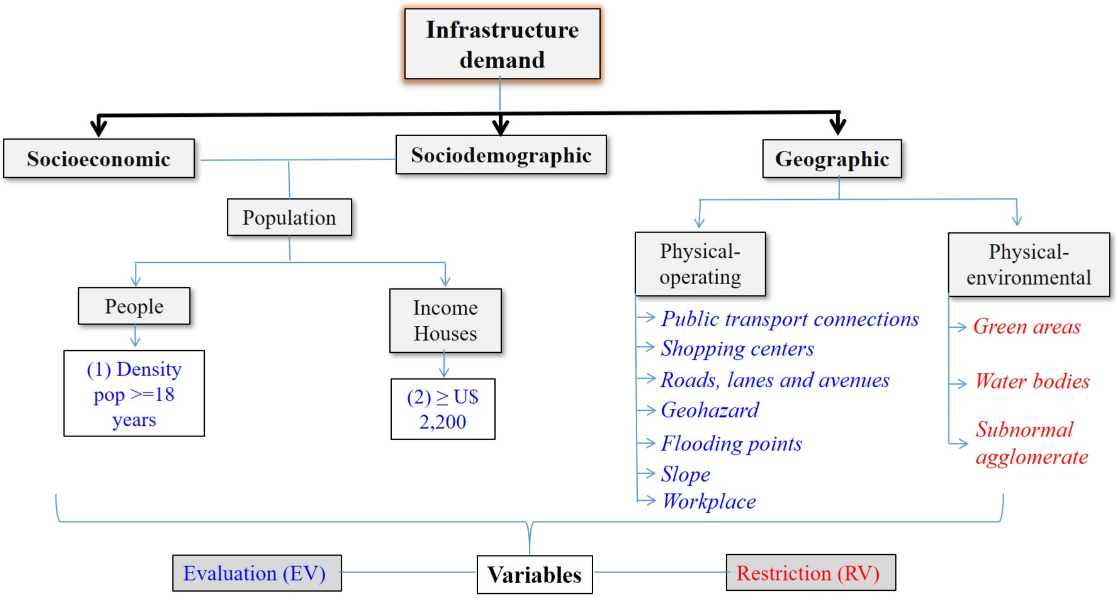

Figure 1.7 – Structure of data processing for Brazilian case studies

In the 1970s, the first vector GIS called ODYSSEY GIS, developed by Harvard Laboratory Computer Graphics, emerged. In the 1980s, several software companies provided several enhancements to the GIS system. Esri, one of the companies that contributed to the enhancement of GIS, has become

[3] There is record stating that the history of GIS all started in 1854 with the British physician John Snow began mapping roads, property boundaries and water lines.

the world's leading GIS software company. GIS can aggregate different processes, techniques, and methods that enable the integration with other technologies. GIS provides various applications and is used in many areas such as engineering, planning, management, transportation, logistics, insurance, telecommunications, marketing, business. (Maliene et al. 2011).

For the studies conducted in Brazil the GIS processed information that was structured according to the data shown in Figure 1.7. GIS was adopted to support the Brazilian study because it is a tool widely used to accurately identify the desired spatial location and is used in several other similar studies (Church 2002; Hakimi 1964), including in Brazil where GIS is widely used for studies in various segments such as energy (Tíba et al. 2010), and transport (Lopes et al. 2014). For the present research, the GIS was used to identify the best location for EV charging infrastructure (Costa et al. 2018; Costa et al. 2017).

Phase "C": Challenges and opportunities from massive adoption of electric vehicles

This phase was carried out to answer question RQ#4 – What are the main perceived challenges and opportunities from the mass penetration of electric mobility in Brazil? The research with the stakeholders of electric mobility in Brazil was the most efficient since it was necessary to identify new knowledge from the accumulation of information obtained from Brazilian electric mobility stakeholders and specialists. With the research, it was possible to gather data from multiple sectors and people with different specialties and characteristics, providing - with the use of consistent techniques and methods - new knowledge capable of identifying opportunities and challenges for the future of electric mobility in Brazil. To valuate socio-technical issues, innovation-environmental and political-economic factors to adequately assess the challenges and opportunities of EV diffusion for the Brazilian case the following method, the following technique and tools were adopted.

i) SWOT analysis considers strengths to be tangible and intangible positive attributes capable of supporting business success. It is a strategic planning method used to evaluate the strengths (characteristics of the business or project that gives it an advantage over others), weaknesses (characteristics that place a business or a project at a disadvantage relative to others), opportunities (external factors capable of benefiting the evolution of the institution and threats are considered externalities capable of hindering the achievement of the desired results), and threats (elements in the environment that could cause trouble for the business or project) in the business area or adapted for other areas (Dyson 2004). The SWOT method also examines the object of study considering the possibilities of growth, development, survival and maintenance.

The invention of the SWOT method is attributed to prof. Albert S. Humphrey, who led a research project at the Stanford Research Institute (now SRI International) in the 1960s and 1970s (Arslan & Er 2008) that was adopted at other universities, such as the Harvard Business School to analyze the business environment and business policies (Markovska et al. 2009; Hill & Westbrook 1997). The SWOT method examines the object of study considering the internal factors (strengths and weaknesses) of the organization and the external environment in which the institution is inserted (external factors: the opportunities and threats presented by the environment external to the organization). The analysis of the internal factors (frank and strong points) must take into account not only the current situation under analysis, but also the objectives of the institution under study. The external factors can be macroeconomic, technological changes, legislation and socio-cultural events, as well as the foreseeable changes in the market and the factors of competitiveness (Dyson 2004).

SWOT analysis has expanded into many areas beyond the business sector. For example, the transport sector often uses the SWOT matrix to evaluate mobility projects (Gil et al. 2011; Barrella et al. 2013), thus revealing that it is appropriate to examine the object of study, from the Brazilian automotive industry perspective.

ii) Statistical Package for the Social Sciences (SPSS) is the original name of the software (currently IBM SPSS Statistics) created in 1968 to meet the need for statistical analysis of the social sciences. The invention is attributed to Norman H. Nie, C. Hadlai and Dale H. Bent. Initially, between 1969 and 1975, SPSS was represented by the National Opinion Research Center of the University of Chicago, USA (Nie et al. 1975). Before 1983, the program aimed at large computers, popularized among institutions of higher education, especially in the USA. In 1984 a version was released for personal computers. Regarding the Brazilian study case, the SPSS was adopted to perform cross-analysis among the different groups represented in the survey.

iii) "Encuestafacil" is an online tool that works through the internet to conduct a survey. The tool is widely used in Europe and Latin America. The "Encuestafacil is a relatively simple and fast software that allows customization and permits the export of data to other tools. The flexibility of the "Encuestafacil” survey – e.g. allowing the respondent to save the information from the survey and continue filling it on another occasion – as well as the clarity of the reports – e.g. information such as open, partially answered or fully answered questionnaires are reported online – simplify the follow-up, the interaction with respondents, and provide speed and improvement in the response rate.

The "Encuestafacil" tool also allows the execution of pre-tests, which helps in improving the questionnaire and consequently optimizing the results. The fact that the tool is in widespread use in Brazil advantaged the interaction with the respondents and contributed to a rapid return of the answers. The biggest obstacle was preventing quiz submissions from being blocked by guests' firewalls. In this study the SWOT analysis was used to analyze the critical factors to the opportunities for the expansion of EV in Brazil. The SPSS tool was used for the elaboration of cross-analyses and the Encuestafacil software for sending and managing of questionnaires and research

1.4 Case studies

Brazil is a big country with many differences across the regions. For this work, different case studies were adopted as a strategy to deal with a coherent and structured transport system, conditioned by specific physical characteristics of each case.

a) for the environmental purpose, the case studies of Sao Paulo municipality were adopted;
b) for EV charging infrastructure assessment (obstacle to expansion of EV), three municipalities (Sao Paulo, Rio de Janeiro and Belo Horizonte) were analyzed;
c) for identification of the strengths, weaknesses, opportunities and threats for the expansion of EV, the whole country was considered.

The main purpose of working with the municipality of Sao Paulo is the fact that it is the largest municipality in Brazil. The State of Sao Paulo holds more than 32 percent of the Brazilian GDP and it is larger than the sum of the GDP of the North, South and Central-West Brazilian regions (IBGE 2017). The inclusion of the municipalities of Rio de Janeiro and Belo Horizonte is justified because they are the second and third largest municipalities in the Southeast region of Brazil. The three municipalities maintain most Brazilian projects in electric mobility and is the location of the major automakers in the country. Hardly a major segment as the electric mobility industry in the country can be developed without the involvement of these three municipalities.

Regarding the choice of the country case study, it is justified by the need for a nationwide promotion of electric mobility and not just isolated initiatives in some regions of the country. In this context, the understanding of how the country's leaders evaluate the large-scale expansion of EV was required. Brazil is among the ten largest automotive markets in the world and is one of the largest economies among developing countries. Other developing economies, such as China and India, have already announced support for massive expansion of electric mobility, and Brazil may follow the same path, since it needs to mitigate transport emission, has a predominant sustainable electricity mix and the country cannot distance itself technologically from the remaining developing world, especially for being among the largest players in the automotive industry.

1.5 Scientific outputs

The research developed produced conference and journal papers, some of which are included as part of this document, as listed below.
Publications.

(i) Costa, E. and J. Seixas (2014). "Contribution of electric cars to the mitigation of CO_2 emissions in the city of Sao Paulo" in Proceedings of the International Vehicle Power and Propulsion Conference (VPPC-IEEE), October 27-30, 2014 – Coimbra, Portugal, DOI: 10.1109/VPPC.2014.7007035.

(ii) Costa, E., J. Seixas, G. Costa and T. Turrentine (2017). "Interplay between ethanol and electric vehicles as low carbon mobility options for passengers in the municipality of Sao Paulo", Journal International Journal of Sustainable Transportation, 11 (7) 518-525. DOI: 10.1080/15568318.2016.1276651.

(iii) Costa, E., J. Seixas, P. Baptista, Costa, G, T. Turrentine (2018). "CO_2 emissions and mitigation policies for urban road transportation: Sao Paulo *versus* Shanghai", Revista Brasileira de Gestão Urbana (URBE), 10: 143-158, DOI: 10.1590/2175-3369.010.supl1.ao15.

(iv) Costa, E., A. Paiva, J. Seixas, G. Costa, P. Baptista, and B. Ó. Gallachóir (2018). "Spatial Planning of Electric Vehicle Infrastructure for Belo Horizonte, Brazil", Journal of Advanced Transportation, 2018, DOI: 10.1155/2018/8923245.

(v) Costa, E, Paiva, A, Seixas, J, Baptista, P, Costa G, and Gallachóir, B (2017). "Suitable Locations for Electric Vehicles Charging Infrastructure in Rio De Janeiro, Brazil", in Proceedings of the International Vehicle Power and Propulsion Conference (VPPC-IEEE), 11-14, December 2017 – Belfort, France, DOI: 10.1109/VPPC.2017.8330964.

(vi) Costa, E, Horta, A, Correia, A, Seixas, J, Costa, G, Sperling, D, and Gallachóir, B (2018). "Challenges and opportunities of electric mobility in Brazil from stakeholders' perceptions", *submitted* to The International Journal of Sustainable Transportation in April 2019.

(vii) Costa, E, Coosemans, T, Seixas, J, Messagie, M, Costa, G, and Vanhaverbeke, L (2019). "Optimizing the location of charging infrastructure for future expansion of electric vehicle in Sao Paulo", *submitted* to The Journal of Transport Literature in April, 2019.

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(i) Costa, E, Paiva, A, Seixas, J, Baptista, P, Costa, G (2017). "The best locations for charging infrastructure of electric vehicles in Belo Horizonte, Brazil", presented on Irish Transport Research Network (ITRN, 2017). Dublin, Ireland, 28-29 August 2017.

1.6 Outline of thesis

This thesis is organized in five chapters. Chapter 2 is dedicated to the state of the art in electric mobility, revealing the current stage of electric vehicles, barriers to mass expansion, public policies to support the electric mobility evolution as well as opportunities to mitigate CO_2 emissions with mass adoption of EV. A timeline is included with the main events involving the electric mobility from its emergence to the present day as well as the evolution of EVs, critical success factors, opportunities, benefits, policies, EV in circular economy context, and a new business model for electric mobility. Chapter 3 analyzes the case of Sao Paulo, with a particular focus on how different methodologies support the studies to assess EV as a low carbon mobility option. Chapter 4 is dedicated to assessing electric vehicles' charging infrastructure, namely regarding the best location of charging stations in Rio de Janeiro, Belo Horizonte and Sao Paulo. Chapter 5 reveals learning from Brazilian stakeholders to identify the challenges and opportunities for mass penetration of EV in Brazil. Chapter 6 presents a general discussion, conclusions, and further suggestions for future research.

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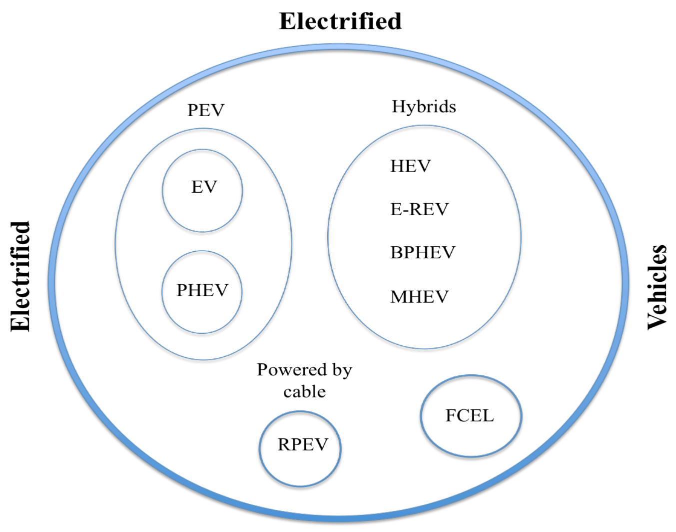
CHAPTER 2 | ELECTRIC MOBILITY: BARRIERS AND CHALLENGES FOR MASSIVE EXPANSION

The transport system has always evolved according to human development. The transportation of passengers is more complex since it involves socio-techno-economic factors such as the expectations of the consumer to commute in the desired time, safely, comfortably, and with the lowest possible cost. The first seeds of electric mobility sprouted in the early XIX century as a process of evolution of the mobility of people. Attempts to expand electric mobility have proved feasible, but with almost insignificant market penetration, and are still limited to road transport. Increasing human population, technological development as well as current and impending global socio-economic and environmental megatrends are strongly influencing the mobility and transport solution, where electrified vehicles will play a key role (Coosemans et al. 2016).

Along with the development of electric mobility different understandings about what characterizes the electric vehicle (EV) have emerged. There is diversification in the models of electrified vehicles, which could generate doubt or disagreement. The main types of passenger vehicles with their definitions are described below (and in Table 2.1). Electric vehicle (EV) is a term that is used inconsistently. Some refer to EV as fully electric synonymous with battery electric vehicle (BEV), while others use EV to refer to plug-in electric vehicle (PEV) or fuel cell electric vehicle (FCEV). For this thesis the EV refers to a model, which uses electricity exclusively to propel the vehicle, and recharges by a plug that transfers electricity from an electric system to the vehicle where it stores it in batteries. It is synonymous with BEV (CMU 2018; IEA 2014).

Electrified vehicle (Figure 2.1) is one in which the electricity needs to power more than basic accessories (such as power windows) for a drivetrain to be considered electrified. "Electrified vehicle covers all vehicles that use electric power at varying stages," such as electric assistance (eAssist), hybrid, plug-in hybrid, and extended-range electric vehicles. The most basic form of electrification is the mild hybrid vehicle, which uses a compact electric motor to complement the fossil fuels engine (IEA 2014; CMU 2018). The most common types of electrified vehicles are described in Table 2.1.



Source: adapted by FGV (2018)

Figure 2.1 – Electrified vehicles scheme

Table 2.1: Vehicle definitions model and engine type

1/2

Abb	Name	Description	ICE	EV
BPHEV	Blended PHEV	“Use a mix of gasoline and electricity when the battery is charged and then switch entirely to gasoline when the battery is depleted. An advantage to the blended operation is that because the electrical system does not need to satisfy peak power demands on its own, it can be smaller” (IEA 2015)	✔	✔
EREV REEV BEVx	Extended-range electric vehicle Range Extended Electric Vehicle Range-extended battery-electric vehicle	A range extender vehicle is a battery electric vehicle that includes an auxiliary power unit (APU) known as a 'range extender' Driving with an e-motor only. The ICE & plug-in (or fuel cell) used to charge battery	✔	✔
EV / BEV	Electric Vehicle	Driving by one or more e-motor, and storing energy in a battery. EV receives electricity by plugging into the electric system and storing it in batteries. EV can consume no petroleum-based fuel and produce no tailpipe emissions. The term battery electric vehicle (BEV) is considered to be a synonymous term		✔
FCEV / FCV	Fuel Cell Electric Vehicle	Driving with an e-motor only and storing energy in hydrogen. “A fuel cell (electric) vehicle (FCV or FCEV) is a vehicle with an electric powertrain that uses the fuel cell as a source of the electricity to provide electric drive. FCVs may also include an electric storage system (ESS) and be HEVs or PHEVs, although an ESS is not technically necessary in an FCV” (IEA 2015)		
HEV	Hybrid Electric Vehicle	Driving with combustion engine and / or e-motor. “A hybrid vehicle is one with at least two different energy converters and two different energy storage systems (on vehicle) for the purpose of vehicle propulsion. A hybrid electric vehicle (HEV) is a hybrid vehicle in which at least one of the energy stores, sources, or converters delivers electric energy” (IEA 2015)	✔	

Abb	Name	Description	ICE	EV
ICE	Internal Combustion Engine vehicle	Driving with conventional combustion engine only	✔	
PEV	Plug-in Electric Vehicle	Driving with a combustion engine and / or e-motor, plug-in to charge battery. “A plug-in electric vehicle (PEV) is a vehicle that draws electricity from a battery and is capable of being charged from an external source. In this way, the PEV category includes both EV and PHEV” (IEA 2015)	✔	✔
PHEV	Plug-in hybrid Electric Vehicle	Driving with a combustion engine and / or e-motor, plug-in to charge the battery. “A plug-in hybrid electric vehicle (PHEV) is an HEV with a battery pack that has a relatively large number of kilowatt-hours of storage capability. The battery is charged by plugging a vehicle cable into the electricity grid; thus, more than two fuels can be used to provide the energy propulsion” (IEA 2015)	✔	✔
MHEV	Mild Hybrid Electric Vehicle	MHEV describes “an electric motor is not the sole source of driving power, but provides supplementary torque to the internal combustion engine when peak power is needed. Like a micro-hybrid, the system also features start/stop technology and regenerative breaking” (IEA 2015)	✔	✔
RPEV	Road Powered Electric Vehicle	All those who receive electricity through external cables. They work only when connected to the electricity grid by cable		✔
MHV	Micro Hybrid vehicle	Micro Hybrid vehicle “the technology has a starter-generator system coupled to a conventional engine. An electric motor provides stop- start operation of the engine, plus (usually) regenerative braking to charge the battery. The electric motor does not supply additional torque when the engine is running” (IEA 2015)		✔

EV uses a large battery The PHEV uses a medium-sized battery, and the HEV uses a small battery.

2.1 Evolution of electric vehicles

The literature classifies the EV evolution in multiple perspectives. Some authors consider this by using a timeline division of 50 years, others by technology evolution or major historic factors. I choose remarkable phases to classify EV evolution, as shown in Table 2.2.

Table 2.2: EV evolution by remarkable phases

1801-1896 | 1^{st} phase	1897-1965 | 2^{nd} phase	1966-2000 | 3^{rd} phase	2001 - Present | 4^{th} phase
Almost 100 years	Almost 70 years	34 years	18 years
From the invention of the battery to the production of the first EV	*From large-scale production to near extinction of EV*	*Renewed interest in EV*	*Renewed growth of EV mass production*

The first observation of the EV timeline is that each phase significantly reduces the duration time compared to the previous phase, due to the natural advances of knowledge, especially in the area of science, with inventors, scientists and engineers contributing to the development of the electrification of transport. In the first phase of EV evolution, from 1801 to 1896, the evolution occurred mainly due to the advances in the development of technologies that later led to the discovery of the battery.

1801-1896 | First phase

1820 The first device that transformed electrical energy into mechanical energy was invented (Britannica 2018c)

1828 The first electromotor was built by Ányos István Jedlik from two magnet coils (Kokowski 2006)

1832 A crude electric-powered carriage by non-rechargeable primary cells was built (Guarnieri 2012)

1834 The first direct current electrical motor was created (Center 2014)

1859 The first electric storage battery widely used in the automotive sector was produced (Britannica 2018a)

1880 A satisfactory material for filament vacuum tube lights that improved commercial generation and distribution of electricity was made (Britannica 2018d)

1888 The invention of the AC motor by Nikola Tesla was patented (History 2018)

1890 The first four-wheel electric road vehicle in the USA was built (Britannica 2018b; JournalHistory 1995)

1896 An electric version of a cab for major American cities was built (Mom 2013)

Figure 2.2 – The remarkable facts on electric vehicles evolution from 1801 to 1896

The EV presence started in the second decade of the 19th century with the invention of the first electromotor from two magnet coils Ányos István Jedlick[4] and an electric device by Michael Faraday that transformed electrical energy into mechanical energy (Britannica 2018c; Kokowski 2006). The

[4] There are publications (Britannica 2018c; Kokowski 2006) claiming that Jedlik only reported his invention decades later and the true date of it is uncertain.

evolution of battery research allowed the electrification of the first vehicle (a carriage) in the 19th century. The early EV evolution phase was the design of the first EV cab. This was realized in 1896 by Henry G. Morris and Pedro G. Salom as a result of the evolution of the USA popular horse drawn Hansom cabs (Mom 2013; New World Encyclopedia 2018). The remarkable facts of this phase are shown in Figure 2.2.

The second phase started in 1897 and was characterized by the large-scale electric automobile production by Pope Manufacturing Company. They produced a line of electric cabs for use in New York City, USA and a few years later in London, United Kingdom. The first cab could run at a speed of about 15 kilometers per hour for 30-50 kilometers on one charge. Other industries such as the production of batteries and electric bicycles began to emerge in the USA and Europe to support the growth of electric mobility (David Corrigan 2018). The following years experienced fast-growing sales and EV were responsible for around one third of the market share in the USA (Guarnieri 2012).

The success of the EV began to be negatively affected with the emergence of the Internal Combustion Engine Vehicle (ICEV) and the increased use of petrol as a fuel for road transport. The launch of the Model T by Henry Ford in 1908, inaugurated the assembly-line production process and reduced the price of ICE cars, and as a result they were a market success. The ICE cars had a greater range, were faster, had less refueling time, were easier to maintain and cheaper when compared to EV. The ICEV Model T attracted the interest of the consumer. With the sales growing quickly, the Golden Age of the gasoline cars started (Bak 2003), and the EV quickly disappeared from the market. The remarkable facts of this period are shown in Figure 2.3.

1897-1965 | Second phase

- **1897** The first large scale electric automobile was manufactured by the Pope Manufacturing Company (Handy 2018)
- **1900** 38 percent of all automobiles produced in the United States of America were electric (Handy 2018)
- **1908** The internal combustion engine (ICE) Ford Model T was introduced (Handy 2018)
- **1920** There was no EV in mass production (Center 2014)
- **1935** The EV was almost obsolete due to the popularity of ICEV (Center 2014)

Figure 2.3 – The remarkable facts of electric vehicle evolution from 1897 to 1965

The third phase, from 1966 to 2000, was characterized by renewed interest in EV (Figure 2.4). The renewed interest in the EV was basically influenced by two components: the concern with the environment (reduction of GHG emissions from vehicles using fossil fuels), and energy security due to the oil crisis of the 1970s and 1980s that substantially raised the price of a barrel of oil (Energy Information 2007). These two facts contributed to the introduction of the first bill by Europe and the USA endorsing alternatives to gasoline automobiles in an attempt to reduce air pollution. Many incentives were provided for research programs for the development of alternative vehicles mainly focused on hybrid and battery electric vehicle (EV).

The first hybrid car was developed for testing in 1982, and in 1995 Toyota debuted the Hybrid Electric Vehicle (HEV) concept car at the Tokyo Motor Show. It can be said that in relation to the EV the remarkable fact in this period was the launch by General Motors (GM) of the EV1 electric car project. To comply with the Zero Emissions Vehicle[5] (ZEV) mandate, in 1996, GM started the production of a car, called the EV1. Based on GM's EV1 program, some manufacturers announced investments in EV, with some EV models being released such as Honda's EV Plus, Ford's Ranger pickup EV, Nissan's Altra EV, Chevy's S-10 EV, and Toyota's RAV4 EV. Most of them were available for lease only. However, GM withdrew EV1 from production at the end of 1999 and the following year all of the major automakers' advanced all-electric production programs were discontinued (Paine & Confidential 2006; Hanssen 2002). The remarkable facts of this period are highlighted in Figure 2.4.

1966-2000 | Third phase

- **1966** The United States Congress introduced the first bill endorsing alternatives to gasoline cars to reduce air pollution (Gubrud 1975)
- **1973** The oil crisis; Organization of the Petroleum Exporting Countries (OPEC) has led to high oil prices led to renewed interest in EV (Energy Information 2007)
- **1976** The French government launched the "PREDIT" program to foster the acceleration the Research, Development and Demonstration (RD&D) of EV (Anderson & Anderson 2010)
- **1982** The first modern hybrid car was presented (Yak Max 2018)
- **1995** Toyota debuted the hybrid electric vehicle (Toyota 2008)
- **1996** General Motors began producing electric car EV1 (Hanssen 2002)
- **1997** The first hybrid Toyota Prius went on sale in the Japanese market (Yak Max 2018)
- **2000** Hybrid cars are a “success case” (Yak Max 2018)

Figure 2.4 – The remarkable facts related to electric vehicle evolution from 1966 to 2000

The fourth phase, from 2011 until now, can be characterized by the third attempt of EV to become mainstream technology. The main aspects in this new phase are: a) environmental – issues such as climate change, low air quality of urban centers, and the quest for the circular economy being highlighted (Dijk et al. 2013; Radkau 2014); b) the energy transition – focus on increasing the share of renewable energy aimed at reducing energy dependence on fossil fuel (Geels et al. 2017; Schwedes et al. 2013); c) technological diffusion – focus on the diversification of energy sources as well as their applications (Steinhilber 2013). The remarkable facts of this period are shown in Figure 2.5.

5 ZEV is a vehicle that emits no exhaust pipe gases.

2001 - Present | Fourth phase

2003 Tesla Motors (USA) and BYD (China) started EV operation (Tesla Motors 2018; BYD 2018)

2008 Oil prices reached more than USD 145 per barrel. The gas prices reached record highs of more than $4 per gallon in USA (Trigg et al. 2013)

2008 Tesla Motors released Tesla Roadster with more than a 300 km range and EV Smart For-two debuted in the USA (Tesla Motors 2018)

2009 Some hybrid cars debuted and UK decided to promote the use of electric cars (Hybrid Cars 2009; Herald 2009)

2010 The EV Nissan LEAF is launched (Trigg et al. 2013)

2011 Autolib: the world's largest electric car-sharing service is launched in Paris, France. The global EV stock reached peak of 50,000 units (Trigg et al. 2013)

2012 The global EV stock exceeded 180,000 units (Trigg et al. 2013)

2013 The global EV stock exceeded 360,000 units (IEA 2018c)

2014 Tesla Motors broke ground on the Gigafactory in Nevada, USA. The global EV stock reached 665,000. Spotlight on China with EV sales: 230 million e-bikes; 83,000 e-cars and 36,500 e-buses (IEA 2015; Tesla Motors 2018)

2015 The global stock of EV reached around 1,450,000 million units and Norway is the first and the only country that EV reached a market share above 20 percent (IEA 2016)

2016 Tesla Motors secured an estimated 500,000 pre-orders for the Model 3. The global electric car stock surpassed 2 million vehicles (Randall 2018; Electec 2016; IEA 2017)

2017 More than a million EV were sold and the stock exceeded three million units. Norway EV market share reached almost 40percent. Electric bus sales were about 100,000 units and sales of two-wheelers were estimated at 30 million (IEA 2018c)

2017 Private chargers at residences and workplaces estimated to number almost 3 million worldwide (IEA 2018)

2018 There were 174 PHEV models worldwide of which 99 were EV, as shown in Appendix A, Table A1 (in 2012, there was only 9 EV) (WattEV2BUY 2018; InsideEVs 2018)

Figure 2.5 – The remarkable facts regarding electric vehicle evolution after 2000

This new phase was unlike previous times when the attempt to produce mass-market EV was motivated primarily by the energy crises that involved oil production causing peak prices such as those that occurred in the second half of the 20th century and at the beginning of the 21st century (Energy Information 2007). In this new phase there are new drivers for mass-market EV such as electric mobility (EM) potential to contribute to climate change goals, to mitigate CO_2 from the transport sector, to improve air quality (specially in urban centers), and to improve efficiency (EV versus ICEV). After all, the size of the road vehicle fleet globally and the anthropogenic emissions derived from transport are much more expansive than in 1897 when automakers first thought of producing large scale EV. In this context, the governments of some countries, especially in Europe, North America and part of Asia, are working to improve alternative transportation such as ZEV to improve air quality (Dijk et al. 2013; IEA 2018c).

In addition, the quest for energy efficiency and to increase the share of renewable energy puts the EM evolution into a different perspective when compared to the other two phases. The concern and attempt to decarbonize the energy sector has received continued global attention (Dijk et al. 2013; IEA 2018c). In Brazil, light-duty electric vehicles (LDEV) did not circulate until early in the 21st century. The diffusion of LDEV in Brazil is still in an early stage. Across the country from 2011 to 2016 around 3,500 LDEV were registered (the majority in research projects). In this same period, more than 15.3 million ICE light-duty vehicles (LDV) were registered (ANFAVEA 2017). The first electric vehicle to be circulated in Brazil was a trolley car owned by Ferro-Carril in Rio de Janeiro. The vehicle entered service on October 8, 1892 (Bazani 2017; Brandão & Martins 2017). The first electric bus was introduced in 1917, also in Rio de Janeiro, and circulated between 1918 and 1928 (Bazani 2017). In 1947, electric trolleybuses began operations on April 22, 1949 by the Municipal Company of Collective Transportation.

The development of the modern electric bus in Brazil took place through Eletra – Traction Technology Electric, which started in 1990 in Sao Bernardo do Campo Sao Paulo. Eletra's electric vehicles serve mostly the population of Sao Paulo, but it supplies its products to other regions of the country and abroad. Eletra offers four products: hybrid buses, trolleybus, pure electric bus and dual bus (possibility to operate more than one technology). Eletra, since its foundation, has marketed more than 400 thousand units of its buses (Eletra 2018).

Despite the initiatives and potential for the development of electric mobility in Brazil, the participation of passengers transported by electric vehicles in the country is almost negligible compared to the national passenger numbers transported by public transportation.

Finally, EV as a disruptive technology (Geels 2002) has gained some increments in mobility due to: a) the increase in battery density, increasing the range of the EV; b) the possibility of using the EV batteries as a back-up for intermittent renewable sources; c) the potential of balancing the electric network with the use of the EV (Vehicle to Grid – V2G[6]), especially for consumption at peak time; d) diversification of production; i.e. Plug-In Electric Vehicle (PHEV) and Fuel Cell Electric Vehicle (FCEV); e) the emergence of fast charging station technology; f) the demand for mobility diversification as Car-as-a-Service (CaaS), and g) the higher efficiency of EV when compared to ICEV.

2.2 Technological disruption

EV is a disruptive technology capable of causing profound transformations in the road transportation passenger system, automotive industry, energy sectors, and society in the future. In relation to private road transportation the disruption includes topics such as cars-as-a-service (CaaS), connectivity, autonomous vehicles, and electrification of cars.

2.2.1 Private road personal transportation technology disruption

The urbanization process has been a dominant global event, due to the large populations worldwide living in cities. In 2018, around 55 percent of the world’s population lived in urban areas, and the

[6] Describes a system in which EV communicate with the power grid.

projections reveal that this proportion will increase to almost 70 percent in 2050 (Nations 2014). In this context, an innovative transport system – one that charges quickly and has an uncertain future – is fundamental to support the need for the development of low carbon mobility to support the movement of people and products.

Technological disruption in urban passenger transport must take place in line with sustainable development in order to mitigate climate change. In this sense, the disruption occurring in the technological and operational fields contemplates gains in energy efficiency and consequently reduction of emissions in relation to the current model; i.e. EURO VI vehicles are more efficient than EURO V and other previous versions (Merkisz et al. 2014).

The EV is an example of a disruptive technology (Pilkington & Dyerson 2004; Pilkington et al. 2002) that has not only attracted the interest of global automakers but also of companies from others market segments such as Google, Apple, Uber, Lyft, and Alibaba. Although initially a large part of the automotive industry and the oil industry denied that EV could become mainstream, EV's trajectory in recent years reveals that the EV may cease to be a niche product and become a mass-market product Just one example is Tesla Motors sales success – EV's first mass-production automaker – as well as the increased interest of many automakers (Appendix A, Table A1).

Table 2.3: Countries that demonstrated their intention to limit sale or ban fossil fuel vehicles

Item	Country	From	Source:	Item	Country	From	Source:
01	Austria	2030	(Autovista 2017)	10	Israel	2030	(Reuters 2018)
02	Belgium (Brussels)	2030	(Hope 2018)	11	Italy (Rome)	2024	(Pullella 2018)
03	China	2030	(Reuters 2017)	12	México (México City)	2025	(Coren 2018a)
04	Denmark	2019	(Dennis 2017)	13	Norway (Oslo)	2025	(Coren 2018a)
05	France	2040	(Chrisafis 2017)	14	Spain (Madri)	2025	(Coren 2018a)
06	Germany	2030	(Schmitt 2016)	15	Taiwan	2035	(Taiwan 2017)
07	Greece	2025	(Coren 2018b)	16	The Netherlands	2030	(Lambert 2017)
08	India	2030	(Brodie 2017)	17	United Kingdom	2040	(Cowburn 2017)
09	Ireland	2030	(Kennedy 2018)	18	Scotland	2032	(Gray 2017)

EV's market evolution is, to date, slower than other disruptive technologies such as the cell phone innovation, whose market acceptance has been much faster. The difficulty of the EV's market expansion can be partly attributed to the technological blockage derived from the dominant players of the road transport system anchored in gasoline and diesel-powered vehicles (Cowan 1996). However, there are other factors that should help unlock the diffusion of EV; i.e. the scientific community has been questioning and attempting to quantify the negative impact of ICEV on local climate change (Cowan & Hultén 1996). In this context, governments in a number of countries (especially European) are announcing restrictive measures to fossil fuel vehicles and encouraging environmentally more positive technologies such as the EV (Table 2.3). The tendency is for governments, especially in Europe, to continue to act rigorously in trying to mitigate transport emissions, especially after the Volkswagen scandal involving several fraudulent techniques used from 2009 to 2015 to reduce carbon dioxide and nitrogen oxide emissions from some of its diesel and gasoline engines. To further aggravate government and society's distrust of vehicle manufacturers, the European Commission recently revealed that automakers are manipulating the results of a new test for CO_2 emissions to inflate fuel economy results from their vehicles, compromising future targets for the mitigation of transport emissions (Archer 2018).

Sterling (2018) argues that for the first time in half a century there is a real-world transformation in passenger transport. Sterling argues that providing more transportation options, greater accessibility and healthier and more livable cities are the positive side of change. There will therefore be a reduction of greenhouse gas emissions, and an increase in innovation and technological advances. Together, these facts can contribute to new sustainable transport modes paved by motor vehicles (connected), shared mobility (pooled) and electric vehicles. On the negative side, with more transportation options available, there is the potential for an increase in urban sprawl, energy use and greenhouse gas (GHG) emission, and polluted cities, as well as an increase in the number of users and number of kilometers travelled, if polices fail to create incentives to encourage the adoption of renewable energy, EV, and car-pooling and become indifferent to the development of personal transportation (Sperling 2018).

Car-as-a-Service (CaaS)

CaaS is emerging in the beginning of the 21st century with potential to cause disruption of the passengers' roads transportation system, as we know it (Seba 2018). Some authors consider this disruption just as important as the transition from the horse transportation system to ICE cars that occurred at the beginning of the early 20th century. If in the past the main disruptions were vehicles and ICEV, now the main actors are vehicle electrification, the potential of autonomous vehicle (AV), connectivity, and CaaS – all enabling vehicles to talk to each other about road infrastructure and traffic control centers allowing vehicles to become autonomous (Hewitt 2018). The use of the internet as a resource associated with other applications in personal road transport has become more evident at the beginning of the second half of the 21st century; i.e. in 2016, after some years in operation, using an App, Uber received more bookings than the whole cab industry in America (Seba 2018). The main phases of the private road transportation disruption are shown in Figure 2.6.

One of the major trends in transport disruption is that personal transport is moving towards user ship rather than ownership. In some European countries, where the CaaS system is developing more consistently, consumers seem to be moving towards a subscription and pay-per-use model. This movement will probably change the automobile industry business model. The automakers will probably focus on the CaaS market – such as ride-hailing[7], ride-sharing[8] (car-pooling or car-sharing) – to increase revenue instead of making money just by selling cars. The CaaS segment is developing in two ways:

[7] The customer books a vehicle to take them exactly where they need to go using an online application; i.e. Uber and lyft.

[8] It's an innovative transportation strategy that enables users to gain short-term access to transportation modes on an as-needed basis. It's a kind of service that connects drivers and passengers so they can share a ride.

private customers such as car-pooling, and new mobility providers – car-sharing such as Uber, Car2Go, Lyft, Autolib, and ZipCar (Brenner et al. 2018).

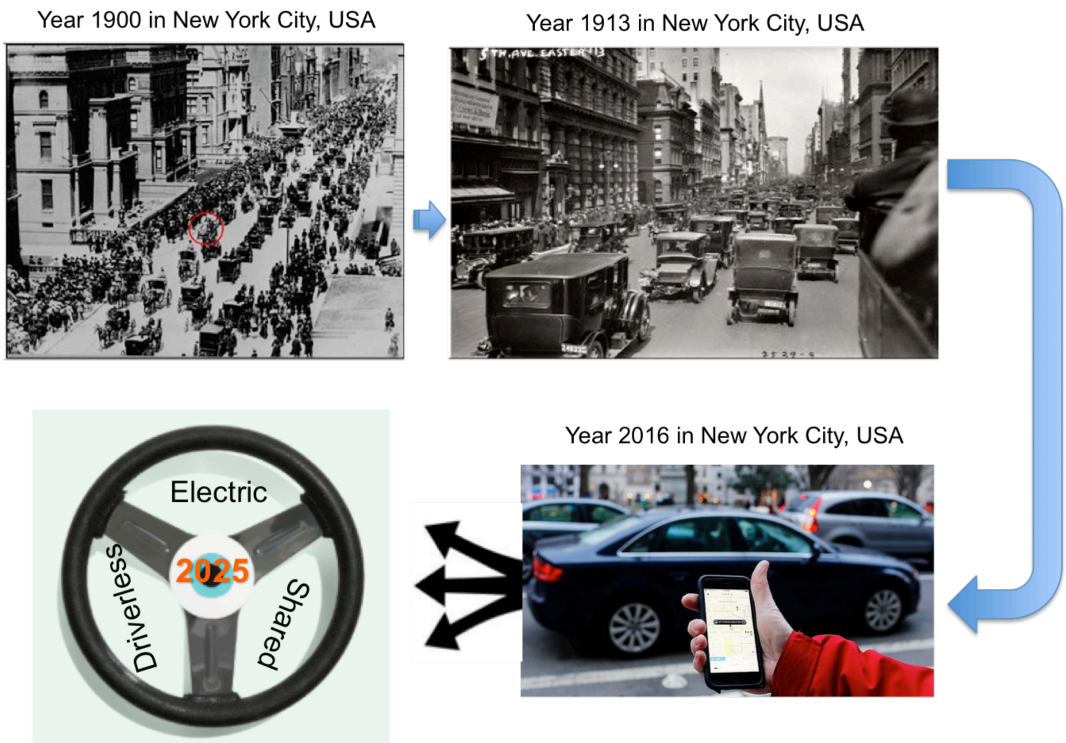


Figure 2.6 – Phases of private road transport disruption (Adapted from Archives 2018, Hewitt 2018)

The ride-sharing or car-pooling system could be a positive response to the changing urban transport challenges. Rising population in urban centers is expected to cause the global fleet of vehicles – currently around 1.2 billion units – to double in size by 2030 (Dargay et al. 2007). If these challenges were not enough, the demand for urban transport should also increase due to new entrants. Many people today do not own a car (especially teenagers and the elderly) due to existing limitations such as driving costs, investment needed to buy a vehicle, and maintenance costs. Those people will be able to use the ride-sharing or ride-hailing system thus boosting the growth of the number of users.

Governments in urban centers recognize the complexity of managing the ride-sharing system, but they already realize that the best option is not to combat it but to find the best way to make it efficient and increase confidence in it. Two types of platforms should dominate ride-sharing. The first group is organizations that coordinate the ride through a platform, such as Uber, Lyft and BlaBlaCar. The second type is inventory-based: companies that have assets such as car fleets that are shared among users such as car2go and Zipcar.

The car-sharing platform is an attempt to rationalize the use of individual transport by offering locomotion in LDV in a simple economic and adequate way to urban centers. The car-sharing system allows people who do not have their own vehicles to use them without the burden of ownership. The idea is the vehicle can be a complement to other forms of transport (bus, subway, bicycle) allowing the person to use the vehicle only when necessary. The diffusion of car-sharing should offer the following benefits: i) reduction of the number of vehicles on the streets (between 4 and 10 cars in Europe); ii) reduction in cost to the user – offers the advantage of having a car without the responsibilities, costs and maintenance that a private car requires; iii) improves the supply of transport; iv) decreases public investment; v) reduces CO_2 emissions – from 39 to 54 percent in Europe; vi) and reduces the GHG and reduces the cost of transportation to the local population (Shaheen & Cohen 2013; Martin & Shaheen 2011; Ryden & Morin 2005).

The car-sharing system has expanded rapidly. By October 2016, the numbers show that the system was in operation in almost 50 countries, reaching more than 2,000 cities and 15 million members sharing a fleet of more than 157,000 vehicles (Table 2.4). Asia leads with almost 60 percent of the membership and more than 40 percent of the shared global fleet. The second most important market of car-sharing is Europe, which holds around 30 percent of members worldwide and almost 40 percent of the fleet of vehicles shared globally. Since it began to expand in Europe and North America, the car-sharing system has not stopped growing; i.e. in 2014, around 35 countries had adopted car-sharing (Shaheen et al. 2018).

Table 2.4: Global car-sharing market trends

	2006	2008	2010	2012	2014	2016
Members	346.610	670.822	1.163.645	1.788.027	4.842.616	15.050.192
Member Growth Rate (2 yr)	0	193%	173%	153%	270%	310%
Vehicle fleet	11.501	19.403	31.967	43.554	104.125	157.416
Fleet Growth Rate (2 yr)	0	168%	164%	136%	239%	151%
Member-Vehicle Ratio	30.1	34.6	36.4	41.1	46.5	95.6

Source: (Shaheen et al. 2018)

Many other modes of ride-sharing have arisen including car-pooling and peer-to-peer car-sharing[9]. All these modes of shared services require drivers for the vehicles. However, the modality that causes important expectations is driverless CaaS because this is a new modality of transport with potential to cause profound transformation in urban transport and create a rupture in the urban transport of passengers in the way we know it. CaaS has attracted the interest of large business groups, essentially in the extent of sharing autonomous cars such as Google, Apple, Uber, Lyft, Baidu, Tesla Motors, Volkswagen Group and Toyota (Culver 2015).

Google, for example, has a strategy to develop software and map technology capable of serving as the basis for autonomous vehicles in the near future. Of course, the growth of the CaaS market is expected to expand more rapidly among the Organization for Economic Co-operation and Development (OECD) countries where greater investment and technological development are expected (Culver 2015). The impact of the CaaS system should not be limited to the private sector, but should also require adaptations in public transportation structures, as well as adaptations to the semi-public transportation segment such as taxi services.

[9] It's a system by which the existing car owners make their vehicles available for others to rent for short periods of time.

The CaaS system followed by other technologies; i.e. EV, AV, and connectivity, should encourage other transformations such as (Hewitt 2018): i) reduction of the need for parking spaces, enhancing the use of these spaces for the construction of green areas (Oslo, Norway was in the process of eliminating the remaining 700 street parking spots in its city center by the end of 2018 as part of its plan to turn the area into a car-free zone); ii) reduction of car ownership rate (ratio of cars by inhabitants); iii) cheaper, and more accessible transport for the population; and iv) probably reduction of CO_2 emissions. The CaaS system should support the increased role of EV in the mass-market – and be supported by electric mobility as well – because the use costs of EV are lower than ICE models (Nordelöf et al. 2014) and current environmental policy aims to reduce CO_2 emissions (Table 2.3). Therefore, it’s favorable to use electric models.

Connectivity

Diffused as the Internet of Things (IoT) accelerates the evolution of communication networks, development of the software industry and applications that adopt online technology is capable of capturing data in real time, analyzing them and interacting with vehicles and infrastructure. A connected vehicle is equipped with internet connection allowing the vehicle to share online access with other devices inside or outside of the vehicle. The main reason for connectivity will be to enable data capture, analysis and control of vehicles and interaction with support and control infrastructure as well as other service providers (Hewitt 2018). Using a smartphone, you will be able to provide online interaction between the car, passenger, service providers, and public services.

Connectivity will allow the user to stay connected 24/7. Online technology such as smartphone applications is giving the user more service options while traveling. Connectivity is providing great diversification in transport services. The car OEMs can monitor and diagnose the car conditions as well as offer online support. The service providers can interact with the passenger during the trip; i.e. the passenger may have his or her health monitored while on the move. Using this increase in connectivity, the public authorities will have new mechanisms of traffic control and management, and the service user can have real time transit information and estimated travel time. The connectivity will change the way the user will use the transport services and will facilitate the exchange of vehicle data and give control over the data to the stakeholders involved (e.g. in China all EV must automatically inform the localization to government-backed monitoring centers). In this case, the government can, for example, control subsidies use and the automaker’s technical and behavioral standards (Meola 2016). On the other hand, increased vehicle connectivity is expected to increase security, requiring investment in research, development of security mechanisms, and increased government attention.

There are high expectations on the part of investors, vehicle manufacturers, and the software industry among others in the growth of the market of connected cars. In 2016, there were about 21 million cars connected, representing around 35 percent of cars produced in the same year. It is estimated that around 82 percent of cars manufactured in 2021 (94 million units) will be connected (Meola 2016).

Currently, it is believed that global automakers will dominate the expansion of connectivity in vehicles (KPMG International 2018). However, telecommunications industry giants like AT&T as well as tech heavyweights of the technology industry (e.g. Microsoft, Apple, Pandora, Sprint, and Google) are making large investments in technology (Meola 2016).

Autonomous

Driverless or self-drive vehicles are part of a new mobility solution that will contribute to the disruption of the transport sector, and are expected to support the increase of CaaS penetration. The automotive industry considers the automation of cars a strategic issue because it is a part of the core business of the automakers. The desirable thing seems to be the completely autonomous vehicle supply, but what is observed is the gradual expansion of the driverless vehicle market at different levels of automation, which should work as a sort of buffer for adapting to the new technology. The evolution of the automation levels is as follows (SAE 1997):

Level 1 or driver assistance – the vehicle can perform a few tasks without human intervention; i.e. steering or acceleration. Therefore, human intervention is required to control almost everything.

Level 2 or partial automation circumstances – the vehicle has some more advanced functions in addition to Level 1; i.e. as autopilot and some security measures. However, the driver needs to be alert at all times.

Level 3 or conditional automation – the vehicle can perform some "critical safety functions" under certain conditions. The main driving tasks are automated; i.e. the vehicle is capable of driving on highways most of the time without human intervention, but the vehicle still requires human intervention.

Level 4 or high automation – the vehicle can travel almost all the time without any human intervention. Human intervention will be required only in specific circumstances; i.e. unmapped roads or in the face of severe weather conditions. In this level, the vehicle is capable of driving in urban stretches without human intervention.

Level 5 or full automation – all the functions can be automatically performed by the vehicle.

Despite the interest and investment in autonomous vehicle research and development (R&D), there are still many doubts to be clarified about the future of this technological innovation, such as: i) whether automation will continue to be implemented in phases in respect to the different levels of automation; ii) whether the consumer will trust and adopt the driverless cars; (iii) the extent to which they will impact the transport sector and the auto industry; and iv) whether driverless vehicles are really safe and reliable.

More than 44 car manufactures and tech companies worldwide are investing in autonomous vehicles (Hewitt 2018), and global business leaders apparently do not doubt that the future of LDV will be autonomous. For them the autonomous vehicles will dominate the streets in different periods (Table 2.5). Most of the leaders believe that levels 4 and 5 of automation will dominate the production of cars in the next ten years.

Despite estimates, full automation levels 0 and 1 currently dominate the automotive industry. Level 2 is being tested in different regions of the world. Level 3 should be on the streets by 2020. Levels 4 and 5 are expected to be consolidated from 2025 to 2030 respectively (Berger 2018).

Most vehicle manufacture that are involved in autonomous vehicle projects believe that control of technology from level 3 will only be possible with the use of LIDAR[10] technology. However, some manufacturers led by Tesla Motors and some startups believe that the following stages can be achieved without adoption of the LIDAR (Herger 2018). The introduction of autonomous driving will drastically reduce the cost of mobility services as well as associated costs, making it an affordable transportation solution for a large number of the global population.

Automation will extend the provision of mobility services to a much larger number of people, since there are no restrictions – such as driver's license or the driver's physical ability will not be obstacle in the future – to use the services (Macharis & Keseru 2018). The IHS Company estimates that almost 85 percent of the world's population – 6.2 billion people – do not have a driver's license and about 12 million autonomous cars will be sold globally in 2035, equivalent to 10 percent of total global LDV sales (Culver 2015).

Studies suggest there are natural synergies between shared AV and EV (Pilkington & Dyerson 2004; Cowan & Hultén 1996; Archer 2018; Dargay et al. 2007). Besides that, there are other benefits, such as the reduction of noise in urban centers, the issue of traveler range anxiety[11], and charging time management leading to the belief that the AV and EV will have an important market share in the composition of the urban fleet of LDEV.

Electric Vehicle

EV can be considered a disruptive technology as its dissemination is creating new transport options leading to a new transport system. The return in the interest to EV at the beginning of the second half of the 21st century reveals an increasing potential for mass-market use of this alternative technology due to its advantages over ICEV technology. Currently, the stock of EV exceeds three million units and market penetration continues to grow at rates much higher than those recorded by the market of ICEV (IEA 2018b).

Among the indicators that point to EV as mainstream technology are: (i) government policy focused on energy security with a view to promoting the diversity of clean energy sources, energy efficiency, and greater flexibility and reliability of fuels and energy sources – the EV using the V2G concept brings together real potential to increase the use of renewable energy; (ii) environmental awareness of energy production and consumption in order to reduce air pollution, and mitigate climate change, especially in urban areas; (iii) technological development. The EV market has led to the emergence of new technologies as well as the improvement of existing technologies; i.e. evolution of batteries with

[10] It is a technology type that measures distance to a target using a laser light.
[11] It is the fear or anxiety that the vehicle cannot reach the final destination due to lack of charge on the battery.

Table 2.5: Predictions about the future of driverless cars (ND = not declared)

Prediction	Announced	Market	Driverless level	Source:
Nvidia Corp's chief executive Jensen Huang	2017	2021	ND	(Yu 2017)
Audi of America's head Scott Keough	2017	2020	ND	(Ross 2017)
NuTonomy's executive Doug Parker	2016	2020	4	(Abbugao 2016)
Delphi's president Kevin Clark	2016	2019	4	(Hawkins 2016)
Ford's CEO Mark Fields	2016	2021	4	(Alexandia Sage 2016)
Volkswagen's appointed head of Digitalization Strategy Johann Jungwirth	2016	2025	4	(Wish n.d.)
General Motor's head of foresight and trends Richard Holman	2016	2020	ND	(Stoll 2016)
BMW's CEO Harald Krueger	2016	2021	ND	(Lambert. 2016)
Ford's head of product development Raj Nair	2016	2020	4	(Ciferri 2016)
Baidu's Chief Scientist Andrew Ng	2016	2019	ND	(Gubicza 2018)
Tesla's CEO Elon Musk expects first fully autonomous by 2018	2014	2023	5	(Kaufman 2014)
Tesla's CEO Elon Musk expects first fully autonomous by 2018	2015	2018	4	(Korosec 2015)
US Secretary of Transportation's Anthony Foxx	2015	2025	ND	(Hars 2015)
Uber's CEO Travis Kalanick	2015	2030	ND	(Goddin 2015)
Audi's head of Product and Technology Communications Stefan Moser	2014	2017	ND	(Feann Torr 2014)
Jaguar and Land Rover's Director of Research and Technology Wolfgang Epple	2014	2024	4	((Hawley 2014)
Daimler's Chairman Dieter Zetsche	2013	2018	4	(Jack Ewing 2013)
Nissan Motors Executive Vice President of California Andy Palmer	2013	2020	4	(Kuhlman 2013)
Insurance Information Institute's President Robert Hartwig	2013	2025	ND	(Bronson 2013)
Nissan's CEO Carlos Ghosn	2013	2020	ND	(Bigman 2013)
Continental automotive supplier	2014	2016/20	2 e 4	(TANNERT 2014)
Intel's CTO Justin Rattner	2012	2022	ND	(Gaudin 2012)
Google's founder Sergey Brin	2012	2017	ND	(Tam 2012)
Institute of Electrical and Electronics Engineers (IEEE). Professor Dr. Alberto Broggi	2012	2040	5	(Stickel 2012)
Honda's Research and Development America Jim Keller	2016	2020	4	(Alexandria Sage 2016)
Geely's chairman Li Shufu	2016	2020	4	(Spring 2016)

increased density capacity and reduction of cost production, development of the EVSE network and greater range of the EV; iv) economic development. The growth of the EV market is in line with the search for development with a low ecological footprint. In addition, the electric mobility industry has provided the emergence of innovative business models (e.g. CaaS), thus supporting the desired development of the circular economy (e.g. reuse of the EV batteries by others sectors until the final recycling of the product).

2.2.2 Current stage and future perspective of EV

The EV is increasing its market penetration and becoming more common as a choice of road transport for passengers' vehicles. There is a tendency for electrified mobility to become, in the near future mainstream, replacing ICE vehicles. Supported by environmental causes the EV has increased its presence in developed economies and in some developing countries as well, as discussed in the following sections.

Global stock and market share of PEV

The numbers of countries that support the electric mobility has increased and consequently the PEV market penetration has been increasing. In the last five years, the LDEV stock has been almost doubling every year globally. In 2013, the PEV stock was less than 400,000 units and by 2017 it exceeded 3 million passengers (PEV – China surpassed 1 million units in stock). The Asian country holds around 40 percent of the global passenger PEV fleet.

In 2017, around 44 countries carried out some initiative with PEV with 20 percent of them holding 95 percent of the global PEV stock. Although the present study focuses on passenger EV, it is important to show that globally, in 2017, there were 250 million electric two-wheelers (99 percent in China), and the stock of electric buses increased to 370,000 units (IEA 2018b). In 2017, EV's stock penetration fell below 1 percent in most countries. Only Norway (6.4 percent) and Netherlands (1.6 percent) registered a market share above 1 percent.

Global sales and market share of EV

Overall PEV sales in 2017 exceeded 1 million units (1.2 million) – 2/3 were EV – with China accounting for around half of global sales. Globally, there was a 72 percent increase in PHEV sales compared to 2016. The highest sales growth in 2017 occurred in Germany and Japan, where sales more than doubled compared to 2016 sales levels. However, PHEV sales fell down from 44 percent market share in 2012 to 34 percent in 2017 due the growth of EV sales.

In terms of global market share, the seven countries with the highest penetration of PEV are: Norway, which is the leader with 39.2 percent of passenger PEV sales, then Iceland with 11.7 percent, which is around four times lower than Norway. Sweden has the third largest market share with 6.3 percent, and around six times lower than Norway. The other countries are China (2.2 percent), Germany (1.6 percent), USA (1.2 percent) and Japan (1.0 percent).

Expectation of global PEV stock market share by the year 2030

There are several scenarios for the future of EV. For example, the IEA (2018b) works with two scenarios. Scenario "A" (New Polices) considers that governments will adopt announced measures of support for the EV. This scenario projects a global stock of 13 million of PEV by the year 2020 (from 3.7 million in 2017), and around 130 million PEV by the year 2030. This scenario also projects sales of 5 million (in 2017 it was 1.4 million) by 2025, and is expected to expand to around 21 million by 2030. In this scenario, sales would grow by an average of 24 percent a year over the projected period (Hertzke et al. 2018; IEA 2018b). PHEV has high penetration in this scenario.

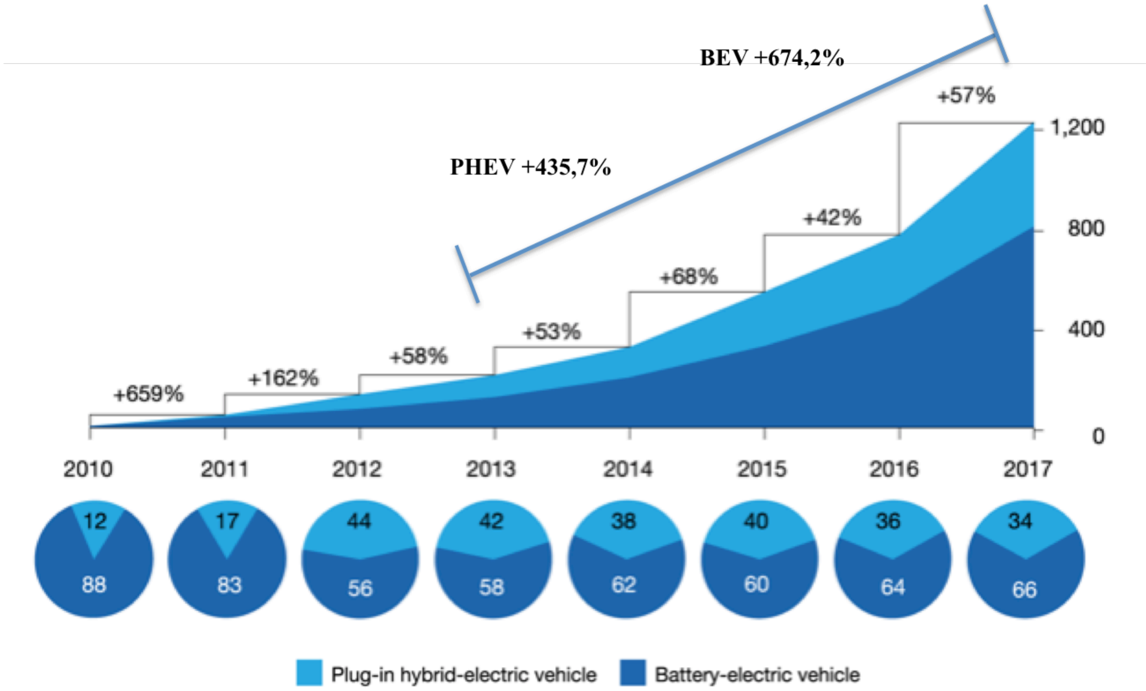


Figure 2.7 – Global stock scenarios of passenger PEV from 2017 to 2030 (Adapted from Hertzke et al. 2018

Scenario "B" (EV30 @ 30) was built on the basis of the possibility of meeting commitments from countries that support electric mobility, and are part of the IEA Electric Vehicle Initiative Program (EVIP). This scenario considers a market share for PEV of 30 percent (compared to LDV) and a reduction of carbon intensity in the generation of energy exceeding 50 percent by 2030. EV has high penetration in this scenario. Scenario "B" is in line with the Paris Agreement, resulting in overall stock of 228 million EV by 2030 (IEA 2018b). The two scenarios do not consider EV of two- and three-wheelers and show a rapid and significant expansion of passenger PEV.

The electrified vehicles market could grow rapidly and reach around 240 million passengers PEV in 2030, according Randall (2018). Several studies, mostly optimistic, point to different scenarios of participation in the global sales of EV and PHEV vehicles (Figure 2.7). Despite the divergences between the scenarios, most of them point to greater penetration of the PHEV models, a different situation compared to the current results in which the EV market share has been growing consistently since 2012, as shown in Figure 2.8.

The increased EV sales can be attributed to joint efforts between public and private initiative. Governments of several countries have allocated large investments in recent years to the development of electric mobility. As a result, there are increased sales (and car models) available from manufacturers. Overall, in 2010 there were only 9 EV models available in the market worldwide. By May 2018 around 99 EV models (Appendix A, Table A1) were available in the globally market, and automakers recently announced 340 EV launches for the 2018-2020 triennium (Hertzke et al. 2018).

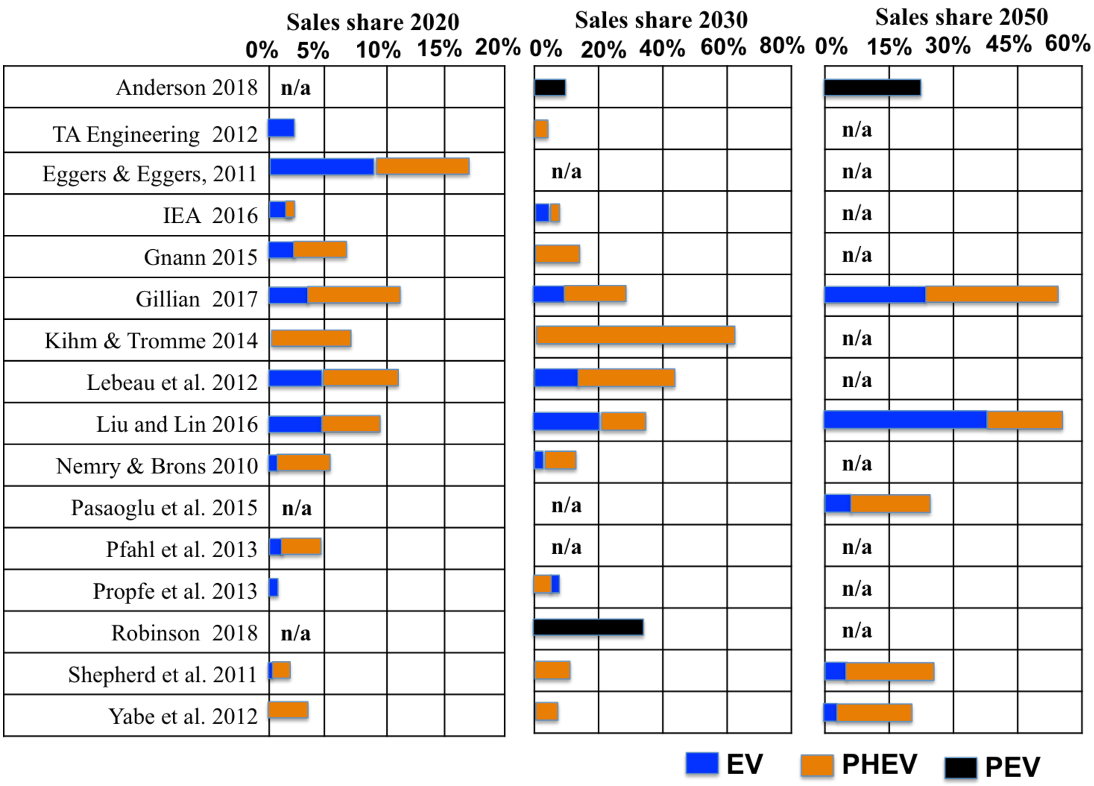


Figure 2.8 – Market share of the sales shares based in scenarios for 2020, 2030 and 2050 distinguished by EV type

A 2018 European survey (Archer 2018), points out that 40 percent of citizens surveyed said they would buy or lease EV powered for the next car. In some countries such as Italy and Spain the people were likely to say that they would probably buy or lease an EV or FCEV as their next vehicle (Archer 2018), and a report argues by 2027 half of new cars sold in Europe will be EV. In USA and China, the same proportion will be achieved five years later. A survey conducted in May of 2018 in the USA revealed that around 20 percent of the people surveyed in the USA said that they intend to buy an electric car in the future (Barry 2018).

2.3 Incentives and subsidies for EV adoption

2.3.1 EV benefits

When compared with fossil-fueled vehicles the EV presents some benefits, one of the reasons why some governments offer subsidies for EV. The EV benefits cannot always be considered equally in all parts of the world, due to different factors (energy, vehicle manufacturing process, and battery production).

Therefore, the EV will have more benefits in some regions and little or no benefit in other areas. The source of energy is the dominant factor to achieve EV benefits. Therefore, the cleaner the energy source used for electricity production, the greater the benefits of EV could be. In the table 2.6, the benefits of EV were organized into three categories - industry and retail, vehicle and infrastructure, and government and society- and classified into four sectors – social (s), economic (e), technological (t) and political (p)

Benefits by categories

Most of the benefits are originated from the vehicle and its infrastructure due to technological advances and social aspects. Attributes related to industry hold the second highest proportion of benefits, strongly influenced by economic aspects. Finally, socio-economic aspects influence the benefits from the government.

Benefits by sectors

i) Socio-economic: the EV provides the benefits that almost always a new technology provides; i.e. new economic dynamic with emergence of new industries; new applications, and innovative solutions. The market expansion of the EV has new forms and offers a transport solution with the potential of reducing travel costs, and increasing services such as CaaS, allowing greater integration in the transport sector. Other benefits, such as no pipeline emissions and no noise, contribute to changing user behavior and create a new social dynamic (Bergman et al. 2017; Geels et al. 2017; IEA 2018a; IEA 2012; Erich & Witteveen 2017; Rieck et al. 2017; Dijk & Yarime 2010; Granovskii et al. 2006). The generation of jobs with the expansion of electric mobility is another important socio-economic benefit that may help some countries that invest in electro-mobility.

A study on job creation by the AIE concluded that by 2030 a total of nearly 200,000 permanent jobs could be created in electro-mobility. This is based on a moderate uptake of plug-in vehicles amounting to around 35 percent of new car sales by 2030. Of these 200,000 jobs, 57 percent will come from the installation, operation and maintenance of charging points (IEA 2018). More than 90 percent of electrical transportation companies are small and medium-sized enterprises. Electro-mobility has a potential to generate massive business opportunities for local companies to generate local highly skilled jobs (IEA 2018). Regarding the lower operating costs (Total Cost Ownership – TCO), the cost of operation is lower due to the higher efficiency of the EV, and the lower value of kWh in relation to the fossil fuel cars. A comparative study of electrified models and ICEVs conducted by Harvard researchers Kennedy Scholl (Lee & Lovellette 2011) considering the main costs involved in the purchase and use of the cars, concluded that the TCO of EV is around 2.5 times more favorable when compared to the ICEV mode. Studies point to several types of advantages of EV in relation to ICEV models. As the EV has a higher purchase value than the compatible ICEV model, with a subsidy capable of matching the EV value to the ICEV, the TCO benefits over the life of the vehicle tend to be even more favorable to EV (IEA 2018b; IEA 2012; Erich & Witteveen 2017; Rieck et al. 2017; Brito et al. 2013).

Table 2.6: Key social (s), economic (e), technological (t) and political (p) benefits of EV

Item	Benefits	S	E	T	P
Regarding industry and retail					
1	Electricity is cheaper than gasoline or oil		x		
2	Transfer of the wealth of oil producing countries to the country that develops the electric mobility (energy sector investments)		x	x	
3	Development of new sectors (CaaS, renewables)		x		
4	Expansion of existing industry (EV battery, software)		x	x	
5	Support to the circular economy	x	x		
6	Optimization of energy use (back-up system)		x	x	
7	Development of new technologies (autonomous vehicles, connected cars)		x	x	
8	Help to diversify the transport energy mix	x	x		
9	Encouraging the use of recyclable material in vehicles	x	x		
Regarding vehicle and infrastructure					
10	EV has fewer moving parts than conventional petrol/diesel cars		x	x	
11	Maintaining EV is simpler		x	x	
12	The energy to charge an EV requires around 1/3 the energy compared ICE equivalent model (Total Cost Ownership -TCO)		x	x	
13	Emergence of new business (infrastructure for EV, operator for infrastructure)		x		
14	EV is more efficient than ICEV		x	x	
15	Zero tailpipe emissions	x		x	
16	Reduction of gasoline fuel consumption		x	x	
17	After used, EV battery can be reused by other activities		x	x	
18	Contributes to better local air quality locally	x			
19	Reduces noise pollutions	x			
20	Help to mitigate climate change	x			
21	GHG emission savings can be maximized	x			
22	Strengthens the adoption of V2G			x	
23	Less vibration	x		x	
24	Softer shifts	x		x	
25	Fast acceleration	x		x	
26	Possibility of charging at home	x		x	
Regarding government and society					
27	There are several types of subsides (for EV, Battery and infrastructure)	x	x		x
28	EV drivers are protected from the price fluctuations intrinsic to global oil markets (electricity versus gasoline prices)	x	x		
29	Generation of employment locally	x	x		
30	Public health aspects	x			

Source: (Bergman et al. 2017; Geels et al. 2017; IEA 2018a; IEA 2012; Erich & Witteveen 2017; Rieck et al. 2017; Dijk & Yarime 2010; Granovskii et al. 2006; Brito et al. 2013; Lee & Lovellette 2011; Todd et al. 2013; EPA 2018)

Regarding the efficiency and maintenance costs the EV is significantly more efficient than the ICEV model (Brito et al. 2013). An electric motor typically is between 85 percent and 90 percent efficient (Eaves 2004). That means it converts that percentage of the electricity provided to it into useful work. When charged by electrical energy from the grid it converts from 59 percent to 62 percent of the power to the wheels, whereas the conventional gasoline vehicles only converts from 17 percent to 21 percent of the energy stored in gasoline to power at the wheels (EPA 2018). Regarding maintenance the basic mechanics of an electric motor are very simple, containing less than a dozen moving parts, whereas the ICEV has several hundred moving parts. This is an advantage for EV owners as they will not have to perform maintenance service with oil changes, fuel filters, spark plug replacement, or an emissions check (IEA 2018b; IEA 2012; Erich & Witteveen 2017; Rieck et al. 2017; Brito et al. 2013).

The subsidies to encourage the adoption of EV are a significant benefit to the market expansion of the EV. The region where the buyer resides will determine the value and extent of the financial and non-financial benefits of the EV (Lee & Lovellette 2011; IEA 2018b; Erich & Witteveen 2017). There is also the energy issue that places EV at the heart of the discussions. It can be argued that EV would not be recommended in countries with significant oil production. However, Norway reveals that this is not a true argument. Although Norway is a major producer of oil it is a global leader in electric mobility by the market share parameter. In addition, the evidence shows that EV and renewable energy are interlaced (IEA 2018b; IEA 2012; Erich & Witteveen 2017; Rieck et al. 2017; Brito et al. 2013).

The social aspects of EV are connected to improve air quality, health issues and comfortable features for its occupants. People who have a good experience driving an EV show more favorable attitudes towards e-mobility (Reiner & Haas 2015). A study in Europe found that 71 percent of participants expressed interest in considering an imminent purchase of an electric vehicle after a test drive (Kannstätter & Meerschiff 2015).

ii) Technological and political: technological innovation, especially the improvement of batteries has been responsible for much of the benefits of EV. Thanks to the evolution of batteries, the EV is expanding and contributing to the emergence of new applications in transport (i.e. car-sharing, ride-hailing, ride-sharing) and new technologies (i.e. applications for system management, connect car, and driverless vehicles). The technological advances of the EV have shown benefits in several sectors, including the environment with more energy efficiency and reduction of GHG emissions; health with better air quality in urban centers; social services with greater transport supply and lower costs for the user; and improving the economy with the emergence of new businesses. One important benefit to some countries is the possibility of source diversification with greater participation of renewables, less dependence on fossil fuels and greater energy security (IEA 2018; Todd et al. 2013; IEA 2012; Erich & Witteveen 2017; Rieck et al. 2017).

EV benefits provided by sector

The benefits of transport electrification span multiple sectors. The environment, energy, socio-economic, and mobility areas are most benefited by the advancement of transport electrification (Geels et al. 2017; Scalise et al. 2018). These areas interrelated with at least three categories: transformation of transport by electrification, grid transformation, and transformation in mobility. Analysis from this new perspective reveals a more diversified view of the benefits, as shown by Table 2.7.

The complementary benefits from this analysis

Considering the benefits of transformation of transport and impact for the environment the EV has a smaller ecological footprint compared to an ICEV. Reducing pollution can be translated as better air quality, especially in large urban centers. There is also noise reduction providing a better environment for human and animal life, resulting in a greater protection of ecosystems and increase in the quality of life (Erich & Witteveen 2017; Brito et al. 2013; Rieck et al. 2017).

Transformation of transport and impacts for the energy consumption

With the large-scale use of the EV, the greatest benefit of using EV relies on is the use of renewable energy as the source of electricity, however the rising numbers of EV present challenges as well. The increased use of the EV is justified with clean energy, so the electrification of transport has the potential to improve renewable energy market penetration (EV battery can be used as a back-up system, and help to manage intermittent renewables), but it is necessary that there is more investment in renewable energy, and in technology to manage the distribution system.

Table 2.7: Summary of EV benefits provided by complementary perspective

	Environment	Energy	Socio-Economic	Mobility
Transformation of transport by electrification	Reduces emissions, improves air quality and reduces noise.	Diversifies energy use	Reduces spending on oil imports	Reduces TCO
Grid transformation	Reduces energy emissions	Improve the use of renewables	Creates employment locally	Supports the emergence of new solutions: Back-up, V2X, V2H, V2G
Transformation in mobility	Sustainable use of resources	Diversifies the transport energy mix, and supports network management	Supports the emergence of new businesses: CaaS	Higher transport offer with lower user cost
Macro benefits	Conservation of ecosystems	Sustainable energy use	Supports a circular economy	Rationalization of transport

Source: (Adapted of Joseph Scalise 2018)

In 2017, an estimated 26 percent of the electricity consumed by EV came from renewable sources, roughly in proportion to the renewable share of electricity generation. In 2016, renewable energy accounted for around 18 percent of total final energy consumption, and modern renewables[12] were responsible for about 10 percent. Furthermore, the number of countries with renewable energy targets and support policies increased again in 2017, and several jurisdictions made their existing targets more ambitious (Hales 2018; Erich & Witteveen 2017).

Transformation of transport and the socio-economic sector

The transport transformation and the socio-economic sector benefits by the advancements of the electrification of transport due to the reduction of expenses associated with the import of oil and also reducing the risks of energy dependence. The development of electric mobility is being followed by the emergence or technological improvement and emergence of several new businesses as well as the transformation in transport organizations, automotive components industry and the energy sector. Jonathan (Mullan et al. 2012) analyzed the impact of EV in regard to technical, economic and commercial viability, and found that investments will be necessary in the energy sector to bring about significant economic benefits (Granovskii et al. 2006).

Bergman and Savacool (Bergman et al. 2017) noted that electrification in transport could boost the local economy as a result of new transport solutions (CaaS) that involve smaller and regional firms with the potential to create jobs locally. Additionally, there will be growth of the renewable industry and its applicability to replace oil imports and meet growing demand for electricity. In addition, the evolution of electric mobility has contributed to the emergence of new transport options (ride-hailing and ride-sharing) thus moving the local economy.

The social aspect will also be affected by the emergence of new ways to use cars (CaaS), the tendency of improving the CaaS system, growth and diversification of the personal transport system and by the possibility to improve the transport integration system (Bergman et al. 2017; Wolsink 2012).

Transformation of transport and mobility

The technology is another factor that will benefit as EV increases its market penetration. Various technologies and applications have emerged, and are developing in new forms of transportation leading to a greater consumer supply and lower travel costs for users. The software industry has been responsible for many innovations, enabling new business from the expansion of electrified mobility such as industries for charging infrastructure, charging station operators, service consolidators, integrators as well as V2G[13], and V2H[14] services (Dijk & Yarime 2010).

2.3.2 Public policy and subsidies to encourage EV mass adoption

The EV technology is ready and available to the market with significant advantages over ICEV; the EV is an emerging technology embedded in a century-old automotive industry, which in turn is backed by the powerful oil industry. Although the oil industry shows no interest in the expansion of EV,

[12] Renewable technologies with the exception to traditional biomass: hydropower, solar, wind, geothermal and modern biofuel production, and modern forms of waste-to-biomass conversion.
[13] Vehicle-to-Grid (V2G) describes a system in which EV communicate with the with power grid.
[14] Vehicle-to-Home (V2H) is a system that allows supplying the home with energy stored in an EV battery.

governments in several countries seek to reduce transport emissions through subsidies to electric mobility, since the expansion of EV has been shown to be dependent on adequate public policies, as suggested in Figure 2.9.

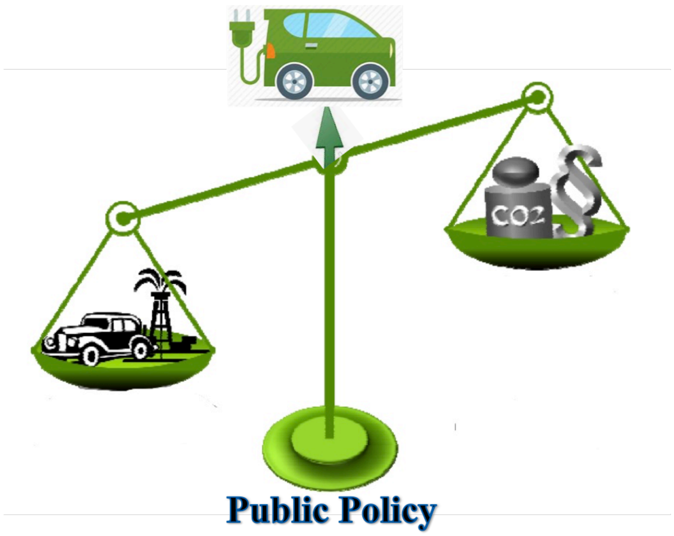


Figure 2.9 – Public policy is needed to support EV mass-market penetration (Adapted from Pellischek, 2013)

Public policies to stimulate electric mobility

There are several types of policies to support electric mobility. Public policies are usually regulatory and in financial incentives format. Currently, the main policies are aimed at regulating and encouraging comprehensive activities in the following topics (IEA 2017):

i. Consumers: financial support for vehicle purchase and installation of EVSE outlets.
ii. Manufacturers: subsides to produce the vehicle, and to install charging infrastructure.
iii. Energy companies: support for EV demand, investments in charging infrastructure, upgrade in distribution network, and subsidies for expansion of renewable energy.
iv. Cities: support the implementation of EVSE (parking lots, public parking).
v. Buildings: to implement EVSE outlets in new constructions.
vi. Private-public companies: to facilitate the consumer e.g. free or priority to park, and high occupancy vehicle (HOV) access.
vii. Stimulate an environment conductive to private investments in electric mobility.

Policies can be adopted in various government levels (central, state or local government). Among the various policies adopted by the countries that support the EV, here are some examples that show the types of initiatives adopted.

i. Norway: government provides EVSE public funding for the introduction of fast charging stations every 50 km (IEA 2018).
ii. France: recent legislation mandates that 50-75 percent of parking bays in any new or renovated residential building must be pre-installed with conduits that allow for the easy installation of

EVSE. In commercial buildings, 5-10 percent of parking bays must have conduits suitable for installing EVSE with a power rating (Legifrance 2016).

iii. Amsterdam: metropolitan area has adopted one of the most interesting policy strategies, which involves zoning actions using a demand-based approach for deploying its EVSE network (Bardok 2016).

iv. Austria: government gives permission to EV to drive faster in freeways than those with gasoline, diesel, or hybrid vehicles; i.e. during low-pollution times, owners of EVs will be allowed to travel at 130 km/h compared to 100 km/h for ICEV cars (Halvorson 2018).

In Brazil, the EV is in an incipient phase, and there are almost no EV models for sale in Brazil. In 2017, BMW i3 model was the only 100 percent electric car available for consumers in the country, and the price is much higher than the equivalent ICEV model. Almost all LDEV in the country is for the purpose of research studies and most of the projects for studies on EV were interrupted in Brazil. For example, Nissan ended its EV testing program for taxi drivers in Sao Paulo and Mitsubishi also ended a test with distributors of electricity in Rio de Janeiro and Sao Paulo. Renault (partnership with CPFL in Campinas) is one of the few projects that is still active. Brazil does not have financial incentives for buyers of EV. However, the central government provides some benefits for EV such as import tax reduction, and reduction of manufacturing tax. The states and local government provide some benefits such as Individual Voluntary Arrangement (IVA) rebate, and high occupancy vehicle (HOV) access.

Financial subsides, and other forms of incentives

Financial subsidies are fundamental to the expansion of electric mobility. There are different categories of subsidies. The predominant kind of benefits are: i) fiscal subsides that are usually intended to encourage vehicle, battery, and infrastructure production, but may also be adopted for consumption; ii) financial subsidies that are usually intended to encourage consumption with financial subsidies (money for purchase of the product), and iii) operational subsidies that are used to encourage the use of the product (reduced or exempt parking fee, priority parking, congestion exemption, high-occupancy vehicle access, among others).

The subsidies for EV can reach different levels of public management: economic block (e.g. subsidies provided by the EU), country (e.g. central government), state (regional government) and local (local management). There may also be subsidies by organizations such as automakers through the so-called "cross subsidies."[15]

Countries from different continents offer subsidies to EV as shown in Table 2.8. The subsidies were grouped into eight categories to simplify the analysis, as follows.

i. Direct Purchase Subsidies (DPS) are subsidies provided by federal and state levels for EV buyers.

[15] It occurs when the organization subsidizes a particular product or service to increase its market penetration. Typically, this type of subsidy is offset by revenue from other products or services marketed by the company.

ii. Registration Taxes Benefits (RTB) are subsidies provided for vehicle owners regarding the registrations of the vehicles for the time of purchase.
iii. Ownership Tax Benefits (OTB) are fees that owners of EV must pay for the vehicle i.e. annual road tax.
iv. Company Tax Benefits (CTB) are subsidies provided to companies that adopt EVs.
v. Value Added Tax (VAT) is a type of tax that is assessed incrementally, based on the increase in value of a product or service at each stage of production or distribution such as electric vehicle case.
vi. Local City Incentives (LCI) are subsidies provided for cities or municipalities for EV buyers. The subsidies can be financial (value per unit purchased) or non-financial (HOV lane access, reduced cost, free parking in downtown area, toll free in bridges and freeways, or subsidized access in some part of the city).
vii. Infrastructure National Incentives (INI) are subsides provided for the infrastructure of EV.
viii. Other Benefits (OHB) is all other subsides not considered in previous topics.

2.3.3 The EV potential to mitigate GHG: opposition and advocates

Globally, GHG emissions are a concern. To avoid emissions affecting the climate system, mankind will need to adopt mitigation measures that will ensure the achievement of the targets of the Paris Agreement. However, there are many challenges. The transport system is constantly evolving and its path to the future is uncertain. Probably, mobility will increase as more people and goods move around. It is estimated by 2030, compared to 2015, annual passenger traffic will increase by 50 percent.

Global freight volumes will increase by 70 percent, and the volume of cars on the road will double in size, reaching another 1.2 billion cars, states the Global Mobility report (Sumo4all 2017). Transport-related emissions are growing worldwide, and currently account for around 28 percent of total end-use energy GHG emissions from the transport sector (more than doubled since 1970). The penetration of light-duty vehicle ownership has steadily increased, and is expected to double in the next few decades (Transport 2017). Therefore, the transition to a low-carbon transport system will be crucial to prevent the increasing consumption of fossil fuels which can cause an increase in emissions, air pollution, degradation of the environment, number of deaths and diseases (Sumo4all 2017). Expanding the penetration of low emission vehicles is a promising path in the transition to a low carbon transport system. EV is an accessible and potentially capable technology to help mitigate GHG emissions. However, for EV to achieve the Sustainable Development Scenario[16] (SDS) goal and help mitigate emissions at the projected levels by the Paris Agreement, the EV will have to reach at least 14 percent of the global market share by 2030 (IEA 2018a). This is apparently only possible with the adoption of appropriate public policies and subsidies that are capable of encouraging consumers to adopt EV.

[16] SDS outlines a scenario with major transformation of the global energy system, showing how the world can change course to deliver energy Sustainable Development Goals (SDGs), agreed by 193 countries in 2015 simultaneously.

Table 2.8: Subsidy types available for EV by country by the month July 2018

Country	DPS	RTB	OTB	CTB	VAT	LCI	INI	OHB
Africa								
Turkey					✓			
Asia								
China	✓	✓	✓			✓	✓	✓
Japan	✓	✓	✓			✓		
South Korean	✓	✓	✓		✓		✓	
Europe								
Austria	✓	✓	✓	✓	✓	✓		
Belgium	✓	✓	✓	✓				
Croatia		✓						
Cyprus		✓	✓					
Czech Republic					✓	✓		
Denmark	✓	✓			✓	✓	✓	
Finland	✓	✓	✓				✓	
France	✓	✓	✓	✓		✓		
Germany	✓		✓	✓		✓		✓
Greece		✓	✓		✓			
Hungary		✓	✓	✓		✓		
Iceland		✓	✓		✓	✓	✓	
Ireland	✓	✓	✓	✓		✓	✓	
Italy	✓		✓				✓	
Latvia		✓	✓			✓		
Liechtenstein	✓							
Lithuania		✓				✓		
Europe (cont.)								
Luxembourg	✓		✓	✓				
Malta	✓	✓	✓	✓		✓	✓	
Netherlands		✓	✓	✓				
Norway		✓	✓	✓	✓	✓	✓	✓
Portugal	✓	✓	✓	✓		✓		
Romania	✓	✓	✓				✓	
Slovakia	✓	✓				✓		
Slovenia	✓	✓	✓					
Spain	✓	✓	✓			✓	✓	✓
Sweden	✓		✓	✓				
Switzerland			✓					✓
Turkey					✓			
United Kingdom	✓	✓	✓	✓		✓	✓	
North America								
USA	✓	✓	✓	✓	✓	✓	✓	✓
Canada	✓				✓	✓	✓	✓
Mexico		✓	✓		✓		✓	
Oceania								
Australia		✓						✓
New Zeeland								
South America								
Brazil			✓		✓	✓		
Colombia					✓			✓

Bulgaria, Estonia and Poland do not provide subsides for EV

Source: (ACEA 1998; EERE 2018; EMC 2018; Mexico 2017; EAFO 2018; Stratas 2017; Vehicles 2018; Portafolio 2018; He et al. 2018)

Opposition to EV on GHG mitigation

The issue of benefits for EV has been controversial. Studies question the declared environmental benefits of EV. One study (Babaee et al. 2014) looked at a number of scenarios for 2050 and concluded that even if EV accounted for 42 percent of US passenger cars, there would be little or no reduction in the emission of air pollutants. Zehner (Zehner 2012) argues that the EV is more symbolism and marketing than an environmental and fossil-fuel savior. In many cases, it is stated the EV is worse for the environment than traditional gas-powered vehicles (Zehner 2012).

The critics' current view – which claims that the EV does not bring benefits or the benefits are not significant (Zehner 2012; Babaee et al. 2014) – is based predominantly on arguments involving the environment and energy aspects. Those who question the benefits of EV in relation to power systems (He et al. 2018) argue that the increase of EV connected to the network may cause overload problems with the risk of loss of electricity to the population (Hu et al. 2012; Fernandez et al. 2011; McLaren et al. 2016; Babaee et al. 2014). Some authors also argue the EV will cause increased CO_2 emissions and therefore it will not bring the expected environmental benefits due to the increasing electricity production required to charge the EV (Hawkins et al. 2012; Notter et al. 2010; Brady & O'Mahony 2011).

Among those who do not identify benefits for EV, there is an argument that since motor vehicles are going to pollute, it is better to do it directly in the ICEV vehicle – because it is increasingly more efficient thanks to the technological advances – thus avoiding the increase in investments needed in the energy source and the charging infrastructure for EV. In addition, there is a claim that electric cars put all their carbon emissions into the atmosphere before they drive a single kilometer, as the production process of the EV battery is responsible for high emissions. Therefore, the EV will have to run around ten years or 150,000 kilometers to offset emissions from production. The emission from battery manufacturing depends on the battery size, lifetime, chemistry, and how clean the energy is to produce the battery; i.e. the electricity in China (0.69 $kgCO_2/kWh$ 2013), in Poland (0.65 $kgCO_2/kWh$), in South Korea (0.54 $kgCO_2/kWh$), EU average (0.45 $kgCO_2/kWh$). By LCA methodology when the European fuel mix for electricity is considered, EV moderately reduces GHG emission compared to both diesel and petrol-driven ICEV (Poliscanova 2018).

Other studies claim that gas and coal powered EV pollute more than diesel and petrol cars. The "EV charged using coal-based electricity yields higher lifecycle emissions than ICEV. Thus, the potential climate benefits of EV compared to ICEV cannot be harnessed everywhere and under all conditions. LCA studies consistently report moderate climate benefits for EV, powered by the average European electricity mix compared to ICEV of a similar size." (European Parliament 2018). The EV opponents also argue about operational issues unfavorable to EV such as greater vehicle acquisition value, limited charging infrastructure and low battery autonomy (see section 2.4 barriers) among others.

EV advocates on GHG mitigation

The EV advocates (Sperling & Gordon 2010; Chan 2017; Seba 2018; MacHaris et al. 2007; Van Mierlo et al. 2013; Sovacool & Hirsh 2009; Baptista et al. 2014) highlight of positive impact for the environment of EV by use and by life cycle of the vehicle, as shown below.

1. The main environmental benefits of using EV are: i) the EV does not emit tailpipe pollutants (although the power plant producing the electricity may emit them); ii) it provides better air quality in urban areas; and iii) technological advances are providing more environmental benefits to EV than to ICEV models.

2. LCA environmental benefits: taking into account the manufacturing process and the entire product life in Well-To-Wheels[17] method (WTW) studies that can be fractionated into Well-To-Tank[18] (WTT) and Tank-To-Wheel[19] (TTW) stages, the EV is more beneficial than ICEV, and reduces overall emissions by 51 percent over the life of the car (Nealer et al. 2015).

The energy efficiency studies to identify EV environmental impact revealed in all methods analyzed – WTT, TTW, WTW – EV is more efficient than ICEV models (Jorgensen 2008). The study concludes – by the WTW method – that even in the worst-case scenario where the EV is charged with carbon intensive energy, there is an efficiency gain of 11 percent. In all other scenarios EV is much more beneficial from an environment perspective (Helmers & Marx 2017).

A study by the Union Concerned Scientists (UCS) in the USA concluded that only a minority of the population (17 percent) resides in regions where emissions are comparable to the most fuel-efficient non-hybrid gasoline vehicles (Anair & Mahmassani 2012). Therefore, only in a small part of the USA did the EV show no benefits. The study also reveals that even in a country where the energy source is not predominantly clean, there may be some regions where generation from renewable sources is possible, thus justifying the adoption of EV.

Another USA study based on the LCA method points out that the EV produces lower GHG emissions than the average fossil fuel vehicles. The study assesses regional power grids in the USA based on the emissions produced by electricity generation and compares emissions produced by EV with emissions produced by gasoline-powered vehicles. The study concluded that across the USA even when electricity is produced primarily from coal in regions with "dirtiest" electricity grids, the EV produces lower emissions than the average compact gasoline-powered vehicle and claims that more than 80 percent of the US population live in an area where the EV can have lower emissions than the most fuel-efficient gasoline or hybrids vehicles (Anair & Mahmassani 2012).

A similar study for the European territory using the LCA method to assess environmental impacts revealed that the EV, even when fueled by electricity with higher carbon intensity, emits less GHG than a conventional diesel vehicle. The study also revealed that critical metals and rare earth minerals –

[17] Is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling (includes resource extraction, fuel production, delivery of the fuel to vehicle, and end use of fuel in vehicle operations).

[18] Includes activities from resource extraction through fuel production to delivery of the fuel to vehicle. Compared to WTW, WTT does not take into consideration fuel use in vehicle operations

[19] Analysis includes actual combustion of fuel in a motor vehicle for motive power.

thanks to technological innovation and new extraction methods associated with discoveries of new reserves and regulation – would not halt the expansion of EV in the coming decades. The study further reveals that future EV will be even more beneficial to the environment due to increased participation of renewables and technological advances in the production of EV batteries (Messagie 2014).

A bottom up study to identify whether EV can be a cost-effective option for the consumers of each EU27 member state by the year 2050, revealed that EV "will reduce by one-quarter the total EU final energy consumption of the transport sector, with oil products decreasing by 65 percent and electricity increasing five times compared with 2010" (Seixas et al. 2015).

One LCA study aimed at identifying how much of the CO_2 is produced by driving an electric car one kilometer. It compared the main EV models with compatible ICEV models in countries such as the USA, China and the United Kingdom. It concluded that some electric cars in some countries emit less carbon dioxide per kilometer than best-selling petrol vehicles, if we follow a well below 2^0C pathway. Currently in Brazil, CO^2 emissions are much lower for EV when compared to ICEV, as shown in Figure 2.10.

A Brazilian study to evaluate the EV emission balance in Sao Paulo revealed that the mass adoption of EV represents significant energy and environmental benefits for the largest Brazilian city with a predominantly clean energy matrix (Costa & Seixas 2014).

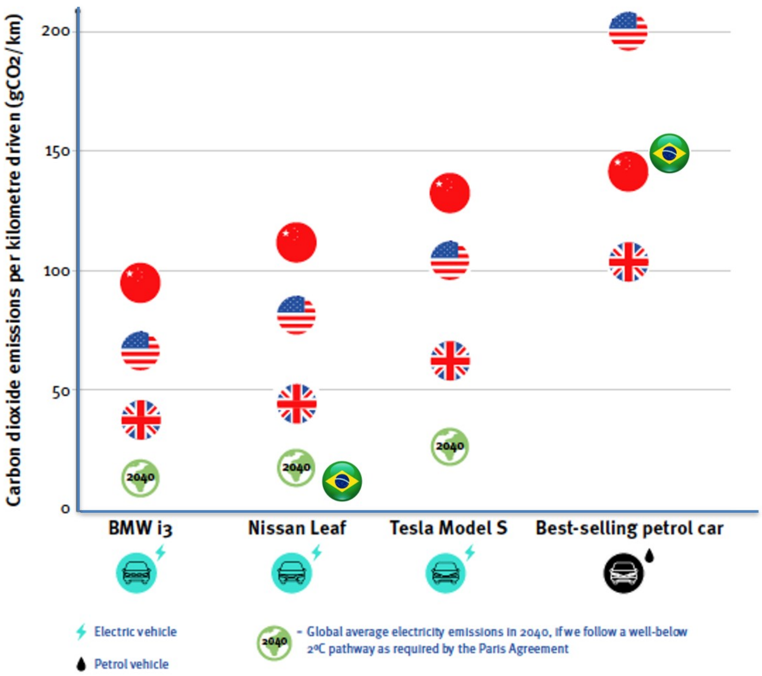


Figure 2.10 – Comparison of CO_2 emissions between EV and ICEV (Adapted from Gambhir, A. et al. 2018)

Divergences between LCA studies

There are divergences between LCA studies due to the non-parameterization of the indicators adopted by the authors. For example, the study that claims that gas and coal powered EV is dirtier than diesel and petrol cars, "EV charged using coal-based electricity yields higher lifecycle emissions than ICEV" (European Parliament 2018), the carbon intensity figures used for both natural gas and coal electricity are global (0.67 $kgCO_2/kWh$ and 1.16 gCO_2/kWh respectively), much higher than the relevant USA figures (Poliscanova 2018).

In order to try to clarify the differences presented in several LCA studies Nordelöf (2014) carried out an investigation that included 79 papers, and concluded that the main reasons for the divergences between the studies (pros and cons) can be explained in four points: 1) variations in systems boundaries, (2) electricity mix divergence, (3) divergences in the tailpipe emissions monitoring system, and (4) divergences in parameter and data choice such as lifetime and battery lifetime, and kilometers traveled annually by vehicle. The study points out that the cleaner the energy that carries the EV the more benefits there will be for the environment (Messagie 2014; Nordelöf et al. 2014).

There are those who defend the use of EV even when supplied with dirty energy, because the EV does not pollute the air by use, thus saving the large urban centers from polluted air. In addition, the energy industry discharges emissions outside urban areas and with high chimneys. In an LCA study to identify how clean EV are, Mierlo (Van Mierlo et al. 2017) concluded: “The electric propulsion seems to be a better option for city driving, mainly because of their zero tailpipe emissions and high energy efficiency. Also, the emissions from electric power plants are discharged through high chimneys in a controlled manner, mostly out of city limits.” Besides, if there is progress in the CO_2 capture process, it will probably be much more feasible to do so in a single location (power generation plant) than in the exhaust of the millions of vehicles on the streets and roads worldwide. Further, technological advances have allowed battery manufacturers to use clean energy for the production of both the battery and the vehicle (e.g. Tesla Motors gigafactory), contributing to the reduction of the ecological footprint and consequently increasing the benefits of EV against the ICEV model. Additionally, the recent IPCC report recommends using EV as a way to mitigate road transport emissions to meet the goal of reducing GHG emissions (IPCC 2014).

2.3.4 Energy dependence reduction, efficiency, and the renewable energies

Increasing the market share of EV can be a way to diversify energy sources, as well as reducing dependence on fossil fuels especially by oil importing countries. Transport – the second most energy consuming segment – is highly dependent on oil, as more than 90 percent of global transport is fueled by fossil fuel (REN21 2018). In this context, the growth of the share of renewables becomes essential for the large-scale electrification of road transport. Despite the increasing penetration of electric passenger transport, EV share is practically insignificant from an energy point of view. The share of renewables has gradually increased. Between 2007 and 2017 the average growth rate of modern renewables was 5.4 percent (REN21 2018). Apparently, the growth of penetration of renewables will continue to slow, because in 2017, the investments in renewable considering power and fuels (not including hydropower projects) was of 2 percent (although wind has grown almost 11 percent and photovoltaic around 33 percent). However, when comparing the new investments of 2017 with 2015 there is a drop of around 15 percent.

The investments would have to be more expressive, in order to have a more significant share of renewables in the short and medium term. However, there may be changes in the political scenario, since the investments so far were not on the scale necessary to meet the goals of the Paris Climate Agreement. To meet expectations of keeping global temperature rise well below 2°C would require USD 12 trillion investment in the renewable power supply by 2040. This translates to investment levels on the order of USD 500 billion per year, and in 2017 the global investment was around USD 280 billion (Energy & Transformations 2017).

For Kingsmill (Bond 2018), there are some other factors that must be taken into account when assessing the growth potential of EV penetration with increased production of renewables: (i) the cost of solar panels has fallen from 85 percent over the last seven years, and is becoming materially cheaper; (ii) EV battery costs have fallen 73 percent to $268 per kilowatt hour (kWh), and Tesla Motors, the electric car maker, predicts they will reach $100 per kWh by 2020; (iii) growth of policies restricting the use of ICEV (in large urban centers) to limit carbon emissions; (iv) incentives for EV and renewable energy; and (v) EV could be cheaper than conventional internal combustion engines by 2020.

The total or partial integration of these factors – the engine of change appears to be the solar PV, EV lithium-ion (Li-ion) batteries – reveals the potential to quickly increase market share of both EV and photovoltaic energy, since the investments in this case are pulverized (consumer interest), and can get you a quick and mass acceptance as happened with the emergence of Urbe and AirBnB. From a strategic point of view, there are three major drivers of change with the potential to lead the transition to a new low-energy mix: environmental, geopolitical, and technological. The environmental drives include the need to reduce carbon dioxide and air pollution control, especially in cities. The geopolitical side is based on the desire to escape energy dependence. On the technological side, the thrust of change is the evolution of technology enabling new business models and management mechanisms.

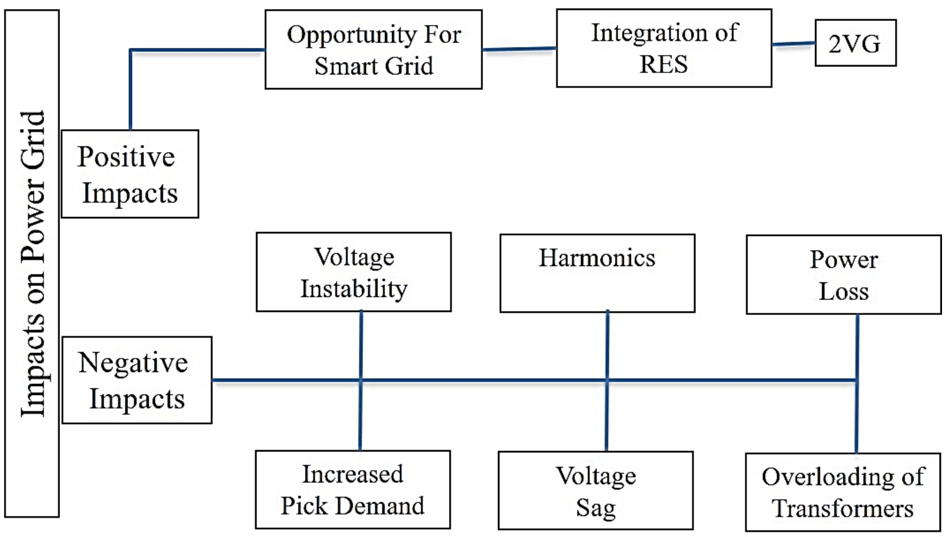
In this context, the expansion of renewables and electric mobility becomes even more important, as mechanisms such as renewable energy sources (RES), and the EV complement each other (i.e. EV users can use RES to generate power locally and charge EV). The roofs of large real estate (logistic centers, stadiums and railway station), and private spaces such parking lots and shopping centers have great potential to install photo-voltaic panels to charge EV, and supply the network in case of excessive generation. The expansion of solar panels can also be expected due to the reduction of costs as the solar module costs have dropped by around 99 percent over the past 40 years (Tulpule et al. 2013).

Energy service providers – and society – can benefit from the synergy of EV with renewable energy, mainly through the implementation of coordinated pricing from V2G technology. It allows them to adopt better strategies to avoid stress of the peak consumption, as well as integrate and absorb the generation of renewable sources. There are many benefits to charging the electric vehicle with renewable energy. The main benefits of integrating EV with renewables energy such as solar energy photovoltaic and wind turbine energy are reveled in Table 2.9. Although there are benefits arising from the increase in the penetration of renewables in the energy mix, it is necessary to consider, on the other hand, possible impacts of the expansion of electric mobility on the electricity distribution network in the current format.

Table 2.9: Positive impacts (benefits) of integrating EV with renewables

Kind	Application	Main contribution
Solar PV	Smart home	Reduce emissions with the growing number of smart homes. Growth of photovoltaic technology use in the residential sector. Growth of homes using V2G and V2H with solar energy
	Parking lot	Use of solar energy for intelligent parking lots. Use of V2G system with scheduling.
	Grid distribution network	Integration of grid connected by EV and solar PV. Creating strategies for charging EV by solar PV.
	Micro grid	Implement EV and solar PV for micro grid schemes
	Smart manufactory	Integration of EV battery and solar PV to increase renewable use.
	Public & private spaces	Encourage integration of EV battery and solar PV to increase renewable use in large areas; i.e. sports stadium, shopping, and hospitals.
	Back-up system	Used EV batteries to serve as back-up in schools, public buildings, and hospitals.
Wind turbine	Grid distribution network	Integration of EV with wind energy generation. Development strategies for charging EV by solar and wind energy generation.
	Micro grid	Implement EV and wind energy generation for micro grid schemes.

The analysis of the impact of EV interaction on the electricity distribution channel – due to the increase of the load needed to meet the growth in the EV fleet – can represent considerable risks for the electricity distribution system. It requires coordination to analyze the location of the growth of the fleet of EV and identity the performance of upgrade needed in the distribution network system. The main impacts caused by the growth of the EV fleet on the electricity distribution network are shown in Figure 2.11.



Source: (Adapted from Un-Noor Un-Noor 2017)

Figure 2.11 – The main impacts caused by the growth of the EV in the electricity distribution network

Negative impacts

EV affects the distribution of electricity as like any electrical equipment needs to connect to the grid to receive the energy necessary for its operation. In the case of EV, this energy is stored in batteries, which requires high charge power (Yao, 2017). A model such as the Nissan Leaf is equipped with a 24 kWh battery and is able to consume the equivalent of a week's worth of energy from a Brazilian home and when connected to a 3.3 kW charger in a 220V, 15A system may increase demand (Mwasilu et al. 2014), thus directly affecting the electricity distribution system and its components e.g. transformers, cables, and fuses (Kütt et al. 2013; Richardson et al. 2012). To avoid interference of the EV in the electricity distribution network it is necessary to tailor the charging infrastructure of the location where the EV will be charged.

i) Among the main impacts of EV in the electricity network it can cause voltage instability, and increased peak demand – due to increased demand and certain load characteristics in the network; e.g. extracting large amounts of energy in a short time, as is the case of EV – may lead to system crashes (blackouts). As electricity distribution systems normally work close to the stability limit, increasing demand on the network will require system adaptation and control (Gómez & Morcos 2003; Rajakaruna et al. 2016) through a set of actions capable of covering system upgrading, coordination of activities, and even local generation with PV cells. In many cases, the impacts on the distribution network can be minimized or solved with small upgrades (Richardson et al. 2012).

ii) Harmonics: normally, the charging functions are not linear because the voltage and current of the terminal change during the charging process are fragmented into two phases: a) the charge current is kept constant, and the level of the battery increases linearly over time until the battery terminal voltage increases to a maximum value; b) the current decreases exponentially and the terminal voltage is kept constant to avoid damaging the battery. These non-linear characteristics give rise to a high frequency of current and voltage components, known as harmonics, and their quantity in a system reveals total current harmonic distortion (THD) parameters. Harmonics distort current and voltage waveforms (which can reduce power quality). It can cause stress on power system equipment such as cables and fuses. These effects can be eliminated by, for example, the use of filtering equipment in the feeding system, among other resources (Gómez & Morcos 2003; Balcells & García 2010).

iii) Voltage seg: also known as voltage dip occurs when there is a short duration reduction (one minute) in the root mean square (RMS) value of the voltage. The cause may be overcharging during starting of the electric charge. A possible solution to avoid or minimize the problem is the use of intelligent networks (Misra et al. 2017).

iv) Power loss: the EV connection in the distribution network can cause extra loss of power, especially if the load occurs at peak consumption. Coordinated vehicle loads associated with distributed generation may be an alternative to help solve the power loss problem (Sortomme et al. 2011).

v) Overloading of transformer: EV charging generates heat and affects the transformer (depending on the ambient temperature) and may cause shorter transformer life (in regions with low temperatures the problem is not significant). The impact on the transformer is more sensitive when using more powerful equipment (level 2 and Level 3) and plugging in several vehicles simultaneously (Gómez & Morcos 2003). Among the solutions to the problem is the network upgrade and coordinated EV charging equipment.

2.4 Barriers and challenges to mass expansion of EV

Despite the declared benefits of electric mobility for the environment, EV has not been able to achieve significant market penetration worldwide. Several efforts have been launched to identify and explain the barriers faced by electric mobility. Indeed, the barriers of the EV are manifold. Among the main barriers to mass diffusion of EV are the lack of charging infrastructure, limited range of EV, high EV prices compared to ICEV, long charging time of the EV, and counter arguments to the environmental benefits of EV. Careful examination of the challenges for large-scale expansion of electric mobility points to several other types of barriers that, if combined, may better indicate the challenges faced globally for EV to enter the mass-market.

In this section the main types of barriers faced by EV are examined. The barriers are divided into three groups: vehicles and infrastructure, industry and retail, and government. The objective was to identify which sectors least affect and which sectors most impact the mass expansion of EV. The groups were then classified into five categories: Social (S), Economic (E), Technologic (T), Political (P) and (O) Others. Finally, the categories were classified into two variables: information and adaptation. The latter classification aims to identify if the most impacting barriers occur due to lack of adequate clarifications to the consumers or to technical-operational factors that limit the adoption of EV, as shown in Figure 2.12. The data used for this analysis is listed in Table 2.10.

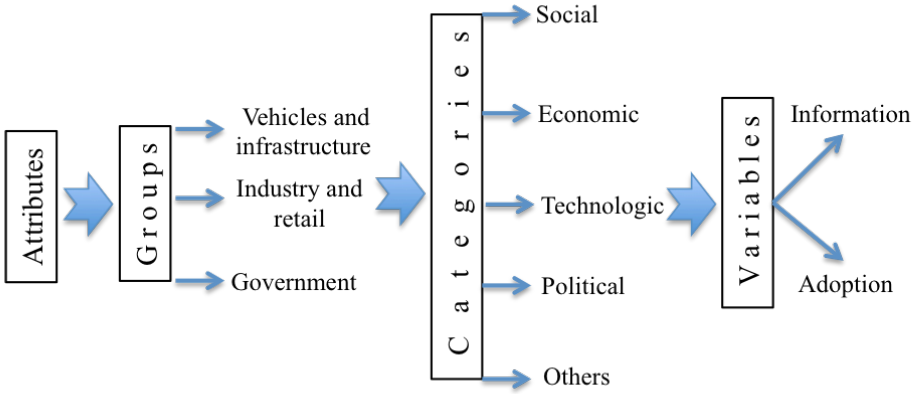


Figure 2.12 – Scheme for the analysis of EV barriers

2.4.1 Barriers by market stakeholders' group

The barriers are basically focused on the industry, the vehicle and the infrastructure supporting the EV. The barriers of the government despite appearing in smaller numbers are of great importance, since it is the government that creates the public policies. As has been observed, the expansion of EV depends mainly on government subsidies.

Regarding industry and retail

The industry and retail sectors dominate for a number of barriers, probably due to the evidence that the main agents – the automotive industry, the oil sector and the franchise car dealership – show no interest in the mass development of EV (globally, only a limited number of automakers offer EV models). The automotive industry in the format we know is dependent on fossil fuels, so it is strongly influenced by the oil industry. Car dealerships are dependent on their sole supplier, which is the automotive industry, so it will act according to the interests of the industry. The barriers of this group are strongly characterized by economic factors.

Regarding the vehicle and charging infrastructure

The barriers that integrate this group are strongly impacted by technical characteristics limiting the expansion of EV. The low volumes of EV models available for sale does not favor the EV's market expansion; i.e. consumers often lack the options to meet their needs. In addition, the higher price than similar ICEV models is another important limiting factor for the EV in the mass-market. This group is strongly characterized by technological aspects. The issue of infrastructure for EV can be considered a "chicken and egg " dilemma. On the one hand, the market does not want to invest in EVSE without knowing if there will be enough EV to remunerate the infrastructure investments. Besides that, the consumer does not want to buy the EV if there is nowhere to charge the car. There is also another dilemma: the automotive industry feels unsure about investing in EV without knowing if there will be adequate charging infrastructure (without EVSE networks the consumer will not buy the EV) and investors are unsure about investing in EVSE (without large-scale EV the investment is doubtful).

Faced with this, Tesla Motors decided to set up its own EVSE network. However, this has not been shown to be the best solution for mass expansion of EV. Finally, the question of the best location of the EVSE is complex and requires further studies to accurately identify the best solutions to solve this challenge.

There are also important operational aspects that need to be overcome to better utilize the charging infrastructure. An example is the question of choosing EVSE by level and type. There are basically four charging EV grades: (i) Long-range Battery (e.g. Tesla Motors models); (ii) Small or medium-range battery (most of EV i.e. Nissan Leaf); (iii) Extended-range electric vehicles (EREV) that is supplemented by gasoline back-up engine; and (iv) All PHEV models. The problem is that the DC charging stations basically serve the longer-range vehicles (e.g. Tesla S), which has a limited number of EV in the market. All other models (most in the EV market) usually do not have the technical capability to use the DC Fast Chargers. Therefore, the government's effort should be to reconcile the platforms so that all types of EV can be charged in any EVSE (as the case of ICEV).

Regarding government policies

The government needs to tailor policies that can support the expansion of EV, but the decision is not simple. Often the government is faced with a trade off because if on the one hand the subsidies for EV

Table 2.10: Key EV (Social (S), Economic (E), Technologic (T), Political (P), Information (I), and Access (A) barriers 1/2

Item	Barriers	S	E	T	P	I/A
Regarding industry and retail						
1	Small number of automobile manufacturers are offering EV models - new EV platforms require substantial investment (Nelson 2014)		x			A
2	Little promotional action by the auto industry for EVs (Nelson 2014)		x			I
3	Technical challenges to development of pickup trucks and SUVs - because of the capacity, weight, and volume of the batteries required for adequate performance (Council 2013)			x		A
4	Low interest of the auto industry in developing EV due to high risk investments (Sovacool & Hirsh 2009; Nelson 2014)		x			A
5	Industry's low interest in automotive components due to the threat of electric mobility (Council 2013)		x			A
6	Opposition of the oil industry (Sovacool & Hirsh 2009)		x		x	A
7	Utility's interest: the increase of EV penetration requires investments (to ensure that distribution capacity is adequate) with uncertain returns or above investors' expectations (Council 2013)		x		x	A
8	Provide generation and distribution capacity to charge EV – needed due to significant EV electricity consumption (Council 2013)		x	x		A
9	Restriction for decentralized power generation - limited photovoltaic installation (Council 2013)		x		x	A
10	Dealerships do not appear to be fully prepared to explain about EV (McCutcheon-Schour et al. 2012)				x	A
11	Lack of interest of car dealerships in selling EV (McCutcheon 2012)		x		x	A
12	Dealership barriers: (i) ICEV sales are more profitable because there is more maintenance and sale of parts. Some dealership in USA and UK account 44 percent of gross profits to sales of parts, services, warranties, and financial services; (ii) EV can start secondary delivery channels such as car-buying services, major membership organizations, and internet which results in a threat to the dealerships (Henry 2012; Busse et al. 2013; Lee & Lovellette 2011)		x		x	A
13	Depreciation of EV. The nonexistence of the used EV market leaves consumers insecure without knowing if they will be able to sell the EV for a reasonable value in the future (Council 2013)		x			I
14	Business model - by being less profitable for the dealership, the EV needs an innovative business model capable of maintaining profitability (Council 2013)		x			A
Regarding vehicle and infrastructure						
15	Higher upfront costs than their conventional-vehicle counterparts (Council 2013)		x			I
16	Few model choices are offered to customers (Council 2013)		x			A
17	High battery cost (Council 2013)		x	x		A
18	Limited driving ranges (Council 2013)			x		I
18	Long battery-charging time (Council 2013)			x		I
20	Uncertain battery life (Council 2013)			x		I
21	Battery power loss in extremer temperature (Council 2013)			x		I
22	Lack of public charging infrastructure (Council 2013)		x		x	A
23	Impossibility to charge the EV at home due to lack of garages or socket points or technical limitation to install residence-charging points (May 2015; Nelson 2014)	x		x		A
24	Work place to offer charging points (Nelson 2014)		x			A

2/2

Item	Barriers	S	E	T	P	I/A
Regarding of vehicle and infrastructure						
25	Low capacity to remunerate investments in infrastructure; low value of electricity, lack of scale and difficulty in selling aggregates, e.g. traditional fuel stations sell other products, which helps to monetize the business (May 2015)		x			A
26	Different types and levels of charging stations: DC models (basically only for long-range battery) vs AC (for short and medium-range battery- most of EV and all PHEV) (May 2015)			x	x	I
27	The payback period for EVs can vary between six and eight years, which is longer than the three to five years that a car owner traditionally would hold onto a car (Hertzke et al. 2018)		x			A
Regarding government and society						
28	Lack of standardization of plugs - multiple plugs (Hayward, 2015). Two types of standards, the CHAdeMO protocol accepted by Japanese car manufacturers, and SAE International's Combined Charging System (CCS) approved by German and U.S. industries, are currently competing for fast-charging stations globally (Haddadian et al. 2015)		x		x	A
29	Taxes for governments - motor-fuel taxes generated $70 billion in revenue for federal and state governments in 2010 (APTA 2012)		x		x	A
30	Governments fear losing jobs (May 2015)		x		x	A
31	Low investment in research: (i) to identify why potential customers would or would not purchase; (ii) to determine which EVs are the most successful and why; (iii) which government incentives are most influential in affecting customer decisions; (iv) which public education efforts work best; (v) which kinds of demonstration activities are most helpful (Axsen & Kurani 2012; Heffner et al. 2005; Council 2013)		x		x	I
32	Mindset: people are not familiar with EV options (May 2015)	x				I
33	People are not familiar with cost and benefits of EV (May 2015)	x				I
34	Consumers do not understand how EV work (e.g. charging systems). They do not know that buying electric "fuel" from a public charging station should be as simple as filling a car at a gas station (May 2015)	x				I
35	Perception about the safety of EV; i.e. accidents in US and China, some with vehicle fires, have been widely publicized and may create consumer insecurity (Wang et al. 2012)	x				I
36	Perceptions about range ("Range Anxiety") of EV and real driving needs (Nelson 2014; Santos et al. 2011)	x				I
37	Social skepticism that causes barrier to new technologies i.e. German study reveals consumer's misconceptions about EV and casts doubt on the large-scale acceptance of electric vehicles (Bühler et al. 2014)	x				I
38	Lack of marketing, education and consumer enlightenment programs that can demonstrate the environmental, energy and other benefits of EV (Krause et al. 2013; Burgess et al. 2013)	x				I
39	In some countries the government (somehow) subsidizes oil (Coady et al. 2010)		x			A

can reduce the greenhouse anthropogenic emissions and help mitigate climate change, on the other hand it can mean tax reduction, and loss of jobs. A 2018 study suggests that the automotive industry will lose about 306,000 jobs by 2030, and almost 30 percent will be due to the expansion of electric mobility (Der & Die 2018). However, the report explains that only 27 percent of the total (about 84,000 seats) will be specifically due to the expansion of electromobility. The remaining 73 percent will be the result of increased productivity in industry.

Some countries such as Germany, which has a robust auto industry, may gain or lose jobs. If the country decides to adopt EV for the mass-market, the country may lose job openings during the transition time once the batteries (and battery components) are manufactured outside the country (e.g. Asia), and the EV assembly is simpler and requires fewer workers than ICEV. On the other hand, in China the expansion of EV generates jobs since the Asian country processes the raw material and produces the EV batteries cell, and manufactures the battery and the EV. In addition, the German government will lose revenue from ICEV, which will no longer be produced, as well as from fossil fuel consumption (electricity is cheaper than fossil fuel, and EV is more efficient than ICEV). The expansion of renewable energy may be a solution to keep jobs, but it requires investments and subsidies that can jeopardize the government's budget.

2.4.2 Information and adoption barriers' analysis

Another way of classifying barriers, besides those presented in previous topics, is to identify information barriers and barriers of access, as discussed in the following sections.

Information barriers limit the penetration of EV due to lack of adequate clarification about the product (e.g. benefits, subsidies, characteristics, safety, and performance of the EV) and its use (e.g. charging methods, cost of use, and EV charting time). With few vehicles in circulation consumers are without reference and need information about the product from sales channels. For instance, the consumer does not always know the distance traveled with the vehicle daily and thus, they tend to want autonomy above what they really need – research reveals that 92 percent of drivers drive less than 110 km per day (Nelson 2014).

Therefore, many users fail to buy an EV due to "range anxiety". The EU ELVIRE project also realized that the density of EVSE can affect the user's perception, and, in part, the decision to adopt EV or not (Liao et al. 2017). In order to solve the problem, the EU ELVIRE project created an advanced information and communication technology (ICT) solution, in which software selects the routes pointing out the charging stations. Around 92 percent of the users were satisfied with the solution adopted by the project (Putrus et al. 2018). The EU ELVIRE Project reveals that with proper technological features, clear clarification, and EV test-drive can help accelerate the expansion of EV. As the market is expanding issues such as "range anxiety" tend to disappear or significantly reduce due to increased knowledge sharing among users. When this is not the case, the role of stakeholders (automakers and car dealerships) should act as a driving force in breaking down information barriers, but they are likely to hesitate to do so because of the threat of loss of profitability with reduced market share of ICEV (Liao et al. 2017).

Access barriers

For this analysis, the access to all types of barriers, except information barriers, will be explained, e.g. lack of charging infrastructure, not being able to charge the EV at home, limited number of models available for sale, and high EV price. This dominate type of barrier limits or impedes the expansion of the EV market, and should receive appropriate treatment to allow the expansion of electric mobility in volume capable of helping to achieve transport mitigation targets.

2.4.3 The Brazilian market barriers

Most of the barriers identified in the countries that are developing electric mobility should remain in the Brazilian market when the EV market is expanded. However, the expansion of electric mobility should also take into account local characteristics, especially with regard to the infrastructure supporting EV. Brazil presents the following additional barriers.

Biofuels barrier

Brazil stands out in the international arena for its leadership in the production of biofuels, especially ethanol from sugarcane. The Brazilian government has been continuously launching policies to encourage the production and consumption of biofuels, such as Pro-alcohol (National Alcohol Program) and PNPB (National Program for the Production and Use of Biodiesel).

The Brazilian National Biofuels Policy was restructured in 2017, with the enactment of Law 13,576, giving rise to the RenovaBio program with an increased share of various biofuels in the Brazilian energy mix, such as the strengthening of the presence of ethanol, biodiesel, biogas and aviation bio-kerosene (EPE 2018). Regarding ethanol several government actions, direct or indirect, have been adopted to ensure the success of the program, e.g. increases in the percentage of anhydrous ethanol in gasoline from 20 percent to 27 percent since March 2015 (Ministério da Agricultura 2015). The government's goal was to increase ethanol production by 7.5 percent by 2015 (EPE 2018). On the other hand, there is no target for EV production.

Therefore, considering: i) the massive investments by the Brazilian government in biofuels (it's responsible for generating 1.2 million direct and indirect jobs, representing more than 16 percent of the Brazilian energy mix and generating economic foreign exchange (TÁVORA 2011); and ii) the understanding that the National Biofuels Policy is a tool to support the Paris Agreement under the UN Framework Convention on Climate Change, with an emphasis on its role in mitigating GHG emissions. Therefore, EV is expected to face a strong biofuels (ethanol) barrier in Brazil.

Pre-salt oil barrier

Naturally, the oil barrier affects the expansion of electric mobility worldwide. What makes this approach peculiar to the Brazilian case is: (i) Brazil is one of the major oil producers. In 2017, the country ranked 11th in the list of the world's largest oil producers (BP 2018) – being a major oil producer should not be a barrier to EV, as Norway, for example, is a major oil producer and is a worldwide leader in EV penetration; (ii) Brazil has adopted policies to ensure the development of the oil industry.

The country's target for the next 10 years is to triple annual oil production, making the sector responsible for almost 70 percent of the projected investment equivalent to $250 billion for the entire Brazilian energy sector (EPE 2011); (iii) Brazilian oil production is expected to increase from 2.1 million barrels per day to 6.1 million barrels per day in 2020, as a consequence of pre-salt exploration (EPE 2011). Given the robustness and economic and energy importance of the oil industry to the country, as well as the policy incentives of the Brazilian government to increase oil production, it is foreseeable that the EV faces an even greater barrier from the domestic oil sector in Brazil.

Operational barriers

The charging system of the EV as we know it requires a longer charging time compared to the supply of the ICEV, requiring the vehicle to be parked during the charging period. Factors such as vehicle safety and vehicle occupant's safety should be considered for the implementation of the EV charging network, and may be characterized as an additional domestic barrier to this type of mobility in Brazil, and in other regions with the same characteristics.

Business barriers

One of the great challenges for the expansion of EV that deserves attention is to find innovative business models. Identifying means for stakeholders (especially car dealership and infrastructure players) to be adequately remunerated and provide investor safety is among the major challenges for electric mobility to expand at the expected rate (Vimmerstedt et al. 2015). The country that fails to have significant share in electric mobility (contemplating especially the Car-as-a-Service system) will probably have difficulty in developing business model innovation. More information about business models is in Section 2.5.2 of this chapter.

Other barriers

Some other factors may become barriers to the expansion of EV in Brazil:

i) The Brazilian automotive industry is amongst the ten largest worldwide. Consequently, the Brazilian automotive industry will have to make significant investments if it decides to produce EV for the mass-market.

ii) Production of EV lithium-ion batteries is under Asian control and their importance is likely to increase the cost of production (although neighboring Chile is a major supplier of raw material for EV batteries).

iii) If it is decided to produce EV batteries in Brazil, there will have to be large financial investments in plant construction, and it will be necessary to import the raw material increasing the vehicle cost of production as well (a possible solution could be the large-scale EV production for export).

iv) Brazil's neighboring countries of South America have not prioritized the development of electric mobility, which may be a limiting factor for export options.

v) Brazil is a country that can require long journeys. For example, crossing the state of Minas Gerais, covers more than 1,000 km of roads (from Pouso Alegre to Sao João do Paraíso, 1,125 km), and to cross Brazil by car from Chuí, Rio Grande do Sul to Oiapoque, Amapá is more than 7,000 km. In addition, the distances between cities and the countryside would require robust charging infrastructure. Therefore, the long distances require greater investments in EVSE network.

2.5 Circular economy and innovative business models

Economic development based on the linear model, guided on the "take, make, and dispose" principle, is reaching its limit. The business-as-usual demand for consumer goods is rapidly depleting natural resource reserves, putting the continuity of human development at risk. In spite of all the technological advances registered – especially in the last three decades contributing to the increase of around 40 percent in the productivity of the production systems – the demand in this same period increased around 150 percent (Giljum et al. 2013).

The need for human development based on restorative and regenerative principles finds support in the circular economy that provides economic growth with less ecological footprint by reducing the use of virgin raw material, optimizing production processes, and minimizing systemic risks with generation of renewable flows. In other words, generating and recovering values of products and services, maintained for long term and comprehensive to all parties involved in the economic system.

In the context of electrified transport, despite the environmental impacts caused by the extraction and processing of raw materials for EV battery production, the evolution of EV to the mass-market brings environmental, and socio-economic benefits. Probably the EV will no longer be seen as an asset of high economic value. For those who do not own their own home it is usually the most valuable asset, and for those who own a home, the car is usually the second most valuable asset. It can be perceived as an appliance capable of storing energy, supplying the house with electricity whenever necessary, help in the management of the electricity distribution system, generating revenue for the owner, as well as serving as family transportation. The advancement of electric mobility is likely to provide economic advancements and deep shifts in transport business models (BM) by enhancing the strength of the circular economy and finding a profitable position in the current emerging business framework.

2.5.1 Synergies between EV and circular economy

Concern about avoiding anthropogenic emission and mitigating the climate change leads us to seek new forms of managing the economy with a sustainable pathway. Actually, the majority of business operates in a linear economy (LE) under the view of production scale where the source materials are as cost-effective as possible in order to sell the largest volumes. This system is based on the principle that there is an infinite amount of resources available in our planet, a fact that all of us know not to be real.

Therefore, the need (opportunity or challenge) arises to change our production system and consume a more sustainable model called circular economy (CE), based on a "make, use, and return" model. Unlike the LE, the CE treats resources as finite. The CE model aims to reduce dependency on raw materials, and limit waste. In this context, the new business is based on leasing, subscriptions, or various types of shared economies. In the case of electrified mobility, its application becomes possible as the cars can be shared (CaaS) and the charging station is shared as well. After the end of life the batteries will then find a second life (e.g., dummy stations on schoolyards, and back-up systems), and the cars and charging stations are brought back for refurbishment or recycling. This process is repeated until the vehicle and EVSE are fully reused or recycled.

A European study to identify the economic and environmental EV battery impacts in the environment revealed that Europe already recycles lithium-ion batteries and the scenarios point to minimum recycle rate of around 60 percent and a maximum of 94 percent. In addition, research investments to improve the EV battery recycling process can provide significant economic gains for Europe as there is a proposal for the creation of an 'EU Battery Alliance' to support the full value chain of batteries in Europe, with large-scale battery cells capable of making Europe a global leader in sustainable battery production, use and recycling in the context of the circular economy (European 2018).

In addition, in 2018, the European Commission commenced the new innovation deal entitled "From E-Mobility to recycling: the virtuous loop of the electric vehicle" to encourage the large-scale deployment of the EV based on the principles of a circular economy. The Renault Group (which accounts for more than 150,000 EVs in the market around the world) is a partner in the project; the automaker is committed to a large-scale deployment of 100 percent electric mobility (EEA 2018).

To support the EU project for a circular economy, the Renault Group will develop solutions that will increase the energy storage capacity of the EV' batteries as well as the use of renewable energy such as solar and wind power to promote the production of green electricity. The project reveals that EV is becoming a key element of the energy transition to affordable and low-carbon electricity in line with the development of the circular economy (EEA 2018).

Table 2.11: EV by types, cars and battery weight

EV type	Battery weight (kg)	Vehicle weight (kg)
Luxury car	553	2 100
Large car	393	1 750
Medium car	253	1 500
Small car	177	1 100

Source: (Ellingsen et al. 2016)

Regarding the problem relating to rare earth elements (REEs) for production of EV batteries, it will be difficult to substitute with the other fully sustainable materials in the near future, but with improvements in the EV battery's production processes it will be possible to reduce environmental impacts without compromising the performance of the battery (Widmer et al. 2015), as shown in Table 2.11.

In addition, new resilient methods associated with prioritization of smaller batteries for EV may help reduce the problem of REEs since the smaller battery contains correspondingly lower quantities of raw materials. A typical luxury car weighs almost twice as many small cars in total, and their batteries weigh about 3 times as much (Ellingsen et al. 2016), as shown in Table 2.11.

However, investments in research will be necessary to help overcome the environmental challenges caused by the extraction of the raw material for the EV battery that may result, in addition to the actions already mentioned, with better raw material extraction techniques, adequate handling of waste, greater participation of renewable energies throughout the EV production process, and efficient reuse and recycling of the EV battery.

In summary, from the circular economy and environmental perspectives the impacts with the expansion of the EV can be minimized with the following actions (EEA 2018): (i) recycling – increase the use of recycled materials and reduce the use of REEs; (ii) consumption – encourage changes in consumption patterns through the reduction of personal assets and increases in the sharing economy; (iii) waste – to reduce waste generation through technological advances, new production techniques, economies of scale and incentives to change the behavior to sustainable consumption; (iv) battery – improvement in the processes of production of the battery and opting for battery types with the lowest impact per unit of energy provided.

The EV battery usually reaches the end of its life for the vehicle after about 8 to 10 years or 150,000 to 160,000 km, with a loss of storage capacity of about 20 percent at this point (EEA 2018). Thus, there are full conditions of reuse of the battery for other functions, before following other alternative routes. One of the main aspects of electric mobility is that the EV provides the emergence of different applications and incorporation of new resources (e.g., connectivity and sharing), which can contribute to the reduction of consumption of virgin raw materials. The electric mobility industry does not have as much need to launch a new car model every year, as does the ICEV industry because the pursuit of profit in the EV industry is not in the sale of the product but essentially in the sale of services.

The consumer who has a shared vehicle will not have to have a new car model every year as the important thing will be to maintain technical and operational conditions of the vehicle which can be tracked and updated online. Compared with someone who may want to drive a car of the year for the status, the person who uses the car-sharing system may not care whether the vehicle is a fashionable model or not. The person wants the vehicle to be a good condition for a safe and efficient commute.

Therefore, the sharing system with EV as it increases efficiency, enhances the rational use of the product and distances the ownership interest from the private good to private use, and can make a great contribution to the development of the circular economy, thus supporting the sustainability of transportation.

2.5.2 Innovative business model to support EV evolution

Creating an innovative BM will be critical to the mass expansion of EV. New BM is likely to support a new individual transportation system that should be quite different from the one we are currently familiar with. In order to do so, it will be necessary to overcome the status quo barrier and move towards innovative offerings of products and services that are capable of providing new solutions, capturing aggregate values, attracting investments to the electrified transportation business, capturing new players and adequately remunerating current and future enterprises.

Indeed, changes are already occurring. Some automakers are investing in car-sharing and other electrified and connected transportation activities. Vehicle manufacturers are probably realizing that the source of profitability of the auto industry business should shift from profit from car sales to car services (i.e. CaaS). Some automakers already prefer to rent and not sell their cars. Volvo, for example, suggests that if the customer likes one of their models, they should not buy it but lease it. Volvo began to promote the Care by Volvo program in Germany in October 2018. The brand wants to lease the cars to the customers for a fixed monthly amount (the "subscription") instead of selling the vehicle to the customer (Nicola 2018).

Innovative BM is likely to influence how electric mobility will work in the future. The problem is that the innovations have been slow perhaps due to the still low EV market share. It is hoped that the advancement of electric mobility could further boost the new BM.

In addition to infrastructure, innovative BM must find fertile ground in connection to renewable energy sources driven by electric mobility. The photovoltaic market has expanded considerably and stakeholders linked to electric mobility reveal interests in the expansion of this market segment. Several European projects seek to identify new solutions using EV with photovoltaic panels and innovative new BM for electric mobility, as shown in Appendix A, Tab-A2.

Among the innovative designs of BM for EV and EV infrastructure, are:

i) Amsterdam ArenA – Developed under the coordinates of the SEEV4-City project. The project is exploring how to harness Information and Communication Technologies (ICT) to structure the energy system; i.e. the EV is charged by locally produced energy from photovoltaic panels and energy is stored in the car batteries.

It was built at the Amsterdam ArenA, the largest sports stadium in the Netherlands, a system with more than 4,000 photovoltaic panels installed on the stadium ceiling with a minimum capacity to generate 3 MWh. The generated energy is stored in electric car batteries (63 Leaf used batteries and 85 new Nissan Leaf batteries). In addition to increasing the penetration of renewables in the grid, the project will help manage peak electricity demand, ensuring stability in the region's electricity distribution network. The next step of the project is to identify a BM that can support the expansion to the market of EV and photovoltaic projects (City 2018).

ii) Riversimple – This is a UK vehicle manufacturer working in partnership with a research laboratory in Wales to expand a hydrogen-powered fuel cell electric vehicle (FCEV) market system. The Riversimple mission statement is: "To pursue, systematically, the elimination of the environmental impact of personal transport." (Riversimple 2018)

Riversimple is developing a new business model called "Whole System Design". The model is to support the cost-effective development of car factories created for small-scale production (5,000 cars per year). The design is challenging because the BM of traditional manufacturers requires large-scale production to be profitable.

Riversimple designs energy-efficient cars and currently has two models: Morgancar and Riversimple Urban Car. Several elements are considered during each phase of the project, including a hydrogen fuel cell light carbon fiber composite material, open source design and development, leasing instead of car sales, manufacturing distribution focused on small companies and broad corporate ownership.

Riversimple's BM consists of offering the monthly car subscription to customers, such as cell phone plans, in which the value charged covers everything – the car, the maintenance, the insurance, and the fuel (Riversimple 2018). Riversimple's BM is flexible, accessible, and collectivist (e.g. car-sharing) and is a socially-framed initiative. To be successful, this BM relies on more service-intensive sales and good governance to ensure low operating costs (Wells 2018).

iii) Tesla Motors – This is an American automotive and energy company based in California, USA. Tesla Motors proposes to manufacture EV in the luxury segment of the industry like its main competitors Mercedes-Benz, BMW, Audi, and Lexus. The luxury car market has an average price of around $44,000. In comparison, Tesla's Model S P85D all-wheel drive retails for a price of around $128,000. To thrive in a conservative, ICE-driven segment, Tesla Motors had to abandon centennial concepts in the automotive industry and innovate its business proposition (Tesla Motors 2018) as described below.

Traditional automobile industry business model

Since it was created, the auto industry has its BM focused on the sale of vehicles. Therefore, the more units sold, the greater the opportunities to profit.

Business model proposed by Tesla Motors

The innovative BM proposed by Tesla Motors takes into account the aspects of such a high-end product with a high level of innovation adaptation – Tesla Motors realized that EV is simpler to produce and maintain than ICEV. The number of moving parts of EV is reduced drastically, as the drive shaft, fuel tanks, transmission, and internal combustion engines are all removed. With the vehicle needing less maintenance and being simpler to maintain than the ICEV, Tesla Motors realized that it would not be necessary to have a network of franchised dealerships, which provides a financial reduction of around $2,000 per vehicle sold (Team 2015).

High integration of information technology into many aspects of EV business model – the mechanical parts of the ICEV have been replaced by information technology. This allowed Tesla Motors to sell the car online, monitor the maintenance of the vehicle, and offer some services over the internet. The value saved with these steps is transferred to Tesla Motors, which holds control of all steps of the production process (from the production to the sale of the car). While traditional automakers, in order to maintain sales volumes, need to make large investments with the launch of new models of ICEV every year, Tesla Motors only updates the software of their cars online (e.g. updates on Model S was priced around $10,000, and can be done by internet), generating additional revenues and avoiding investments for the production of new annual car models.

Tesla Motors own a sales network that provides the benefit of having its teams trained for the new concepts of EV. Tesla Motors prides itself on its smart technology and different approach to consumers if compared with ICEV – which provides some competitive advantages such as customer satisfaction and incentive programs; i.e. In 2018, Tesla Motors launched a program that allows Model S owners to refer a Tesla Motors vehicle to someone for a $1,000 credit at service or rebate to a new car. In addition, the network itself avoids conflicts of interest. For example, the franchise car dealers (usually multi brands) could prioritize the sale of the brand that was more convenient; i.e. when we buy a phone at a dealer like Best Buy or Amazon the product that will be highlighted will be the one that is of greater interest of the dealer (Team 2015; Chen & Perez 2018).

iv) Vertical integration from EV manufacturing (battery software and battery manufacturing) – Tesla Motors performs all production' processes (batteries, car and software). The advantage is that scaling up will lead to reduced costs. Currently, costs are high due to the low sales volume and the complexity of production logistics; i.e. the raw material for the battery arrives in the USA from South America. After initial processing it goes to Asia for the final processing of the parts of the battery, and returns to the USA for installation of the battery in the vehicle. In the future, reducing operating costs and shortening the production time of the EV should change this logistics. In addition, improving the use of renewable energy could reduce production costs and at the same time reduce the carbon footprint in the production of battery, car and vehicle components; i.e. in 2019, Tesla's Gigafactory 1 in Nevada was planned from the start to be a fully self-sustaining facility, with a combination of rooftop solar, nearby wind turbines, and, of course, Tesla Power packs for energy storage (Field 2018).

Tesla Motors has developed its own charging network for its electric models so it can monetize infrastructure investments in the product price. In addition, it will have more flexibility to perform upgrades, pays a considerable attention to reduce range anxiety by a high performance supercharger station network and high capacity batteries, and negotiates the purchase of wholesale energy (or produces it with solar panels) as long as there is an increase in EV sales (Team 2015; Chen & Perez 2018). In summary, while the ICE vehicle automakers focused on the profit from the sale of the cars, the Tesla Motors profits come from the sale of the cars, plus by the sale of the services throughout the life of the vehicle as well.

However, achieving success in a new BM is not an easy task. The electric mobility sector has revealed attempts that did not thrive; i.e. Better Place attempted to innovate with a "battery exchange" BM by establishing service stations to process battery replacement as quickly as fueling a fossil fuel vehicle (Christensen et al. 2012).

The BM considered, among other factors, trying to solve the problem of consumer range anxiety and optimize the process of charging the electricity with the lowest possible cost, since the user could choose the best time to charge them and would have greater bargaining power to buy electricity in large volume, in addition to being able to charge the batteries with renewable energy (e.g. photovoltaic panels), reducing the transport carbon footprint (Granovskii et al. 2006; Hawkins et al. 2013). The Better Place BM failed due to lack of scale in the production of vehicles equipped with the swap system (only Renault made huge investments).

Another example of the difficulties faced by the new BM in the electric mobility sector was experienced by the car-sharing system Autolib (subsidized by Paris public authorities and strengthened by the federal government's support), which became the second largest car-sharing program worldwide (after Hangzhou, China). Started in 2011, and operated by the Bolloré industrial group, Autolib was a pioneering car-sharing scheme intended to serve the city of Paris and 18 surrounding communities with a car-sharing system. By 2017, Autolib had around 4,000 operational vehicles, more than 3,000 parking spots, around 1,100 self-service docking stations across the city, and more than 100,000 subscribers. Services were closed in July 2018 due to high financial deficits and operational failures (McPartland 2018). After all, the main elements of a successful BM, whether from an accounting or strategic perspective, are the positive financial flows and profits that ensures the return on investment (Chesbrough 2010). The unsuccessful attempts are described in Table 2.12.

Table 2.12: Some new electric mobility businesses model that did not thrive

Example	Value creation	Value capture	Value context
Rydek	Design concept only	Separate body EV with batteries; split public / private ownership	Pre-dated support for EVs
Think	Modular assembly in micro-factories. Internet sales plus mobile service support. Later outsourced assembly	2 seats urban EV	Multiple trials and experiments e.g. Think@bout London
Better Place	Infrastructure of recharging stations and swaps stations; tie in with Renault for initial supply of 100,000 cars. Retain ownership of battery	4-seat Renault Fluence EV. Separate ownership of battery	Sought support in specific locations e.g. Denmark; Israel
Autolib	EV car fleet; parking spots; charging stations; subscription managing system	Bolloré Bluecar is a small four-seat, three-door battery electric car	Car-sharing service in Paris, France and 18 surrounding communities

Research may support the regulatory framework that allows the power sector to make its BM more flexible in order to encourage decentralized energy production, as well as allowing individuals and companies to market electricity outside the distribution network. This would, for example, allow anyone to set up a mobile charging station (e.g. in a truck's bodywork) and sell the energy where it is convenient; i.e. large events such as exhibitions, seminars, and fairs.

The market for green wash vehicle services can illustrate the potential of new BMs. Anyone in any country can purchase green wash equipment and sell vehicle cleaning services at a client's home. Changes in the regulation of the generation and commercialization of electricity could provide the emergence of an innovative BM to offer, for example, recharging services for EV in the client's homes and workplace spaces as well. Another sector that reveals opportunities for the exploration of a new BM is smart charging for the EV. The system can help in the management of the electricity distribution network in addition to providing a back-up to the variability of renewable energy sources, as an intelligent network manages the charging of the vehicle.

In addition, other complementary services reveal potential for EV development as well as being a facilitator in the transition to electric mobility. Moreover, innovative BM with EV expansion may find fertile ground in activities including: navigation packages for charging services, payment system access, registration services for EV, charging installation and maintenance services for charging stations; battery swapping technologies, and smart grid applications. For example, EV drivers could look for an EVSE compatible with their car, using a set of applications that can facilitate the identification of a suitable EVSE, and manage the reservation system for charging, associated or not with a payment system, and tariff control (Waller 2011; Mitchell et al. 2010).

2.5.3 Circular economy and business model to support Brazilian EV market

From the point of view of the economy and the BM for the expansion of electric mobility, the Brazilian market should benefit from advances made in other countries, thus making the necessary customization based on domestic market characteristics.

An introductory study to identify the initial vision of activities of the circular economy already exists for Brazil, which pointed out possible opportunities in the areas of agriculture and biodiversity assets, in the building and construction sectors and electrical and electronic equipment. The preliminary study concluded that the Brazilian transition to the circular economy has the potential to generate opportunities in areas of innovation. Brazil has a special market, with its own social characteristics and robust natural capital, enhancing advances in the development of national organizations with the consolidation of processes capable of giving more solidity to the development of socio-economic, and natural capital (MacArthur 2017).

There are low expectations of diffusion of CaaS with EV in Brazil. There are some car-sharing projects in operation in the country, dominated by small businesses, which are mostly startups. Currently, the seven companies that offer car-sharing services (Moobie, Olacarro, Target, Turbi, Urbano, VAMO and Zazcar) control about 8,000 vehicles (almost all ICEV) and have 230,000 registered users, most of them in Sao Paulo. The first company founded was Zazcar in Sao Paulo in 2010, with only ICEV cars. Currently, the company has 130 cars (all Ford Ka models) available for rent in more than 100 parking lots throughout the city of Sao Paulo, where cars are picked up and returned.

Urban LDSharing

Inaugurated in 2017 the company offers some electric cars shared in the city of Sao Paulo. Vehicles are parked in locations throughout the city, accessed by an App, and customers pay for the time they use the vehicle. The project is an initiative of the LDS group in partnership with the French company Vulog, which provides the sharing technology. The services were inaugurated with 15 electric vehicles in the fleet, and in August of 2018 the company registered a fleet of 60 mini-cars Smart and 5 BMW i3 electric (Urbano 2018).

VAMO

This is an alternative mobility project launched in Fortaleza, the capital and large city of the state of Ceará, in 2016. The goal is to use shared EV to promote sustainable urban mobility. It is a partnership between the City of Fortaleza (that has provided areas for 12 charging stations, and a parking lot) and the Sertell Company, which is responsible for the management of services. VAMO has 20 electric cars in Fortaleza, of which 15 small cars are from China's Zhidou and 5 are BYD (Vamo 2018).

The few models of EVs available for sale in Brazil, together with other factors, such as the lack of an EVSE network, and the lack of public policies to adequately encourage the expansion of EV, hinder the innovation of BM in the vehicle sharing market similar to other countries. This probably, helps to explain the fact that automakers have no interest in investing in the CaaS system in Brazil, a decision different from that adopted in other European, North American and Asian countries, where automakers have contributed large financial resources in EV and the car-sharing system.

2.6. Key Findings

The key findings after analyzing the current state-of-the-art in electric vehicles are:

i. There is a fourth attempt for EV to enter the mass-market (1st Phase: 1801-1896; 2nd phase: 1897-1965; 3rd phase 1966-2000; 4th phase: 2001-present). At each phase the time of its duration has been reduced to almost half.

ii. The first three EV phases were led by the West (North America and Europe) while the fourth EV phase has active participation from Eastern countries, led by Far Eastern countries (China and Japan).

iii. The second EV phase was marked by the great penetration of EV that reached almost 40 percent of all automobiles produced in the United States of America.

iv. From the first to the third EV phases, the energy issue (oil market instability and the search for energy security) was highlighted. Already the fourth and current EV phase is being marked by the search for energy security and environmental issues (GHG emissions).

v. The first and fourth EV phases can be considered as periods of disruption. The first EV phase marked the transition from animal transport (horse) to mechanical transport (motor vehicles). The fourth EV phase is making the transition from private road vehicle as a property asset to the vehicle as a service (CaaS), giving rise to different uses of the car (V2H, V2G, V2X) and new forms of personal transportation (autonomous, shared, connected, and electrified).
vi. Technological advancement and government policies (motivated by environmental issues) make EV a viable and affordable solution to reduce GHG emissions and mitigate climate change.
vii. The EV plays a leading role in reducing transport emissions and improving air quality in large urban centers.
viii. Socio-economic issues dominate the benefits of EV, as techno-economic issues dominate the EV barriers.
ix. EV reveals more environmental and energy benefits than ICEVs.
x. The information barriers, although presented in smaller numbers, are important due to their characteristics and the weight of the agents involved (production and distribution system).
xi. The EV aligns with the development of the circular economy and affords new business models.
xii. The expansion of the EV provides opportunities for renewable energy expansion and opportunities for economic and social gains for nations investing in diffusion of EV.
xiii. The EV should continue to expand consistently from developed countries. In Brazil the EV must confront local barriers to its large-scale expansion, such as ethanol, oil industry, and business model for recharging infrastructure network (i.e. issues related to personal and property security).
xiv. Since 2011, sales of EV have almost doubled each year.
xv. EVs should become dominant from 2040
xvi. The hybrid plug-in models have and should continue to have significant participation in the transition to EV.
xvii. There are already more than 170 PEV models worldwide (in 2011 there were only 9 EV models), of which EVs represent around 60 percent.

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Appendix A

Acronyms of the Table A.

UA-United States Of America;
CH-China,
EU-European Union;
JP-Japan;
OM-Other Market

Table A1 - Plug-in vehicles in circulation 1/4

	Brand	EV Models	Kind	US	CH	EU	JP	OM
1	Chevrolet	Chevrolet Volt	E-REV	x				
2	BMW	BMW i3S Rex REEV	E-REV		x			
3	WorkHorse	WorkHorse W15 Pickup	E-REV		x			
4	BMW	BMW i3 (BEV + REX)	E-RE EV	x		x		x
5	Toyota	Toyota RAV4 EV	EV	x				
6	Honda	Honda Fit EV	EV	x			x	
7	Tesla	Tesla Model S	EV	x	x	x	x	x
8	Chevrolet	Chevrolet Bolt EV	EV	x				
9	Tesla	Tesla Model X	EV	x	x	x		x
10	Nissan	Nissan LEAF	EV	x	x	x	x	x
11	Ford	Ford C-Max Energi	EV	x				x
12	Fiat	Fiat 500e	EV	x				
13	BMW	BMW Active E	EV	x				
14	Volkswagen	Volkswagen e-Golf	EV	x		x		x
15	Kia	Kia Soul EV	EV	x		x		x
16	Ford	Ford Focus Electric	EV	x				
17	Tesla	Tesla Model 3	EV	x				x
18	Mercedes-Benz	Mercedes B- Class E	EV	x				
19	BMW	BMW 740e	EV	x		x		x
20	Smart	Smart ED	EV	x	x		x	x
21	Smart	Smart Fortwo EV	EV	x		x		
22	Hyundai	Hyundai IONIQ EV	EV	x	x	x	x	x
23	Chevrolet	Chevrolet Spark EV	EV	x				
24	Mitsubishi	Mitsubishi i-MiEV	EV	x			x	x
25	Jac	JAC iEV65 SUV	EV		x			
26	Zhidou	zhidou D2	EV		x			
27	JMC	JMC E200	EV		x			
28	BAIC	BAIC EX260	EV		x			
29	ZOTYE	zotie Zhi Ma E30	EV		x			
30	BYD	BYD e5	EV		x			
31	ZOTYE	Zotie Zhidou E200	EV		x			
32	Jac	JAC EV4	EV		x			
33	BYD	BYD Qin EV300	EV		x			
34	Geely	Geely Emgrand	EV		x			
35	BAIC	BAIC EU260	EV		x			
36	Chery	Chery eQ	EV		x			
37	ZOTYE	zotye TT EV	EV		x			
38	JMC	JMC E100	EV		x			
39	BAIC	BAIC E180	EV		x			
40	Changan	Changan Benni EV	EV		x			
41	Chery	Chery eQ1	EV		x			
42	Dongfeng	Dongfeng ER30	EV		x			

	Brand	EV Models	Kind	US	CH	EU	JP	OM
43	JMC	JMC E160	EV		x			
44	Horki	Horki E300	EV		x			
45	Lifan	Lifan 330 EV	EV		x			
46	Hawtai	Hawtai EV160	EV		x			
47	BYD	BYD Song EV300	EV		x			x
48	Hawtai	Hawtai E70	EV		x			
49	BAIC	BAIC EH300 EV	EV		x			
50	Saic	SAIC Roewe RXS EV	EV		x			
51	Audi	AUDI Q6 e-tron Quattro	EV		x			
52	BAIC	BAIC EH300L SUV	EV		x			
53	BAIC	BAIC EX400L SUV	EV		x			
54	BMW	BMW i3S	EV		x			
55	Bollinger Motors	Bollinger B1 SUT 60kWh	EV		x			
56	Bollinger Motors	Bollinger B1 SUT 100kWh	EV		x			
57	Bollinger Motors	Bollinger B1 SUT 4 Door	EV		x			
58	Bollinger Motors	Brilliance Zhiyi EV180	EV		x			
59	Chery	Chery Tiggo 3Xe SUV	EV		x			
60	Chery	Chery Carry K50	EV		x			
61	Chery	Chary Carry K60	EV		x			
62	Chery	Chery Carry "YouYou"	EV		x			
63	Dial	Dial Crossover SUV	EV		x			
64	Dubuc Motors	Dubuc Tomahawk	EV		x			
65	Electra Motors	Electra Meccanica Solo	EV		x			
66	FAW	FAW SENYA R7EV	EV		x			
67	GAC	GAC GE3 SUV	EV		x			
68	Geely	Geely X1 MINI	EV		x			
69	Geely	Geely GSE400 CROSS	EV		x			
70	Han Teng	Han Teng Compact Sedan	EV		x			
71	Han Teng	Han Teng MPV	EV		x			
72	Hawtai	Hawtai LU SHENG S1 160	EV		x			
73	Hawtai	Hawtai Santa FE 2 EV 180	EV		x			
74	Hawtai	Hawtai Santa FE EV 380	EV		x			
75	Hawtai	Hawtai SHENG S5 EV330	EV		x			
76	Hyndai	Hyundai Kona Base	EV		x			
77	Hyndai	Hyundai Kona Long	EV		x			
78	Hyndai	Hyundai Elantra	EV		x			
79	Jaguar	Jaguar i-pace	EV		x			
80	Kia	Kia Niro EV	EV		x			
81	Kia	Kia Stonic	EV		x			
82	Leopaard	Leopaard CS9	EV		x			
83	Luxgen	Luxgen US	EV		x			
84	Mahindra	Mahindra KUV100	EV		x			
85	NEVS	NEVS 9-3	EV		x			
86	NIO	NIO ES8	EV		x			
87	Roewe	Roewe ei5 Wagon	EV		x			
88	Singulato	Singulato iS9	EV		x			

	Brand	EV Models	Kind	US	CH	EU	JP	OM
89	Sinogold	Sinogold m3 MPV	EV		x			
90	Soueast	Soueast DX3	EV		x			
91	Tesla	Tesla Model 3 Standard	EV		x			x
92	Tesla	Tesla Model 3 Loaded	EV		x			x
93	Weima	Weima EX5 SUV	EV		x			
94	Xpeng	Xpeng G3	EV		x			
95	Yudo	Yudo n 1 City	EV		x			
96	Yudo	yudo n1 inter City	EV		x			
97	Yudo	yudo n3	EV		x			
98	ZHI	ZHI DOU D3	EV		x			
99	ZOTYE	Zotye SR7	EV		x			
100	ZOTYE	Zotye T300	EV		x			
101	Renault	ZOE EV	EV	x	x	x	x	x
102	Renault	Kangoo EV	EV	x	x	x	x	x
103	Pininfarina Bolloré	Bolloré Bluecar	EV	x	x	x		x
104	Honda	Honda Clarity	FCEV	x		x	x	x
105	Hyndai	Hyundai i35 Tucson	FCEV		x			
106	Hyndai	Hyundai NEXO	FCEV					x
107	Nano	Nano Flowcell Quant E**	FCEV	x	x	x	x	x
108	Nano	Nano Flowcell Quant FE**	FCEV	x	x	x	x	x
109	Nano	Nano Flowcell Quantino**	FCEV	x	x	x	x	x
110	Toyota	Toyota Mirai	FCEV	x	x		x	x
111	Toyota	Toyota Prius Prime - PHEV	PHEV	x		x	x	
112	Ford	Ford Fusion Energi	PHEV	x				
113	BMW	BMW X5 xDrive 40e	PHEV	x		x		
114	BMW	BMW 2-SER Active Tourer PHEV	PHEV			x		
115	Chrysler	Chrysler Pacifica Hybrid	PHEV	x				
116	BMW	BMW 330e PHEV	PHEV	x	x	x		
117	BMW	BMW 530e - PHEV	PHEV	x	x	x		
118	Volkswagen	Golf GTE PHEV	PHEV			x		
119	Audi	Audi A3 Sportback e-tron	PHEV	x	x	x		
120	Hyundai	Hyundai Sonata PHEV	PHEV	x	x			x
121	Volvo	Volvo XC90 T8 PHEV	PHEV	x		x		x
122	Porsche	Porsche Cayenne S-E	PHEV	x				x
123	Kia	Kia Optima PHEV	PHEV	x		x		x
124	Honda	Honda Clarity PHEV	PHEV	x			x	x
125	Mercedes-Benz	Mercedes C350e PHEV	PHEV	x		x		x
126	Mercedes-Benz	Mercedes S 550e	PHEV	x		x		x
127	Volvo	Volvo XC60 PHEV	PHEV	x		x		x
128	BMW	BMW i8	PHEV	x	x	x	x	x
129	Mini	Mini Countryman SE PHEV	PHEV	x		x	x	x
130	Mercedes-Benz	Mercedes GLE 550e	PHEV	x		x		x
131	Cadillac	Cadillac CT6 PHEV	PHEV	x				
132	Volvo	Volvo S90 T8 PHEV	PHEV	x		x		x
133	Mitsubishi	Mitsubishi Outlander PHEV	PHEV	x	x	x	x	x
134	Porsche	Porsche Panamera E-Hybrid	PHEV	x		x		x

	Brand	EV Models	Kind	US	CH	EU	JP	OM
135	Cadillac	Cadillac ELR	PHEV	x				
136	Saic	SAIC Roewe e950	PHEV		x			
137	Saic	SAIC Roewe eRXS	PHEV		x			
138	BYD	BYD Song DM	PHEV		x			
139	Saic	SAIC Roewe I6	PHEV		x			
140	Buick Velite	Velite 5	PHEV		x			
141	Chery	Chery Arrizo 7	PHEV		x			
142	GAC	GAC GA3 PHEV	PHEV		x			
143	GAC	GAC GS4 PHEV	PHEV		x			
144	Audi	AUDI Q3 RS	PHEV		x			
145	Audi	AUDI Q8 PHEV	PHEV		x			
146	Bentley	Bentley Bentayga	PHEV		x			
147	BMW	BMW X1 xDrive25Le	PHEV		x			
148	BMW	BMW 530e xDrive	PHEV		x			
149	BYD	BYD Song MAX	PHEV		x			
150	Changan	Changan CS75 SUV	PHEV		x			
151	Changan	Changan Eado	PHEV		x			
152	Changan	Changan Ford Mondeo	PHEV		x			
153	Changan Ford	FUSO eCANTER ET	PHEV		x			
154	Chery	Chery Exceed TX SUV	PHEV		x			
155	Dongfeng	Dongfeng Yueda Kia K5	PHEV		x			
156	GAC	GAC GA4	PHEV		x			
157	Honda	Honda Clarity	PHEV		x			
158	Kia	Kia Niro PHEV	PHEV	x	x	x	x	x
159	Kia	Kia CEED	PHEV		x			
160	Land Rover	Land Rover	PHEV		x			x
161	Land Rover	Ranger Rover	PHEV		x			x
162	London EV Cia	TX EV Taxi*	PHEV			x		
163	Mercedes-Benz	Mercedes-Benz 560e	PHEV		x			
164	Mercedes-Benz	Merdeces-Benz C-CLASS	PHEV		x			
165	Saic	SAIC eMG 6	PHEV		x			
166	Opel	Opel GranLand	PHEV		x			
167	Porsche	Porsche Panamera Turbo S	PHEV		x			x
168	Soueast	Soueast DX7	PHEV		x			
169	Volvo	Volvo XC40 T5	PHEV		x			
170	Volkswagen	VW Phideon	PHEV		x			
171	Volkswagen	VW Passat GTE PHEV	PHEV			x		
172	Volkswagen	VW Tiguan L	PHEV		x			
173	Mercedes-Benz	Mercedes-Benz GLC350e	PHEV	x	x	x	x	x
174	Honda	Honda Accord	PHEV	x		x	x	x

Source: Insideevs-https://insideevs.com/monthly-plug-in-sales-scorecard/, wattEV2Buy-https://wattev2buy.com/chinese-new-energy-vehicle-market-china-ev-sales-h1-2017/

Table A2 – EV Projects 1/2

Project name	Partners	Project Characteristics	Location	Project type
NewMotion	Mitsubishi motors, Enel, NewMotion, Nuvve and TenneT	EV as an energy buffer. Stability by maintaining supply-demand dynamics, based on request from Grid System Operator	Netherlands	V2B[20] V2G
Amsterdam Vehicle2Grid	Alliander, Hogeschool van Amsterdam, Amsterdam Smart City, Engie, Mitsubishi motors	Solar and V2G combination to store and supply electricity when required. Energy buffer solutions and societal issues are explored in this project.	Netherlands Austria	V2S[21], V2N [22] V2B
SEEV4-City	13 European cities partners	NSRS smart charging and V2G concept Operational environments: V2H, V2S, V2N and V2B Reduction in 150 tons of CO_2 emissions/annum25percent increase in Energy	Netherlands Norway UK	V2G V2H[23]
SMART Solar Charging, Utrecht, Netherlands	USI, LomboXnet, Hogeschool Utrecht, Universiteit Utrecht, Last Mile Solutions, We Drive Solar, New Solar, Vidyn, Jedlix, Stedin, ElaadNL	Bi-directional/compact charger alternating current (AC) Solar charging. Car-sharing. Up scaling to 20 stations	Netherlands	V2X[24]
Solar-powered bidirectional EV charging station	Delft University, Delft; Power Research Electronics, Breda; Last Mile Solutions, and Nissan, ABB, Utility Austin	Integrated EV-PV charger, smart charging algorithm based on EV user, energy prices, PV forecast, multiplexing and distribution network constraints	Netherlands	2VG, V2H, V2B
Grid motion	Groupe PSA, Direct Energie, Enel, Nuvve, Proxiserve and the Tec. Univ. of Denmark	Shifting charging times from periods when electricity prices are higher to periods when electricity prices are lower.	France	V2B, V2N
Parker	Nissan, NUVVE, Frederiksberg Forsyning, Mitsubishi, PSA ID, ENEL, Insero and DTU Electrical Engineering	Experimental validation across several series-produced V2G enabled EV models and brands. Access to the world's first commercial V2G hub of EVs providing Frequency Control Reserve (FCR). Reserve (FCR).	Denmark	V2X

[20] Vehicle-to-Business (V2B) reflects a vision of integrating vehicles into business operations by Intelligent Transportation Systems (ITS). Common to all application domains is the integration of real-world vehicle data into business applications in order to generate additional revenue by means of innovative services or to reduce costs based on business process improvements.
[21] Vehicle-to-Safety provides safety to vehicles connections.
[22] Vehicle-to-Neighborhood (V2N) permits the neighborhood connection, enabling a large group of customers with different types of EVs to connect and communicate with the system.
[23] Vehicle-to-Home (V2H) is a system that allows supplying the home with energy stored in EV battery.
[24] Vehicle-to-Everything (V2X) permits vehicle communication with any entity that may affect the vehicle, and vice versa.

2/2

Project name	Partners	Project Characteristics	Location	Project type
Integrated Transport and Smart Energy Solutions (ITSES)	Costain Limited and CENEX	Finds new technical solutions and BMs for integrating V2G with two urban systems: energy and transport.	UK	V2G, V2B
Intelligent Transport, Heating and Control Agent (ITHECA)	Cofely, CENEX, European Bioenergy Research Institute (EBRI), Open Energi	Integrated energy system (Heat, power and V2G)	UK	V2G, V2B
SHAR-Q	ATOS Spain, bAvenir, UBIMET, ENERCOUTIM, EEE, Basque Energy Cluster, RWTH Aachen, HEDNO, Energie Gussing, ATOS CZ relevant to V2G HEDNO.	Interoperability to boost the exchange of information between energy batteries from vehicles to power the grid and balance it.	Greece	V2N
Denmark V2G	Nissan, Enel, Nuvve, Frederiksberg Forsying and Energinet.dk	Commercial vehicle-to-grid	Denmark	V2G, V2B
Genoa Pilot	Enel, Nissan, Italian Institute of Technology (IIT)	It is a combination of corporate car-sharing, EV and V2G. The project uses the only vehicle ready for bidirectional energy exchange, the Nissan Leaf.	Italy	V2G, V2B
mySMARTLife	Helen, Virta, Nissan	V2G charging point complements an existing solar power plant and stationary energy storage, and enables using EVs as energy storage and to stabilize the electricity grid	Finland	V2G, V2N
City-Zen Smart City	Alliander, NewMotion, Enervalis, MagnumCap	A social research is part of the project, focusing on the appreciation of the technology by the users.	Netherlands	V2G, V2B
Net-Form	Encraft, Solihull Metropolitan Borough Council, Costain PLC, Aston University, WPD and Cenex	Develop secure, dynamic data management platform that collects, aggregates and optimizes energy collected by large populations of grid-connected EV batteries.	UK	V2B
UK-V2G	Nissan, Enel	Investigates vehicle-to-grid V2G, V2B, and V2N in the UK	UK	V2G, V2B, V2N
GrowSmarter	20+academic and industry partners	The six V2X chargers will be installed in an Endesa Building with Distributed Energy Resources (DER) including a PVPlant, a storage system, chargers (normal, fast and V2X) and a Demand Management System (DMS).	Spain	V2X, V2B

Source: (Union European 2018)

CHAPTER 3 | ELECTRIC VEHICLES AS LOW CARBON MOBILITY OPTION: THE CASE OF SAO PAULO

Part 1: Paper publishd in International Journal of Sustainable Transportation, 11 (7) 518-525. DOI: 10.1080/15568318.2016.1276651

Costa, E., J. Seixas, G. Costa and T. Turrentine (2017) . "Interplay between ethanol and electric vehicles as low carbon mobility options for passengers in the municipality of Sao Paulo".

Part 2: Paper published in the Revista Brasileira de Gestão Urbana (URBE), 2018, DOI: 10.1590/2175-3369.010.supl1.ao15

Evaldo Costa, Julia Seixas, Patrícia Baptista, Gustavo Costa, Thomas Turrentine (2018). CO_2 emissions and mitigation policies for urban road transportation: Sao Paulo versus Shanghai.

Part 3: Paper publishd in Proceedings of the International Vehicle Power and Propulsion Conference (VPPC-IEEE), October 27-30, 2014 – Coimbra, Portugal, DOI: 10.1109/VPPC.2014.7007035

Costa, E. and J. Seixas (2014). Contribution of electric cars to the mitigation of CO_2 emissions in the city of Sao Paulo

3.1 INTERPLAY BETWEEN ETHANOL AND ELECTRIC VEHICLES AS LOW CARBON MOBILITY OPTIONS FOR PASSENGERS IN THE MUNICIPALITY OF SAO PAULO.

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ABSTRACT

The Brazilian cities as well as many of the large urban centers in the world continue to expand, increasing the demand for mobility and transport, while, at the same time, the same cities are investing in greenhouse gas (GHG) mitigation to avoid climate change. Brazil's urbanization rate increased from 26% in 1940 to almost 70% in 1980. During this period, the Brazilian population tripled and the urban population multiplied by seven. In 2010, the transport sector in Sao Paulo accounted for 71% of the total emissions released by the energy sector. Ethanol has been considered a fuel with less greenhouse gas emissions, when compared with fossil fuels. However, ethanol production would have to double to meet the expected demand. Electric vehicles (EVs) market is expanding around the world, and is also an option to reduce the transport emissions, if powered by clean electricity. To assess whether the adoption of EVs might bring more benefits than the current ethanol, we develop prospective scenarios supported by the Long-range Energy Alternatives Planning (LEAP) simulation tool, taking a bottom-up tank-to-wheel approach to consider the CO_2 emissions of car in Sao Paulo. The scenario considering a substitution of 25% of gasoline-powered cars by EV in 2030 showed a reduction in energy consumption and CO_2 emissions, around 15% and 26% respectively in that year in comparison with 2015. We discuss the interplay between ethanol and EV, also considering emission coefficients from life cycle analysis conducted in Brazil, and concluded EV will have higher positive impact on climate change mitigation than ethanol.

KEYWORDS: CO_2 emissions; electric vehicles; ethanol; hybrid plug-in; Sao Paulo

3.1.1 Introduction

The expansion of the Brazilian transport system in recent years, namely the vehicles fleet, has demanded increasing attention due to related energy consumption and environmental impact, mostly in cities. Three factors contributed to the growing demand for transport and increasing road urban fleet in Brazil: (1) Urbanization growth rate jumped from 26.35% in 1940 to 68.86% in 1980, meaning that population has tripled and urban population has multiplied by seven (Santos, 2008). Urbanization has continued to grow in Brazil up to 2010 and the average rate of the population living in cities has risen to 84.35% (IBGE, 2010).

(2) Public policy for urban road transportation has not been able to adequately meet the growing demand for transport, especially in metropolitan areas of the country where the situation has worsened and is considered unsatisfactory by most of the population (Santos et al., 2015). (3) Brazilian Government incentives to stimulate production and cars sales, including tax rebates to local production, and consumer credit (between 2009 and 2013 consumer credit grew 58%) to purchase vehicles, contributed significantly to the increase on the vehicle fleet (between 2009 and 2013 consumer credit grew 58.1%) (Schwengber et al., 2014).

Together, these factors contributed to the growth of car sales in the country, resulting in 135% increase in the number of licensed units between 2000 and 2013 (ANFAVEA, 2014). Along with the increase of the Brazilian fleet of motor vehicles came other problems, such jams, increased fuel consumption, noise pollution, and rising green- house gas (GHG) emissions. The estimated fleet of Brazilian automobiles in 2014 was 55.0 million units, 66% relatively to 2007 (SINDIPEÇAS, 2014). In 2014, the Brazilian transportation sector accounted for 32.2% of the energy consumption, just after the industrial sector (32.9%). In the same year, total anthropogenic emissions from the Brazilian energy system reached 485.2 $MtCO_2$, with the transport sector accounting for almost 46% (MME, 2015).

3.1.1.1 Passenger transport in Sao Paulo

Sao Paulo is the most populous Brazilian municipality (IBGE, 2015a), with 11.9 million inhabitants in 2015 (IBGE, 2015b), spread over an area of 1,523 km^2, with a GDP of $151.8 billion, a per capita income of $13,500, HDI of 0.814 and a urbanization rate of 99% (IBGE, 2012). In the first decade of this century, the GDP of Sao Paulo grew 248%, income per capita increased 223% and population increased 7.85% (IBGE, 2012). In the first decade of this century, the GDP of Sao Paulo grew 248%, income per capita increased 223% and population increased 7.85% (IBGE, 2012).

The municipality of Sao Paulo recorded the highest concentration of road vehicles in
emissions of Brazilian ethanol (Palma-Rojas, Brazil. Between 2010 and 2014, the proportion remained around 28,000 cars per 100,000 inhabitants. In 2014, the city recorded 73.2% of passenger cars, com- posed by flex-fuel vehicles (58.4%), gasoline vehicles (38.9%), and vehicles driven solely by hydrated ethanol (2.7%) (CETESB, 2014; Costa & Seixas, 2014; SINDIPEÇAS, 2014). The increase in GHG emissions from the vehicle fleet growth is a key problem. In 2010, the transport sector in Sao Paulo accounted for 71.2% of CO_2 emissions related to the energy sector (PMSP, 2013), reaching slightly over 16 $ktCO_2$, where 50% came from gasoline (“A/C”), 26% from diesel, 22% from ethanol (hydrous and anhydrous), and 3% from other fuels. Compared to 2003, CO_2 emissions from road urban transport in the city of Sao Paulo grew 80%.

Clean energy sources are fundamental to the low carbon and clean energy goals of electric mobility. Fortunately, the power supply of the State of Sao Paulo is predominantly clean (the share of renewable energy sources in the Brazilian energy matrix in 2014 was 65.2%, remaining among the highest in the world) (MME, 2015).

3.1.1.2 *Sustainable transportation*

Reducing emissions from passenger vehicles is recognized as a major goal by the governments to reduce global warming and limit temperature increase to 2°C by 2100. Energy efficiency appears to be the most cost-effective way to reduce emissions of the energy sector. Since 1990, investments made in 29 countries on energy efficiency, also including transport, avoided the emission of approximately 10 billion tCO_2 (IEA, 2002). In Europe, one of the mitigation policy goals refers to the reduction of GHG emissions from transport by 20% by 2030 and by 70% by 2050 compared to 2008 levels (Commission European, 2014).

Several regions have perceived electric mobility as an alternative to fossil fuels, as in the case of Africa (Gajjar et al., 2016), Asia (Chandran et al., 2013; Ong et al., 2012; Yedla et al., 2003), European countries (Andersson, 2010; Daly et al., 2012; Smith, 2010), and the USA. (Commission European, 2014; IEA, 2016; Leighty et al., 2012). The growth rate of EV sales in recent years has been significant globally, with 665,000 sales in 2014 and 1.3 million sales in 2016 (IEA, 2016). Addi- tionally, estimates point to 46,000 electric buses and 235 million electric two-wheeled vehicles on the roads by the end of 2014, especially in China, which records 230 million e-bikes, 83,000 electric cars, and 36,500 e-buses (IEA, 2015). However, EVs must be powered by clean electricity to keep sustainable future pathways.

Biofuels have also been adopted as a sustainable and CO_2- neutral fuel, when considering the well-to-tank approach. However, under a Well-to-Wheel (WTW) approach, biofuels present important GHG emissions coefficients. The life cycle assessment (LCA) analysis of ethanol and hydrous ethanol, tak- ing a WTW approach, reveals emissions of 14,50 gCO_2/MJ (Flórez et al., 2015) and of 417 kg CO_2 m^{-3} respectively (Macedo, Seabra, & Silva, 2008). Several other studies (LCA) confirm the Caldeira-Pires, & Nogueira, 2015; Roberto et al., 2009; Walter et al., 2015).

3.1.1.3 *Electric mobility potential to promote sustainable passenger transport in São Paulo*

To expand sustainable transport, Brazil adopted an automotive energy efficiency program, named INNOVATE-AUTO, as well as ethanol fuel, making the country the world leader in ethanol production from sugarcane. Between 1990 and 2011, for example, the cultivated area increased 45% and yields increased about 8 and 40 Gt $year^{-1}$, growing by an average of 1.5 billion tons per year (Filoso et al., 2015).

Despite the huge success of ethanol in Brazil, the situation is far from ideal and needs to be better studied, because the increase of ethanol production has increased deforestation, soil contamination, and water and air pollution, and there is also a possibility for it to interfere with food prices (Ferreira et al., 2014; Filoso et al., 2015; Gauder et al., 2011; Martinelli et al., 2011). In 2012, the country launched the program INOVATE-AUTO that aims to support technological development, innovation, safety, environmental protection, energy efficiency, and the quality of vehicles (R.F.Brasil, 2016).

The recent progress of electric mobility, namely in terms of autonomy and costs, makes them as feasible transport options. In addition to gasoline and ethanol, EV will help lowering GHG emissions, since the Brazilian electric matrix is based on a high share of renewables, 75% in 2014 (MME, 2012), and also the Sao Paulo matrix, based on 92% renewables (PMSP, 2012) and technological expectation is in favor of the adoption of electric mobility in large Brazilian city. We conducted this study to assess the interplay of alternative fleet composition in terms of energy consumption and GHG emissions compatible with a sustainable mobility pathway.

We consider three fuels, gasoline, ethanol, and electricity, to achieve the highest reduction of energy consumption and CO_2 in the city of Sao Paulo. This study is innovative over others because it generates future scenarios of passenger fleet composition for one of the major cities in the world with high impacts on GHG emissions, while taking into account policy programs in place, as the INNOVATE-AUTO. This delivers a realistic perspective over the impacts on energy consumption and Turnbull et al., 1967b; Yan et al., 2009), and emissions reduction.

The study was conducted following a prospective scenarios analysis supported in five scenarios generated by the Long- range Energy Alternatives Planning System (LEAP) model to understand and deal with uncertainties, and to answer the following questions: (1) What is the fleet composition that pro- vides the lowest CO_2 emissions for the city of Sao Paulo? (2) How the fleet composition impacts the energy consumption of the Sao Paulo transportation sector? (3) How compatible is the energy matrix of Sao Paulo with the selected fleet composition?

The prospective scenarios followed a tank-to-wheel (TTW) approach that was adopted to explore how alternative fleet composition in the future will impact energy consumption and CO_2 emissions regarding passenger transport in Sao Paulo. Furthermore, we use data from life cycle analysis (LCA) regarding ethanol (Flórez et al., 2015; Macedo et al., 2008; Palma- Rojas et al., 2015; Roberto et al., 2009; Walter et al., 2015) and electricity, to take into account the emissions from the whole fuel chain, from production to final use, for the assessment of transport fuel options.

The next section presents the methodology used to conduct the study, Section 3 presents and discusses the results concerning the energy consumption and emissions of passenger cars in Sao Paulo, and Section 4 concludes and suggests policy guidance.

3.1.2 Methodology

We adopted a bottom-up approach to investigate the impacts on energy consumption and GHG emissions from the interplay between ethanol and EVs for passengers in the municipality of Sao Paulo. We assumed a TTW approach and used prospective scenarios generated by the LEAP model. Two categories of passenger EVs (PEVs) were considered for the near future of Sao Paulo transport system: (1) battery EVs (BEVs), which use only electricity and (2) hybrid plug-in vehicles (PHEVs), which use electricity and gasoline.

The prospective scenarios begin with the settlement of a future desirable situation, which normally encompasses goals or targets set between the current and future situations. Several areas have adopted the prospective approach (Ab Kadir & Yaaseen Rafeeu, 2010; Pardo et al., 2013; Schwanen et al., 2011), including the assessment of future sustainable pathways. We selected the LEAP model because it is adequate to assess the effects of alternative energy programs, technologies, and other energy initiatives.

LEAP is an energy end-use oriented tool for scenario analysis. LEAP can size the emissions of each fuel chain step, including the reduction of GHG emissions from extraction, processing, distribution, and combustion that may result from more efficient use of electricity and other fuels. LEAP models also may accomplish a complete accounting framework of the power system framework that allows consideration of both sup- ply and demand side technologies and is responsible for overall impacts of the system. It is a widespread tool with wide applications in energy (González et al., 2016; Haydt et al., 2011; Papa giannis et al., 2008), environment (Hao et al., 2015; Turnbull et al., 1967b ; Yan et al., 2009), and in the transport sector (Dias et al., 2014 ; Manzini, 2006 ; Turnbull et al., 1967a).

The road passenger transport sector in Sao Paulo was modeled following the energy reference system presented in Figure 3.1. The demand categories appear on the right side covering eight different end uses, expressed in vehicle kilometers traveled (VKT). The fuels listed at the top left include "conventional" and "alternative" fuels; the former referred to diesel and petrol; and the later referred to ethanol, biodiesel, natural gas (CNG), and electricity.

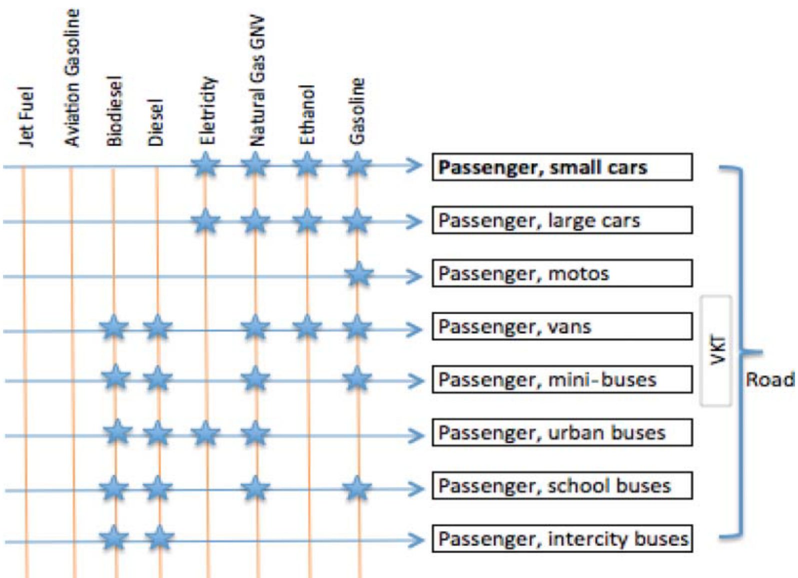

Figure 3.1 – The energy reference system of passenger transportation sector in Sao Paulo

Currently, passenger vehicles in Sao Paulo equipped with an internal combustion engine (ICE) are powered by fossil fuels (petrol and diesel); alternative fuels (ethanol, biodiesel, and natural gas); and hybrid fuels (gasoline–electricity). Current fleet of passenger cars consists of 73.2% of ICE cars, most of them flex-fuel (able to use both gasoline and ethanol), as well as electric (BEVs) and hybrid ones (PHEV), although in insignificant amounts (less than a thousand units). Figure 3.2 shows the structure of the current fleet of passenger cars in Sao Paulo. LEAP model accommodates the current fleet, as well as the expected fuel efficiency of the ICE vehicles over the years, as stated below.

The model calculates the final energy consumption, according to the following equation, and CO_2

emissions using the emissions factors presented in Table 3.1, both addressed to the fuel consumed in Sao Paulo' s transportation system.

$$\text{Final energy (MJ)} = \sum_i \left(\text{Average kilometer}_i \left(\frac{\text{km}}{\text{year}}\right) \times n^{\circ} \text{ vehicles}_i \times \text{Average specific consumption}_i \left(\frac{\text{MJ}}{\text{km}}\right) \right)$$

where i is the type of vehicle presented in the system, according to the fuel used (gasoline car, ethanol car, flex-fuel car, battery electric vehicle, and plug-in electric vehicle); the 50% ethanol; average mileage is constant for passenger cars, equals to 18,000 km/year vehicle; the number of vehicles varies annually according to the assumptions made in the model for each scenario; the average consumption varies to the horizon of 2030, according to the type of fuel used per vehicle.

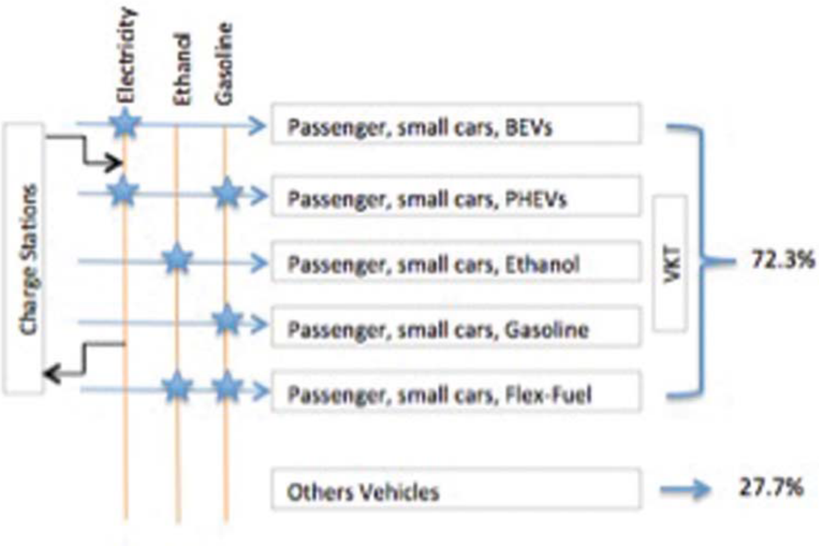

Figure 3.2 – The energy reference system of small passenger cars in Sao Paulo

Table 3.1– CO_2 emission factors

Source	Rate
Gasoline A	2.269kg/L*
Anhydrous ethanol	1.233kg/L*
Hydrous ethanol	1.178kg/L*
Electricity	0.025 tCO_2/MWh**

Source: (PMSP 2013; PMSP 2012)

Prospective scenarios were built regarding the evolution of passenger cars fleet between 2015 and 2030, taking a penetration rate of 25% for PEV. These penetration rates took into account several factors, namely, (1) the early stage of Sao Paulo with the infrastructure for pure EVs, thus hindering a rapid expansion of the BEVs models market; (2) the Brazilian public policy to promote the expansion of ethanol consumption; and (3) the domestic auto industry production policy based on INNOVATE-AUTO law. Table 3.2 presents the objective and a brief description of each scenario. Moreover, a set of assumptions for all scenarios include:

1. The average consumption of the introduced passenger EV fleet was calculated from two sets of

vehicles. The group of pure electric (BEV) was composed by the following cars: Nissan Leaf, VW Golf, Ford Focus, and BMW i3 EV.

Table 3.2 – Measures to support low-carbon mobility

Scenario Name	Objective	Scenario description
Reference	Evaluate the results of projections based on historical data and other known factors.	The evolution of the fleet (vehicles powered by gasoline, ethanol and flex-fuel) up to 2030 follows the trend of historical data for the period that goes from 2010 to 2014. The fleet of vehicles powered by gasoline decreases 7% / year; ethanol vehicles to decrease at a rate of 10% / year by 2030; flex-fuel fleet will increase, not only to replace the cars powered by ethanol and gasoline, that will be leaving the system, but also to secure an increase of 0.5%/ year of the total automobile fleet since 2014. The estimated average consumption assumed average consumption was 9 km / l for vehicles powered by gasoline and 6.3 km / l for ethanol vehicles (IBGE, 2012). The average mileage for passenger cars was 18,000 km per year (ESV, 2013). The rules of the Brazilian program for energy efficiency, INNOVATE-AUTO, listed below, were considered.
Eth_4_Gas	Assess mobility options of low CO_2 emissions with the use of ethanol (Eth) as primary fuel.	The flex-fuel passenger cars stop using gasoline from 2015 and start using only ethanol
EV_4_Gas	Assess mobility options of low CO_2 emissions using the plug-in hybrid vehicles and pure electric (PEV) vehicles instead of passenger cars powered by fossil fuel only.	25% of gasoline vehicles in 2030 are replaced by PEVs (in proportion of 30% BEVs and 70% PHEVs). The flex-fuel vehicles replace ethanol vehicles and guarantee an increase of 0.5% per year of the total car fleet
EV&Eth_4_gas	Assess mobility options of low CO_2 emission using hybrid plug-in, pure electric and ethanol-powered (ENP + Eth) passenger cars as major energy consumers.	25% of gasoline and ethanol vehicles are replaced by PEVs (in proportion of 30% BEVs and 70% PHEVs). This scenario is similar to the previous one with the difference that the ethanol vehicles leaving the system are also replaced by PEVs. In addition, after 2015, all flex-fuel cars in the system only use ethanol
EVP&Eth_4_Gas	Assess mobility options of low CO_2 emission using pure electric cars and ethanol-powered (BEV + Eth) passenger cars as major energy consumers	Pure electric vehicles (BEVs) replace vehicles powered by gasoline and ethanol. This scenario is the same as the above with the difference that all electric vehicles entering the system are BEVs (no PHEVs). In addition, after 2015, all cars in the flex system only use ethanol

The group of plug-in hybrid models (PHEV) was composed by the following vehicles: Toyota Prius, Ford Fusion, Mitsubishi Outlander, and Golf GTE plug-in. The selected car models took into account their overall sales performance and the prestige to the Brazilian consumer.

2. All scenarios took into consideration the rules of the Brazilian program for energy efficiency, INNOVATE- AUTO. Based on the requirements of the program and international advancement of the automobile industry efficiency for ICE vehicles indicated in Table 3.2.

3. The flex-fuel vehicles consume 50% gasoline and 50% ethanol;

a) between 2017 and 2020, 70% of the fleet will get 13.6% reduction in the consumption of gasoline, 20% of the fleet will get a 25.5% reduction compared to 2014, and 10% fall under the Reference scenario;

b) between 2021 and 2030, 70% of the fleet will get 25.5% reduction in the consumption of gasoline compared to 2014 and 30% will be in the Reference scenario;

4. The mixture of anhydrous ethanol in gasoline was 25% between 2011 and 2014 and 27% from 2015.
5. The motorization rate at the end of the period should remain on a par with 2014 (around 28,000 cars per 100,000 inhabitants).
6. Electricity consumption of PHEVs was not considered, because there is no information available to determine the amount of electricity that hybrid cars consume in a given

period. However, as the battery life of hybrid cars is, on average, around 5% of the total autonomy of the vehicle, this fact is not very significant for the results of the scenarios.

7. The growth rate of the fleet used was 1.2% and the scrap rate was 0.5%.

3.1.3 Results

3.1.3.1 Passenger cars fleet by technological option

All scenarios present an increase of the total fleet in 2030 com- pared to 2011, from 12%. Flex fuel remains the major component of the fleet in the simulated period, as expected from the assumptions on the penetration ratios stated.

The Reference and Eth_4_Gas scenarios (the latter only differs due to all flex-fuel cars start using ethanol), as well as EV_4_Gas and EV & Eth_4_gas scenarios (the latter only differs from the first because all flex-fuel cars start using only ethanol from 2015 on), have the same fleet projection, as shown in Figure 3.3.

Therefore, in Reference and Eth_4_Gas scenarios, flex-fuel cars grew 121%, while gasoline cars decreased 75% by 2030, in relation to 2011. Cars powered by ethanol only are disappear- ing from the market and will have minimal share in 2030, because we assume there is no replacement. In these two sce- narios, flex-fuel passenger cars represent 88% of the market, gasoline 11%, and ethanol less than 1% in 2030.

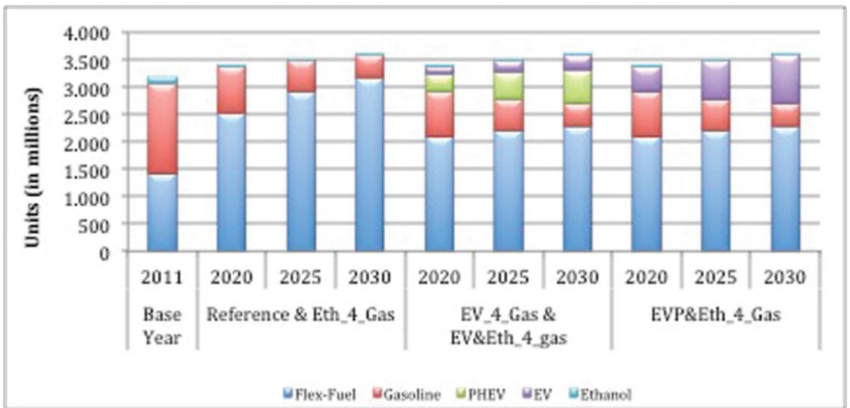

Figure 3.3 – Evolution of the stock of passenger cars by technology in Sao Paulo between 2011 and 2030

The EV_4_Gas and EV & Eth_4_gas scenarios reveal that the flex-fuel passenger cars increased by almost 59%; gasoline models decreased 75%; and passenger cars powered by ethanol decreased around 87%. The flex-fuel passenger cars and vehicles are the majority in 2030, representing almost 64% of the market; hybrids are second with 17%, followed by the gasoline cars with about 11%, pure electric models with 7%, and finally ethanol less than 1% in 2030.

The EVP & Eth_4_Gas reveals a 59% growth of flex-fuel passenger car fleets by 2030 in relation to 2011, while gasoline cars present a decrease of 75% and ethanol cars a decrease 87%. In this scenario, the flex-fuel passenger cars keep the majority of the passenger fleet (64%), followed by pure EVs with 25%, gasoline cars with almost 11%, and pure ethanol less than 1% (Figure 3.3).

3.1.3.2 Energy consumption in passenger cars

As shown in Figure 3.4, the energy consumption increases in the reference scenarios and Eth_4_Gas, while decreases in the other three scenarios. This is mainly due to increased consumption of gasoline and ethanol due to increased vehicle fleet.

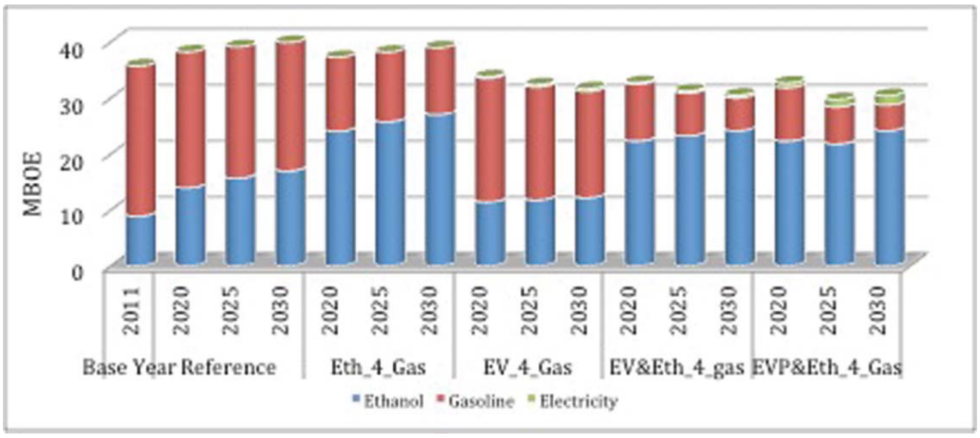

Figure 3.4 – Energy mix in transportation of passenger cars in Sao Paulo between 2011 and 2030

The Reference scenario projects an energy consumption growth of around 12% in 2030 compared to 2011. In the same period the consumption of ethanol increased 91% while the gasoline consumption reduced 14%. By 2030, the consumption of ethanol represents 42% and gasoline 58%. In Eth_4_Gas scenario, the energy consumption of fuels increased around 9% by 2030 in relation to 2011, with ethanol accounting for 70% of total fuel consumption in 2030 and gasoline 30%. The fact that flex-fuel passenger cars or vehicles stop using gasoline from 2015 on, and use only ethanol, caused an increased ethanol energy consumption of around 100% at the end of the simulation period. The energy consumption of gasoline decreased 55%. This scenario is unlikely because the country would hardly double ethanol production in the simulated period with- out causing further harm to the environment.

The EV_4_Gas scenario, in turn, reveals a reduction of around 11% of the total final energy in passenger cars by 2030, justified by the entrance of high-efficient EVs. Consumption of gasoline will likely reduce, during the period, around 29% and ethanol increase by 205%. At the end of the projected year, gasoline would have 60% share of final energy consumption, ethanol 38%, and electricity around 2% (Figure 3.4).

In the EV & Eth_4_gas scenario, the projection shows a reduction in the total energy consumption of 14%, with gasoline decreasing around 78% and ethanol increasing more than 172% in relation to the base year. In 2030, gasoline would have a 19% share in total energy consumption, ethanol around 79%, and electricity about 2% (Figure3.4). The total energy consumption is reduced to the substantial decrease of gasoline consumption and more efficient vehicles because the rules of the INNOVATE-AUTO. EVP & Eth_4_Gas showed a reduction of around 15% in the total energy consumption of fuels, with gasoline reducing around five times the consumption in the base year, while ethanol increasing 172%. By 2030, gasoline gets 15% share of the total energy consumption, ethanol 79%, and electricity about 6% (Figure 3.4).

3.1.3.3 CO_2 emissions

The study reveals that two of the five scenarios analyzed showed an increase of CO_2 emissions in 2030 compared with 2011, explained by the significant increase of ethanol consumption by the vehicle fleet. Three scenarios showed significant emissions reductions (EV_4_Gas, EV&Eth_4_gas, and EVP&Eth_4_Gas); the EVP&Eth_4_Gas scenario being the one providing the highest reduction (26%), due to a shift from gasoline to ethanol and to a high penetration of EVs with almost no emissions. In this scenario, by 2030, the ethanol would account for 81% of total CO_2 emissions and gasoline about 18% from passenger cars, while electricity less than 1% (Figure 3.5).

In the Reference scenario, we observe an increase of nearly 9% in CO_2 emissions by 2030. The increase was not so higher as expected in this scenario, because emissions from ethanol grew around 91%, and emissions from gasoline reduced by 14%. In this case, in 2030, gasoline participates with 61% of CO_2 emissions and ethanol with 38% (Figure 3.5).

In the Eth_4_Gas scenario, CO_2 emissions increased slightly, around 2%, because the emissions reduction from gasoline (55%) was offset by the emissions increase from ethanol (205% in relation to 2011). By 2030, ethanol shares 65% of total emissions of cars in Sao Paulo while gasoline shares 35% (Figure 3.5). The EV_4_Gas scenario achieves 14% reduction of CO_2 emissions of passenger cars by 2030, resulting from a balance of emissions increase (37%) from ethanol and decrease (29%) from gasoline.

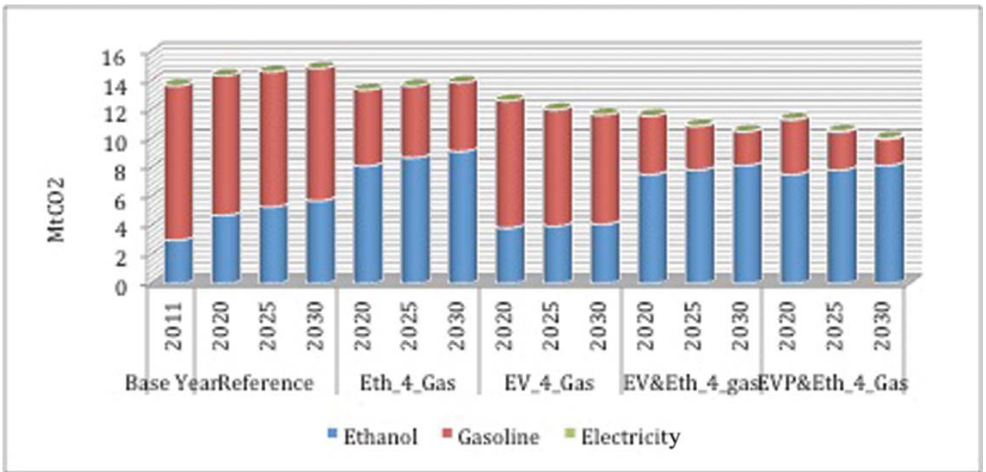

Figure 3.5 – CO_2 emissions of passenger cars in Sao Paulo between 2011 and 2030

In the EV & Eth_4_gas scenario, a 23% reduction of CO_2 emissions from passenger cars was achieved due to a shift from gasoline, with emissions reduction of 78%.

Regarding EVP & Eth_4_Gas scenario, a 26% reduction of CO_2 emissions from passenger cars was achieved due to a shift from gasoline, with emissions reduction of 83%, to ethanol and electricity, both BEVs and PHEVs. Ethanol car emits 42 times more than pure EV in Sao Paulo. It is noteworthy that the benefit is too broad due to a shift from gasoline, with emissions reduction of 83%, to ethanol and electricity, both BEVs and PHEVs.

3.1.4 Discussion

Analyzing the five scenarios, we conclude that, from the point of view of energy consumption and emissions of CO_2, the scenarios EV_4_Gas, EV&Eth_4_gas, and EVP&Eth_4_Gas present the most significant reductions, as shown in Figure 3.6, revealing the benefits of the electric mobility for the Sao Paulo city, up to 2030. The Reference scenario reveals that doing nothing to change the emissions of Sao Paulo's car fleet is the worst option, because the country will hardly keep, in the next decades, the same level of growth in the production of ethanol as the past decades.

Regarding energy consumption, EV&Eth_4_gas scenario (17% of PHEVs fleet) and EVP&Eth_4_Gas scenario (25% EVs fleet) are those with less energy consumption. However, when analyzing the CO_2 emissions, it is clear that the best scenario is the EVP&Eth_4_- Gas, which provides around 26% reduction in emissions and around 15% reduction in energy consumption.

However, when analyzing the CO_2 emissions, it is clear that the best scenario is the EVP&Eth_4_-Gas, which provides around 26% reduction in emissions and around 15% reduction in energy consumption. The electricity would have a share of 6% of the energy consumption of passenger cars by 2030, representing a small impact on the predominantly clean power grid of Sao Paulo.

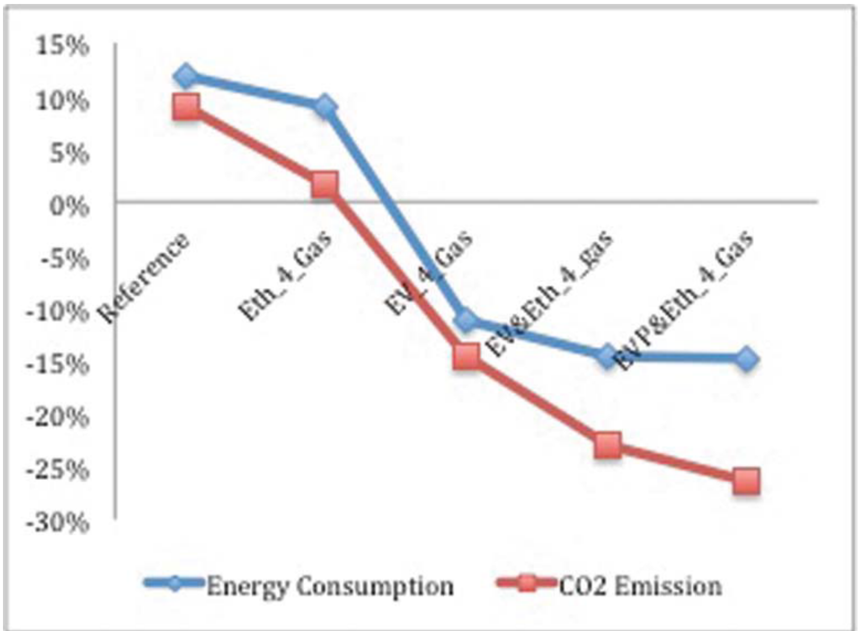

Figure 3. 6 – Performance of energy consumption and emissions of CO_2 in 2030, in relation to 2011

Table 3.3. Comparison of energy consumption and CO_2 emissions between cars powered by ethanol and electric in Sao Paulo[25]

Small passenger ethanol car	Small passenger electric vehicle (BEV)
Consumption = 1 L/7 km	Consumption D 24 kWh/150 km = 0.16 kWh/km
Emissions per unit of energy = 1.178 kg CO_2/L (PMSP, 2013)	Emissions per unit of energy = 0.025 kg CO_2/kWh (CETESB, 2013)
Emissions per unit distance = 0.168 kg CO_2/km	Emissions per unit distance = 0.004 kg CO_2/km

Example the BEV Nissan Leaf with 24-KWh batteries.

However, as many authors suggest, confident scenarios toward sustainable transport options require the use of WTW approach, in order to take into account emissions from the whole chain of fuel production and consumption. For that purpose, we conducted a comparison between two cars, one driven by hydrated ethanol and other pure electric and the results are listed in Table 3.3. The ethanol-powered car emits 42 times more than pure EV in Sao Paulo. It is noteworthy that the benefit is too broad due to the low coefficient of electricity generation from Sao Paulo (about 92% from renewables) and also in part because the rate of consumption of liquid fuels is higher. There-fore, the EV turns out to be the best option for Sao Paulo.

3.1.5 Conclusion

The goal of this study is to get insights on the best low carbon mobility options for passengers in the municipality of Sao Paulo, taking ethanol and EVs. For this, we used a prospective analysis of the passenger car fleets up to the year 2030, using the LEAP (Long-range Energy Alternatives Planning System) simulation model. There is much to be learned by paying close attention to energy consumption and GHG emissions of the vehicle fleet in Sao Paulo.

The sector of road transport in Brazil has benefited from the adoption of ethanol; however, more than doubling their production to keep the demand of a growing fleet may not be feasible, this is also because of the recent financial problems faced by the ethanol industry in Brazil. In addition, the study shows that the EVs offer a real possibility to complement the mix of a fleet that must become less energy intensive in Sao Paulo, and by analogy in the country.

It is evident that if the Brazilian automobile industry develops PHEVs that are fl ex-fuel vehicles, a significant contribution to mitigate GHG emissions could occur, because the scenario that simulated the introduction of PHEVs with ethanol consumption was the second best scenario in terms of energy consumption and emissions of CO_2.

Hence, it can be seen that the introduction of electric and hybrid passenger cars, as well as the

[25] The energy consumption and emission factors may vary according to different authors and years.

maintenance of ethanol as a fuel, would provide Sao Paulo with important contributions to mitigate GHG emissions and reduce consumption of fossil fuels. However, this investigation revealed that from the point of view of emissions, the EV is significantly more advantageous to Sao Paulo than models powered by ethanol, mainly if we take into consideration the WTW approach for CO_2 emissions estimation.

This study can be seen as a valuable tool to support decision-makers with arguments in favor of electric mobility in Sao Paulo, as the results show that BEVs are not ethanol competitors but a complementary technology that provides benefits to the city and the country. Some limitations must be referred, being the accuracy of energy and emissions estimations a major one.

Accurate energy consumption is difficult to estimate due to several factors, including the constant and long traffic jams in Sao Paulo, the traffic from outside Sao Paulo but circulating in the study area, as well as the traffic originated in Sao Paulo municipality but running out of it. Also, other category of passenger vehicles should be considered, as small commercial vehicles, micro-buses, buses, motorcycles, to consider the mobility of whole population at the municipality of Sao Paulo.

Finally, research on the impacts of the biofuel crops area (after deforestation) to meet the growing demand for ethanol, namely the increasing competition of land use for energy and food production, and for biodiversity conservation, should be carried when assessing sustainable mobility options.

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3.2 CO_2 EMISSIONS AND MITIGATION POLICIES FOR URBAN ROAD TRANSPORTATION: SAO PAULO VERSUS SHANGHAI

Emissões de CO_2 e políticas de mitigação para o transportate rodoviário urbano: Sao Paulo versus Xangai

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ABSTRACT

This paper compares the energy consumption, CO_2 emissions and public policies of two mega-cities, Sao Paulo (SP) and Shanghai (SH), in order to identify their GHG emissions mitigation policies. Both cities have experienced rapid growth of the automotive sectors resulting in sizable pollution and CO_2 emission challenges. SP has successfully implemented the ethanol and encouraged the growth of the fleet of light-duty vehicles. SH has coal-based power generation and restricted the ownership of the vehicles in an attempt to reduce GHG emissions, invested in public transportation and electric mobility. Tabular analysis of secondary data was adopted in this study, revealing also that SP has considerably expanded individual transportation. Despite investments in ethanol, the city could not contain the increase in CO_2 emissions from road transportation. SH invested in public transportation and inhibited individual transportation, but also failed to contain CO_2 emissions. Mitigation policies and measures taken were not sufficient to prevent growth of CO_2 emissions in both cities. To reduce CO_2 emissions in transportation, SP and SH should focus on public policies to encourage public and clean transportation and limit the burning of fossil fuels.

KEYWORDS: Sao Paulo, Shanghai, Energy, CO_2 emission, Urban Road Transportation.

3.2.1 Introduction

Urban centers are major greenhouse gas (GHG) sources, since cities produced about 75% of global CO_2 emissions in 2008, with transportation as a major contributor regarding energy use and emissions (IEA, 2008; UNEP, 2015). Globally, in 2012, road vehicles were responsible for 90% of the energy consumed in transportation, and light-duty vehicles (LDV) accounted for 64% of this amount (Agency-IEA, 2015). Motorized road transportation imposes a great burden on the health of the population, resulting in more than 1.5 million deaths annually around the world (Group, 2014).

These impacts are particularly visible in larger cities, with Sao Paulo (SP) in Brazil and Shanghai (SH) in China being two good examples regarding emerging economic and increasing population in developing countries. The growing numbers of motor vehicles in these cities has been a major issue for their authorities due to increasing local pollution, contributing to poor air quality. In SP, the rate of mortality due to air pollution is three times higher than those caused by traffic accidents (China, 2015; Vormittag, 2013).

The municipality of SP is the most populous metropolis in the southern hemisphere (Estatística-IBGE, 2015a), with 11.2 million inhabitants in 2010 (Estatística-IBGE, 2015b). SP has an area of 1,523 km^2, a GDP of 151.8 billion US$, a per capita income of 13.5 thousand US$, a Human Development Index (HDI) of 0.814, and an urbanization rate of 99% (Ministério do Planejamento, 2010). Between 2000 and 2010 the GDP of SP grew 248%, while its per capita income increased 223% coupled with a population expansion of almost 8%.

In 2010, the municipality of SP had 10% of the Brazilian road vehicles, the largest concentration of Brazil's fleet, (Departamento Nacional de Trânsito - Denatran, 2015). The Sao Paulo’s vehicle fleet grew almost 60% since 2000. The main energy source for fueling vehicles in SP is ethanol due to the significant production of sugarcane ethanol. Furthermore, a small fraction of natural gas is also used in SP. Although more than 53% of the SP’s electricity generation mix is renewable (Energia, 2014), the city does not have any policy focused on the promotion of electric vehicles (EV).

In China, the significant growth of the economy, especially since 1990, lead to a substantial growth in the number of vehicles, thus becoming the country with the largest automobile market in the world in 2014 (NEWGEOGRAPHY, 2015). Hence, vehicle emissions have also become an environmental concern in China and especially in mega-cities like Shanghai, where the population and transportation demand are massive (Chan & Yao, 2008).

Shanghai is also one of the largest cities of the world, with 23 million inhabitants in 2010 (Yearbook, 2011). It has an area of 6,340 km^2, GDP of 271 billion US$, a per capita income of 11 thousand US$ (Book-Yearbook, 2012), HDI of 0.814 and an urbanization rate of 88% in 2010 (NEWGEOGRAPHY, 2015). Between 2000 and 2010, the city of SH experienced a GDP growth of 496%, its per capita income increased 333%, and the population expanded 37%. Although SH’s energy mix is predominantly carbon intensive, the city has active policies to promote EV.

The comparison of these cities by assessing their strategies to mitigate GHG emissions from road transportation will help better understanding the effectiveness of mitigation processes and may reveal the most adequate policies to reduce the impacts of transportation (Hannisdahl, Malvik & Guro, 2013; Holtsmark & Skonhoft, 2014; Sierzchula, Bakker, Maat & van Wee, 2014).

Therefore, the aim of this study is to identify and compare the profile of energy consumption and CO_2 emissions of urban road fleets of SP and SH, during the first decade of the XXI century, in order to correlate the mitigation actions taken by both cities (Gibbs, Rigot-Muller, Mangan & Lalwani, 2014; Håkansson & Finnveden, 2015; Harris, 2001). This study will provide assistance for decision makers in other cities in the process of mitigating GHG emissions from road transportation.

The next section of this paper presents the methodology used to compare both cities, and the third section will reveal the data collection covering the urban road transportation sector both in SP and SH. The fourth section correlates and discusses the data, followed by the closing remarks.

3.2.2 Methodology

A methodology based on secondary data that applied the top-down guidelines recommended by the IPCC (Treanton, 2006) was used to estimate CO_2 emissions based on fuel consumption from road vehicles in SP and SH. Data was processed in order to perform its equalization, enabling the comparison of both cities. In the first step, energy consumption data was harmonized in terms of energy units, as presented in Eq.1 for the Sao Paulo case (where fuel consumption data was available in volume), and Eq.2 for the Shanghai case (where data was available in tons of standard coal).

$$CC = CA \, x \, Fc \, x \, 41{,}868 \, x \, 10^{-3} \, x \, Fr \qquad \textit{Eq.3.1}$$

Where:

1 tOE = 41,868 x PJ (terajoule = 1012 J).

· CC = energy consumption in TJ.

· CA = fuel consumption based of fuel sales (m^3).

· Fc = the physical drive conversion factor measurement of the amount of fuel to toe on the basis of the fuel gross calorific value (HHV). The values used were gasoline 0.771 toe / m3; anhydrous alcohol 0.534 toe / m3; hydrous ethanol 0.510 toe / m3; diesel 0.848 toe / m3; dry natural gas 0.880 toe / m3.

· Fr = PCS correction factor for PCI (lower heating value). In BEN the energy content is based on the PCS but multiplying consumption by PCI should make conversion to common unit of energy. For solid and liquid fuels, the Fcorr = 0.95 and gaseous fuels, Fr = 0.90, according to Ministry of Science and Technology - MCT.

For the China case, the conversion from tons of standard coal to energy units was calculated using the following equation:

$$CC = \left(CA \, x \, Fc\right) \, /100 \qquad \textit{Eq.3.2}$$

Where:

CC = Energy consumption in PJ.

CA = Energy consumption in tons of standard coal based of fuel sales.

Fc = Conversion coefficient tons of coal for gigajoule of 29.39.

100 = Coefficient resulting mathematical rounding of 10,000 tons of coal to PJ.

The quantification of CO_2 emissions was calculated using Eq.3:

$$Q = Ej * Cj_{co2} \qquad \textit{Eq.3.3}$$

Where:

Q = Emissions of CO_2 in tons.

Ej = Energy consumption in Joules per type of fuel.

Cj_{CO2} = CO_2 Emission factor of CO_2 (in tons per Joule) per type of fuel.

Both the energy coefficient and the CO_2 emissions were calculated for each year of the periods assessed. This resulted mainly from the variations in the ratio of anhydrous ethanol mixed with gasoline. Consequently, the following information was used:

i. Economic and social data of the cities of SP and SH;
ii. Data on the number of urban road vehicles;

iii. Energy consumption of the fleets of both cities;
iv. Values of CO_2 emission rates by fuel type; and
v. Public policies in place to mitigate CO_2 emissions.

The applied methodology for assessing energy consumption and CO_2 emissions of urban road transportation is summarized in Figure 3.7. The comparison of energy consumption and CO_2 fleet emissions for urban road vehicles in both cities was limited to the period of 2003-2010, due to data availability. In regards to fuel consumption in SP, there was not enough available data for other modes of transportation, such as trains and vessels, and these emission modes were not accounted for. Hence, the fuel consumptions associated to rail and waterway transportation (considered not relevant due to the low consumption of this type of transportation in SP) were incorporated into the roadway item and accounted under these emission factors. In SP, the moped and scooter emissions were accounted in the motorcycles category.

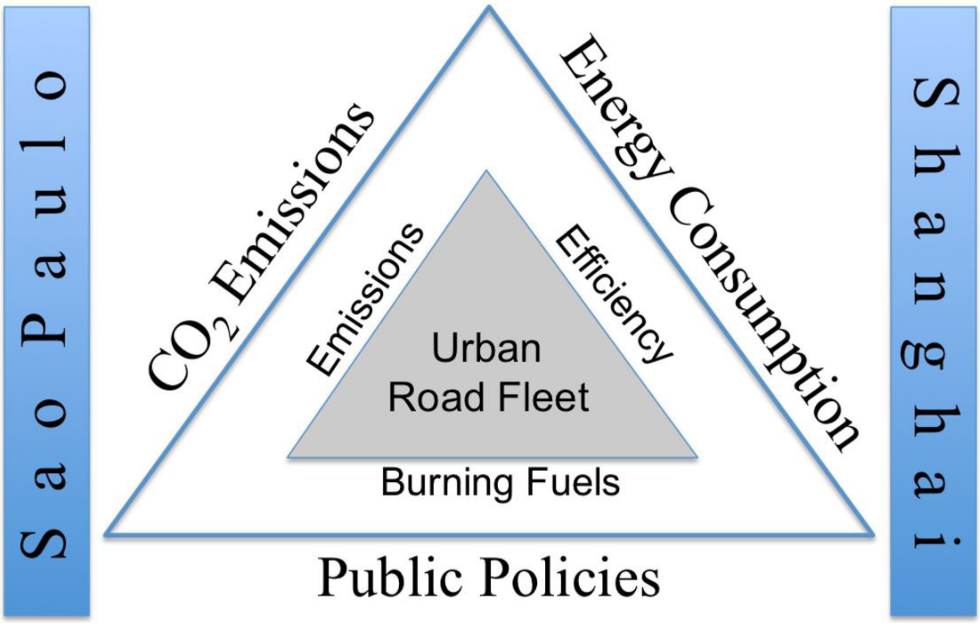


Figure 3.7 – Model for research

The applied methodology will allow assessing which of the fleets consumes more energy and emits more CO_2, what kind of transportation each city prioritizes, what are the strategies of each city to reduce CO_2 emissions, and how do we evaluate these strategies in light of the obvious differences in size, urban form and rates of economic and other forms of growth.

3.2.3 Data Collection For SP And SH

a) Vehicle fleet of SP

In 2010, with an urban road fleet estimated at nearly 7 million motor vehicles and a growth of almost 59% regarding 2003, SP has the largest fleet among Brazilian cities with 73% being LDV (Detran, 2015). The average annual growth of the fleet of SP in the analyzed period was 7%. In 2008, the greatest increase occurred due to government incentives to the automotive industry. From 2003 to 2010, the fleet segment grew 59%. The highest growth was motorcycles with an estimated increase of 160%, while the bus fleet grew 35%. The cars segment grew 51% and trucks, 55%, occupying thus the second place, as shown in Tables 3.4 and 3.10.

Table 3.4 – Motor vehicle fleet evolution in SP: 2003-2010

Category/Year (10^3)	2003	2004	2005	2006	2007	2008	2009	2010
Cars	3,375	3,484	3,580	3,781	4,009	4,731	4,952	5,093
Minibus, bus, truck and utility	455	470	485	518	558	600	653	705
Trucks	115	118	121	124	128	165	164	159
Bus	31	33	34	35	37	41	41	42
Moped, scooter, motorcycle	337	371	404	482	576	756	816	875
Trailer and semi-trailer	52	54	56	59	62	67	69	72
Other	14	15	16	17	18	5	6	6
TOTAL	4,379	4,545	4,696	5,016	5,388	6,365	6,701	6,952
Fleet's growth %	-	3.8	3.3	6.8	7.4	18.1	5.3	3.5

Data source: (Paulo-Detran 2015).

In 2003, SP had around 42,000 vehicles per 100,000 inhabitants. In 2010, this proportion increased to almost 62,000 vehicles per 100,000 inhabitants, representing a 47% growth. In 2010, small passenger cars were more than 45,000 units for 100,000 inhabitants, leading in terms of volume.

However, the greatest evolution in percentage occurred for motorcycles, since it went from 3,000 units for 100,000 inhabitants in 2003 to almost 8,000 in 2010, representing more than 140% increase. This is a point of contrast with the city of SH, which outlawed sales of internal combustion motorcycles to reduce emissions, replacing them with e-scooters, e-bikes and bikes.

b) Energy consumption of the fleet of SP

In 2010, the transportation energy consumption of the largest Brazilian metropolis transportation was about 177 PJ, and it grew about 33% over 2003. The urban road transportation in the Sao Paulo municipality consumed around 167 PJ, which grew 38% since 2003 (the fleet grew 59% in the same period), accounting about 94% of the total consumption of SP road transportation (Table 3.5). The fleet growth (Table 3.4) was substantially higher than the energy consumption (Table 3.5), which indicates that the fleet has become more efficient throughout these years (more ethanol share). Regarding per capita energy consumption, in 2003, the consumption of SH was 32% higher than SP, increasing to almost 50% in 2010.

According to the *Agência Nacional do Petróleo, Gás Natural*-ANP [National Agency of Petroleum, Natural Gas and Biofuels], Brazil spent $4.4 billion on gasoline imports in the triennium 2010/2012. In 2012, the country registered a record by importing 3.8 billion liters of gasoline (Governo do Estado de Sao Paulo: Secretaria do Meio Ambiente. Companhia Ambiental do Estado de Sao Paulo, 2014). In 2003, the share of gasoline in the total consumption of urban road transportation was 43%, having decreased to 31% in 2010. The start-analyzed period, consumption of diesel is about 37% and it dropped to 34% in 2010.

Table 3.5 – Energy consumption of the transportation sector in SP: 2003-2010

Fuel (PJ)	2003	2004	2005	2006	2007	2008	2009	2010
(1) Gasoline	52.4	50.4	52.0	53.1	52.9	51.0	48.0	52.3
(2) Ethanol anhydrous	10.9	11.7	12.0	9.9	11.6	11.8	11.1	12.1
(3) Ethanol hydrated	6.2	9.3	10.4	18.6	28.8	35.8	44.3	40.9
(4) Diesel	45.5	47.8	48.6	43.2	50.0	55.8	53.9	56.9
(5) Biodiesel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(6) GNV	6.4	7.2	8.2	9.8	10.7	9.4	6.4	5.3
(7) Aviation gasoline	0.1	0.2	0.3	0.3	0.1	0.1	0.1	0.1
(8) Aviation kerosene	12.3	12.6	11.3	12.7	12.7	9.8	9.4	10.2
Total transportation (1:8)	133.8	139.1	142.9	147.7	166.8	173.7	173.2	177.8
Total urban road transportation (1:6)	121.3	126.3	131.2	134.7	154.0	163.8	163.7	167.5

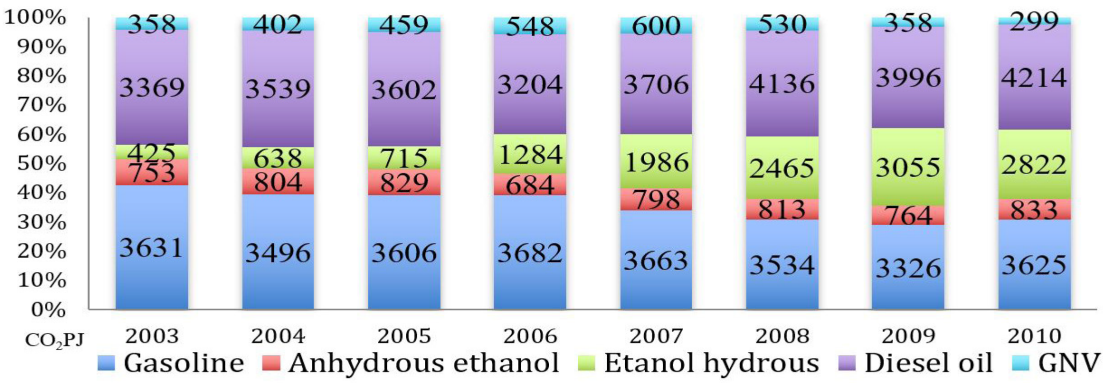
Data source: ((Ministério do Meio Ambiente 2015).

It is the largest energy source used by SP's fleet, mainly due to the heavy-duty vehicle (HDV) fleet. At the end of the first decade of this century, fossil fuel (gasoline and diesel) accounted for 65% of the energy consumption of urban road transportation in SP, as shown in Tables 3.5 and 3.13.

c) CO_2 emissions of SP from road urban transportation

According to the Nature and Environment Secretary of the City of SP, the energy industry to which the transportation is integrated represents 82% of emissions, resulting from fuel combustion.

In 2010, the transportation sector in SP accounted for 71% of the emissions related to the energy sector, including fugitive emissions (Ambiente, 2015) and CO_2 emissions from road urban transportation in the city of SP were 11.8 CO_2PJ and have grown 38% if compared to 2003. Thus, CO_2 emissions from diesel grew 25% in the same period (from 3.3 to 4.2 CO_2PJ) with gasoline emissions remaining stable, as shown in Fiure.3.8.



Data source: (Ministério do Meio Ambiente 2015).

Figure 3.8 – CO_2 emissions from fuel consumption of motor vehicles in SP: 2003-2010

d) Actions to mitigate the SP's fleet CO_2 emissions

SP has given some demonstrations of commitment to the mitigation of transportation emissions in order to improve air quality and prevent climate change. In spite of that, emissions - especially from motor vehicles - have increased, but they would have reached an even higher level if those actions had not been implemented. In this context, the main actions taken to reduce emissions in SP have been the following:

i. In 2009, the creation of the law 14933 set the goal of reducing GHG in SP by 30% by 2012, in comparison to 2003 (Sao Paulo, 2015a).
ii. In 1997, the creation of the Restriction Program For Motor Vehicle Traffic in SP. This regulation applied based on license-rotation to restrict vehicle access in some areas of the city (Sao Paulo, 2015b). However, this action has not been sufficient to prevent the growth of vehicle emissions in the analyzed period.
iii. In 1993, the Secretariat of Green and Environment was created to carry out emission inventories (Sao Paulo, 2015b).
iv. In 1975, the National Alcohol Program (Proálcool) was created in order to produce ethanol as an alternative to gasoline consumption. The Brazilian federal government funded the program after the oil crisis of 1973. The Proálcool allowed Brazil to replace 25% of the gasoline consumption (Cavalcanti, 1992; Ferreira & Ruas, 2000).
v. The Brazilian legislation of road vehicle emissions control follows the characteristics of Euro directive (Ambiente, 2015) but with its own nomenclature (P= heavy, L= light).

After the analyzed period, the municipal law 15997/2014 was created, implementing tax incentives for the ownership of electric and hybrids cars in Brazil's largest city (Sao Paulo, 2015b). The owners had a discount of 50% on the registration fee and they were released from the system of license control. Nonetheless, the total number of EV part of the fleet of SP is so small that they are not relevant from an energy consumption standpoint.

e) SH urban road transportation

China is the largest market for automobiles in the world, but its statistics regarding the automotive sector are so far quite limited (Huo, He, Wang & Yao, 2012). With an urban road fleet estimated of 2.5 million motor vehicles in 2010 (Corps, 2015b), and a growth of 42% from 2003 to 2010, SH's fleet grew at an average annual rate of 5% in the analyzed period. In 2004, occurred the greatest increase (15%). The Chinese road transportation sector is dominated by LDV that represent 68% of the total fleet of vehicles (HDV account for 17%), as shown in Table 3.6.

Although private cars have a large participation in transportation, the SH government has kept a restrictive policy towards car ownership (Gordon & Sperling, 2009). From 2003 to 2010, SH maintained a share of 10,000 vehicles for each 100,000 inhabitants. This fact was due to the population growth, which has been higher than the growth of the city's vehicle fleet. Small passenger cars registered the highest growth (95%).

Table 3.6 – Current urban road transportation of Shanghai Municipality: 2003-2010

Categories (10^3)		2003	2004	2005	2006	2007	2008	2009	2010
Car	Small Passenger*	505	609	715	819	936	1,046	1,180	1,355
	Large coach	33	34	35	36	39	47	54	63
	Truck	185	199	204	201	209	213	216	230
	Other	30	30	34	39	45	49	52	58
	(A) Subtotal	753	872	988	1,095	1,229	1,355	1,502	1,707
Motorcycle	Motorcycle	125	111	98	81	73	67	63	58
	Moped	863	1,024	1,019	944	956	909	853	706
	(B) Subtotal	988	1,135	1,117	1,025	1,029	976	917	764
Other		8	9	10	11	12	13	14	16
Total Vehicle (A+B)		1,749	2,016	2,115	2,131	2,270	2,344	2,434	2,488
Fleet's evolution %		-	15.3	4.9	0.8	6.6	3.3	3.8	2.2

* It includes small buses and vans. Data source: (Corps 2015a; Corps 2015b).

f) Energy consumption of the SH urban road transportation

Table 3.7 – Energy consumption of the urban road transportation of Shanghai: 2003-2010

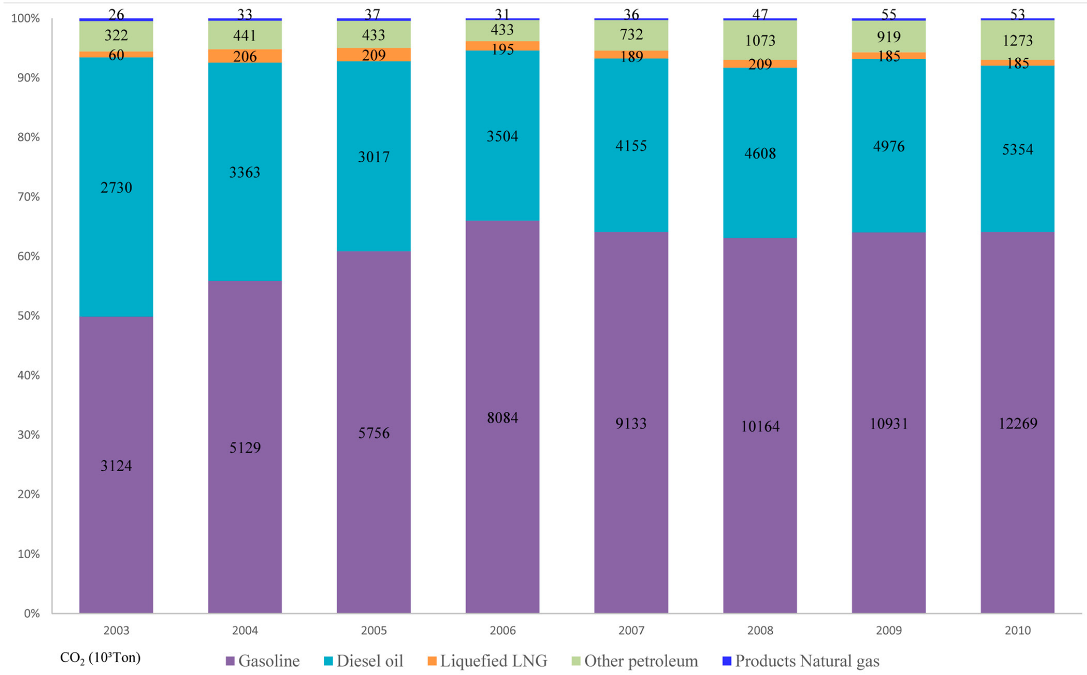
Fuel (PJ) / Year	2003	2004	2005	2006	2007	2008	2009	2010
(1) Raw total	3.3	2.2	1.9	1.3	1.3	1.5	1.4	1.2
(2) Fuel oil	153.8	190.4	226.8	256.0	289.3	281.4	266.6	270.1
(3) Kerosene	43.5	71.4	80.1	112.5	127.1	141.4	152.1	170.7
(4) Gasoline	16.1	18.6	26.5	29.2	32.9	38.9	40.6	42.4
(5) Diesel oil	36.9	45.4	40.7	47.3	56.1	62.2	67.2	72.3
(6) Liquefied LNG	1.1	3.7	3.7	3.5	3.4	3.7	3.3	3.3
(7) Petrol gas (LPG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(8) Other petroleum	4.1	5.6	5.5	5.5	9.3	13.6	11.6	16.1
(9) Products Nat. gas	0.5	0.7	0.8	0.7	0.7	1.0	1.1	1.1
(10) Heat	0.1	0.2	0.2	0.3	0.3	0.3	0.8	0.9
(11) Electricity	11.1	13.3	13.6	16.3	18.3	21.9	9.3	12.3
Total combustion fuel	270.4	351.5	399.8	472.4	538.6	565.9	554.1	590.5
Total urban road Tran	69.9	87.4	91.1	102.6	121.0	141.6	134.0	148.4

Data source: (Song, Wu, & Wu 2014; Wang, Fu, Zhou, Du, & Ge 2010).

The total energy consumption in SH in 2010 is around 590 PJ, and urban road transportation about 148 PJ. Around 25% of the total energy consumed is burned fuel by road vehicles, as shown in Table 3.7. Diesel (49%) and gasoline (29%) together accounted for 78% of the total energy consumed in urban road transportation. In 2010, the gasoline consumption of the SH urban road transportation grew 163% in relation to 2003. In the same period, diesel increased by 96%, as shown in Table 3.7.

g) CO_2 emissions from transportation in SH

The emissions of road vehicles have become a dominant source of local air pollution in major Chinese cities. (Huo et al., 2011). SH is among the three largest cities in the country and Government policies have failed to prevent the increase in emissions from motor vehicles (Huo et al., 2011). From 2003 to 2010, CO_2 transportation emissions from burning fuels in SH grew about 120%. In this period, CO_2 emission from urban road transportation increased 306%. The energy consumption of road urban transportation grew significantly more than it did for other types of transportation - diesel (28%) and gasoline (64%) together accounted for 92% of CO_2 emissions of SH urban road transportation, dominating road transportation emissions - as shown in Figure 3.9 and Table 3.14.



Data source: (Huo et al. 2011).

Figure 3.9 – CO_2 emissions of the SH municipal urban road transportation: 2003-2010

h) Actions to mitigate vehicle emissions SH

Air pollution has increased faster than the global average in many Chinese cities. The Chinese government has increasingly focused its attention in reducing emissions from motor vehicles. Air pollution related to transportation costs about 8.7 million US$ to the country (Bhalla et al., 2014). The main measures implemented by the government to reduce air pollution from road urban transportation in SH have been the following (Bank, 2015; T. N. D. a. R. C. China, 2014; Emissions, 2015; Feng & Li, 2013; Lohry, Yiu & Lu, 2014):

i. In 2002, SH banned the circulation of internal combustion motorcycles in urban centres.
ii. Since 2001, China adopted control emissions standards (Euro equivalent).
iii. In 1986, SH adopted the auction system for Private Car Licenses whereby the government sells permit for car buyers, facilitating control of the private fleet expansion, and in 2000 the rules have become more restrictive.
iv. The SH government states that during peak hours, vehicles that are not registered in the city cannot drive in the city.

After the analyzed period, two other measures were adopted:

i. From 2014 on (until 2020), SH offers free license to buyers of green vehicles (license costs around US$12,000), plus other benefits, like not being subject to limited circulation. However, to be eligible, vehicles need to be manufactured in China and, in some cases, in the region where the benefit is offered. The control of the fleet in SH is being accomplished without major disruptions to the economy. The same cannot be said about the attempts of the central government to remove the yellow label vehicles because many of them are being sold in the black market in rural areas where it is not easy to control them.

ii. In 2015, SH has provided licenses only for owners of class V Chinese vehicles, and

iii. The Chinese government adopted the China V emission standard (equivalent to Euro V) for gasoline and diesel vehicles (China, 2015).

3.2.4 Correlation Analysis

SP selects the fleet based on the type of vehicles (LDV and HDV) and SH on fuel type (gasoline and diesel). The CO_2 emission mitigation policies are shown in Table 3.8.

3.2.4.1 Correlation of the actions to mitigate CO_2 emissions in SP and SH's urban road transportation.

In the analyzed period, not all the CO_2 emission mitigation actions taken by these cities have been unsuccessful. Mitigation actions taken prior to 2000 had the most impact to mitigate emissions in the first decade of this century. During the analyzed period, the policies adopted did not have significant impact, since many of them only came into force after 2010, as shown in Table 3.8.

Table 3.8 – Actions to mitigate CO_2 emissions from 2000 to 2010 in SP and SH

	SP			SH		
Action	Adopt[1]	Date[2]	Imp[3]	Adopt[1]	Date[2]	Imp[3]
Removal of old cars from circulation	No	-	□	Yes	2011/13	□
Restriction of circulation (licenses rotation)	Yes	1997	>	Yes	1986/2000/2004	>
Annual survey of the urban road transportation	Yes	2008/10	<	Yes	2004	≥
Emissions inventory	Yes	2003	>	Yes	2004	≥
Reducing urban road transportation emissions as goal	Yes	2009	<	Yes	2010	□
Adoption of alternative fuel (ethanol)	Yes	1975	>	No	-	□
Implementation of emission control system (Euro)	Yes	1987/89	>	Yes	2001/3	>
Prioritized investments in public transportation	No	-	□	Yes	2004	≥
Subsidy for purchase of green vehicles	No*	-	□	No*	-	□
Benefit for the use of green vehicles	Yes	2014		Yes	2014	□
Incentive policy to exchanging old cars for new ones	No	-	□	Yes	2014	□
To ban motorcycle circulation	No	-	□	Yes	2002	>
Politic of old bus exchange for new hybrid and electric vehicles	No	-	□	Yes	2012	□
Emission reduction	Yes	2003/10	>	No	-	□
Reduce emissions of the urban road transportation	No	-	□	No	-	□

[1]In the case, the city implemented the policy; [2]Date the city implemented the policy [3]How important was the policy to mitigate CO_2 in the first 2000 decade, where: > Very Large Impact; ≥ Relevant; ≤ Medium relevance; < Low relevance; □ No relevance. * SH offers free license and SP discount, both considered in this study as "Benefit to use green vehicles". Data source: (Ambiente 2015; Book-Yearbook 2012; Chan & Yao 2008; Emissions 2015; Lohry et al. 2014; C. M. d. S. Paulo 2014; Paulo, 2015a).

Netherlands, California, United States, Japan, France and Germany showing how useful it is for policy makers, society and other stakeholders. These studies help to understand the social, economic, political and environmental contributions in adopting electric and hybrid vehicles (Vergis, Turrentine, Fulton & Fulton, 2014). Recent case studies compared electric and hybrid mobility between seven regions: Norway,

3.2.4.2 Correlation economic and social data from SP and SH municipalities

Albeit SH has twice the area and population of SP, the Brazilian city has a larger concentrated population and urbanization rate: this rate is 11% higher if compared to the Chinese metropolis. Even though in 2010 SH GDP was 179% higher, SP's per capita income is 14% higher than in the Chinese city (Table 3.9). SH was driven by substantial growth of the Chinese economy with an average annual rate of 8% in the analyzed period (Bank, 2015) and a significant population growth (Table 3.9) due to the migration from the countryside to the city. On the other hand, the city of SP did not have the same trend, because of low economic growth (around 2% (Bank, 2015)) and the tax competition among Brazilian states to attract producers (Macedo & Angelis, 2013; Torres, 2012).

From 2003 to 2010, the Brazilian city fleet experienced a noticeable growth, higher than SH. In SP, the largest increase in fleet segment occurred in small passenger vehicles (51%) and motorcycles (160%). In China, the most significant growth was LDV’s (168%) and buses (100%). While in the beginning of this century SH and SP had quite a similar bus fleet size, by the end of the first decade the fleet of the Chinese city has surpassed the Brazilian city´s fleet by 50%, as shown in table 3.10.

Table 3.9 – Economic and social data from SP and SH municipalities

	Municipality					
	SP			SH		
Foundation (year)		1554			751*	
Area (km²)		1,523			6,340	
Indicators/Years	2000	2010	%	2000	2010	%
Population (10^3)	10.4	11.2	7.8	16.7	23.0	37.5
Density (%)	6.85	7.39	7.8	2.64	3.63	37.5
Human Development Index	0.733	0.805	9.8	0.745	0.814	9.2
Gross domestic product (10^6)	43.5	151.8	248.2	45.5	271.4	496.3
Gross domestic product per capita	4.1	13.4	222.9	2.7	11.7	333.6
Urbanization level (%)	94.0	98.9	5.2	82.8	88.3	6.6

* The city of SH is considered a municipality since 1927

Data source: (Book-Yearbook 2012; Chan & Yao 2008; Denatran 2015; NEWGEOGRAPH, 2015; Yearbook 2011).

3.2.4.3 Performance of urban road transportation of SP and SH

The data suggests that SH prioritized public transportation while SP expanded individual transportation. In this stage, the question “what kind of transportation does each city prioritize?” was answered. In the analyzed period, SH halved its motorcycle fleet while SP more than doubled its motorcycle fleet. This fact is explained by the restrictive policy of circulation of this type of vehicle (equipped with internal combustion engine) in SH and in major Chinese cities (Yang, 2010).

3.2.4.4 Comparison of urban road transportation of SP and SH for 100,000 residents

In 2003, SP had four times more urban vehicles per 100,000 residents than SH, as shown in (Table 3.11.

Table 3.10 – Analysis of urban road transportation in Sao Paulo (SP) and Shanghai (SH)

(10^3)	2003			2010			SP	SH
Categories	SP	SH	% SH/SP	SP	SH	% SH/SP	% Growth	
Small passenger	3,375	505	15.0	5,093	1,355	26.6	50.9	168.3
Motorcycles	337	125	37.1	875	58	6.6	159.6	-46.4
Large buses	31	33	106.4	42	63	150.0	35.5	90.9
Other	636	1,086	170.8	942	1,012	107.4	48.1	-6.9
Total	4,379	1,749	39.9	6,952	2,488	35.8	58.8	42.2

Data source: (Corps 2015a; Corps 2015b; DENATRAN, 2015).

Table 3.11 – Urban road transportation for 100,000 residents: SP *vs* SH-2003/2010

SP vs SH: vehicle 100,000 residents	2003			2010		
Per capita rate / Vehicle type	SP	SH	SP/SH*	SP	SH	SP/SH*
Small passenger	32,353	0,302	107	45,259	0,589	77
Large coach	0,299	0,020	15	0,374	0,027	14
Truck	1,111	0,111	10	1,416	0,100	14
Motorcycle	3,231	0,075	43	7,783	0,025	309
Other	5,011	0,538	9	6,969	0,339	21
Total	42,005	10,448	4	61,801	10,807	6

Data source: (Corps 2015b; DENATRAN 2015)

* Number of times SP is greater than SH.

3.2.4.5 Correlation by emission of urban motor vehicle of SP and SH in the 2000s

The largest Brazilian city implemented emission controls a few years ahead of the Chinese city. In 1994, SP started diesel control (equivalent to Euro I) and SH started it in 2001, as shown in Table 3.12

Table 3.12 – Implementation phases of the standards for vehicle emissions: SP vs SH

SP						SH		
Phase Euro	Phase Brazil	Year Bus	Year Truck	Phase Car	Year Car	Phase China	Diesel	Gasoline
-	P-1	1987	1989	L-1	1988-91	-	-	-
Euro 0	P-2	-	1994/6	L-2	1992-96	-	-	-
Euro I	P-3	1994	1996/0	L-3	1997-04	China I-II	2001/4	2003/4
Euro II	P-4	1998	2000/2	L-4	2005-08			
Euro III	P-5	2004/5	2005/6	L-5	2009-13	China III-IV	2008/13	2010/13
Euro IV	P-6	2009		L-6	2014			
Euro V	P-7	2012		L-7	-	China V	2008/13	2015
Euro VI	P-8	-		L-8	-	-	-	-

Data source: (Huo et al. 2011; Paulo 2015b; Yearbook 2011).

Gasoline consumption, SP adopted norms equivalent to Euro I in 1997 and SH started it in 2003 (Table 3.12), suggesting that the Brazilian city fleet should have less emissions than the Chinese city.

3.2.4.6 Correlation between the energy consumption of SP and SH's urban transportation

From 2003-2010, the energy consumption of SH fleet grew more than four times compared to SP. The Chinese city significantly increased gasoline consumption (163%), while in SP almost no growth was observed in the same period.

The significant increase in consumption of urban transportation in the Chinese city (with a low fleet growth) can be explained by a greater use of public transportation. The restriction of the use of motorcycles and LDV has forced an increase in the public transportation offer in SH. In 2010, the consumption of gasoline in SH was about 30% (in 2010, it was 36%) of the SP gasoline consumption (Table 3.13) due to the SH's car fleet that was about six times smaller than SP.

Table 3.13 – Analysis of energy consumption of urban road transportation SP and SH

	2003			2010			SP 03 vs 10	SH 03 vs 10
Categories (PJ)	SP	SH	% SH/SP	SP	SH	% SH/SP	% Growth	
Gasoline	52.4	16.1	30.7	52.3	42.4	36.3	0.0	163.3
Diesel oil	45.5	36.9	81.1	56.9	72.3	27.1	25.0	95.9
Ethanol anhydrous	10.9	0.0	-	12.1	0.0	-	11.0	0.0
Ethanol hydrated	6.2	0.0	-	40.9	0.0	-	659.6	0.0
Other	6.4	16.9	89.9	5.3	33.7	635.8	(17.2)	99.4
Total urban transp.	121.4	69.9	55.1	167.5	148.4	88.6	38.0	112.3
Per capita consumption (MJ)	30.2	39.9	32.3	35.1	59.6	69.9	16.2	49.2

Data source: (Emissions 2015; Song et al. 2014).

Regarding the consumption of diesel, in 2003 SP consumed about 20% more diesel than SH. In 2010, it was the opposite, and SH began to use around 27% more than SP (Table 3.13). The increase of diesel consumption in SH (96%) is explained by the increase of about 25% of the truck fleet, 91% of the bus fleet, and the public transportation growth. The population of SH in the first decade of the 21st century increased 37%, as shown in Table 3.13. From 2003 to 2010, the energy consumption grew about 38% in SP (Table 3.13), while the fleet of vehicles grew 59% during the same period, revealing that the fleet has become more efficient.

In 2003, SH's road fleet was about 55% less energy consuming than the SP's fleet. In 2010, it was 11% less energy consuming. From 2003 to 2010, SP per capita energy consumption grew 38%, while SH grew 112% (Table 3.13), revealing that ethanol had an important role in preventing the growth of energy consumption in SP (SP fleet grew 59% in the same period). The growth of the truck fleet (Table 3.10) that is powered by diesel oil (38%) causes higher energy consumption in the Brazilian city in 25% (Table 13). This data also reveals that both cities are increasing the energy consumption of urban road transportation.

The substantial increase in ethanol consumption is explained by the significant growth of the flex fuel vehicle fleet in SP (and in Brazil). A study about the SP fleet showed that the number of flex cars continued to grow even after 2010, representing 53% of the total city fleet in 2012 (Costa & Seixas, 2014). In addition, the low energy consumption of the SP's fleet compared to SH fleet is because LDVs are relatively new, benefiting from legislation regarding the control of automotive pollutants and the developments in the energy efficiency of the automobile industry (Zamboni, Tsai, Pires, & Cremer, 2015). Even though this study focused on urban road fleet, it revealed that SH also uses water as main transportation due to the seaport connection with various areas of the city by the Huangpu River. In contrast, the city of SP does not have this feature, which is the reason why this mode of transportation is negligible.

3.2.4.7 Correlation of CO_2 emissions of urban road transportation of SP and SH municipalities

In the period analyzed, SH doubled its emissions while SP had a 25% growth. In 2003, the urban fleet of SP was responsible for more than twice the CO_2 emissions than the SH fleet. In 2010, this situation was reversed and SH registered nearly 20% more CO_2 emissions in relation to SP. To paraphrase Sperling, "From Paris to Fresno, and Delhi to Shanghai, conventional motorization, conventional vehicles and conventional fuels are choking cities, literally and figuratively." (Sperling & Gordon, 2010).

The figures show that government efforts to limit individual transportation - even though significantly - reduced the number of motorcycles in circulation. In 2003, CO_2 emission from gasoline consume by the SH fleet was around 39% of the SP emissions. In 2010, there was another reversal of values and the Chinese city exceeded the emissions from the Brazilian city by 152%. Regarding CO_2 emission from diesel oil, in 2003, SH was 81% of the SP emission (Table 3.14). In 2010, it grew to 127%.

Table 3.14 – Analysis of CO_2 emissions from urban road transportation of SP and SH

	2003			2010			SP 2003 X 2010	SH 2003 X 2010
CO_2 emission (PJ)	SP	SH	% SH/SP	SP	SH	% SH/SP	% Growth	
Gasoline	8,014	3,124	39.0	8,082	12,268	151.8	0.8	292.7
Diesel oil	3,369	2,729	81.0	4,213	5,353	127.1	25.1	96.1
Ethanol hydrous	425	0.0	-	2,821	0,0	-	563.8	0.0
Other	1,111	407	36.6	1,133	1,511	133.4	1.9	271.5
Total	12,919	6,261	48.5	16,249	19,133	117.7	25.8	205.6
Per capita emission	2.95	3.58	21.4	2.34	7.69	328.6	(20.7)	214.8

Data source: (Huo et al. 2011; Paulo 2015b).

In 2003, the SH's per capita emissions of CO_2 were 21% higher than the SP's. In 2010, per capita emissions of the Chinese city fleet were 329% higher than in the Brazilian. Between 2003 and 2010, SP increased 26% its fleet CO_2 emissions, and SH in the period prescribed, increased it in about 206%. Ethanol helped to keep SP's CO_2 emissions even higher. However, the EV has greater potential of mitigation. A study on the potential mitigation of emissions in SP adopting EV concluded that replacing 100% of the gasoline cars would provide a reduction of 11 $GtCO_2$ in 2030 (Costa & Seixas, 2014).

3.2.5 Conclusion

The comparative analysis of CO_2 emissions between SH and SP indicated that mitigation policies and measures taken in that period were not sufficient to prevent the growth of CO_2 emissions in both cities.

Actions beyond those already implemented are needed to curb CO_2 emissions and its contribution to climate change. SP should act mainly to reduce the individual transportation by increasing public transportation, while SH should reduce the consumption of dirty fuel. This study also revealed that in order to reduce transportation emissions, in addition to restricting vehicle ownership and use of individual vehicles, it is necessary to ensure that the purchases of new vehicles, if they happen, are of low emission vehicles. In this case, there should be a package of measures that includes incentives capable of making the TCO of low emission vehicles attractive to its owner.

Regarding the urban road transportation, some actions have the potential to mitigate the burning of fossil and CO_2 emissions, as: a) improve vehicle's efficiency; b) replace polluting vehicles (old) by low emission vehicles; c) discourage the use of internal combustion engines; and d) encourage the use of green mobility. In this context, it is recommended that future studies be performed to update public policies and evaluate the effects of the mitigation measures adopted by both cities in the ongoing decade. The scarcity of data limited in some ways the performance of this study.

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3.3 CONTRIBUTION OF ELECTRIC CARS TO THE MITIGATION OF CO_2 EMISSIONS IN THE CITY OF SAO PAULO

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ABSTRACT

Adoption of the electric car to mitigate air pollution and climate change: myth or reality? This study aims to bring out the energy and climate mitigation impacts of mass introduction of electric cars in city of Sao Paulo, Brazil. A working scenario of 10 percent penetration of electric cars replacing gasoline-powered vehicles by 2020 and 20 percent by 2030 was set. The impact on the energy mix and CO_2 emissions was based on indicators available for the city of Sao Paulo. Preliminary results indicate significant energy and environmental benefits to the city. We identified a potential reduction of up to 2030 will be about 11 $MtCO_2$ representing more than 10 percent compared with the total emissions from the fleet of gasoline-powered cars.

KEYWORDS: Electric Cars; Sao Paulo; Energy Matrix; Electricity; Greenhouse Gas; Vehicle Fleet.

3.3.1 Introduction

Electric cars have been stated as an effective alternative to internal combustion engines due to CO_2 emissions mitigation, and energy efficiency, mostly if the power system is supported by renewable sources.

Aiming to identify the impacts of massive introduction of electric cars on mitigation of CO_2 emissions as well as energy changes in Sao Paulo, this study examined other related works published in Brazil. We found that our aim is differentiated by being a pioneer in the investigation because i) it focuses on the city of Sao Paulo in contrast with the state of Sao Paulo; ii) it incorporates in the scope of our study the Brazilian Law No.12,715 of September 17, 2012 [1], which provides for the Incentive Program Technology and Densification Innovation Supply Chain Motor Vehicles - INNOVATE-AUTO; and iii) it considers only cars 100 percent electric replacing gasoline cars.

The city of Sao Paulo has 11.8 million inhabitants and is the most populous municipality in Brazil, the American continent and the entire southern hemisphere [2]. With Gross Domestic Product (GDP) of \$477 billion [3], Sao Paulo is considered the major financial center of South America and the 10th richest city in the world [4].

Sao Paulo accounts for the largest vehicle fleet in the country: in December 2012, the total fleet was set at 4.3 million of vehicles, of which cars represented 73.2 percent [5]. With more than 32,000 taxis, the city meets the third largest fleet of taxis in Latin America. In the year 2011, the transport sector accounted for emissions of about 11.8 million tons of CO_2 [6] thereby contributing to almost 80 percent of total emissions from energy sector (also including power, industry and fugitive emissions) in the city [7]. Therefore, there is the need and the opportunity to consider electric cars as a major driver change of the city mobility aiming to reduce energy consumption and CO_2 emissions. The goal of this paper is to assess whether a scenario of battery electric vehicles (BEV) substituting gasoline-power cars in the city of Sao Paulo in the medium term (2020 and 2030) could be feasible and to estimate its impact in energy consumption and in CO_2 emissions.

A. Current fleet of cars, energy consumption and CO_2 emissions

The vehicle fleet consists of cars, light commercial vehicles, motorcycles, light trucks, medium, heavy and semi-heavy, urban and highway bus. The present study focuses on the fleet of gasoline-powered Otto automobiles for passengers' mobility with seating for up to eight occupants, including the driver. The fleet of cars registered in 2012 in Sao Paulo was 3.2 million units, representing 73.2 percent of the total fleet of the most populated city in Brazil, as shown in Table 3.15 [5].

Table 3.15 – Estimated Current Fleet In Sao Paulo (SP) (2012)

Category	Fuel	Fleet State SP	Fleet City SP
Cars	Gasoline	4,173,008	1,501,375
	Ethanol	406,215	116,773
	Flex	4,878,146	1,607,066
Sub-total		9,458,369	3,225,214
	Share of total cars Over total fleet		73,20%
Truck, bus, motorcycle		4,886,401	1,178,469
Total Fleet		14,344,770	4,403,683

Data source: [5].

Almost half (46.5 percent) of the car fleet in the city Sao Paulo consists of vehicles powered by gasoline and 53.5 percent for flex (which can run both gasoline and alcohol), as shown in Table 3.15. In 2011, the fleet of vehicles in Sao Paulo reported an average age of 8 years [5] and in the case of cars the average run of 12,000 kilometers year. Around 80 percent of the fleet is ten years or less of use in 2012.

In 2011, the fleet of Sao Paulo consumed 2,061 m^3 of gasoline and 2,170 m^3 of ethanol, thus adding around 4,231 m^3, compared to 2,500 m^3 in 2003, which represents an increase of both fuels of about 67.3 percent. Focusing on gasoline consumption, statistics show an increase of 17 percent in that period, as shown in table 3.16 [6].

According to the National Agency of Petroleum, Natural Gas and Biofuels (ANP), Brazil spent US$4.4 billion on gasoline imports in the triennium 2010/2012. Incidentally, in 2012, the country reported a record when importing 3.8 billion gallons of gasoline.

The country in 2013 consumed a daily average of 2.9 million barrels (up 42 percent over 2003) and produced 1.5 million barrels daily. Together the 14 refineries processed 1.9 million barrels per day (an increase of 4.4 percent over 2003). In summary, the country refines around two thirds of its needs, consumption grows rampant, and keeps refining the nearly stagnant [8].

Table 3.16 – Consumption Of Gasoline And Ethanol In Sao Paulo

Year / 10^3m^3	Gasoline A	Ethanol A*	Ethanol H**
2003	1,711	514	304
2004	1,647	549	456
2005	1,699	566	511
2006	1,735	467	918
2007	1,726	545	1,420
2008	1,655	555	1,763
2009	1,567	522	2,185
2010	1,708	569	2,018
2011	2,061	687	1,483

* Anhydrous ** Hydrous - Source: [8].

In this context, Sao Paulo adopted public measures, such as the Law 14,933/09 which established targets for reducing GHG emissions in the order of 30 percent in 2012 compared with 2003 [9], but the goal was not achieved and instead of cutting emissions, the city of Sao Paulo increased the release of greenhouse gases in the period (15,110 Gg of CO_2e in 2003 and 16,430 in 2011). It should be underlined that the increase of emissions was not higher due to the share of ethanol in fuel composition used in the fleet of city vehicles [6].

B. Vision for the development of electric cars in Sao Paulo

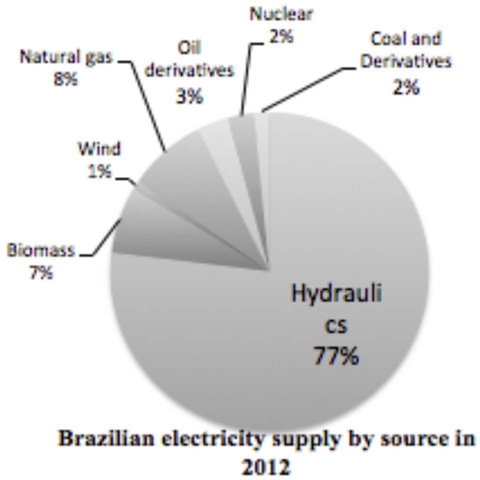
The Brazilian government has not regulated the manufacture and sales of electric vehicles (BEVs) in the country. However, there are indications that this fact should not take much time to change. The need to reduce fossil fuel consumption and air pollution; the encouraging results from mass introduction of BEVs in other regions such as the United States and Norway; the robust investment from global automakers, such as BMW, Renault-Nissan Alliance and other incipient like Tesla, and the recent decision by China to adopt massively BEVs may influence the decision of the Brazilian government in favor of the electric vehicle adoption.

Moreover, considering the sales of the BEV models, 10,064 units were sold in the United States in 2011 against 52,835 in 2012 and 96,702 in 2013, which illustrate a very high increasing growth rate [10]. Therefore, scenarios for the penetration of BEV models in a city like Sao Paulo appear very likely, and should be considered as low carbon options, due to the low emission factor of the electricity production, as presented in the next section.

C. Electricity production in Brazil

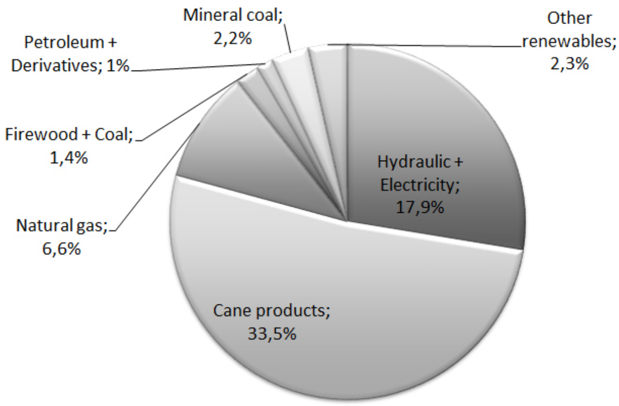
The array of Brazilian electricity generation is 85 percent renewable sources in 2012, as shown in Figure 3.10, which is quite favorable to supply BEVs, as a low carbon option. For the year 2009, the emission factor of power production was set at $25kgCO_2/MWh$ [11].

During the last decades, renewable sources are becoming increasingly prevalent in the electricity consumption mix in the city of Sao Paulo. In 2010, renewables sources represented more than 55 percent of the total electric composition, as shown in Figure 3.11 [12].



Data source: [11].

Figure 3.10 – Brazilian electricity supply by sources in 2012



Data source: [12].

Figure 3.11 – Share of electricity supply in Sao Paulo in 2010

3.3.2 Methodology

This study applies to the city of Sao Paulo. We assume a very conservative perspective to estimate the growth rate of the car market of 0.5 percent per year for the period 2014 to 2030. This indicator is well below the national average growth occurred between 2003 and 2013, when the average annual growth was 14.7 percent [13]. However, after 2010, the sales have been falling a lot, culminating in the fall of 0,3 percent from 2012 to 2013 [13].

Moreover, we consider the Brazilian market has reached a first stage of ripening, and fleets of cars from major urban centers will grow at more modest rates, compared to the national growth.

We opted for three battery electric models, chosen among the most popular in the international market: Nissan Leaf, Ford Focus and BMW i3. This choice took into account the prices of the vehicles, the reputation of brands in the Brazilian market and the autonomies of the cars. It is worth mentioning that Nissan is introducing BEVs in various sectors in Brazil, especially in Sao Paulo where there is testing electric taxis and fleets along with public and private companies [14]. In Table 3.17, the specific consumption in kWh for each car model we use in our calculations is presented [15].

Table 3.17 – Specific Electricity Consumption And Autonomy

Electric Vehicle	Capacity	Autonomy
BMW i3	18.8 kWh	190 km
Leaf	23 kWh	140 km
Ford Focus	23 kWh	180 km

Data source: [15].

We consider the selected models will replace gasoline-powered cars, due to the following reasons: these types of cars represent almost 50 percent circulating in of the city of Sao Paulo; the country is importing this type of fuel; and we intend to achieve reductions of CO_2 emissions arising from fossil fuel combustion.

We assume the following BEV penetration scenario in the city mobility: 10 percent of gasoline-powered vehicles will be substituted by BEV by 2020 and 20 percent by 2030; the BEV will run the annual average of 12,000 kilometers, compatible with the internal combustion models, taken as short distances within the city.

Surplus electricity consumption and respective emissions were considered. Emissions from the manufacture of cars were not taken into account, because we may consider approximately no significant differences between the production of electric and internal combustion model.

We consider the following assumptions for projection of gasoline consumer, from the incentives under the standards INNOVATE-AUTO [16]:

- 2017 to 2020: 70 percent of the fleet get 13.6 percent reduction in gasoline consumption;
- 2017 to 2020: 20 percent of the fleet will get a reduction of 25.5 percent;
- 2021 to 2030: 70 percent of the fleet get 25.5 percent reduction in gasoline consumption.

For emission we consider the following assumptions (standards INNOVATE-AUTO):

- 2017 to 2020: 70 percent of the fleet get 17 percent reduction in emission;
- 2017 to 2020: 20 percent of the fleet get 20 percent reduction in emission;
- 2021 to 2030: 70 percent of the fleet get 20 percent reduction in emission.

The fact this study was conducted in the city of Sao Paulo where vehicular inspection (providing real vehicle data), helped to reduce the margins of the study bug.

Nevertheless, we recognize several uncertainty sources in our calculations, namely: (i) we assume the empirical CO_2 emission factor of the gasoline-powered cars and electricity production remain constant up to 2030; (ii) we estimate at 7 percent the error regarding fuel consumption, in relation to the cases where the driver letting in another site, and rotates in the city of Sao Paulo.

Therefore, these results should be seen as preliminary and approximate, although general trends could be approached with reasonable significance.

3.3.3 Results

The projections of the gasoline fleet in the city of Sao Paulo will account for approximately 1.7 million cars in 2020 and around 1.8 million in 2030. According to our penetration scenario, we consider 170 thousand units of BEV by 2020 (10 percent) and 360 thousand (20 percent) by 2030.

A. Impacts on energy consumption

We estimate that gasoline consumption accumulated from 2010 to 2020 will be 21.1 billion liters and 43.3 billion up to 2030. Considering INOVAR-AUTO policy and electric car penetration, the accumulated reduction in the same periods will be 1.5 billion liters (7.0 percent) and about 5.7 billion liters (13.1 percent) respectively, as shown Table 3.18.

Table 3.18 – Gasoline Consumption From 2015 to 2030

	2015	**2020**	**2030**
Total gasoline consumption (10^3m^3)	10,423	21,113	43,310
Cons gas with reduction INOVAR+EV (10^3m^3)	10,423	19,645	37,658
Total gasoline reduction (10^3m^3)	0	1,468	5,652
Total Gasoline reduction (%)	0	7.0%	13.1%

The increase of electricity consumption with the adoption of electric cars in the fleet would be 268 MWh in the year 2020, and 536 MWh in 2030, negligible values representing less than 0.01 percent of consumption total of Sao Paulo in 2030.

B. Impacts on CO_2 emissions

Cumulative CO_2 emissions due to gasoline consumption in cars in the city of Sao Paulo for the period 2010 up to 2020 is estimated at 50.0 $MtCO_2$ and 100.6 $MtCO_2$ up to 2030. By 2030, the CO_2 emissions from gasoline consumption represents about 40 percent of total fleet of city of Sao Paulo.

Considering BEV introduction and INOVAR-AUTO policy, emissions will be reduced around 3.5 $MtCO_2$ in the period 2010 to 2020, and 11.0 $MtCO_2$ to 2030, therefore quite significant as shown in Table 3.19.

Table 3.19 – Reduction in CO_2 Emission In 2020 And 2030

	2010	**2015**	**2020**	**2030**
Emissions from gasoline cars (tCO_2)	3,816	27,105	50,990	100,586
Emissions reductions from BEV and INOVAR (tCO_2)	0	0	3,525	10,964
Total reduction (%)	0	0	6.9%	10.9%

CO_2 emissions due to the electricity consumption would be 6.5 tCO_2 in the year 2020, and 13.1 tCO_2 in the year 2030, which are negligible values when compared with the amount of CO_2 emissions from the internal engines fleet, justified by the very low CO_2 emission factor from power production, as refereed before.

C. Impacts on energy costs

The costs breakdown revealed the city of Sao Paulo would have costs increase with electricity consumption amounting to 28 thousand US dollars in 2020 to around 57 thousand in 2030. However, gasoline consumption savings totals around US$1.6 billion in 2020 and US$6.2 billion in 2030, as revealed in Table 3.20, based on date from [8, 17, 18].

Table 3.20 – Economic Gains For Sao Paulo For 2020 And 2030

Increase / Decrease of energy consumption	2020	2030
Increase of electricity costs (10^6US$)	0,028	0,057
Decrease of gasoline costs (10^6US$)	1.6	6.3
Economic Gains (10^6US$)	1.6	6.2

3.3.4 Conclusion

The study revealed that a reduction of about 11.0 $MtCO_2$ by 2030 is achievable in the city of Sao Paulo with the replacement of 20 percent of gasoline cars with battery electric cars, with negligible increase of CO_2 emissions from electricity consumption. This scenario will imply a reduction of about 7 percent of gasoline consumption in 2020 and 13 percent by 2030. Therefore, we are able to conclude that the city has much to gain from the introduction of electric cars, either from energy, environmental and economic point of view.

Sao Paulo would have costs savings in 2030 of approximately 6.2 billion American Dollars with the introduction of electric cars as assessed with the scenarios in this study.

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CHAPTER 4 | ASSESSING ELECTRIC VEHICLES' CHARGING INFRASTRUCTURE AT THE MUNICIPALITY LEVEL: THE CASES OF RIO DE JANEIRO, BELO HORIZONTE AND SAO PAULO

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Part 2: Paper published of the Proceedings of the International Vehicle Power and Propulsion Conference (VPPC-IEEE), December 11-14, 2017 – Belfort, France, DOI: 10.1109/VPPC.2017.8330964

Evaldo Costa, Arthur Paiva, Julia Seixas, Patricia Baptista, Gustavo Costa and Brian Ó Gallachóir (2017). Suitable Locations for Electric Vehicles Charging Infrastructure in Rio De Janeiro, Brazil.

Part 3: Paper VI. Submitted for publication

Evaldo Costa, Thierry Coosemans, Julia Seixas, Maarten Messagie, Gustavo Costa and Lieselot Vanhaverbeke. Optimizing the location of charging infrastructure for future expansion of electric vehicle in Sao Paulo. It is under review.

4.1 SPATIAL PLANNING OF ELECTRIC VEHICLE INFRASTRUCTURE FOR BELO HORIZONTE, BRAZIL

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ABSTRACT

In pursuit of a more sustainable transportation system, electric vehicles (EVs) have the potential to play a fundamental role due to their improved efficiency and lower emissions. The absence of an adequate electric vehicle supply equipment (EVSE) network has been one of the major obstacles for the mass adoption of EV, in large municipalities of developing countries. This is the case in Belo Horizonte (BH), Brazil, which also has a high motorization rate (7 light-duty vehicles per 10 inhabitants). The purpose of this study is to measure and identify the optimal locations for EVSE according to selected criteria to meet the needs of light-duty electric vehicles (LDEV) corresponding to a penetration of 1% by 2025 in the municipality of BH. The study highlights the most important attributes that need to be considered for the installation of an EVSE network in an urban space for a developing country. Multi-criteria Decision Making (MCDM), the Weighted Linear Combination (WLC) method, and the Analytical Hierarchy Process (AHP) technique based on the inputs from a group of Brazilian electrical mobility specialists, coupled with a Geographic Information System (GIS) modeling tool, were used for this study. The results revealed that around 1,200 EVSE units are needed, with a large concentration of EVSE in a small region. We also illustrate where stakeholders should focus their attention for the successful promotion of EV. The development methodology has the potential to be applied in other future EVSE development projects.

KEYWORDS: Electric Vehicle Supply Equipment, Light-Duty Electric Vehicles, Belo Horizonte, Multi-criteria Decision Making, Weighted Linear Combination, Geographic Information System.

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4.1.1 Introduction

There is a large mobility demand in urban centers. These urban centers hold about 80% of global Gross Domestic Product (GDP) and account for two-thirds of all primary energy consumption, and 70% of carbon dioxide (CO_2) emissions (IEA 2017). Global transport is responsible for almost a quarter of energy-related emissions (IEA 2017). In Brazil, more than 32% of final energy consumption is from the transport sector with road transportation accounting for more than 92% of this amount (EPE 2015). Ethanol has an important role for low carbon transportation in Brazil. A Comparative Life Cycle Assessment (LCA) study shows that, when replacing gasoline with ethanol fuels, Greenhouse Gas (GHG) emissions can decrease by around 81%, (Luo et al. 2009). On the other hand, several studies highlight that the agricultural process for producing ethanol can be responsible for considerable problems such as ecotoxicity, soil acidification and human toxicity among others (Ometto et al. 2009; Filoso et al. 2015). Some even studies that identify benefits in the production of ethanol also highlight the negative environmental impacts (Walter 2015). Other studies suggest that the competition from the production of ethanol with food is another substantial problem. (Martinelli et al. 2011; Pimentel et al. 2009; Bray et al. 2000).

Replacing internal combustion engines (ICE) with EV charged with clean energy has the potential to further reduce CO_2 emissions (Baptista et al. 2014; Foley et al. 2015; Messagie 2014; Wolfram 2017; Ambrose 2016; Peters et al. 2017; Hawkins et al. 2013). This makes EVs a more appropriate option for urban space (Hooftman et al. 2016).

A study for Sao Paulo (with adopted emissions by car of 220 gCO_2 / km) reveled that EV could reduce around 11,0 $TgCO_2$, if 20% of its fleet of gasoline cars is replaced by 2030 (Costa et al. 2014). This it is equivalent to removing the emissions of about 140,000 medium gasoline-powered cars in one-year when considering an LCA methodology – European study indicates emissions of 250 gCO_2 / km (Nordelof 2014). Therefore, the EV can eliminate the emission of local pollutants (namely HC, CO, NOx and PM), and significantly contribute to reducing energy consumption and the mitigation of climate change, especially when the electricity is produced from a renewable energy mix (Costa et al. 2017).

Emissions from the transport sector have grown 2.5% annually between 2010 and 2015; however, OECD (Organization for Economic Co-operation and Development) countries aim to reduce emissions by 2.1% annually between 2015 and 2025 (IEA 2017). The development of EV technology and corresponding recharging infrastructure can be one potential way to reduce emissions as well as increase energy efficiency (Sperling 2014).

However, the lack of expansion of suitable electric vehicle supply equipment (EVSE) networks provides a barrier for EV (range anxiety[26] effect) (Thiel et al. 2012), even though features such as Safe-Range-Inventory (SRI) is capable of overcoming the obstacle of range anxiety. In some developing countries other problems also need to be considered when planning for the development of EVSE. These include greater social inequality, public security problems, and lack of logistic support, as developing countries also do not have the same level of experience when compared to developed countries. China is the only developing country that is prioritizing EV. However, this Asian country may not be a good

[26] The drivers fear that the electric vehicle will not have enough range to reach its destination.

benchmark, since China and Brazil have different public safety standards, i.e. there is no significant record of vandalism in Chinese EVSE.

Consequently, the aim of this study is to measure and identify the optimal locations for the installation for EVSE in the municipality of Belo Horizonte (BH), Brazil, to meet a penetration of 1% of light-duty electric vehicles (LDEV) by 2025. This study answers the following questions: (i) what attributes should be highlighted for the installation of an EVSE network in urban areas in developing countries with substantial risk areas? And (ii) where is the optimal location for a network of EVSE network in the municipality of Belo Horizonte?

The literature review is presented in the next section. The third section is dedicated to the methodology, the fourth section presents the results, the fifth section presents the discussion, and the sixth section presents the conclusions, limitations and suggestions for upcoming studies.

4.1.2 Literature Review

4.1.2.1 Characterization of the studied region

A large share of the total GHG emissions in Minas Gerais (MG), whose capital is BH, is due to transportation activities. It ranks second in all of Brazil's 26 states for GHG emissions. The transport sector is responsible for around 36% of the state's total emissions with the road transport sector accounting for more than 96% of these emissions (FEAM 2013).

The estimated population in BH is around 2.5 million inhabitants; the highest population density in the MG state. The municipality of BH has 17% of the total road fleet in the state of MG which is estimated to be 1.8 million units – 70% of these are light-duty vehicles (LDV).

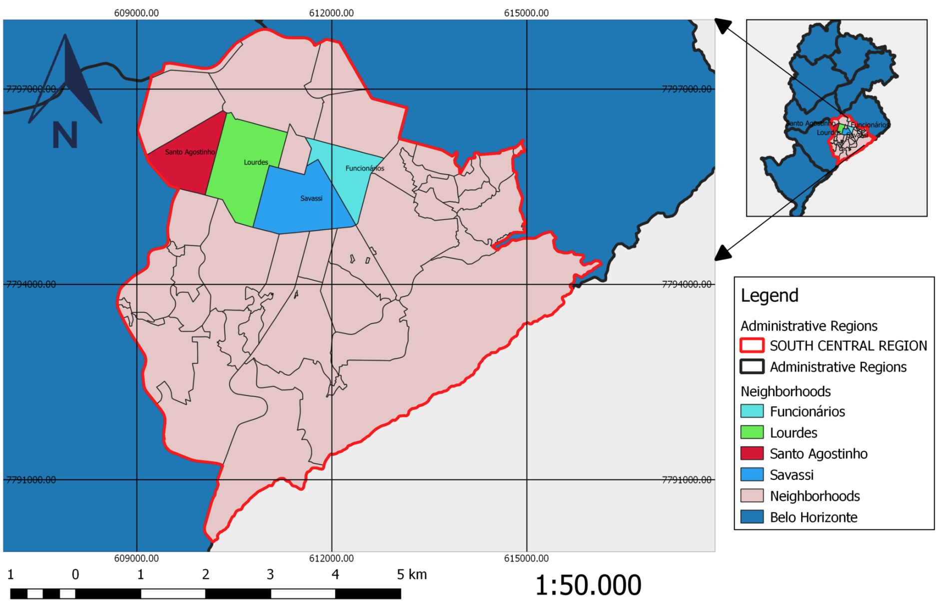

Figure 4.1 – South-Central region of the municipality of Belo Horizonte

BH is divided into 9 administrative regions, 8 districts and 487 neighborhoods (IBGE 2017). Some of BH neighborhoods, such as Sion, Lourdes and Belvedere, have a significant population concentration with an average household income higher than $2.2 thousand monthly. The income square meter price in the area is higher than the average within the BH municipality (Araújo et al. 2005).

Other neighborhoods such as Savassi, Santo Agostinho and Funcionários have a high population concentration. The BH South-Central region (Figure 4.1) is characterized as a metropolitan center with a diversity large quantity of services and a concentration of economic activity (Motta et al. 2011). From an environmental and energy point of view, BH reveals a favorable potential for the expansion of electric mobility since Brazil has a predominantly clean energy mix. In 2016, almost half the energy consumed in Brazil was from renewable sources (EPE 2016). The Brazilian electricity matrix uses 82% of renewables, due to hydroelectric generation that accounts for 68% of the total electric generation (EPE 2016). The use of renewable energy in recharging of EV is crucial to guarantee a reduction in CO_2 life-cycle emissions.

On the other hand, there are some challenges that need to be overcome in the case of large-scale implementation of an EVSE network in Brazil's urban areas. These include irregular urbanization with large areas of subnormal agglomerates[27]. Often it is necessary to cross-areas of irregular urbanization to have access to airports, railway stations, bus terminals, highways, financial zones of the city, and upper middle-class neighborhoods.

In 2010, Brazil registered more than 6,300 subnormal agglomerates – with more than 50% of them in the Southeast of the country – containing around 1.6 million households and a population of around 5.5 million inhabitants (IBGE 2010a)**.** These areas are often associated with urban violence, due to the difficulties in accessing essential public services in these regions. In BH, the situation is not different, in 2009, there were more than 364,000 living in subnormal agglomerates, corresponding to 23% of the population and 10% of the territory of the municipality (Fernandes 2010)**.** Areas of geological hazards and areas subject to flooding should also receive special attention. BH experiences recurrent floods, mainly in the regions of the municipality involving the basins of the Arruda (South and *South-Central)* and Onça (North) due to problems involving irregular soil patterns and steep relief (Cajazeiro 2011)**.**

4.1.2.2 Electric vehicle penetration

Due partially to public policy support in some nations, the global number of EV has almost doubled every year since 2010. In 2016, there were 2 million EV worldwide, with more than 750,000 EVs sold in the same year. In addition, there are more than 200 million two-wheeled EVs and 345,000 electric buses mainly concentrated in the Chinese market. This highlights the increase of EV penetration that can occur over a relatively short period of time, as in 2005, there were only a few hundred EV (IEA 2017). A global goal of 100 million electric cars and 400 million electric 2- and 3-wheelers by 2030 was defined in the Paris Declaration on Electro-Mobility and Climate Change and Call to Action (IEA 2016).

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[27] Cluttered and dense poor settlements, most lacking basic urban utilities and essential services.

Restrictive policies on the use of ICE vehicles adopted by some countries may favor the penetration of EV. Some European countries, for example, are already restricting the circulation of ICE vehicles in some areas, and allowing access only to low emission vehicles such as EV (Canters 2014). Europe has set a goal of reducing transport emissions by 20% by 2030 and by 70% in 2050 compared to 2008 levels (Canters 2014). In Brazil, electric mobility is beginning to develop but the numbers of EV is still insignificant. From 2011 to 2016, around 3,500 units of LDEV (most of them for demonstration purposes) have been licensed in the country (in this period BH does not have any EV registered), while in this period more than 15.3 million LDV (ethanol, gasoline and fuel flex) have been licensed in Brazil (ANFAVEA 2017).

4.1.2.3 Importance of EVSE for the success of EV

In 2016, the EVSE infrastructure grew substantially and reached around 2.3 million charging points globally. However, most EV drivers depend on public charging points to recharge their vehicles (IEA 2017). The lack of charge points near the place of residence, roads and workplace is a potential barrier to EV market penetration due to the range anxiety barrier (Brand et al. 2017). The EVSE network must be adequately planned considering both volume and location (Lin 2011). The characteristics of the EVSE, especially those related to the charging level, are relevant for the creation of an infrastructure network. The EVSE levels (Table A2) considered in this study are (SAE 2018; Hall 2017):

i. EVSE_L1 (level 1) – equivalent to a slow recharging station corresponding to 8h or more for a full charge (SAE 2010; USDE 2017). It's recommended for the area where the driver lives.
ii. EVSE_L2 (level 2) – corresponds to the fast charging station. Accounting for 3h to 8h for a full charge (SAE 2010; USDE 2017). It's recommended for workplaces, public transportation connection areas and shopping centers.
iii. EVSE_L3 (level 3) – characterized by super-fast recharge of up to 30 minutes for a full charge (SAE 2010; USDE 2017). It's recommended for shopping malls, roads, corridors and main avenues.

The optimization of public and private investments in the expansion of EVSE requires research in order to gain knowledge on the main attributes capable of calibrating the supply versus demand equation (Zhao 2016). These attributes include the availability of garages in residential areas, points of public transport connections, high traffic roads, shopping centers, large parking lots and other areas with a considerable concentration of vehicles. In addition, another important factor is the EV range, which continues to improve. For example, in 2011, only three models of pure EV were available for the mass-market in the USA, with a range between 100 to 150 kilometers. In 2017, 15 pure EV models were available in the USA, with a minimum range of 92 kilometers for the Smart Fortwo Electric Drive Coupe model, and a maximum range of 540 kilometers for the Tesla Model S 100D (USDE 2017).

Table 4.1 – Attributes used in similar studies (√ – presence)

Attributes* / Authors (See explanation in supplement 1)	(1)	(2)	(3)	(4)	(5)	(6) This study
(1:9) Selective attributes-SA ([1]Socio-economic-SE; [2]Socio-demographic-SD; [3]Geographic-G)						
1. Inc: Household income (SE)[1]	√	√	√	√	√	√
2. Dens: Population density (SD)[2]	√	√	√	√	√	√
3. PTran: Public transp. Connection (G)[3]	√	√	√		√	√
4. PShop: Shopping centers (G)[3]	√	√	√	√	√	√
5. Dcia: Workplace (G)[3]	√	√	√	√	√	√
6. PPP: Roads, corridors and avenues (G)[3]	√	√	√	√		√
7. PGeo: Geohazard (G)[3]	√					√
8. PWat: Flooding areas (G)[3]						√
9. Slop: Slopes (G)[3]	√					√
(10:12) Restrictive attributes – RA						
10. Green areas	√		√		√	√
11. Water bodies		√		√		√
12. Subnormal agglomerates						√
(1): (Jankowski et al. 1994; VEIC 2014; BEAMA 2016; Parker et al. 2010; Zhang et al. 2013; Xi et al. 2013; Efthymiou et al. 2012; Wagner et al. 2014; Chen et al. 2013a)						
(2): (Zhang et al. 2013; Yang et al. 2016; Efthymiou et al. 2012)						
(3): (Wagner et al. 2014; Bean et al. 2011; Chen et al. 2014)						
(4): (Zhang et al. 2013; Wagner et al. 2014; Bean et al. 2011)						
(5): (Xi et al. 2013; Longley 2005; Yang et al. 2016; Wagner et al. 2014)						

* Contemplated by other studies

Additionally, the availability of physical space to install EVSE must also be accounted for, as well as the impact on the electricity generation network (Yang et al. 2016; Gebauer et al. 2016; Zhang et al. 2012; Rahman et al. 2016; Lebeau et al. 2013), the general attitude towards EV (Gebauer et al. 2016), and consumer attitude (Egbue 2012) and psychological aspects (Skippon 2011) as well. The installation of an EVSE network should include technical and geographic resources in order to meet consumer's expectations of charging the vehicle's battery in the least amount of time and with short displacements (Yang et al. 2016), thus avoiding unnecessary energy consumption.

Among the most important innovations pointed out by the research are the areas of restriction since they are significantly important in projects that contemplate the development of EV infrastructure. A detailed literature review reveals the main attributes for the expansion of the EVSE network in urban areas, as shown in Table 4.1.

4.1.3 Materials And Methods

The study is divided into two parts. The first focuses on establishing the methods, defining geographic criteria, identifying the demand and completing a survey with specialists. The second part of the study aims at parameterizing and processing the data in the GIS tool.

4.1.3.1 Method definition

GIS was used because it is a spatial information system capable of processing different types of data and accurately indicating the desired spatial location. Similarly to other studies (Church 2002), GIS was used to carry out this study and to manage geospatial data analysis supporting the criteria and indicators for the optimal location on EVSE (Hakimi 1964). Furthermore, the Multi-criteria Decision Making

(MCDM) method for locating EVSE is important and requires maximum assertiveness (Massam 1988), as facilities of this type are meant to endure for large periods (i.e. decades)

In the context of applying the MCDM, a multidisciplinary group of specialists were invited to evaluate – through the assignment of the importance of different attributes – the best location for the EVSE network. The MCDM allows the consistent analysis of different quantitative and qualitative elements in a decision-making process. The MCDM method has been widely used for decision-making processes applied to the environment, energy, business and infrastructure for EV (Zhao 2016; Onat et al. 2016; Dobson 1979; Carver 1991). Additionally, MCDM was considered adequate for this study, since Brazil is a incipient EV market, with the additional problem of the limitation and complexity of the available processing data (Coelho et al. 2012), justifying the use of MCDM for the localization of infrastructure for electric vehicles.

The Weighted Linear Combination (WLC) method was applied, as it is an analytical method for dealing with multi-attributes or when more than one attribute must be taken into consideration. The WLC method has been largely used in similar studies (Duc 2006; Joerin et al. 2001). Due to the complexity of the problem, the Analytical Hierarchy Process (AHP) was also considered. AHP helps to solve problems using a comprehensive and rational procedure. The AHP technique is also widely used in studies linked to geographic analysis (Duc 2006; Aruldoss et al. 2013; Joerin et al. 2001).

4.1.3.2 *Territorial divisional*

The geographical area considered was based on the territorial division of the municipality BH, based on the Brazilian Constitution of 1988 and the Brazilian Institute of Geography and Statistics or IBGE (Portuguese: Instituto Brasileiro de Geografia e Estatística). It considers 487 neighborhoods (IBGE 2017; IBGE 2010b).

4.1.3.3 Demand identification

The demand identified in this study corresponds to an estimated LDEV penetration of 1% in BH by 2025. This estimate was based on a report on energy demand for the Brazilian automotive sector (EPE 2016). This is a conservative scenario; however it is justified as after more than half a decade of EV availability, which is comparable with the market share of less than 1% in most countries (IEA 2017). Among developing countries, only China shows a high EV penetration; nevertheless, the EV market penetration in 2016 was only around 1% (IEA 2017). In Brazil, the rate of EV expansion may be affected by the lack of public policies for electric mobility development and the existing governmental ethanol protection policy.

In the absence of a reference for the ideal number of EVSE, as well as the ideal ratio between EVSE level 2 (L2) and EVSE level 3 (L3), the experience of other urban regions was used as a reference. We defined the proportion of one EVSE for each ten electric vehicles for use in this study. This is comparable to a case study of the main Chinese cities that have the same target (Hall et al. 2017).

Regarding the EVSE by level – (L2) and (L3) – the proportion of 80% for EVSE_L2 and 20% for EVSE_L3 was used. This was based on the average number of EVSE for sixteen countries that have a more intensive electric mobility use (EPE 2016; Costa et al. 2017; IEA 2016). This study also considers that each EV owner has a home charger (EVSE_L1).

4.1.3.4 Survey to specialists

The electrified mobility is in very incipient phase in Brazil. There are a limited number of experts in the country. To identify specialists in this topic, we made email and phone contact was made with Brazil electric vehicles associations, car manufacturing association, car dealers federation, automakers, car dealerships, suppliers of EV equipment, union of taxi companies working in EV test projects, specialized media, and research by internet.

After preparing a list containing the names of the specialists, we sent 67-approach e-mail to clarify the research and invite them to participate by answering a questionnaire that would be sent later. The main attributes identified based on the literature review (Table 4.1) used to create the questionnaire that was classified into three groups: economic, socio-demographic and geographic. Before submitting the questionnaire, we carried out a 40-day trial with a group of 17 people formed by researchers and friends linked to the automotive sector. The test proved to be valuable in adjusting some issues.

The survey was conducted by email from 09/05/2016 to 10/09/2016, and the sample covered 51 specialists with an interest in electric mobility.

Table 4.2 – Survey characterization

		% Of the total respondents
Job position	Top management and advice	14
	Executive Direction	57
	Operational management and consultant	29
Sector	Private	79
	Public	7
	Third sector (NGO)	14
Segment	Automobile industry	37
	Transport-related services	21
	Service provider	21
	Government	7
	Energy sector	14
Region	South	21
	Southeast	72
	North	0
	Northeast	7

The survey targeted EVSE_L2 and EVSE_L3, and specialists were required to assign a value for each attribute, according to the criteria explained in the introduction of each question. The comparison between two elements using AHP can be performed in different ways (Triantaphyllou 1995). However, the scale of relative importance between two alternatives proposed by Saaty (Saaty 2005) is the most widely used. Therefore, the specialists assigned values from 1 to 9 for each attribute, where 1 meant that the attribute had no importance to the location of the EVSE and 9 was linked to highest importance. The questionnaire had ten questions with one space for the respondent to identify new attributes.

Although the number of respondents was not expressive, it does not compromise the study's results, because the specialists limited themselves to evaluating the attributes – elements of greater relevance – that were identified in publications covering studies and experiences with EVSE implementation in other countries. Most of the respondents were in executive direction (57%), worked in the private sector (79%), in the automotive industry (37%), and lived in Southeast Brazil, as shown in Table 4.2.

4.1.3.5 GIS analyses

The use of the GIS tool can be considered as the backbone of the study. It is composed of three steps: pre-processing, processing and generation of maps, as described in the next sections.

a) First processing step

The first stage of the GIS analysis called pre-processing was divided into two phases.

Table 4.3 – Data source of the attributes in vector format

Vector format			
Source	Attributes		Source
(EMBRAPA 2017)	Slopes	Household income	(IBGE 2010b)
(SMAGC 2017)	Public transportation connections	Population density	
	Roads, corridors and avenues	Shopping Centers	Desk research
	Green areas	Workplaces	
	Water bodies	Geohazards	(CPRM 2017)
	Subnormal agglomerates	Flooding areas	(SUDECAP 2017)

The first one focused on creating parameters, obtaining and preparing the processing data, and the second phase on management of the attributes. *(i)* Pre-processing and normalization: consists of the pre-processing of the geographic data in order to structure and parameterize the study. The attributes were established in vector format, as presented in Table 4.3.

In the evaluation of the spatial analysis and location of EVSE, operational characteristics for the different levels of EVSE were considered:

I. EVSE_L1 – the attributes considered were household income (equivalent to $2.2 thousand or higher) and population density of people aged 18 or over (Table 4.1).

II. EVSE_L2 – suitable to be located near shopping centers, workplaces or public transportation connections with parking lots with a minimum of 50 parking spaces, among other attributes shown in Table 4.1.

III. EVSE_L3 – the places with the greatest potential for installation are roads, shopping centers and public transportation connections among other attributes revealed in Table 4.1. The attributes were grouped and processed according to the EVSE levels (L1, L2 and L3), as shown in Table 4.4.

Table 4.4 – Attributes considered in the survey (✓ presence, * Benefit)

Class	Attributes	L1	L2	L3
Ben*	Inc	✓	✓	✓
Ben*	Dens	✓	✓	✓
Ben*	PTra		✓	✓
Ben*	PShop		✓	✓
Ben*	Dcia		✓	✓
Ben*	PPP		✓	✓
Cost	PGeo		✓	✓
Cost	PWat		✓	✓
Cost	Slop		✓	✓
Rest	Rest	✓	✓	✓
Rest	Rest	✓	✓	✓
Rest	Rest	✓	✓	✓

The Euclidean distance was adopted and defined as a grouping from the delimitation of the average distance between the attributes i.e. if the average distance between shopping malls is 20 km; 10 km is considered to be the maximum radius (limited to 30 km) from each shopping mall in which the EVSE should be installed. The attributes are standardized by the minimum and maximum values of classification. The Boolean method was applied and consists of the logical combination of binary values, where each attribute was evaluated and standardized at "0" as an unsatisfactory hypothesis and "1" as a satisfactory hypothesis (EPE 2015).

Spatial inference is a step in the MCDM that aims to integrate the data involved. For this, we perform the standardization of attributes (Table 4.3) into two categories: benefits and cost (Malczewski et al. 2015). From the distance condition of the attributes, the benefits criteria are the maximization indicators whose values are always higher (value 1).

Table 4.5 – AHP Analysis Criterion

Intensity	Definition (Saaty 1990)
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Can be used to express intermediate values

The cost criteria are related to distance minimization (value 0). Management of attributes: defines the importance of each attribute from the peer-to-peer comparison between attributes. The AHP that is created under MCDM is composed of techniques that are suitable for ranking of critical management problems. The AHP is a ranking process that is used in making group decision and is widely used around the world in a variety of fields. Through the AHP process and the multi-criteria decision making technique, the quantitative and qualitative aspects were combined generating weights for the attributes (Saaty 2008) that were compared in pairs from an importance definition scale in relation to EVSE installation (UNFCCC 2015). The weights of comparison respected the scale of Saaty, as shown in Table 4.5.

The weights of the attributes were determined in four stages and the AHP technique was performed using the Easy AHP tool integrated with the QGIS software (Lin et al. 2014):

- *1st stage*: establishing the hierarchical structure of the factors influence.
- *2nd stage*: assembling the judgment matrix, based on the AHP technique consisting of comparative notes between the attributes (from 1 to 9) indicated by the experts.
- *3rd stage*: determining the uniformity of the matrix applied to the normalization process. The eigenvector λmax (the highest value of the matrix) was adopted in order to verify the consistency index (CI), the judgment, and consistency ratio (CR), thus indicating the degree of randomness of the matrix (Aslani etal., 2011), and checking the consistency of decisions, as shown in Equation 1 and Table 4.6.

$$CI = (\lambda m\acute{a}x - n)/(n - 1) \text{ and } CR = CI/RI \qquad (3.4)$$

Where:

CI = Consistency Index

Λmax = highest matched array value

CR = consistency ratio

N = number of attributes

RI = Random Index

Table 4.6 – Number of attributes and random index

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Although there are cases in the literature that consider CR > 0.1 because of the low knowledge of the parameters (MOREIRA et al. 2001), in this project we consider that the RC reached the conditions of execution of the model, since only about 12% of cases CR was > 0.1 provoking a re-discussion of the project with the experts.

- *4th stage*: determination and analysis of the weights that are the basis for the MCDM method of linear combination weighted, according to the scenarios modelling.

1) *Modeling for the L1 Scenario*

For the L1 scenario, since these two attributes have the same degree of importance, a comparative matrix was not required.

To refine the model results, a spatial grouping of the average income data by households was applied, considering only the regions with a minimum of 40 households (respecting the principle of equal US $ 2.2 or higher) and people 18 years old or older.

2) Modeling for the L2 Scenario

Table 4.7 – L2 scenario

	Inc	Dens	PWat	Pgeo	Slope	PTrans	Pshop	DCia	PPP
Inc	1.0	1.0	5.0	5.0	3.0	1.0	0.333	0.333	2.0
Dens	1.0	1.0	3.0	3.0	3.0	0.333	0.2	0.2	1.0
PWat	0.2	0.333	1.0	0.5	0.5	0.2	0.143	0.143	0.333
Pgeo	0.2	0.333	2.0	1.0	0.333	0.333	0.2	0.2	0.333
Slope	0.333	0.333	2.0	3.0	1.0	0.333	0.143	0.2	0.5
PTrans	1.0	3.0	5.0	3.0	3.0	1.0	0.333	0.333	3.0
Pshop	3.0	5.0	7.0	5.0	7.0	3.0	1.0	0.333	3.0
DCia	3.0	5.0	7.0	5.0	5.0	3.0	3.0	1.0	5.0
PPP	0.5	1.0	3.0	3.0	2.0	0.333	0.333	0.2	1.0
Scenario	0.11	0.07	0.02	0.03	0.04	0.12	0.22	0.29	0.06

Meaning of acronyms in Supplement 1

3) Modeling for the L3 Scenario

Table 4.8 – Pairwise matrix for L3 scenario

	Inc	Dens	PWat	Pgeo	Slope	PTrans	Pshop	DCia	PPP
Inc	1.0	2.0	4.0	5.0	5.0	0.5	0.5	1.0	0.333
Dens	0.5	1.0	3.0	5.0	5.0	1.0	1.0	2.0	0.5
PWat	0.25	0.333	1.0	2.0	2.0	0.2	0.2	0.333	0.2
Pgeo	0.2	0.2	0.5	1.0	1.0	0.143	0.143	0.2	0.143
Slope	0.2	0.2	0.5	1.0	1.0	0.143	0.143	0.2	0.143
PTrans	2.0	1.0	5.0	7.0	7.0	1.0	1.0	2.0	0.5
Pshop	2.0	1.0	5.0	7.0	7.0	1.0	1.0	2.0	0.5
DCia	1.0	0.5	3.0	5.0	5.0	0.5	0.5	1.0	0.333
PPP	3.0	2.0	5.0	7.0	7.0	2.0	2.0	3.0	1.0
Scenario	0.11	0.12	0.03	0.02	0.02	0.16	0.16	0.09	0.24

Meaning of acronyms in Supplement 1

To ensure the consistency of the judgments and the degree of randomness of the matrix, the eigenvalue λmax (9.57) and the CI (0.072) and CR (0.05) indexes were calculated. Then, the value of the weights for each attribute was determined in order to meet the WLC method. In the modeling for EVSE_L3, the roads, avenues and corridors, shopping centers and public transportation connection were characterized as strong and very strong importance. Table 4.8 shows the importance levels for the L3 scenario. The matrix was consistent and with a low degree of randomness, with the following values being reached: Λmax (9.24), CI (0.031) and CR (0.021).

b) Second processing step

The weights for each attribute in the model were applied according to the given scenario. The WLC method was used in the linear combination of the weights generated by the comparison matrix in each attribute (Roszkowska 2013) and considering the three steps.

i) *Weight Application:* the WLC method was adopted for linear combination and matrix application.

The WLC approach is a widely used GIS-based decision rule technique (Malczewski 2000). Its most common applications are land use analysis, site matching and selection and resource assessment (Chen et al. 2014). In this work, the WLC method is implemented in the GIS environment with the support of the reclassification and map algebra tools. The AHP technique, provided the weights of the attributes and the WLC performed the weights calculation in relation to the attributes in a georeferenced way. The calculation for the identification of the most suitable areas for the EVSE network was performed according to equations 2,3,4:

A) L1 Scenario

("Inc"+"Dens") *(3.5)*

B) L2 Scenario

(0.11*"Inc"+0.07*"Dens"+0.02*"PWat"+0.03*"PGeo"+0.04*"Slope"+0.12*"PTrans"

+0.22*"PShop"+0.29*"DCia"+0.06*"PPP") *(3.6)*

C) L3 Scenario

(0.11*"Inc"+0.12*"Dens"+0.03*"PWat"+0.02*"PGeo"+0.02*"Slope"+0.16*"PTrans"

+0.16*"PShop"+0.09*"DCia"+0.24*"PPP") *(3.7)*

ii) *Grouping of areas:* to identify the areas with the greatest potential for EVSE network, the technique of Natural Break (Jenks) was adopted (Chen et al. 2013a).

iii) *Subtraction of restriction areas:* inappropriate areas for the implementation of any type of infrastructure linked to road transport, i.e. water bodies, irregular settlements, environmental conservation units. Therefore, all restriction areas were unified and subtracted from the global map (Santos, 2006). The term unsafe area was used to refer to subnormal agglomerates considered with a high degree of violence that endangers physical and property integrity, thus resulting in serious material and personal damages. Risk areas refer to the flooding areas that are vulnerable to major floods that can cause damage to materials and endanger personal safety.

c) Third processing step

This stage highlights the appropriate areas by neighborhood, taking into account spatial and cartographic issues. Spatial intersection processing was used in the relation of the maps (municipality and neighborhoods) and the cartographic questions are characterized by mapping indicating the main locations for the installation of the EVSE network. Finally, the cartographic presentation is designed to support decision-makers in the areas with the highest potential areas (percentage) for EVSE and their overall geographic location.

4.1.4 Results

The considered scenarios account for 12,000 units of LDEVs by 2025 in BH, corresponding to a total of 1,200 EVSEs. The study revealed new attributes in this type of research, such as subnormal agglomerates -– a patrimonial and physical risk in the region studied because it deals with areas with high violence rates, and flooding areas – in the case of high rainfall event. These findings were fundamental for this and future studies.

4.1.4.1 Survey results

Around 30% of the response rate was obtained from the 51 expert surveys. The sectors with the highest percentage of participation were taxi companies and EV associations. The sector with the lowest return was the industrial segment. The experts evaluated that for the EVSE_L2, the most important attributes were workplace, shopping centers, public transportation connections and household income.

When compared to EVSE_L3, the household income and workplace attributes had higher weights. For EVSE_L3, the best-evaluated attributes were roads, public transportation connections, shopping centers and population density. When compared to EVSE_L2 the roads, shopping centers, public transportation connections, population density and geoharzards were considered the most important attributes, revealing experts' preference for super-fast charging stations (L3), as shown in Figure 4.2.

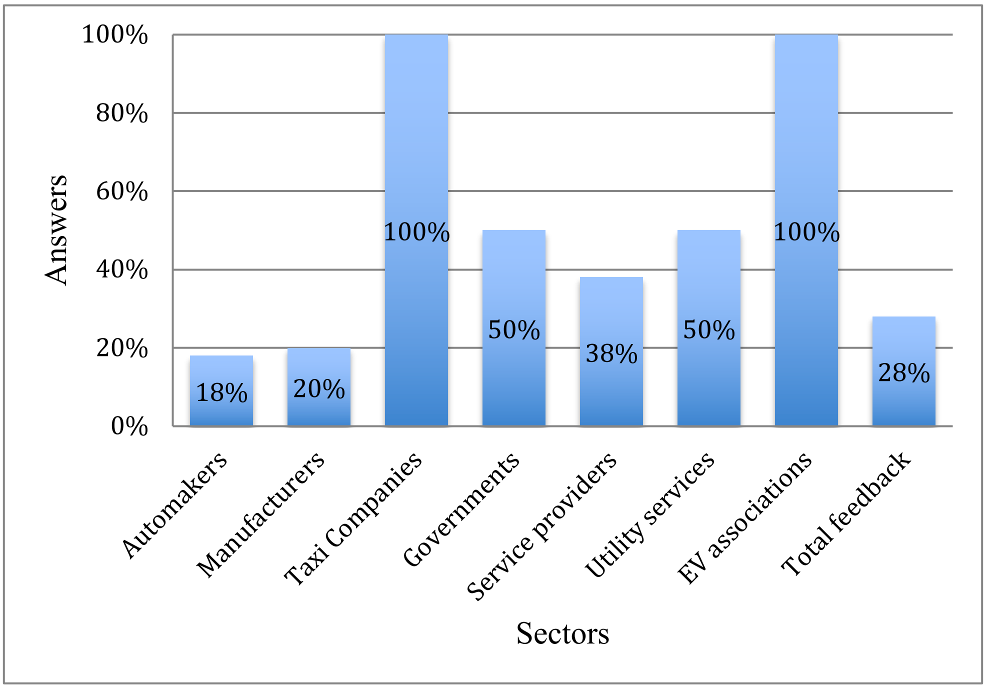

Figure 4.2 – Replies received from the specialists

The experts also revealed the further away the EVSE are from the violence zones such as subnormal agglomerates and risk zones such as flooding areas the better. The result of the analysis also revealed a wide standard deviation, especially in attributes as flooding areas and slopes. The most plausible explanation for this deviation is that attributes characteristics directly affect those who regularly live or access the region and these respondents usually give higher value to these attributes.

On the other hand, the roads attribute presented the lowest standard deviation, which revealed a more balanced evaluation due to the fact that it shows a common and widespread demand in the diffusion process of the electric mobility infrastructure, as shown in Figure 4.3.

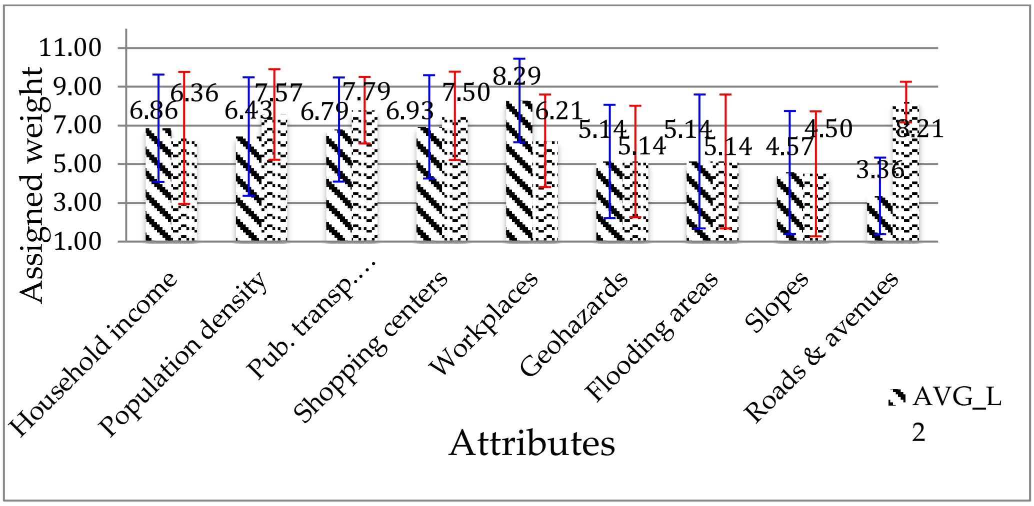

Figure 4.3 – Average rating of expert rated attributes and standard deviation

Regarding the GIS analysis, the optimum location of Level 1 installations of the EVSE network is largely affected by attributes like household income and population density. However, proximity of attributes like shopping centers, public transportation connections, workplaces and roads, corridors and avenues, have positive impacts on Level 2 and Level 3 installations of the EVSE network, while attributes like flooding areas, slopes and geohazards areas have negative impacts.

4.1.4.2 GIS analysis results of recommended area for EVSE_L1

The study showed that 65% of the recommended EVSE L1 installations were located in 10 neighborhoods located in the South-Central region, as shown in Figure 4.4. This is due to higher household income concentration and people aged 18 years old or over in the targeted regions.

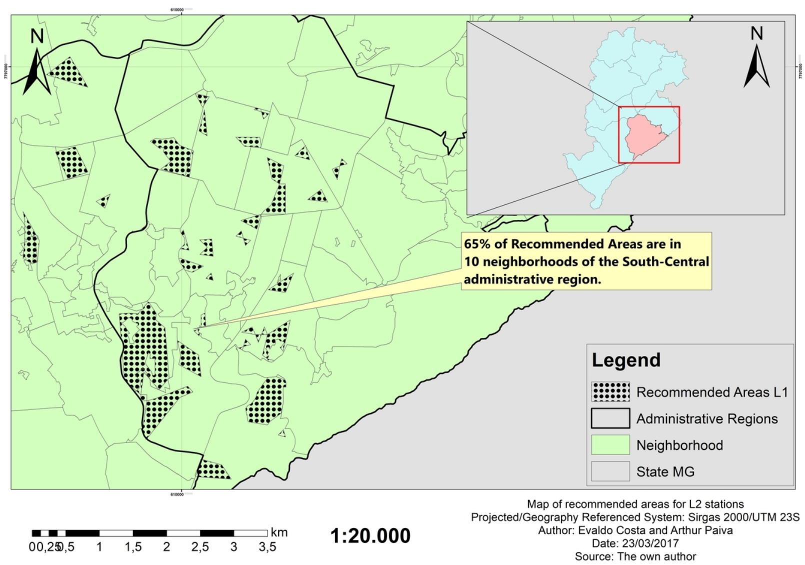

Figure 4.4 – Optimal locations for EVSE_L1

The analysis revealed that the suggested areas for installation of the EVSE_L2 network are contained in 45% of the BH neighborhoods, covering the South-Central and East regions (Figure 4.5) mainly due to the greater concentration of companies (workplace), shopping centers and public transport connections, attributes that have been well evaluated by the specialists for this type of infrastructure.

4.1.4.3 GIS analysis results of recommended area for EVSE_L2

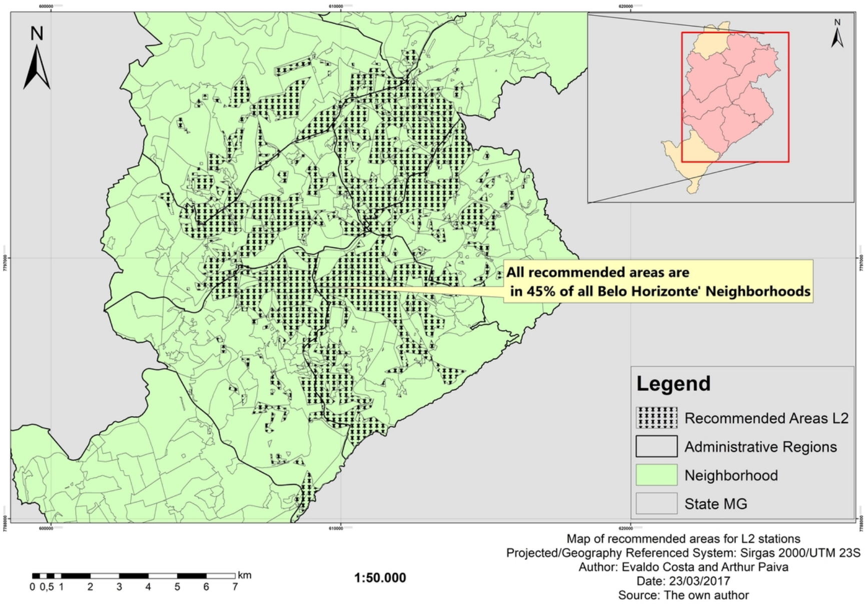

Figure 4.5 – Optimal locations for EVSE_L2

4.1.4.4 GIS analysis results of recommended area for EVSE_L3

Around 36 neighborhoods of the municipality of BH hold about 40% of the location recommended areas for EVSE_L3, as shown in Figure 4.6. These areas are distributed in the Northeast, Northwest, West, South-Central and Pampulha regions.

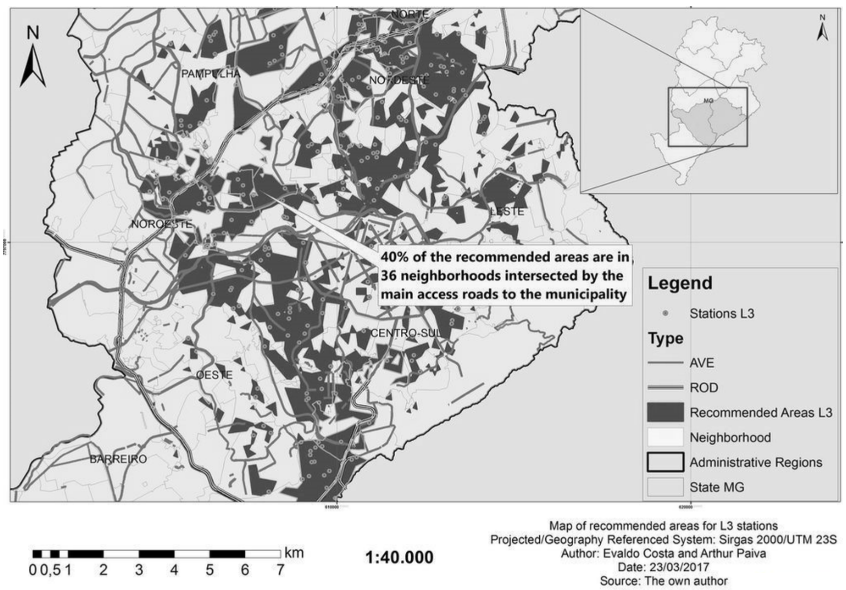

Figure 4.6 – Optimal locations for EVSE_L3

They are located near expressways, major avenues and highways such as the Celso Mello Azevedo ring road that connects the South-Central (economic pole) to the other regions of BH and neighboring municipalities, as well as the Cristiano Machado avenue, Dom Pedro Primeiro Avenues, access to Pampulha Airport and Confins International Airport, Contorno Avenue among others. This region has some important shopping malls in BH, public transportation connections, a high population density as well as access to major highways.

The distances between the extreme areas in the municipality of BH are short and compatible with the use of EVs. For example, the connection from extreme North to extreme South is around 37 km and from East to West it is less than 20 km. From the central area in the municipality to the farthest point (from extreme South to extreme North) the distance is close to 17 km.

4.1.5 Discussion

The identification of unsuitable areas for infrastructure installation in developing countries has been considered in other investigations. The study to analyze the best locations for new filling stations in Malaysia, Asia, Khahro indicated that 24% of the planned areas for EVSE installation was in inadequate areas (Khahro et al. 2014). In the aforementioned study, the adaptations of the areas were carried out based on environmental risk factors, and not as inadequate areas due to risks of public security. In the present study, this problem did not occur, since we excluded the risk areas from the recommended areas for EVSE installation. However, the problem is not completely solved because it is necessary to take into account the areas close to the risk areas, i.e. many access routes in the studied region cross long areas of subnormal agglomerate – which are not recommended for EVSE installation, due to the risks of violence during the loading time. Therefore, our recommendation is for the EVSE to be installed as far as possible from unsafe areas, in order to avoid serious occurrences with risks of physical integrity and damages.

Other studies proposing an assignment model to distribute charging infrastructure in Beijing, China, and to investigate the development of optimal EV charging station assignments in Seattle, USA Hao and Chen (Hao 2015; Chen et al. 2013b) also did not address the issues of risk areas with a high rate of urban violence. Actually, almost all of the projects on the expansion of electric mobility are restricted to a few developed countries and public safety issues are focused on the safety of people and the vehicle with regard to the potential for battery accidents that can cause fires or explosions. However, the expansion of electric mobility in urban areas of some developing countries will probably require concern with other factors, such as unsafe urban areas highlighted in this study.

4.1.6 Conclusions, Limitations, And Recommendations

This Brazilian pioneering study aimed at identifying the optimal locations to implement EVSE in the municipality of BH and identify what attributes should be prioritized for the installation of an EVSE network in urban areas. Some attributes such as subnormal agglomerates and flooding areas were identified for the first time in this study, and support the identification of the best locations for EVSE (L2 and L3) in BH, and in developing countries with substantial risk areas. Therefore, projects for the development of infrastructure for electric vehicles in regions with a high risk of violence and therefore subject to material and personal damages should include projects risk attributes such as those identified in this study.

In this context, the study reveals that EVSE_L3 should not be located in public places, only in places that offer 24/7 personal security, as they do with gas stations currently in Brazil, and places as hotels, airports, and shopping malls. Besides that, the flooding areas may be obstacles to the expansion of its infrastructure network in Brazil. Similar regions around the world, especially in developing countries, are likely to present the same limitations for EVSE network expansion and require the development of business models capable of overcoming this issue.

Most of EVSE should be concentrated in small and specific areas of the municipality of BH. This can be a facilitating factor for optimizing the investment potential and maximizing the offer of user services by the expansion of the EV. The installation of an EVSE network will depend on government regulation and potential financial incentives for the users. Participation of the public sector and other stakeholders will likely create sustainable business models capable of attracting investments to EVSE. In this context, the involvement of utilities, automakers and companies that own large fleet and various level of government (i.e. federal, state and municipal government) could be a promising start for the development of electric mobility and an incentive to support the EV infrastructure network.

The short distances that connect the main regions to the central region of the BH municipality may be favorable for the adoption of EV, as with a full charge the range of most EVs is much higher than the distances needed to cross the BH municipality (maximum distance of 37 km from extreme North to extreme South). The results of this research can contribute to better understand the diffusion of the charging infrastructure for EV and guide stakeholders and public policies in Brazil and other regions (not restricted to South America) with similar characteristics as BH in electric mobility projects.

Although it was not the objective of this study, it was possible to observe that the specification of the types of EVs during the vehicle registration process (up to now, the Brazilian authorities haven't started this process) will be of great importance for the stakeholders and for future studies. This type of practice and information on various types of EVs might reveal significant differences in energy consumption and have an impact on the grid.

This study was limited due to the difficulty of locating specialists in electric mobility in Brazil, and further studies are still required to complement the current one. These include incorporating the EVSE financial aspect, evaluating the impacts of the EVSE network growth on the grid, incorporates the drivers' psychological aspects, and consumer attitudes towards e-mobility.

Data Availability And Conflicts Of Interest: All the data used to support the findings of this study are included within the article. There is no conflict of interest in this research.

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Supplementary Material: the description of all the attributes used in the study is in Table B1, and the technical specifications of the charging by level, typical use, energy interface, power level, and charge time are in Table B2 of the supplementary material.

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4.2 SUITABLE LOCATIONS FOR ELECTRIC VEHICLES CHARGING INFRASTRUCTURE IN RIO DE JANEIRO, BRAZIL

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ABSTRACT
Governments have begun to pursue alternatives within the transport sector to reduce its environmental footprint and the deployment of electric vehicle charging infrastructure is an adequate way of promoting the penetration of the electric vehicle. In this study, we sought to identify the best locations for EVCI in Rio de Janeiro (RJ), Brazil. To achieve this objective, based on the opinion of a group of EV specialists, a Multiple Criteria Decision Analysis Method coupled with a geographic information system tool was used. The result shows that RJ would need around 2,000 EVCI- concentrated in a reduced area of the city- to support the penetration of 1% of EVs by 2025.

KEYWORDS - Charging station, Infrastructure, Electric vehicle, Electric Mobility, Rio de Janeiro

4.2.1 Introduction

Governments in various regions are seeking to mitigate greenhouse gas (GHG) emissions from transport. Europe, for example, aims to reduce transport GHG emissions by 20% by 2030 and by 70% by 2050 compared to the 2008 level [1]. Furthermore, global transport emissions are responsible for almost a quarter of all energy-related emissions [2]. In Brazil, the transport sector accounts for more than 30% of final energy consumption, from which road transport accounts for more than 90%, with oil and its derivatives accounting for half of Brazil's energy consumption [1]. Furthermore, road passenger transport was responsible for 90% of CO_{2e} emissions from the passenger transport sector in 2013, with individual transport (mostly light duty vehicles) being responsible for 78% of the emissions associated with road passenger transport [3].

A) Contextualizing the studied region and EV as a mitigation agent

This work focuses on Rio de Janeiro (RJ), where the road transport sector of RJ was responsible in 2005 for 80% of transport CO_2 emissions and 50% of the energy sector [4]. In 2010, the total fleet of RJ was of almost 1.9 million of light duty vehicles and the city held almost 50% of the fleet in the state of RJ [5]. However, the transport sector is an important component for human development, particularly in a big city such as Rio de Janeiro's municipality that, in 2010, had an area of 1.2 million km^2, a population of 6,300 million inhabitants, 161 neighborhoods, 33 districts, 4 regions and an urbanization rate of 99% [5], [6].

The RJ's districts, which include the neighborhoods of Botafogo, Copacabana and Lagoa, underwent a process of renovation of their real estate network by big developers both for luxury apartments and shopping centers [7]. The district that includes Barra da Tijuca is a region of economic development that is reflected in the current real estate projects and urban expansion [8]. The districts of the Northem region of the city are characterized by the concentration of public-rail transportation, subway and bus rapid transit (BRT) stations [9] and also commercial centers such as the district that incorporates the neighborhoods of Madureira and Méier [6]. To reduce greenhouse gas (GHG) emissions and to contribute to avoiding global warming potential (GWP) and climate change, a viable alternative may be the replacement of fossil fuel vehicles by electric vehicle (EV) [10]–[12], since they are more efficient than their fossil fuel counterpart. Consequently, pure electric mobility with zero tailpipe emissions is an ally in ambitions to decarbonize the transports sector and to pursue sustainable development. The potential of electric mobility to replace traditional vehicles is dependent on the growth in its market penetration. Globally, more than 750,000 EV were sold in 2016, recording the stock number of 2 million electric cars worldwide [13]. The "Paris Declaration on Electro- Mobility and Climate Change & Call to Action" defined as a goal for a global penetration of 100 million electric cars and 400 million electric 2- and 3-wheelers by 2030 [14].

B) The EV and Suitable location for EVCI

However, the lack of electric vehicle charging infrastructure (EVCI) is a considerable obstacle to the expansion of electric mobility. Currently, EV volumes outperform six-to-one charging points indicating that most drivers of EV depends on public charging points to recharge their cars [13], [14]. Despite the growth of EV infrastructure - reaching around 2.3 million charging points globally in 2016, with 87% being private - the sector still depends of the studies to identify the ideal proportion of EV versus EVCI and the ideal location for them. The optimization of public and private investments in the expansion of EVCI also requires research in order to identify the main attributes to develop an optimized infrastructure [15].

Consequently, the main goal of this study is to assess the ideal location for the installation of EVCI in RJ, considering a penetration of 1% of electrified light-duty vehicles in 2025. To perform this study, a Multiple-criteria Decision analysis (MCDA) method [15], [16] coupled with a Geographic Information System (GIS) [17], [18] was used in order to incorporate the opinion of stakeholders matched with a spatial resolution. The next chapter presents the study's methodology. The third section describes the results and the fourth and last section concludes the study, highlighting the limitations and recommendations for future research.

4.2.2 Methodology

In order to find ideal locations for EVCI in RJ, the identification of demand for EVCI in 2025 was performed and survey to identify the best areas to expand it was conducted.

4.2.2.1. For EVCI demand in Rio de Janeiro

Current data [1], [19]–[22] suggests that the RJ EV fleet is expected to reach about 20,000 vehicles by 2025 and about 2,000 demands for EVCI. The calculation of the demand projection of the electric fleet in RJ is relevant to the study, because it is directly related to the number of EVCI to be installed in the region. The average of full charge time for EVCI, are: more than 8h (L1); between 3h and 8h (L2) and up to 30 minutes (L3) [23], [24]. The calculation of the number of station levels was performed according to the following equation 1:

$$C_t = [(0.08 * N_{ev})_{L2}] + [(0.02 * N_{ev})_{L3}] + [(N_{ev})_{L1}] \quad (3.8)$$

Where:

Ct = Total Charging

0.08 = Value participation number charging stations 2

Nev = Number of EV

L1 = standard loading station or home station

L2 = fast-charging station

L3 = super-fast charging station

4.2.2.2. Survey to identify the best areas to expand EVCI

A Brazilian group of electrical mobility specialists was consulted to help identify the best locations for EVCI. Brazil is at an early stage in electric mobility and there are not many specialists in the country. We sent by e-mail 51 questionnaires via email to specialists from different sectors: Automakers (22), components industry (10), Taxi Company (1), Government (2), Service providers (8), Utility (2), Electric Vehicle Association (2) and rental agencies (4). The decision variables were divided into two categories: evaluation variables and restrictive variables, as shown in Table 4.9.

The territorial division was based on the Brazilian Constitution of 1988 and the Brazilian Institute of Geography and Statistics or IBGE (Portuguese: Instituto Brasileiro de Geografia e Estatística). The study was carried out based on 33 districts with an average population of almost 200,000 inhabitants and the reference to the term level (L1, L2, L3) refers to the power output of an EVCI. For areas with large extensions, the cut by Planning Areas was used in the analysis and the municipality of RJ contains 5 Planning Area.

The EVCIs were processed according to the equations 2-4:

EVCI_L1 = ("Inc"+"Dens")*Rest (3.9)

EVCI _L2 =

(7*"Inc"+7*"Dens"+7*"PTrans"+7*"PShop"+9*"DCia"+5*"PPP"+4*"PGeo"+5*"PWat"+5*"Decl")*Rest (3.10)

EVCI _L3 =

(7*"Inc"+8*"Dens"+8*"PTrans"+8*"PShop"+7*"DCia"+10*"PPP"+4*"PGeo"+5*"PWat"+4*"Decl")*Rest (3.11)

Table 4.9 – Attributes Used In Research

Var	**Explanation**	**L1**	**L2**	**L3**
Inc	Total of permanent households with monthly nominal income per capita equal to or greater than 10 times the minimum wage (equivalent to US $ 2.200 or higher)	✓	✓	✓
Dens	Population density 18 years and over		✓	✓
PTra	The proximity to the main connections with the main public transportation (airport, bus terminals, subway) with 50 or more parking spaces	✓	✓	✓
PShop	Proximity to largest shopping centers in the region		✓	✓
Dcia	Density companies		✓	✓
PPP	Proximity to public place: roads, corridors and avenues		✓	✓
PGeo	Proximity to the geohazard areas		✓	✓
PWat	Proximity to areas subjected to risk of flooding		✓	✓
Slop	Proximity to areas with slope		✓	✓
Rest	Restriction (or embarrassment). Formed by the sum of the polygons that represent water bodies (dams, major rivers, channels); green areas and subnormal agglomerate (slums)	✓	✓	✓

4.2.2.3. Data processing

The geographic data processing was aimed at identifying potential areas for the creation of an EVCI network in the region studied

Table 4.10 – Input Variables And Treatment Sig

Vector format			
Source	Variables		Source
SEDR AP-RJ [27]	Geohazard	Household income	IBGE [28]
	Water bodies	Pop. density	
	Roads, corridors	Pub. Tran. Conn.	IPP [29]
	Green areas	Subnormal agglomerate	
	Flooding points	Water bodies	
	Slope	Shopping	Desk research
		Workplace	

The combination of GIS and MCDA Modeling is a suitable approach for the evaluation and adequacy of locations, since GIS allows the computation of the criteria, while the MCDA can be used to group them correctly [25]. Multi-criteria analysis provides operational gains on sustainability projects by having analysis methods become increasingly popular in sustainable energy decision-making because of the multidimensionality of the sustainability objective and the complexity of socioeconomic and biophysical systems [26]. Thus, the modeling of potential areas for the EVCI involves the attributes of Table 4.10, as well as the respective sources.

4.2.2.4. Evaluation of variables

To consider a range of quantitative and qualitative variables, a scale of representation was established. In this project, the geographic cut of analysis was the districts. Initially, the scale can be associated to all the cartographic representations in the form of maps. In order to represent an area of the earth's surface, a ratio or scale relation must be adopted, defined by the linear dimensions of the area in the terrain and the representation [31]. The scale was then defined as 1:25,000, with a level of detail compatible with a representation of the districts. A multicriteria project with the support of GIS tools must present geographic consistency of the variables involved. The data model for the representation of geographic information was the geodatabase that allows storing and managing spatial data within the multicriteria decision process [32].

The weighted multicriteria modeling becomes very consistent when we work the data in the raster format [33] to facilitate the accomplishment of operations of mathematical sum between the maps, fundamental process for the project. As the various factors taken into account in the description of each of the alternatives of choice can be measured in different units, the evaluation matrix needs to be transformed into a normalized scale (1 = max, 0 = min) [34]. In this way, the individual analysis of each layer is applied using the maximum and minimum weights of evaluation. The criteria of maximization and minimization is carried out occurred according to equation 5 and 6:

Maximization = $x'_{ij} = (x_{ij} - xj_{min})/(xj_{max} - xj_{min})$ (3.12)

Minimization = $x'_{ij} = (xj_{max} - x_{ij})/(xj_{max} - xj_{min})$ (3.13)

Where:

x'_{ij} = standardized value of the variable

x_{ij} = variable

xj_{min} = minimum value of the attribute j

xj_{max} = Maximum attribute value j

Data processing in a GIS environment complied with the steps shown in Figure 4.7.

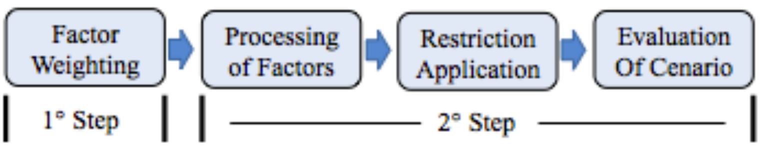

Figure 4.7 – Data processing in a GIS environment

Proximity analyzes were considered in the individual evaluation of each criterion. The pixel classification used was natural breaks (Jenks) by defining intervals based on the natural distribution of breaks or grouping of well-defined levels [35]. All data were classified in order to receive viability weights in each evaluation scenario.

A. Factor Weighting

In the first stage, suitability values was established for each variable, individually. For the weighting and subsequent processing of the factors involved, it is necessary to transform them into raster format.

The matrix format allows facilitating the calculations in the multicriteria analysis, since it represents in grid form (pixels) the surface of interest [36]. The factors involved present different units of representation. For multicriteria operations, it is necessary to normalize them, allowing the mathematical operation between them. Thus, to normalize the range of factor coverage, an evaluation matrix was constructed to be used in the model [37].

From the proximity criterion, the areas with the highest cost (improper) and with the highest benefit (proper) are judged with absolute weights of 0 and 1, respectively. The degrees of proximity were established by data generated by Euclidean distance, suitable for studies of multicriteria evaluation of areas [38].

B. Processing of Factor

According to the scenario addressed, all factors weighted in the past stage where be related to each other for the generation of recommended areas. For L1 processing, two factors were considered: population density and income. To extract the quantitative concentration for the two factors the classification of sites by natural breaks of Jenks was used. The method defines a grouping of the values with smaller variation statistically establishing the spatial patterns of the data used [39]. Thus, the spatial correlation of the data involved was considered in the processing.

As for L2 and L3, all the factors involved were multiplied by previously established coefficients of importance and then added to generate the model for the scenario, with the support of map algebra. Experts who evaluate the importance of each factor define these coefficients. The weighting of each factor depends on the study area addressed, meaning that the coefficients change according to the region addressed. The map algebra tool presents itself as a mathematical operator of geographic data. Once standardized, all the information plans corresponding to the scenarios are summed and their areas included within the evaluation criteria of each level.

C. Restriction Application

The restriction areas considered in the model (Table 4.9) functioned as a limiting factor to the model, ensuring the territorial organization of the area in question. After processing the model, the result was subtracted from the restriction areas, in order to guarantee the total suitability of the sites for the EVCI installation.

D. Evaluation of Scenario

The evaluation of the recommended areas was performed considering the districts as geographic unit of analysis, indicated by the number of districts they covered in the model and the percentage values of all areas in the districts. In scenarios with extensive recommended areas, geographic patterns were investigated by larger area cuts such as Planning Areas that contributed to the better understanding of the scenario. In this case, the proportion of districts contemplated by Planning Areas determined the choice of the most advantageous areas to install the network.

4.2.3 Results

Survey result

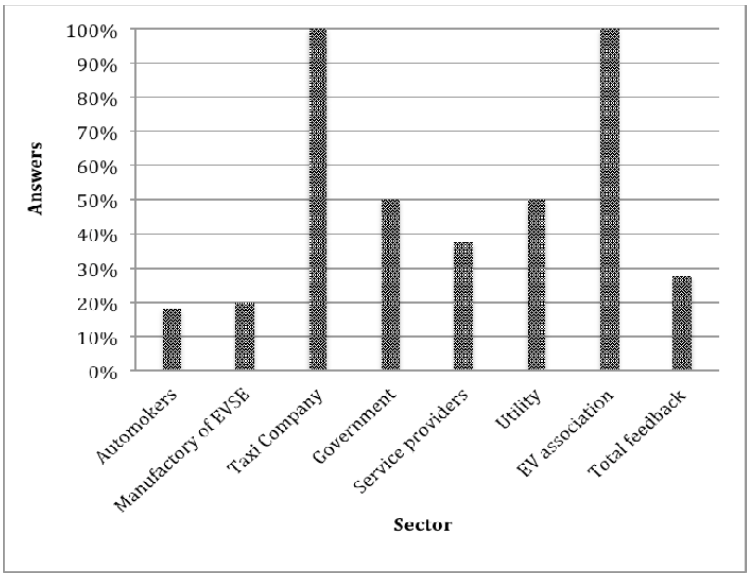

Figure 4.8 – Sending and responses of survey questionnaires

An average 27% of fully completed surveys were received back, as shown in Figure 4.8. The result of the research revealed that the three attributes evaluated (income, workplace and slope) had superior notes for charging stations level 2. For all other attributes the highest scores were for the charging stations level 3, thus revealing the preference of investigated by fast charging, as shown in Figure 4.9. The attributes roads, corridors and avenues were reported by nearly 50% of respondents (space "other specify") and we incorporated it in this study.

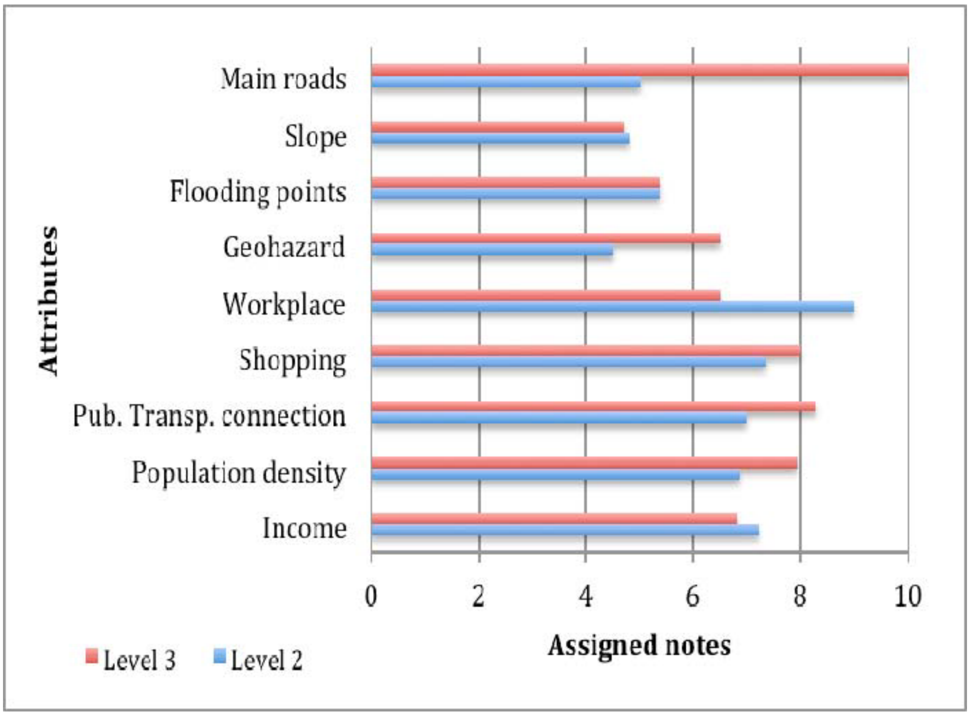

Figure 4.9 – Values attributed to attributes by the experts

This study identified the attributes described in Table 4.11 as being the most important.

Table 4.11 – Selected attributes (√ = presence; ✗ = absence)

Attributes* / Authors	[40] [41]	[42] [43]	[44] [45]	[46] [47]	[48] [49]	This study
1. Inc	√	√	√	√	√	√
2. Dens	√	√	√	√	√	√
3. PTran	√	√	√	✗	√	√
4. PShop	√	√	√	√	√	√
5. Dcia	√	√	√	√	√	√
6. PPP	√	√	√	√	✗	√
7. PGeo	√	✗	✗	✗	✗	√
8. PWat	✗	✗	✗	✗	✗	√
9. Slop	√	✗	✗	✗	✗	√
10. Rest	✗	✗	✗	✗	✗	√

* The attributes explanations are in table 1. Source: Authors' own work

4.2.3.1 Recommended location for the EVCI_L1

The areas recommended for L1 are characterized by a higher level of income and high population density. The result showed that around 12% of districts in the municipality hold 85% of the indications for the installation of EVCI_L1, as shown in the Figure 4.10.

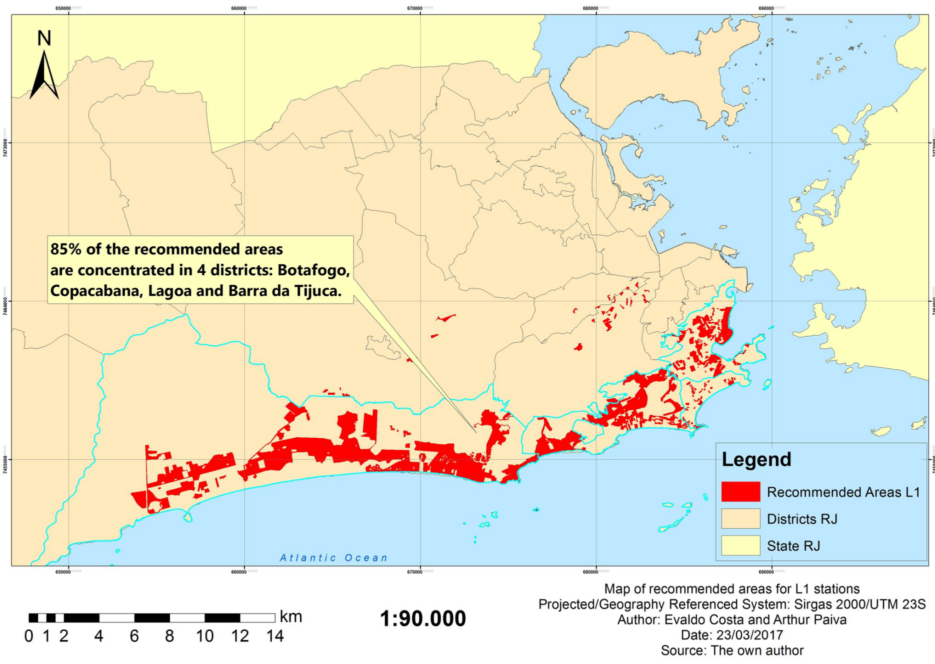

Figure 4.10 – Ideal location for EVCI_L1

4.2.3.2. Recommended location for the EVCI_L1

The geographical model for the areas recommended for L2 includes districts that present a relevant concentration of commercial establishments, shopping malls and road or rail transport stations, such as those located in the Northern region of the municipality. The districts closest to the Central region, such as Sao Cristovao and Vila Isabel, also have a wide network of transport and shopping centers a factor well evaluated by experts to contemplate EVCI_L2. The model revealed that 36% of the districts of the

Municipality of RJ, encompassing of Ilha do Governador, Inhauma, Iraja, Madureira, Meier, Vila Isabel, Sao Cristovao, Pavuna, Zona Portuaria, Ramos, Penha and Vigario Geral are responsible for 60% of the indications for L2. These regions make up the Planning Area 3, as shown in Figure 4.11.

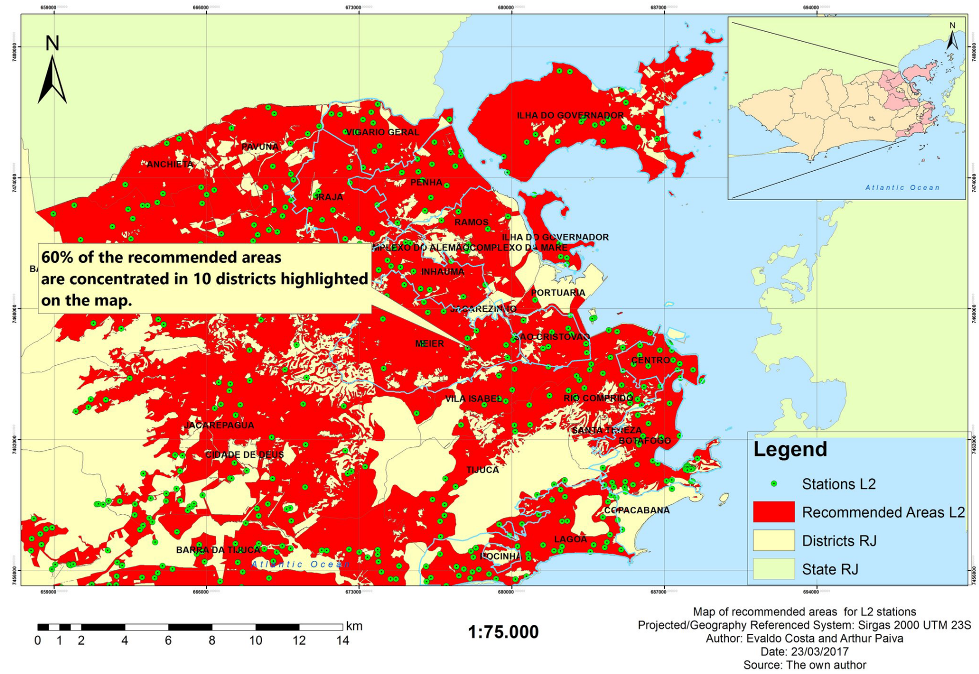

Figure 4.11 – Ideal location for EVCI_L2

4.2.3.3. Recommended location for EVCI_L3

Considering that the vicinity of highways and access roads are important attributes for the installation of L3, the areas with higher incidence of high traffic flow paths have had their importance diminished.

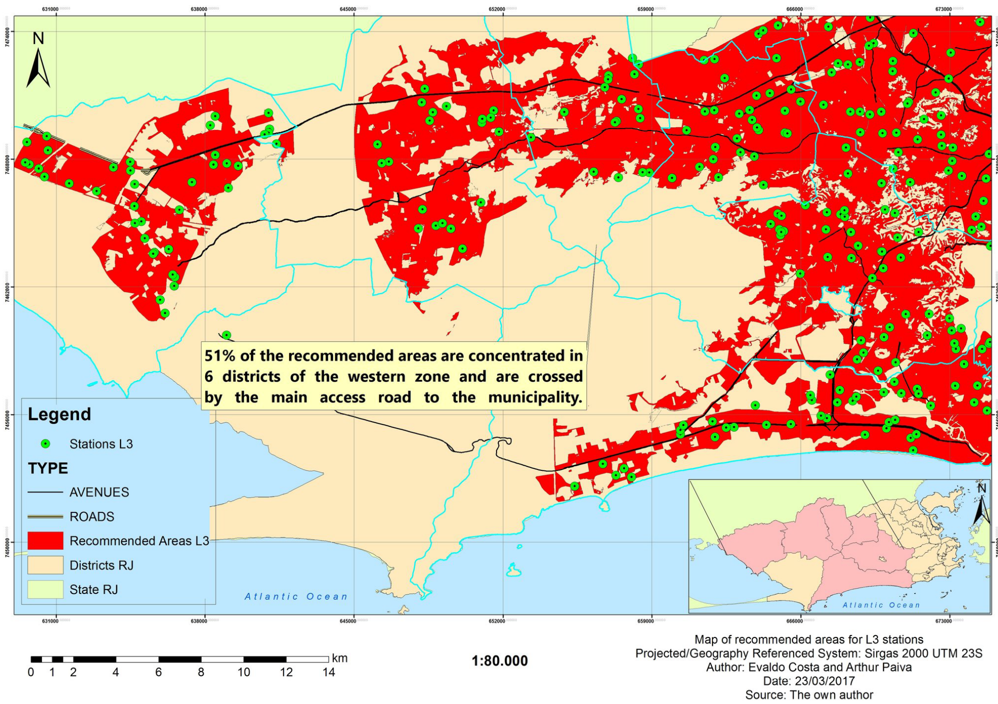

Figure 4.12 – Ideal location for EVCI_L3

Thus, districts contemplating areas such as Santa Cruz, Campo Grande, Barra da Tijuca and Jacarepaguá with access to expressways such as Av. Brasil, Rod. Predidente Dutra, Linha Amarela, Linha Vermelha and Av. Das Américas. The model showed that about 20% of the districts- covering areas such as Santa Cruz, Barra da Tijuca, Jacarepagua, Bangu, Campo Grande and Realengo, had 51% of the L3 indications, as shown in Figure 4.12.

4.2.4 Conclusions

The concentration of the charging infrastructure in specific regions of the city of RJ, demonstrated in the study, can be a facilitator for investments and operational issues in the management of an EVCI network. Although electric mobility is in an incipient phase in Brazil due to its economic burden, politics and geographical position, RJ can become an important agent in the expansion of national electric mobility. In this context, this study points out the first operational paths to support the expansion of infrastructure for EVs, revealing important data for the development infrastructure for low carbon mobility and at the same time helping to mitigate global warming and climate change.

This study also identified the need for government regulation and the interactions of the federal, state and municipal authorities with private initiative aimed at creating business models capable of attracting investments to improve EV and infrastructure sectors. Besides, the identification of different types of electric vehicles by the government will be of great importance for future investigations. Finally, the study revealed that security limitation could be a major obstacle to the expansion of the EVCI network in Brazil, demanding architecture of business models capable of overcoming this issue. We recommend further research to enrich this area of work, for example, by acting at the census level, incorporating minimum distances between EVCI and evaluating the impacts of the growth of an EVCI network in the electricity generation grid.

Acknowledgment

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4.3 OPTIMIZING THE LOCATION OF CHARGING INFRASTRUCTURE FOR FUTURE EXPANSION OF ELECTRIC VEHICLE IN SAO PAULO

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ABSTRACT

The increase in greenhouse gas (GHG) emissions is among the main problems faced by the growth of road transportation in Sao Paulo, the Brazilian city with the highest concentration of vehicles accounting 28,000 vehicles per 100,000 inhabitants. Electric mobility has the potential to catalyze the development of transport, contributing to mitigate GHG emissions, especially in large urban centers providing an adequate electric vehicle charging stations (EVCS) network. This study comes up with the mapping of well-suited locations for EVCS by using geographic information system (GIS) analysis in combination with knowledge from a survey conducted with local electric vehicle (EV) experts. The method was tested to meet the increasing demand for EVs in the municipality of Sao Paulo by 2025, assuming the need for around 3,300 EVCS stations to support a penetration of 1% of EV in the urban private cars. EVCS is ideally situated in 1/3 of the municipal districts of Sao Paulo, namely Center, South Center, part of West and Southeast areas. Risk factors as subnormal agglomerates and places subject to floods were highlighted as new findings to take into attention in large cities, with similar characteristics as others in Latin America.

KEYWORDS: charging infrastructure, electric vehicles, geographical information system, electric vehicle charging station, light-duty electric vehicle

4.3.1 Introduction

Air pollution has been recognized as one of most serious threats to public health, especially in large urban centers, with around 7 million premature deaths worldwide in 2012 [1]. For outdoor air pollution, vehicles are among the largest emitters of CO_2. The transport sector in Brazil is responsible for about 32% of energy consumption in the country, from which road trips represent around 92% [2]. Oil and its derivatives, represent half of Brazil's energy consumption [2]. Studies taking a life cycle approach [4] show emissions reductions from replacing fossil fuel powered vehicles by EVs. Therefore, EVs are becoming an advisable option for urban space [5],[6] to mitigate the Global Warming Potential (GWP) that has been causing so much concern [7]. Former investigations [8], [9] have revealed that if Sao Paulo replaced 20% of its fleet of gasoline cars by EV by 2030, emissions would be reduced around 11.0 $MtCO_2$, with negligible increase of CO_2 emissions from electricity consumption.

Naturally, more environmentally friendly energy sources are better for electrified mobility. In this sense, in 2014, the share of renewable energy sources was around 65% (dominated by hydropower) in Brazilian energy mix, remaining among highest in the world [10] and Sao Paulo has the benefit of having a predominantly clean energy matrix as well.

Despite these EV benefits, market uptake is still low which is mainly due to the lack of charging infrastructure. This study aims to identify the volume and the optimal locations to install electric vehicle charging stations (EVCS) in Sao Paulo municipality, considering a market uptake of 1% of electrified passenger cars in 2025. We address two questions: (i) what factors do locally influence the suitability of EVCS locations? And (ii) where are the optimal locations situated in municipality of Sao Paulo?

Major novelty of this study refers to the mega city of Sao Paulo, which carries specific challenges to address when planning the design of the charging network. For example, the large areas of subnormal agglomerates (between 2000 and 2010, 11% of the population of SP municipality inhabited 2,098 subnormal agglomerates), and the recurring occurrence of geohazard and flooding areas, present significant challenges to tackle when locate an EV charging infrastructure. These characteristics are also presented in other cities, namely in Latin America, and thus our methods and results may benefit them. The contributions to the policymakers of Sao Paulo on how to approach the charging infrastructure to serve the electric mobility in the municipality may be of high utility for the policymakers of other large cities with similar characteristics as Sao Paulo.

This article is structured as follows: the next section presents an overview of previous relevant studies; next the methodological approach is discussed in detail and in section 4 we present the results. Section 5 contains the conclusions, limitations and future directions of research.

4.3.1.1 Literature review

China, United States of America and some European countries are the markets where electric mobility is expanding consistently. The current market of EVCS has globally around 425,000 units installed and should reach the amount of 2.5 million in 2025 [10]. A survey requested by the European Commission on the behavior of European EVs users concluded that an adequate re-charge network is perceived as crucial by electric car drivers [11]. In this section, we review other studies on the factors that can influence the location of suitable EVCS and on optimal location analysis.

a) Factors influencing EVCS location suitability

Several studies investigate the most influencing factors for location of EV infrastructure (Table 4.12). Chen's [16] investigations revealed the importance of attributes as income, housing, population density, public transportation connections, shopping destinations, workplaces, and roads, corridors and avenues, to best satisfy demand for public charging stations of EVs. Parker [12] studied the electric vehicles charging station infrastructure in USA, and slopes and hazards of water pooling (geohazard) were considered inadequate to install EV infrastructure. The existence of shopping and workplace activities are attributes extensively explored as important ones, in studies on EVCS location [13], [14], while attributes such as income house, population density, work place and roads were also underlined by Efthymiou [15].

Other studies aiming at the development of infrastructure for electric vehicles in urban centers, complement this list of attributes, as is the case of Wagner's study [16] on the factors that inflate the utilization of charge points in Amsterdam, pointing out attributes as income house, population density, shopping and workplace.

Table 4.12 – Attributes used in studies related with EV charging infrastructure

Attributes / Authors	(1) [12], [17]	(2) [15]	(3) [13]	(4) [16]	(5) [14]	(6) This study
(1:9) Selective attributes ([1]Socio-economic (SE); [2]Socio-demographic (SD); [3]Geographic (G)						
1. Inc: income house (SE)[1]	✓	✓		✓	✓	✓
2. Dens: Population density (SD)[2]	✓	✓		✓		✓
3. PTran: Public Transportation Connection (G)[3]	✓					✓
4. PShop: Shopping (G)[3]	✓		✓	✓	✓	✓
5. Dcia: Workplace (G)[3]	✓	✓	✓	✓	✓	✓
6. PPP: Roads, corridors and avenues (G)[3]	✓	✓		✓		✓
7. PGeo: Geohazard (G)[3]	✓					✓
8. PWat: Flooding areas (G)[3]						✓
9. Slop: Slope (G)[3]	✓					✓
(10) Restrictive attribute (RV)						
10. Rest: Green areas, Water bodies and subnormal agglomerates (RV)						✓

Providing adequate EVCS is a way for EVs to gain the streets on a larger scale [18], to prevent the user of feeling anxiety for having no possibility to re-charges, which limits the willingness to buy this type of vehicle. A study in Japan has revealed that BEV owners rarely use public rechargers but they wouldn't have bought an EV if there weren't any public stations available [18].

Investments in public chargers can be reduced depending on the characteristics of the region, where the charging network will be implemented, taking into account various attributes [19] such as the availability of garages in residential areas, installation of slow charging points in the workplace, in some parking lots, airport and bus terminals.

Presumably, workplace and car parks, especially at points of connections to public transports, are the places where most vehicles are parked for longer time intervals, just after residence. In addition, research on evaluating the EV charging behavior in urban central California, USA, has revealed that fast charging was not very important for the sample under study, suggesting users could easily replace fast charging station use by using level 1 and level 2 charging stations [20], [21].

b) Optimal location analysis

Choosing the optimal location to install EVCS is a major challenge for the agents who work in the electric mobility sector, like among others, the automakers, charging point operators, property owners, and government. Research conducted in the metropolitan region of Stuttgart, Germany, reveled EV infrastructure should be focused on the few biggest urban centers, mostly due to economic reasons, [21]. Besides, there are others factors determining the location of the EV charging infrastructure that need to be better understood, such as the most used routes, limitations to install home chargers and consumer charging behavior [22].

Charging time and EVCS location significantly influence the decision of EV drivers. The EV drivers prefer fast EVCS that are on their routes to charge their cars in the shortest time possible, so if they are installed at unwanted places, the benefit of quick charging might be impaired with long dislocations [22]. Gebauer [23] has investigated the impact of new fast-charging technologies for electric vehicles and also found that fast charging is key for the driver preferences. In addition, it is recommended to get to know better the demand for each type of EV, battery characteristics, drive range, availability of physical space to install EVCS, demand for recharging, energy consumption, and impact on the grid [24]–[26].

The use of Geographic Information System (GIS) tool is suitable [27] to study the demand for geographically distributed charging stations in an urban area, as it has been used for many years as a location tool, for example to determine the points where its location can be minimized or maximized in relation to specific geographical reference [28]. GIS has the ability to manage multiple spatial layers of data, through specific algorithms, to provide a spatial explicit result, which makes it suitable for the identification of the optimal locations of infrastructure.

Using GIS in combination with MCDM based on a survey among local EV experts, one can visualize the results of different location scenarios [30]. Selective attributes allowing for the identification of the optimal locations for EVCS installations, and restriction attributes preventing the installation of EVCS, due to environmental and socio-economic constraints [31] was adopted.

4.3.2 Methods

A case study was conducted in the municipality of Sao Paulo, Brazil, to illustrate how GIS tools can be used to analyze and identify the feasible and optimal location for EVCS, based on the valuation of selected attributes by EV experts.

4.3.2.1 Case study: Sao Paulo

The municipality of Sao Paulo has a surface of 1,530 km², counted 11.9 million inhabitants in 2015, resulting in a density of 7,762 inhabitants/km^2 and an urbanization rate of 99% [32]. Sao Paulo is the most populous city in Brazil and the entire southern hemisphere of the American Continent. In Brazil, the highest concentration of road vehicles is recorded in Sao Paulo. In 2014, the total fleet was of almost 4,6 million vehicles: 3.3 million passenger cars; 0.6 million light commercial vehicles and 0.7 million other vehicles. The city held about 30% of the fleet in the state of Sao Paulo [3]. The pure electric vehicle fleet (BEV) is negligible recorded in March 2016, only 223 units [33]. The road distances within the city of Sao Paulo are relatively short and favorable to the use of EVs. For example, the connection between North and South is around 50 km and between East and West around 35 km. From the central area to the farthest point is around 37 km, much less than the range of most of the electric models currently available in the market [34].

The municipality of Sao Paulo has 2,489 neighborhoods, 96 districts and 32 sub-municipalities. The territorial division was based on the Brazilian Constitution of 1988 and on the Brazilian Institute of Geography and Statistics or IBGE (Portuguese: Instituto Brasileiro de Geografia e Estatística). This study is carried out based on 96 districts, accounting for an average population of 124,000 inhabitants, which make up the municipality of Sao Paulo, as shown in Figure 4.13.

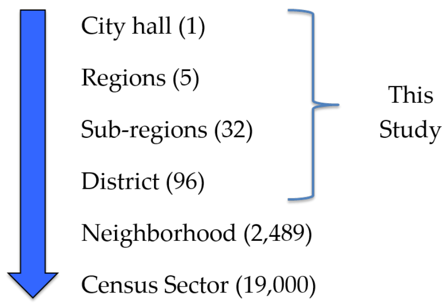

Figure 4.13 – Territorial divisions of the municipality of Sao Paulo

4.3.2.2 EVCS demand and proportion of EVCS by level

We aim to present the optimal location of EVCS for a scenario of light-duty electric vehicle (LDEV) penetration of 1% in Sao Paulo by 2025, following the study on energy demand for the Brazilian automotive sector [35]. This scenario is consistent with the current penetration of EVs globally. Although EV has been launched for the masses for nearly a decade, EVs have a market share of around 1% in almost all the countries where they are marketed [10].

In addition to the natural obstacles to expand in large volumes in Brazil, EVs have to overcome the obstacles from competition with the ethanol and petroleum industry, both very active in the country. Under that scenario, LDEV can reach about 33,000 units by 2025, requiring about 3,300 EVCS. This 1 charging station per 10 vehicles rate is based on the experience of large cities in developing countries with electric mobility, such as China where the government requires large cities, such as Shanghai, Beijing, Shenzhen, and Guangdong to have approximately one EVCS for every ten EVs [36].

Table 4.13 – Technical specifications of the different levels of EVCS

Level	Typical Use	Energy interface	Power Level	Charge Time
EVCS_L1 AC 120 V EVCS 1 DC 200 - 450 V	Home or Office	Convenience outlet	Up to 2 kW ≤ 20kW	12 to 18 hours
EVCS_L2 AC 240 V EVCS 2 DC 200 V– 450 V	Dedicated Outlets	Dedicated outlet	≤ 20 kW ≤ 80kW	3 to 8 hours From 20 min to 7 hours
EVCS _L3 AC Undefined EVCS 3 DC 200 V – 450 V	Commercial Station	Dedicated EVSE	50 – 100 kW ~120 Kw	Less than 30 minutes

Source: [37], [38]

For the purpose of this work, we consider the technical and operational characteristics, for the different levels of EVCS, as presented in Table 4.13, recommended as follows.

i) EVCS 1: recommended for the area where the driver lives. The residential area with many garages is not recommended to have stations level 2 and level 3 nearby, because in area with this characteristic most BEV's drivers, normally, have home stations.

ii) EVCS 2: recommended to workplace, some public transportation connection areas and shopping malls as well.

iii) EVCS 3: recommended to shopping malls, main freeways, corridors, main avenues, and some business areas.

There is no standard relation between the EV stock and the number of EVCS per level. For this study, from the total EVCS, we adopted the average percentage of 20% for EVCS_L3 and 80% for EVCS_L2 installed in public spaces, as happen in the sixteen countries that adopt EVs [35, 9]. The United Kingdom and Sweden, which are emerging countries in the electricity mobility market, also make available 20% of EVCS_L3 in 2015 [10].

4.3.2.3 Survey to identify and value the attributes determinants of the EVCS location

We selected the most common attributes reported in the literature, as presented in Table 4.12, including economic, socio-demographic and geographic aspects.

Table 4.14 – Participation of the sectors surveyed

Sectors	Number of stakeholders' contacted	Number of Respondents	%
Automobile industry	22	5	14
Transport-related services	7	3	43
Service provider	8	3	38
Government	6	1	17
Energy sector	8	2	25
Total	51	14	28

Table 4.15 – Survey characterization

		Number of respondents	% of the total respondents
Gender	Female	1	7
	Male	13	93
Business segment	South	3	21
	Southeast	10	72
	North	0	0
	Northeast	1	7
Work Sector	Private	11	79
	Public	1	7
	Third sector (NGO)	2	14
Business segment	Automobile industry	5	37
	Transport-related services	3	21
	Service provider	3	21
	Government	1	7
	Energy sector	2	14
Job position	President	2	14
	Director	8	57
	Manager and consultant	4	29

A survey over selected EV specialists was conducted with the objective to gather their valuation of each attribute with respect to the installation of EVCS (levels 2 and 3). Each specialist valued each attribute through weights, from 0 to 10, where 0 means the attribute has no importance for the location of EVCS, and 10 has the maximum importance. The questionnaire was made available through e-mail between May and June 2017 to a selected number of EV experts, from different business segments as shown in Table 4.14. The responders are mostly males (93%), living in southeastern Brazil (72%), the most populous and industrialized region of Brazil, working in the private sector (79%) with a director position (57%) in the Automobile industry (37%). A total number of 14 individuals (28% of the total population) responded to the survey. The transport-related services (43%) get the highest response rate, followed by the service providers (38%) and the energy sector (25%), as shown in Table 4.14.

4.3.2.4 GIS analysis

GIS analysis was conducted to manage spatial data of Sao Paulo municipality, to categorize the attributes as surveyed from the EV experts and to manage all the spatial data to come up with the mapping of the optimal location of EVCS levels 1, 2 and 3.

a) Spatial data

Table 4.16 – Spatial data, used and sources

Attributes	Source[1]	Attributes	Source[1] [39], [40]**
‘	IBGE, Censo 2010**	Geohazard	GeoSampa*
Population density	IBGE, Censo 2010**	Flooding areas	GeoSampa*
Public transp. con.	Desk research	Slope	GeoSampa*
Shopping	Desk research	Green areas	Desk res. /GeoSampa*
Workplace	IBGE, Censo 2010**	Water bodies	GeoSampa*
Roads, corridors and avenues	Desk research	Subnormal agglomerates	IBGE, Censo 2010**

We used the spatial data mentioned in Table 4.17 to characterize the municipality of Sao Paulo, as needed for the methodology to select the optimal location for EVCS

b) Spatial analysis for EVCS location

All the spatial data in vectorial format was rasterized to allow performing the map algebra operations, as explained in the next steps. In Brazil, the geographic coordinates of features are based on the Geocentric Reference System for the Americas (SIRGAS2000) [39]. The location of EVCS per level was guided primarily by a set of selective and restrictive attributes, whose criteria are stated in Table 4.18. It should be underlined that geohazard, flooding areas and slope are important characteristics in the context of the region under analysis, being the first and second recurring problems in the municipality of Sao Paulo, with huge financial losses and structural damage [41], [42].

The optimal location of the different levels of EVCS was derived from specific map algebra operations, based on the criteria of the attributes as well as on the weights from the EV experts, as explained bellow.

EVCS_L1 network was obtained from 'house income' and 'age' (Equation 1), and did not involve the specialists' scores.

EVCS_L1 = ("Inc"+"Dens") (4.1)

EVCS_L2 and EVCS_L3 networks were determined following three steps.

Table 4.17 – Criteria used in GIS analysis for the three types of EVCS

		EVCS		
Attribute	Criteria of selection	L 1	L 2	L 3
Selective attributes				
Inc	Equal or higher then US$2.200 per month per household.	✓	✓	✓
Dens	Inhabitants older than or equal to 18 years		✓	✓
PTran	Public transport connections with parking facilities to accommodate at least 50 vehicles	✓	✓	✓
PShop	Shopping centers with parking facilities to accommodate at least 50 vehicles		✓	✓
Dcia	Workplace: areas with at least 50 organizations		✓	✓
PPP	Roads, corridors and avenues: (i) connecting the municipality of SP with other municipalities or states (ii) linking one or more regions of the city of SP (iii) connecting with inter-municipal and interstate highways (iv) connecting the central region with two or more neighborhoods			✓
PGeo	Geohazard identified by the city administration with building restrictions		✓	✓
PWat	Flooding identified by the city administration.		✓	✓
Slope	Slope smaller than 25 degrees.		✓	✓
Restrictive attribute				
Rest	Restricted areas for the installation of EVCS include Water bodies (dams, major rivers, channels) green areas and subnormal settlements (slumps).	✓	✓	✓

(i) identification of the allowed and non-allowed areas for the installation of EVCS, through a Boolean model [43], based on the attributes and criteria presented in Table 4.18. Cells are assigned the value of 1 if for each attribute the criterium was met (benefits criteria), otherwise 0 [44]. For example, if the area is identified by the city administration as in risk of geohazard (cost criteria), then the 0 value is assigned to the cell, if not, then 1. The result of this step is a set of Boolean maps, one for each criterion.
(ii) assessment of the Euclidian distance between selected attributes, as public transportation connections, shopping centers and workplaces (Table 4.18), to calculate the radius distance, determining the proper location to install EVCS. For example, if the average distance between shopping malls is 10 km, we consider 5 km as the maximum radius (limited to 35 kilometers) from each shopping mall in which the EVCS should be installed.
(iii) determination of the optimal location to install the EVCS network considering the expert valuation of the attributes. We assume that the higher the score indicated by the experts to an attribute (in a range of 0-10), the closer the EVCS should be located to the site with such attribute. The opposite works on the same logic, that is, the smaller the score assigned the farther the EVCS will be from the evaluated site. The scores (weights) indicated by the experts were averaged and incorporated into the map algebra

operations, denoted as wi_L2 and wi_L3, in the following Equations 2 and 3, to determine the sites to install EVCS level 2 and 3, respectively. The names of the parameters in the equations are explicit in Table 4.18.

EVCS_L2=(w1_L2*"Inc"+w2_L2*"Dens"+w3_L2*"PTrans"+w4_L2*"PShop"+w5_L2*"DCia"+
w6_L2*"PGeo" + w7_L2*"PWat"+ w8_L2*"Slop" + w9_L2*"PPP") (4.2)

ECVC_L3=(w1_L3*"Inc"+w2_L3*"Dens"+w3_L3*"PTrans"+w4_L3*"PShop"+w5_L3*"DCia"+
w6_L3*"PGeo"+ w7_L3*"PWat"+w8_L3*"Slop"+ w9_L3*"PPP") (4.3)

Finally, the restriction areas (attribute 'Rest' in Table 4.18) were excluded to generate the final maps with the optimal locations for the EVCS_L2 and EVCS_L3 network in Sao Paulo. Figure 4.14 illustrates the flowchart of the methodology followed in this work.

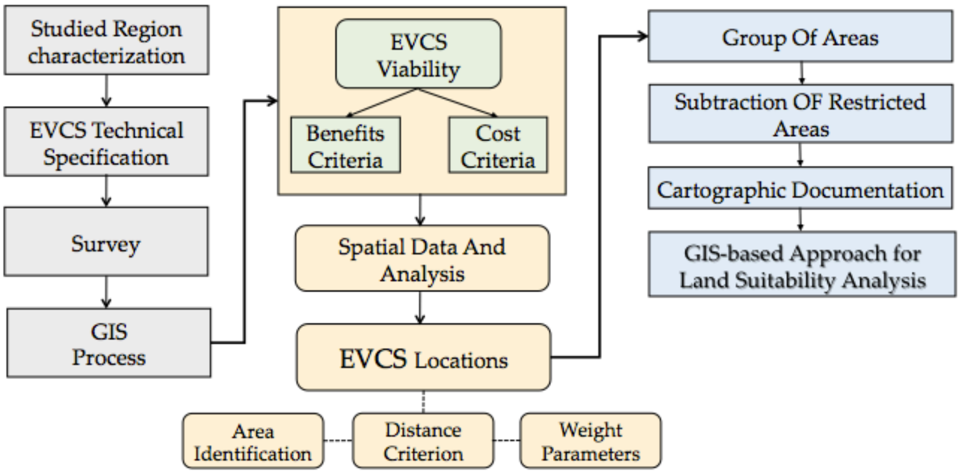

Figure 4.14 – Works flowchart

4.3.3 Results And Discussion

4.3.3.1 Score values from the EV experts' survey

Table 4.18 presents the score values (0-10) gathered from the respondents regarding the importance of each attribute to the installation of EVCS in municipality of Sao Paulo. The attributes 'workplace' 'shopping', and 'income', got the highest average scores for the location of charging stations level 2, meaning the experts selected these as most important. This choice was probably due to the fact that the 'workplace' is where the private passenger vehicles stay longer, just after the place of the driver's residence. Usually, 'workplaces' are the second most common location for electric vehicle charging, after homes. The 'shopping' attribute probably was selected because even in fast EVCS, it is recognized that EV charging may require significant time, so it is advantageous to load into service, shopping, restroom and restaurant areas, allowing EV owners to occupy their time while the vehicle is connected.

For the EVCS level 3, the attributes 'roads', 'public Transportation connection' and 'shopping' were scored as the most important. The choice for 'roads' can be explained by the fact that the super-fast charging only needs 20 or 30 minutes to provide the drivers a great range. Then a rapid stop to rest on highways, use the bathroom and take a coffee will be enough to charge the EV battery. Although experts have indicated 'public transport connection' more suitable for the location of EVCS_L3, they also assigned a high score for EVCS_L2.

Table 4.18 – Scores from the EV specialists on the attributes to condition the location of EVCS in Sao Paulo

	Level 2				Level 3			
Attributes	Min.	Average	Max.	Final score (Eq.2)	Min.	Average	Max.	Final score (Eq. 3)
Income (Inc)	1	7.21	10	w1_L2 = 7	1	6.79	10	w1_L3 = 7
Population density (Dens)	1	6.86	10	w2_L2= 7	1	7.93	10	w2_L3= 8
Public Transportation connection (PTran)	1	7.00	10	w3_L2=7	5	8.29	10	w3_L3=8
Shopping (PShop)	1	7.36	10	w4_L2=7	1	8.00	10	w4_L3=8
Workplace (Dcia)	1	9.00	10	w5_L2=9	1	6.50	10	w5_L3=6
Geohazard (PGeo)	1	4.50	10	w6_L2=4	1	4.64	10	w6_L3=5
Flooding areas points (PWat)	1	5.36	10	w7_L2=5	1	5.36	10	w7_L3=5
Slope	1	4.79	10	w8_L2=5	1	4.71	10	w8_L3 =5
Roads, corridors and avenues (PPP)	0	5.00	10	w9_L2=5	10	10.00	10	w9_L3=10

In our view, a partial charging period from 2 to 3 hours is more than enough for the driver to leave the car, move from public transport to a quick appointment and, upon returning, pick the vehicle with a charged reasonable range. Other studies confirm these hypotheses[12], [16], [17]. Attributes like the proximity of the distribution network, hospitals, restaurants, business centers, supermarkets, residential condominiums, parking lots, bike lanes and fuel stations are pointed out a least once (under 'specify') in the answers of respondents.

4.3.3.2 GIS analysis

The distribution of the areas to locate the EVCS is presented in Figure 4.15, for the three EVCS levels, presenting different location patterns. Analysis of the locations for EVCS_L1 (Figure 4.15a) revealed that 11% of the municipality of Sao Paulo will likely account for 67% of the sites for those charger points. The Center, South Center and part of the West and Southeast are the areas with the greatest potential to accommodate an increase of this level of charger. These are the areas with a higher concentration of households with a monthly income equal or greater than 2.2 thousand dollars and a higher population density with 18 years old or over. The result for the EVCS_L1 shows consistency with other studies [12], [16], [17] that also considered age and income as essential attributes.

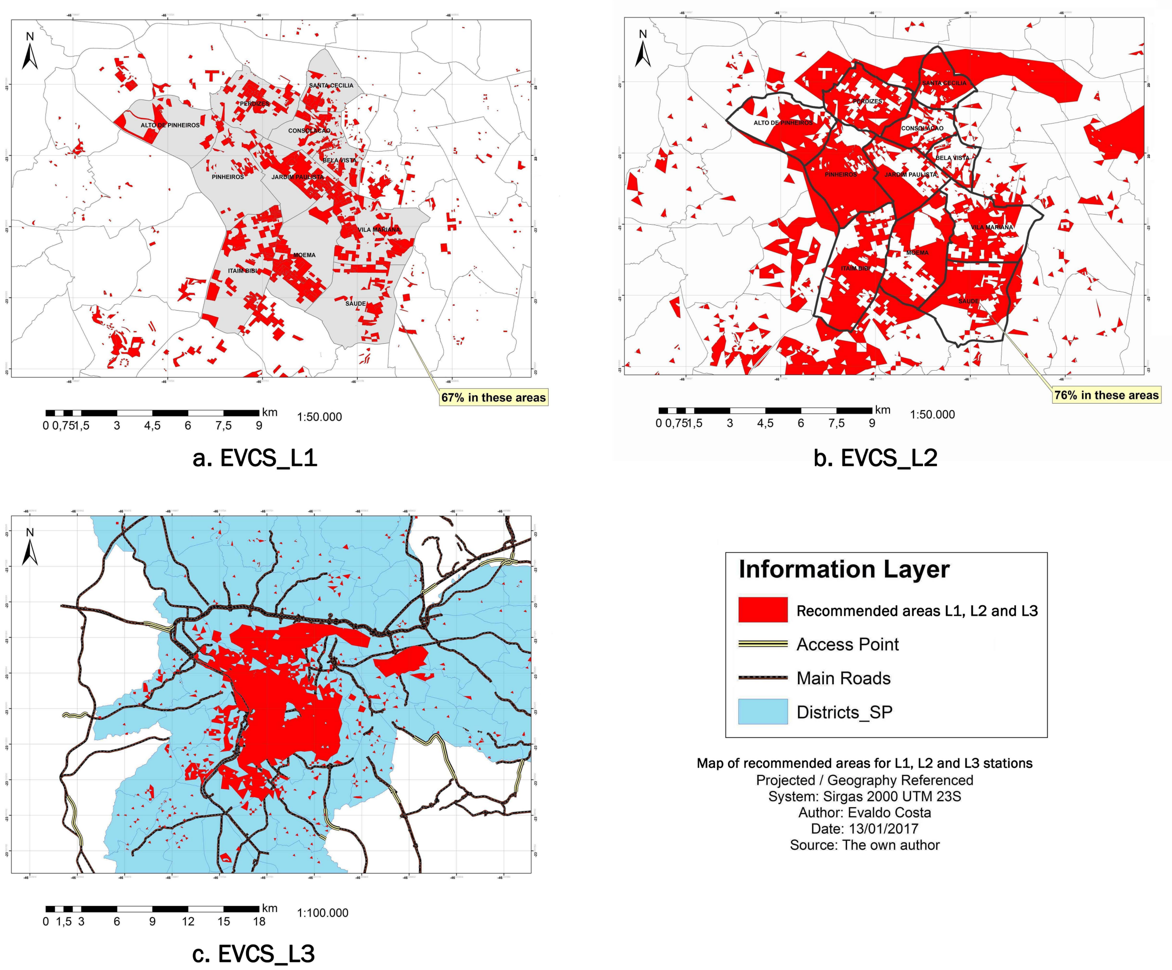

Figure 4.15 – Areas for the optimal location of EVCS in Sao Paulo municipality

Regarding EVCS_L2 (Figure 4.15b), the results suggest that 11% of the municipality of Sao Paulo’s municipality will potentially account for 76% of the sites for the installation of those charger points. For EVCS-L2 sites are situated in the Eastern and the Northeast areas, South Central, West and Southeast areas. The most determinants attributes include the 'workplace', 'shopping malls', and 'income'. On the other hand, 'geohazard' and 'flooding areas' got the lowest average rate from the experts.

The results suggest that the EVCS_L3 (Figure 4.15c) will likely cover 57% of the Sao Paulo municipality. The locations of these chargers are mainly due to the high importance of the busy access roads to the city of Sao Paulo, especially those connecting the Eastern, Southeast, West and Northwest Areas. The busiest East-West and North-South corridors, as well as the large and congested avenues also had emphasized importance in determining the outcome of EVCS_L3. The three following attributes have had the highest average: ‘roads’, ‘shopping’ and ‘public transportation connection’. The attributes with the lowest average score are ‘slope’, and ‘flooding area points’ and ‘workplace’.

4.3.4 Conclusions, Limitations And Future Research

The research presented in this paper aimed to identify the demand and the optimal locations to install EVCS in municipality of Sao Paulo, as well as to gather the factors that most influence the suitability of a territory to locate EV charging infrastructure. A methodology based on a survey among Brazilian EV experts and GIS analysis was applied to a scenario of 1% of LDEV in 2025. Major conclusions from this study revealed: (i) the EV charging network requires 3,300 EVCSs for the vehicle stock corresponding to 1% of LDEV in 2025, (ii) the EVCSs will be restricted to an area of about 1/3 of the municipality, with the potential to optimize the investment and maximize the provision of services to the users; (iii) the proximity to 'roads', 'shopping malls' and 'connections with public transport' were pointed out as the most important to install EVCS_L3; (iv) the proximity to 'workplaces', 'shopping malls' as well as the 'income' of the users were found the most important attributes for EVCS_L2.

The municipality of Sao Paulo has favorable conditions regarding the adoption of EVs due to (i) clean electricity and (ii) the distance to cross the county from North to South and from East to West (less than 50 km) is lower than the autonomy range of most EVs in the market.

The novelty of this study relies in the use of GIS to identify optimal locations for electric vehicle infrastructures, in combination with MCDM based on a survey among local EV experts. Moreover, the case study analyzed deserves to be mentioned due to its huge extension and potential electric mobility in the near future.

Implications of this study are the need of the government to identify, at the time of licensing, the types of electric vehicles, in order to differentiate, for example, Battery Electric vehicles (BEVs) from Hybrid Electric Vehicles (HEV) and Hybrid Plug-In Electric Vehicles (PHEVs), which is important regarding the vehicle range. Such data will be extremely valuable for future studies, especially those linked to EVCS, energy and GHG emissions. Also, was identified of specific risk factors, as subnormal agglomerates and places subject to floods.

A limitation to this study refers to the few numbers of EV specialists in Brazil that limited the survey sample. This is due to the fact that electric mobility is still incipient in the country. Future research must evaluate the impact of the growth of the EVCS network on the power network of the municipality in order to identify additional investments to accommodate the high potential of EVs in the region.

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CHAPTER 5 | LEARNING FROM BRAZILIAN STAKEHOLDERS: CHALLENGES AND OPPORTUNITIES ASSOCIATED WITH THE MASS PENETRATION OF ELECTRIC MOBILITY

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5.1 CHALLENGES AND OPPORTUNITIES OF ELECTRIC MOBILITY IN BRAZIL FROM STAKEHOLDERS' PERCEPTIONS

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HIGHLIGHTS

** Clean power in Brazil is a positive factor to boost EVs market penetration, but challenges remain*
** A survey was conducted with 144 stakeholders in Brazil with direct interest in EVs*
** A SWOT analysis identified more* weaknesses/threats than strengths/opportunities for EVs
** The pure electric car is the best option for the Brazilian market*
** Purchase incentives should be prioritized for the LDEV increase the market penetration*

ABSTRACT

A major challenge for the humankind is to reduce global carbon dioxide (CO_2) emissions to avoid the most harmful impacts of climate change. The transport sector is responsible for almost 1/4 of the world energy-related emissions, with road transportation representing 1/5 of the fuel consumption. Electric vehicles (EVs) may contribute to reduce CO_2 emissions, but their diffusion is uncertain due to market barriers. This paper contends that it is necessary to adopt a socio-technical perspective to adequately assess the challenges facing the adoption of electric vehicles for the case of Brazil. The views and dispositions of social actors offer insights into critical factors affecting this diffusion process. The analysis was carried out based on a survey administered to a wide range of stakeholders. A SWOT analysis was performed to understand the most critical factors conditioning the future of EVs in Brazil. The results suggest pure EVs as the first option for low-carbon passengers mobility and that EV expansion will require market regulation, incentives and adequate charging infrastructure. The consumers and society will benefit most from the expansion of EV due to low emissions and Total Cost of Ownership (TCO). The results show where decision-makers should focus their attention.

Keywords: Electric Vehicle, Greenhouse Gas Emissions, CO_2 Emissions, Ethanol, Climate Change, SWOT Analysis, Brazil.

5.1.1 Introduction

A major challenge for all humankind is to tackle the effects of climate change, which can be achieved by cutting global carbon dioxide (CO_2) emissions in order to maintain the global average temperature between 1,5°C and 2°C above pre-industrial levels (Pachauri et al. 2014). In 2014, the transport sector was responsible for almost 1/4 of worldwide energy-related emissions and road transportation was responsible for around 1/5 of the fuel consumption (Energy & Transformations 2017; IEA 2016). The search for low-emission transport should be a priority for governments in various regions of the world, as they attempt to achieve the goal of reducing emissions set in the Paris Agreement (Agreement & Nations 2015). Indeed, the electric vehicle (EV), has a smaller ecological footprint when compared with other options (Costa and Seixas, 2014; Hooftman et al., 2016; Seixas et al., 2015) and is currently the most accessible low emission transport technology at the moment.

In 2010, the EV became an accessible technology (IEA 2016). However, due to socio-technical obstacles, the increase of its market penetration has been slow and restricted to few countries. The issues surrounding the expansion of EVs (see section II) may seem simple, but they are not easy to implement, requiring specific knowledge (Zheng et al. 2012), for example on the parameters for the charging infrastructure development in each region, to guide public policies to properly support its implementation. Some cities, such as Beijing or Shanghai in China and Tokyo in Japan, are characterized by high population density, concentrated in residential buildings without garages. Such an arrangement has required dedicated public policy attention in order to increase the number of fast charging stations, which has made China and Japan currently account for more than 65% of fast-charging outlets (IEA, 2016)

On the other hand, in some regions of the United States of America for example, with a large number of residences with garages, more than 65% use domestic charging for EVs (Idaho National Laboratory 2015). Therefore, there is the need to research on what are the critical factors and opportunities to guide policy makers towards EV market expansion, especially in emerging countries in this type of mobility. Such information is relevance for public and private stakeholders to support the expansion of low-carbon mobility (Tsang et al. 2012).

The case of Brazil is particularly interesting. The fast growth of its automobile market, due to increasing urbanization and consumers' access to cars, has contributed to worsening the levels of CO_2 emissions. In 2014, the transport sector represented more than 32% of energy consumption in Brazil with road transportation accounting for more than 92% of that amount (EPE 2015). Brazil has invested in ethanol as a clean fuel, becoming the world leader in the production of sugarcane ethanol. From 1990 to 2011, the cultivated area increased 45% and ethanol production increased by an average of 1,5 billion tonne per year (Filoso et al. 2015).

It is undeniable that ethanol has contributed to avoiding the growth of transport emissions in Brazil. However, increased ethanol production has led to other problems, such as deforestation, soil contamination, water and air pollution (from biomass burning), and the possibility of competing with food production (Bento et al., 2014; Filoso et al., 2015; Gauder et al., 2011; Martinelli, Garrett, Ferraz, and Naylor, 2011). Therefore, investigating road transport options, complementary to ethanol, such as EV, is an important research goal. EV is a good option because of its potential low emissions when used with electricity with low-carbon intensity (Messagie 2014; Hooftman et al. 2016; E. Costa et al. 2017). This may be an option in Brazil due to clean power in the country (EPE 2015). The diffusion of the EV in Brazil is still in an early stage, as better knowledge of the dynamics that may hinder or facilitate its diffusion is needed to inform decision-makers about the best strategies to adopt.

As argued by Sovacool and Hirsh (Sovacool & Hirsh 2009), even though transport studies tend to focus on the technical barriers and solutions to the adoption of EV, it is necessary to draw on insights from a socio-technical perspective. As put by Rogers (Rogers 1995) in his renowned diffusion of innovations theory, "the diffusion of innovations is essentially a social process", and the meanings attributed to an innovation are socially constructed. The ways that individuals subjectively perceive technological innovation, such as the EV, and how these can be integrated into their everyday lives, shape the diffusion processes. Furthermore, individuals are influenced by (and learn from) others in their social networks, either to express distinction (when an innovation is adopted by individuals with higher social status and subsequently emulated by others) or because personal connections reduce the uncertainty associated with innovations (Bartiaux et al. 2016; McMichael & Shipworth 2013). In fact, interpersonal relations have been considered one of the most powerful influences on behavior (Watts & Dodds 2007; Buttle 1998), and its influence has been observed regarding consumers' perceptions of plug-in hybrid electric vehicles (Axsen & Kurani 2012). In Brazil, social issues linked to the expansion of electric mobility, i.e. how individuals subjectively perceive technological innovation in transport sector, need to be better understood in order to advance its adoption.

Our study aims at identifying the strengths, weaknesses, opportunities and threats for the expansion of the light-duty electric vehicle (LDEV) in Brazil, regarding socio-technical, political-economic, and innovation-environmental aspects. The study is based on SWOT matrix principles (Gil et al. 2011; Markovska et al. 2009; Barrella et al. 2013) applied to a survey which has been conducted among different types of stakeholders with an interest in EV. Due to their professional occupations, social status and expertise on this matter, their views and dispositions regarding the EV provide valuable information for the analysis of the social diffusion process of this technology in Brazil.

The results of this research contribute to a better understanding of the critical factors that are conditioning the potential of diffusion of EV in the country, thus may guide the public and the private sectors on making decisions towards its social acceptance and adoption. The next section will provide a background to the study, section three will present the methodology, while section four will present the results and discussion of the main findings. The fifth section will conclude, highlighting the limitations and making suggestions for future studies.

5.1.2 Critical factors for EV market expansion

In 1897, EVs entered the marketplace and found broad appeal, with the carmaker Pope Manufacturing becoming the first large-scale manufacturer. In 1900, the EV became the best-selling road models in the United States, with 28% market penetration. The second attempt at mass production of EVs occurred in the second half of the twentieth century, in Europe with the French government, launching "The Research And Innovation Program In Land Transport" (PREDIT) to accelerating the EV Research, Development and Dissemination (RD & D) and North America with GM's EV1 project. Around 2010, it was the third time that EV appeared with the possibility of becoming mainstream (Trigg et al. 2013).

Currently, the attempt for the mass adoption of EV presented a new appeal due to the need to cut greenhouse gas (GHG) emissions. In many urban areas, especially in Europe and part of Asia, there has been additional pressure to reduce the number of internal combustion engines (ICE) and encourage low-carbon mobility, such as EVs. Nonetheless, there are significant challenges to overcome the current low EV market penetration, as presented in the following section, and ensure that forecasts are confirmed that by 2040 electric cars will sell more than fossil fuel-powered models (Bloomberg 2017).

5.1.2.1 The EV global evolution, current status and future perspectives

Since 2010, LDEV sales have almost doubled in size each year. However, the EVs in most countries adopting them have an annual average penetration of around 1%, and only five countries (China, USA, Japan, Norway and the Netherlands) own 80% of the world's sales of electrified cars (pure electric and plug-in). The global market penetration of electric cars is led by Norway with a market share of around 30%, in 2016. In terms of sales volume, the leader is China, which registered around 380,000 units in the same period. However, other segments of electric mobility (EM) have revealed significant sales volumes globally. In 2016, more than 200 million electric two wheelers were on the road and 345 thousand buses were registered, primarily in China (IEA 2017).

Studies forecast that the electric car will increase its market penetration in the coming decades. The Paris Declaration on Electro-Mobility, and Climate Change and Call to Action (IEA 2017) sets a global deployment target of 100 million electric cars and 400 million electric 2 and 3 wheelers in 2030 (IEA 2017). By 2040, Europe should have nearly 70% of electric cars, the US around 60% and China 50%, together they will have over 60% of the global EV market (Bloomberg 2017).

The prospects for increased penetration of EV are positive and should be supported by the following: a) environmental appeal as governments of several regions are stimulating low-carbon transport aiming at air pollution and GHG emissions mitigation; b) emergence and expansion of new business models based on "vehicles as service", with economic, environmental and operational benefits suggesting the use of electrified models; c) development of self-driving (private and shared) vehicles are likely to increase electric mobility (EM) since EV offer lower costs of use; d) technological evolution, increasing the battery density and reducing costs as past experiences show that whenever there is a technological evolution and a scale increase costs tend to reduce (IPCC, 2014; Hannon et al., 2016; Porter and Van der Linde, 1995; Sperling, 2014).

5.1.2.2 Policies to develop EV market: barriers, challenges and lessons

a) Barriers to EV market expansion

According to the literature, the three main barriers to the expansion of the electric car are: a) achieve sale value (without incentives) compatible with the ICE model (Lin & Greene 2011; Santos 2017); b) increase range to levels close to fossil fuel models (Catenacci et al. 2013; Lieven et al. 2011); c) adequacy of infrastructure and reduction of the charging time to, as close as possible, that of ICE models

(Sierzchula et al. 2014; Thiel et al. 2012). Overcoming these issues requires that new markets will take up EM by providing increased production scale and predictable reduction in manufacturing costs. For now, only 14 countries, two of them being emerging economies (India and China - the other are developed countries of Europe, North America and Asia) have formalized their commitments to the expansion of the electric car, aspiring to bring 13 million EVs on the road by 2020 (IEA 2016).

b) Challenges to EV market expansion

The great challenge for the expansion of electric mobility comes from a mix of factors including techno-economic, socio-economic, innovation-environmental, market variables and adequate policies capable of making mobility more efficient and ecological (Shepherd et al. 2012; Beise & Rennings 2005; Dijk & Yarime 2010; Geels 2012; Porter & Van der Linde 1995; Stern 2006). One aspect stakeholders have prioritized is the combined development of EV technology, charging infrastructure, increased energy efficiency and emissions reduction (Sperling 2014). The governments are required to create appropriate conditions such as subsidies, incentives and guidelines to provide the sustainable expansion of EVs (Stern 2006; Sperling 2014), which is taking place in some countries.

The social challenges in the transition to a carbon-neutral transport system include social and cultural values, as well as political interests, as they may be as important as technological challenges (Sovacool & Hirsh 2009; Steinhilber et al. 2013). Moreover, other critical factors for the expansion of electrified mobility include the need for investments to improve technological resources and increase the renewable energy share, and advance on new business models for the charging infrastructure, as well as deepen socio-economic aspects (Steinhilber et al. 2013). This is particularly important in emerging markets such as Brazil.

c) Lessons for EV market expansion

The expansion of electric mobility has been slow, but important lessons contributing to the market expansion of EVs have been revealed (Hannisdahl et al. 2013). The main one refers to technological innovation aimed to address social barriers to the expansion of this type of mobility, such as improve fast charging infrastructure of EV to avoid range anxiety that has found political support in some regions of the world to advance the technical development and economic viability of EVs, such as Norway, the Netherlands, France, the United Kingdom, China, Japan, Canada, California in the USA, among others (IEA 2016).

As the carbon footprint of the EV is lower than the ICE models, CO_2 emissions especially in urban spaces are reduced (Costa and Seixas, 2014; Foley and Gallachóir, 2015; Hawkins et al., 2012), contributing to the government support for the development of EV. One example is Norway, which opted to provide benefits for EV, albeit being a major oil producer, as it is also a country with a large source of renewable electric power (Hannisdahl et al. 2013; Holtsmark & Skonhoft 2014). Norway has adopted an expansion policy that includes direct purchase subside (Sierzchula et al. 2014), and also incentives to use electric vehicles, seeking the best balance for the Total Cost of Ownership (TCO).

Policies deployed in different countries result in different purchase incentives. There is the trend that the greater the incentive, the greater the penetration of the EV. Norway's case reveals that policies capable of delivering a incentive package on TCO must be aligned with the attractiveness of the EV to the consumer, such as benefits of having free toll access on highways, free parking, exemption or reduction in licensing fees among others; otherwise the financial incentives alone may not deliver the expected results (Hannisdahl et al. 2013). For example, in 2015 from all the countries that offered some type of purchasing incentive for EV, Norway and the Netherlands presented a higher market share when compared to estimates of indicative purchase incentives (IEA 2016).

5.1.2.3. EV policies, relevance and perspectives in Brazil

Electric mobility in Brazil is in its initial phase. The sector lacks market regulation and policies to promote mass expansion of EV. Across the country from 2011 to 2016 around 3,500 LDEV were registered, still the majority to meet specific study projects. In this same period, more than 15,3 million of light-duty vehicles (LDV) have been licensed, including models like ethanol, gasoline and flex fuel (ANFAVEA 2017). Although the EV is a global theme with many benefits when compared to fossil fuel models, it has been discussed in Brazil within a few small movements aiming at expanding this type of mobility in the country. However, almost all are independent of the traditional automotive sector and without adequate public policy (De Mello et al. 2013).

The country uses predominantly clean energy. In 2014, more than 65% of the Brazilian energy and around 75% of electricity was produced by clean resources (EPE 2015). Moreover, Brazil is among the ten largest automotive markets in the world (ANFAVEA 2017), which justifies why the public and private sectors should pay more attention to EM in Brazil.

Regarding to Brazilian policies to encourage the EV, some government initiatives have been announced with the goal of developing EM, most of them providing a discount or exempting the licensing fee and facilitating the use of the vehicle in restricted areas, as in the case of Sao Paulo (PMSP 1997). However, such benefits are not enough to promote the mass-market of EM, which are dependent on subsidies for production and financial incentive for consumers. In addition, the country has a high tax on EV, burdening the cost and making the commercialization of LDEV an option for a few buyers (Marx & De Mello 2014). An example is the BMW i8 that is sold in the US for $143,400 (BMW 2017b) and in Brazil it is commercialized for the equivalent value of US $258,000 (BMW 2017a).

5.1.3 Methods

Challenges and opportunities for the expansion of the EVs in Brazil were assessed through a methodology based on a survey to a wide range of stakeholders in the country, whose responses were organized through a SWOT analysis. We sought to evaluate how different stakeholders approach the electric mobility in Brazil, and what are their views are on critical factors to its massive adoption.

5.1.3.1. Data production

A questionnaire survey was conducted with stakeholders with direct interest in EV in Brazil, as those listed in Table 5.1, selected as the most relevant individuals with a key role in the automobile, transport and energy-related sectors. Previously to the survey, a pilot study with a group of 38 people composed by researchers, professors and people connected to electric mobility was conducted to test the comprehensiveness of the questionnaire and to refine it. The stakeholders were contacted via email, backed with a phone call to increase response rate. The questionnaire was made available through a web link based on the '*encuestafacil*' tool. Data collection took place between May and June 2017. A total number of 144 individuals (23%) responded to the survey.

The survey was composed of three parts: the first part included questions about the respondents' views regarding different aspects of EV, the second referred to aspects relevant to make a SWOT analysis and a final part to collect data on the social characteristics of the respondents.

Table 5.1 – Participation of the sectors surveyed

Sectors	Number of stakeholders' contacted	Number of Respondents	%
Government	127	16	13
Industry	161	51	32
Non-governmental organizations	96	4	4
Specialized media	23	10	44
Retail and service providers	78	44	56
Consultants, experts and enthusiasts	34	19	13
Total	629	144	23

The structure of the questionnaire is outlined in Table 5.2. Data collected was treated with a statistical analysis software (SPSS) for cross analysis and to gather statistical indicators.

Table 5.2 – Topics of the survey questionnaire

Groups of questions	Topics
Views on EV	- Diffusion (market penetration) - Performance of the vehicle - Environment - Convenience of use - Acceptability
Factors for the SWOT analysis	- Internal factors: Strengths and weaknesses - External factors: Opportunities and threats (Socio-Technical, Political-Economic and Innovation-Environmental)
Social characterization	Gender, age, education, work sector, business segment and job (occupation)

5.1.3.2. Methodology focused on the SWOT analysis

The SWOT analysis was originated within business management, and has been disseminated from the 1960s into academic business policy studies at Harvard Business School and other business schools (Markovska et al. 2009; Hill & Westbrook 1997). Currently, SWOT analysis is being used widely, including the transport sector (Gil et al. 2011; Barrella et al. 2013). In SWOT analysis the strengths are tangible and intangible positive attributes that can support organizational success. Weaknesses are negative factors that can hinder the achievement of desired goals. Opportunities are external factors that can be beneficial to project development and threats are externalities that can compromise desired outcomes (Dyson 2004). The SWOT analysis intends to address the development of the EV in Brazil, from the point of view of the automotive industry not considering any particular organizational context.

The analysis was divided into three categories: a) the socio-technical factors to evaluate the critical factors and opportunities for the expansion of a new low emission transport technology (Sovacool & Hirsh 2009; Faber & Frenken 2009); b) the innovation-environmental factors to evaluate the transition to a more efficient and sustainable transport system, including aspects like the transition to a low-carbon energy system with adequate charging infrastructure (Bruckner et al. 1996); c) the political-economic (Sovacool & Hirsh 2009) factors to identify the potential competition of the EVs with ICE models.

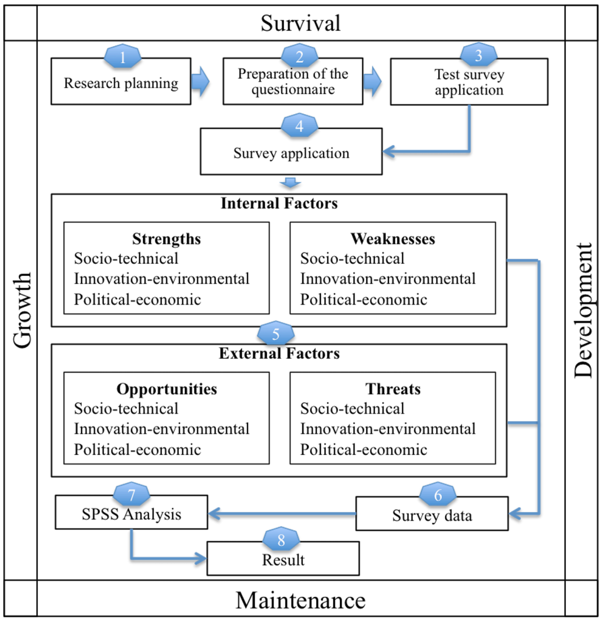

Figure 5.1 – Step-by-step methodology, focused on the SWOT analysis process

In order to perceive how Light Duty Electric Vehicles (LDEV) will develop in Brazil we apply the SWOT analysis following by an eight-step sequential performance, as shown in Figure 5.1. We are interested in understanding whether stakeholders' perceive that LDEV will maintain a low market share, develop gradually or grow vigorously.

Table 5.3 – Topics of the survey questionnaire

Sex *Male* *Female*	Segment of action *Industry* *Service provider* *Education and dissemination* *Electrical energy sector* *Government*
Age *Up to 18* *18 – 30* *31 – 45* *46 – 60* *Over 60*	Profession *Top manager and presidents* *Intermediary manager* *Communication and information*
Education *No higher education* *Bachelor* *Master's and PhD*	Sector of activity *Public* *Private* *Mixed economy* *Third sector*

A cross-analysis between sex, age and education with profession, segment of action and sector of activity was performed (Table 5.3) to deepen the understanding of the answers collected.

5.1.4 Results And Discussion

5.1.4.1. Sample description

Most of the 144 respondents were male (90%), with ages ranging between 46 and 60 years old (43%), possessing a postgraduate degree (61%), working in the private sector (75%), and living in the southeast region (71%), the most populous and industrialized region of Brazil. Details of the sample respondents are provided in Appendix B1.

5.1.4.2. Views from stakeholders on the development of EV in Brazil

This section presents the results of the stakeholders' views on the diffusion of the technology, performance of the vehicle, environment, convenience of use, and acceptability of the electric car.

i) Diffusion of LDEVs

The results revealed that the diffusion of the EV would take place mostly in Southeastern Brazil (71%). More than one third of the respondents expect that by 2030, electric vehicles will have a penetration from 2 to 10%, and say that the country should prioritize investment in EV. The EV would gain the streets in greater volume if there were adequate incentives for acquisition (55%) and adequate regulation by the government (35%). Detailed information on the cross-analysis related to EV diffusion are in Appendix B2.

The cross-analysis of the diffusion revealed the points below (Appendix B3):

a) Hybrid plug-in cars - respondents with higher literacy (master and PhD) are the ones who most (32%) believe the penetration of plug-in vehicles will be from 2 to 10%. People “without higher education” (25%) and “bachelor’s degrees” (25%) believe the penetration will be from 21% to 30%.
b) Pure electric vehicle by age - people between 18 and 45 years old (90%) believe the LDEV penetration will be from 2 to 10%, while people over 60 years old (37%) believe penetration of EV will be from 11 to 20%.
c) Pure electric vehicle by sector - stakeholders from “electric energy sector” (54%) believe it will be from 2 to 10% while those of “industry sector” (26%) believe the penetration will be from 11 to 20%.
d) Respondents identified market “regulation” and “incentives” as the most important features that should be prioritized to promote the penetration of pure electric car in greater volume and less time. Automotive “industry” choices are the upfront group with this perception. It is noteworthy that this sector has prioritized the "acquisition incentive" (61%) and not the "production incentive" (36%), which is not an expected result.

ii) Performance of the electric vehicle

The perception about the performance of the EV revealed that 41% of the respondents perceive the EV is able to achieve speeds of 120 km/h, 30% that the range achieves 300 kilometers, 33% that the acceptable charge time at home if from 5h to 6h, and 73% perceive EVs are capable of being recharged at public charging stations up to one hour. Regarding the recharging of the EV, the cross-analysis revealed that the younger respondents from 18 to 30 years old (71%) consider acceptable charging from 1 to 4 hours, while for people aged 46 or older (65%), it can be from 3 to 6 hours. This trend does not hold for public charging stations options. Appendix B4 presents a comprehensive set of results regarding the perception of stakeholders on the EV performance.

iii) Environment

The majority of respondents identified EV as the best solution for major urban centers, due to the high pollutant emissions reduction, as shown in Appendix B5. Moreover, a clear majority of the respondents state the EV should be exempt from most taxes due to the environmental benefits provided, and in case of a vehicle tax, this should be calculated based on the level of emissions. The polemic issue refers to the use of ethanol as a main fuel for vehicles in Brazil in 2030 with 44% agreeing and 42% disagreeing (Appendix B5). This question becomes relevant when crossing it with the meaningful statement that EV penetration will be from 2 to 10%, the EV market share will be lower than the ethanol-driven vehicle, and gasoline will not be the dominant fuel in the future - only 3% saying that the gasoline cars should be prioritized. Details are provided in Appendix B5.

iv) Convenience of use of EV

Regarding the convenience of using EV, when compared to the conventional car, the survey revealed that 81% of the respondents perceive EV as a more advantageous option. Furthermore, 94% of respondents perceive EV has new advantages to offer compared to the fossil fuels powered models. This suggests that, if the EV price is compatible with the ICE models (with proper conditions of use), the buying preference will be for the EV. Only 18% of the respondents perceive the use of a pure electric car as less beneficial than the conventional car, whereas 37% stated neutral. These answers support the perception that the society and the consumer will be the biggest beneficiaries of EV mass adoption, although there is some controversy about net benefits when compared with a conventional car. Details are provided in Appendix B6.

v) Acceptability of EV

The EV holds the preference of the respondents, regarding the prioritization schemes in Brazil in transport technologies, followed by plug-in models powered by electricity and ethanol. There is a clear perception that future individual transport will likely be low-carbon, backed with electricity and ethanol dominance. The cross-analysis revealed the following aspects. Details are provided in Appendix B7.

a) The pure electric version holds the preference of both men and women, while the plug-in version (ethanol and electric) is the second option, except for the group with jobs related to high levels of "education and information", for whom plug-in (ethanol-electric) should be the first option. It should be mentioned the plug-in (ethanol-electric) version is not currently available in the Brazilian market.

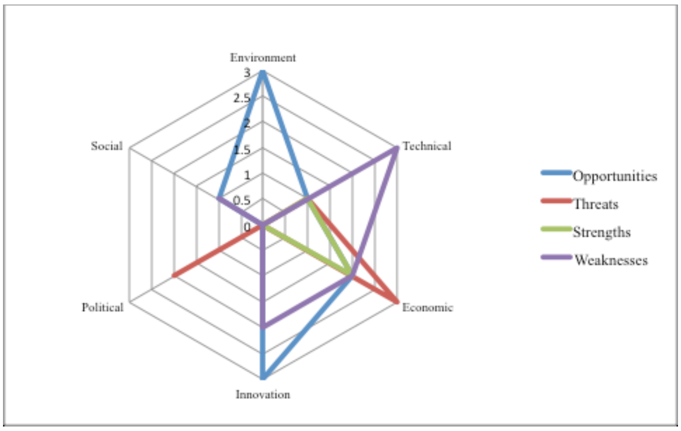

Figure 5.2 – Main results of the SWOT analysis

b) Both men and women believe that the beneficiaries will be society and consumers. However, for 77% of the respondents "without Higher Education", the biggest beneficiary could be the "government".

5.1.4.3. SWOT analysis

The SWOT analysis revealed the expansion of the electric vehicle in Brazil was characterized by the generation of opportunities associated to environment and innovation. On the other hand, some technical, political and economic threats were revealed. The analysis also pointed to weaknesses in the social, technological, economic and innovation aspects. Finally, in a discrete way the strengths highlight the economic and technical aspects, as shown in Figure 5.3 and Appendix B8.

The government is expected to adopt public and regulatory policies for the EV market in Brazil in order to have tax exemption for the electrified models, allowing them to have a tax burden equal or lower than the ICE models. It is also envisioned that there will be incentives for EVs and for the recharging infrastructure. On what concerns the auto industry, public information and promotion of EVs should enable consumers to better evaluate the advantages of buying electrified models. The overall opinion among respondents is that EVs are the best option for low-carbon transport in Brazil and therefore should receive government incentives and private sector support for its development. Furthermore, the analysis revealed that the internal factors were characterized by weaknesses and external factors were dominated by opportunities, as detailed below, as shown in Fig.5.3.

i) Internal factors

a) "Socio-technical factors"

Are characterized by technical aspects. Among the four factors identified as weaknesses, the only one in the social area is the information about EVs. The other weaknesses refer to the range and recharge of EV. The only strengths variable was the efficiency of EV compared to ICE models (Figure 5.3).

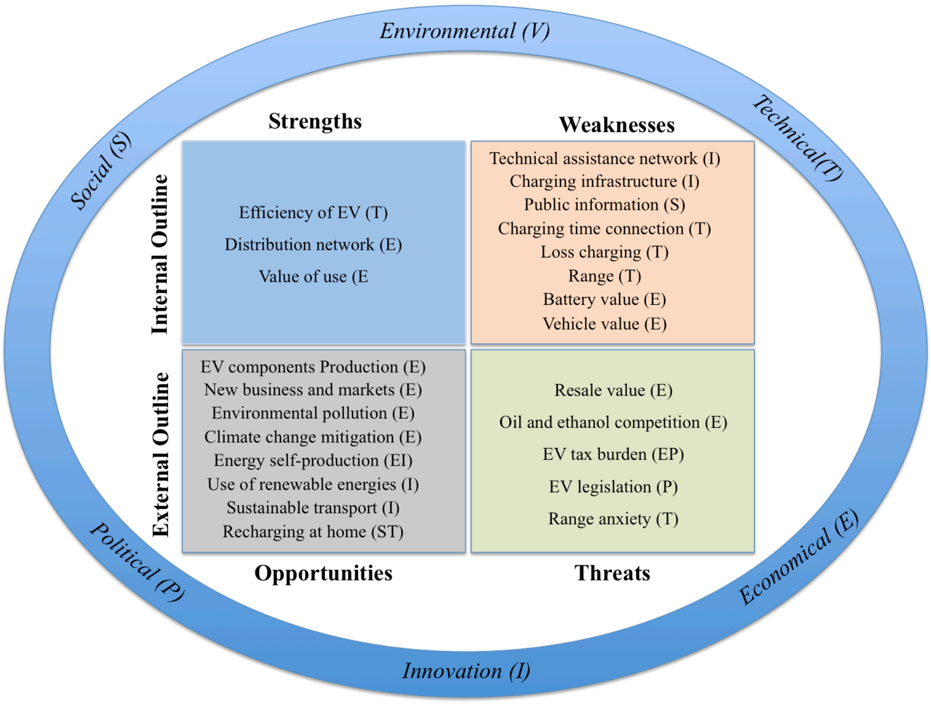

Figure 5.3 – Detailed SWOT analysis result

b) "Political-economic factors"

Revealed two strengths and two weaknesses. The respondents considered that the retail system adopted by most traditional automakers (through distribution networks) is more important than the retail model adopted by Tesla (which has its own distribution system), probably because Tesla does not work in Brazil. The respondents highlighted TCO as an important economic aspect of EVs. On the other hand, they pointed out the price of EV and the battery as weak aspects.

c) "Innovation-environmental factors"

Were considered a variable that only has weak points. Respondents understand that the development of a charging network for EVs is an important weakness. This vulnerability is similar to the situation observed in other countries that are developing an EV mass-market.

ii) External factors

The analysis of external factors revealed that the EV mass-market represents more opportunities than threats (Figure 5.3).

a) "Socio-technical factors"

Include range anxiety (linked to inadequate charging infrastructure, which is considered an important obstacle to the mass expansion of EV), viewed by respondents as an important threat to the creation of a mass-market, and the possibility of charging electric cars at home or at work as an opportunity.

b) "Political-economic factors"

Are characterized by threats. The absence of government action to support the EV market in Brazil is the main reason for these threats. The lack of fiscal regulation was pointed out as the cause of high taxes and the higher value for acquisition of EVs when compared to the ICE models. Respondents understand that the resale value of electric vehicles is a threat. Brands can overcome this issue implementing repo policy for used vehicles, a common practice in the automotive market. On the other hand, the potential for new business opportunities with the expansion of the EV market is seen as a possible break through. Although political-economic factors have been dominated by threats, a change in fiscal policy for EVs may turn weakened economic aspects into opportunities.

c) "Innovation-environmental factors"

Were highlighted as opportunities by almost all respondents. The choices were driven by the possibilities the EV offers to mitigate climate change due to reduced GHG emissions with the opportunity of using renewable energy such as solar energy photovoltaic and wind turbine energy to provide low-carbon transport.

5.1.5 Discussion

The survey revealed some controversial issues that deserve to be explored. The most important refers to the priority Brazil should or should not give to EV, and what features should be the focus of such prioritization.

a) "Should Brazil invest and even prioritize the EV?"

The survey included seven questions to investigate this issue. A clear majority (57%) said the country should opt for the EV, while 14% pointed that the priority should be on ethanol and 29% classified it as controversial. One of the seven questions wanted to know if "in 2030, ethanol will be the main fuel for cars in Brazil”. This was an issue with balanced responses in which almost half of the people agreed and the other almost half disagreed. Another question, "what kind of car should Brazil prioritize?" had 27% choosing EV and 23% choosing hybrid plug-in, 14% pure hybrid.

The only issue in which ethanol has gained wide advantage occurred when asked whether "by 2030, the pure electric car will have inferior penetration only to the flex car?" 57% agreed (35% disagreed and 8% were neutral). Therefore, in general, the survey points out that the country should even choose to invest in EV for the masses and not only in ethanol. This can perhaps be explained by the problems the country has faced in keeping ethanol competitive commercially, without compromising the environmental balance and avoiding competition with food production.

b) "What should be prioritized so that the EV enters the market on a larger scale and in less time?"

For 35% of the respondents it is necessary that the government regulate the EV market. 33% said an acquisition incentive is required and 22% said there should be a production incentive. Despite the little difference between those who opted for regulation or incentive, the choice for regulation is confirmed as 95% of the respondents identified the "high tax burden on electric vehicles" and 82% "no regulation or legislation for EV market" as the main threats to the expansion of EV in Brazil.

These points are part of the barriers and challenges of the EV in several studies (de Souza Ferreira Filho & Horridge 2014; Filoso et al. 2015; Gauder et al. 2011) where the problem of regulation and incentives has been overcome. Therefore, it seems that the discussion makes sense, because in the first place there is search for regulation. Then appear the questions as incentives and operational conditions needed for use of the product.

5.1.5.1 Policy implications

This investigation provided some observations that should require adequate policies to enable the mass introduction of EV in Brazil.

a) Automotive industry: connecting with the future of mobility and manufacturing

The automotive industry in Brazil needs to modernize itself to become competitive. The government program to stimulate automotive sector competitiveness (Inovar-Auto, ended Dec. 2017) was not enough to make the automotive industry technologically competitive, being far behind the leading technological countries (industry 4.0).

Investments in the production of both LDEV and its components (batteries) will be required. The Brazilian government is in a process to approve a new program to boost the automotive industry: Rota 2030. However, the protectionist policy (through high import tax) and the disagreement between players could be an obstacle to the expansion of LDEV in the country. The demand should be for small size LDEV as the largest share of the market is characterized by low cost LDV penetration ("popular cars"). With smaller batteries, the range of LDEV will be smaller as well, requiring a larger number of charging stations and heavier investment to implement them.

b) Energy industry

The decentralized and environmentally sustainable supply trend focused on consumer empowerment, digitization and connectivity, innovation in technology, and processes should not be ignored. Brazil expects a radical transformation in the electricity sector (with less revenues and an increase in investments) due to the possible increase in distributed generation and the large-scale mix inclusion of sustainable sources. The rise defaults, the imbalance between supply and demand, and the difficulty of recovering investments aggravate the problem in Brazil. The introduction of LDEV will require utilities investments that will try to avoid betting on a low-profit market and high-risk investment such as the EV infrastructure.

The Brazilian ethanol incentives policy tends to widen since, in 2017, for the first time the country had a deficit in the ethanol trade balance (445 million liters). Moreover, in 2017, around 12% of gasoline used in the Brazilian transport sector was imported. To reverse this scenario, the country will have to invest in ethanol, and there are risks that financial resources for the LDEV market will not suffice. In addition, oil is an important component of the Brazilian economy, and the petrochemical industry may pose obstacles to the development of LDEV as well.

c) Investments and new business models

The dissemination of EVs in developed markets occurs along side the emergence of new business models and players (automotive industry, utilities, manufacturers and managers of charging infrastructure, online connectivity companies, among others). The representativeness of automakers, utilities, ethanol and oil industry could be a challenge for the dissemination of LDEV in the country.

d) Economic, political and LDEV scenario

The Brazilian unstable economic and political scenario can interfere in the political agenda to spread the LDEV. Apart from that, there are vulnerabilities in the energy production sector as shown by the water crisis that have caused irregular energy supply in several regions of the country. Brazil may choose to expand LDEV fleet slowly in government and private companies in which EV can become economically beneficial and operationally viable. The expansion into the mass-market could occur in a second stage, when EV international market and Brazilian policies would be consolidated.

5.1.6 Conclusion

The aims to identify the strengths, weaknesses, opportunities and threats for the expansion of the LDEV in Brazil considering aspects like socio-technical, political-economic, and innovation-environmental from the SWOT, reveled the opportunities and priorities for the EV to have rapid market penetration were led by innovation-environmental factors. The biggest risks in the expansion of EV are due to political-economic aspects, as the country has clear priorities for the development of ethanol as a fuel, as well as for oil production because of its economic importance for the country. In addition, some technological issues need to be overcome, such as proper charging infrastructure, fast charging time of up to 60 minutes and battery range of around 300 kilometers, thus allowing the EV abilities be compatible with the ICE models. The society and consumers would benefit most from the expansion of EV in Brazil, especially due to the environmental (reducing CO_2 emissions and lower energy consumption) and economic aspects (lower TCO).

The survey clearly pointed to the option of low-carbon passenger vehicles, with the pure electric car being the first option and plug-in (electric-ethanol) the second one. The country has much more to gain from the mass introduction of the EV than to lose, namely in terms of environmental impact (Appendix B4). Besides, the survey revealed the importance of maintaining the use of ethanol in passenger transport. It seems there is the perception that the country could gain more if it is able to operate near break-even point of the energy consumption of ethanol and electricity road fleet. The optimization of energy consumption, minimization of emissions and probably other environmental problems related with ethanol production may be the reasons for such perception.

This research presented a limitation, since some interviewees did not receive the survey link due to the blockade of the spam system. In addition, our access to some target stakeholders was restricted, due to its status of leaders in their sectors. Moreover, the survey conducted did not include a set of stakeholders that would be important to get insights from, mostly related with the market, both consumers and services providers. Therefore, we recommend that future studies will take the car owners, companies with large fleets of vehicles, car rental companies and shared transportation companies, in order to complement the present study with timely information of potential users of EVs in Brazil.

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Appendix B

Table B1 – Social characteristics of survey respondents

		Number of individuals	% of the total respondents
Gender	Female	15	10
	Male	129	90
Age	18-30	14	10
	31-45	41	28
	46-60	62	43
	+60	27	19
Education	Less than university degree	8	6
	University degree	47	33
	Postgraduate degree	89	61
Work Sector	Private	105	73
	Public	26	18
	Mix private/public	8	6
	Third sector	5	3
Business segment	Automobile industry	44	31
	Transport-related services	40	28
	Education, research and information	30	21
	Government	19	13
	Electric energy sector	11	7
Job	Decision-makers and top managers	64	44
	Middle managers	45	31
	Consultants, experts and media	35	25

Table B2 – Results on the diffusion of EVs

Question		Answer
What market share do you believe the electric car will have in Brazil in 2030?	Up to 1% 2-10% 11-20% 21-30%	12% 33% 23% 11%
In 2030, in which region of Brazil the pure electric car will have more penetration?	Southeast South Northeast North Midwest	71% 17% 5% 2% 5%
In 2030, the pure electric car will have inferior penetration only to the flex car (gasoline-ethanol).	Agree Disagree Neutral	57% 35% 8%
What will be the hybrid car plug-in penetration in 2030?	Up to 1% 2-10% 11-20% 21-30%	9% 33% 22% 18%
What will be the pure hybrid car penetration in 2030?	Up to 1% 2-10% 11-20% 21-30%	13% 34% 19% 12%
In 2030, the electrified car (pure EV and plug-in) will have inferior penetration only to the flex fuel car (gasoline-ethanol).	Agree Disagree Neutral	62% 28% 10%
What should be prioritized for the pure electric car increase the market penetration in the shortest time?	Regulation Incentives: Production Acquisition	35% 55% 22% 33%

Table B3 – Cross-analysis of the diffusion LDEV

% of feedbacks	Market-share	Profile
Plug-in electric vehicle		
39	From 2 to 10%	With bachelor's degree
32	From 2 to 10%	With master and PhD degree
25	From 21 to 30%	No bachelor's degree
25	From 21 to 30%	With bachelor's degree
Pure electric vehicle		
90	From 2 to 10%	Between 18 and 45 years old
37	From 11 to 20%	Over 60 years old
55	From 2 to 10%	Electric sector
27	From 11 to 20%	Industry sector
67	Acquisition incentive	By sex
62	Purchase incentive	By sex
40	Production incentive	By sex

Table B4 – Result on the performance of EVs

Question		Answer
What is the speed limit that you consider acceptable for a pure electric car?	120 km 140 km 160 km	41% 24% 23%
What range do you consider acceptable for a pure electric car?	200 km 300 km 400 km 500 km	15% 30% 26% 15%
What is the acceptable charge time the pure electric car at home?	Up to 1h 1-2 h 3-4 h 5-6 h 7-8 h	9% 15% 31% 33% 11%
What is the acceptable charge time for the pure electric car at public charging stations?	Less 1 h 1-2 h	73% 23%

Table B5 – Results on environmental issues related to EVs

Question		Answer
Pure electric car is the best solution to reduce CO_2 emissions from road transport in major urban centers of the country.	Agree Disagree Neutral	90% 6% 4%
The pure electric car is friendly to the environment because it reduces pollution (emissions and noise).	Agree Disagree Neutral	95% 3% 2%
Being environmentally friendly, the pure electric car should be exempt from almost all taxes.	Agree Disagree Neutral	86% 9% 5%
Car taxes should be based on the level of pollutant emissions rather than engine power.	Agree Disagree Neutral	89% 5% 6%
By 2030, ethanol will be the main fuel for cars in Brazil.	Agree Disagree Neutral	44% 42% 14%

Table B6 – Results on the convenience of EV use

Question		Answer
Choosing to use a pure electric car is a cost-effective affair.	Agree Disagree Neutral	81% 11% 8%
The pure electric car offers new advantages compared to the conventional car.	Agree Disagree Neutral	94% 5% 1%
In overall, I believe that the use of a pure electric car provides less benefit than the conventional car.	Agree Disagree Neutral	18% 45% 37%

Table B7 – Results on the acceptability of EVs

Question		Answer
If there were ample supplies of electric cars in Brazil and prices were aligned to internal combustion models, would you buy a pure electric car in the next 5 years?	Yes No Likely	84% 7% 9%
What kind of car should Brazil prioritize?*	Ethanol Gasoline Diesel Pure hybrid (petrol-electric) Pure Hybrid (ethanol-Electric) Hybrid plug-in (gasoline-electric) Hybrid plug-in (ethanol-electric) Pure electric Fuel cell Others	11% 3% 2% 5% 13% 9% 23% 27% 5% 2%
Which would be the biggest beneficiaries with the expansion of the pure electric car in Brazil?*	Government Society Industry The consumer The energy sector The service sector Others	12% 32% 12% 23% 14% 4% 3%

* Maximum of three options

Table B8 – Consolidated SWOT matrix

Strengths	**Weaknesses**
Socio(S)-Technical(T) factors	
Efficiency of EV compared to ICE model (T).	Public information about EV (S); Range of the EV compared to ICE vehicle (T); Charging time connection compared to a ICE supply (T); Loss charging of the EV battery in extreme temperatures (T).
Political(P)-Economic(E) factors	
Distribution network of vehicles (E); Value of use of the electric car (E).	Pure EV battery value in case of spare need (E); Acquisition value of the EV compared to the ICE car (E);
Innovation(I)-Environmental(V) factors	
None	Structuring of specialized technical assistance network in EV (I); Charging infrastructure for EV (I);
Opportunities	**Threats**
Socio(S)-Technical (T) factors	
Possibility of recharging the electric car at home or at work (ST).	Consumer concern about staying on the street with no battery charge - range anxiety (T).
Political(P)-Economic(E) factors	
Industry capacity in the production of components for EV (E); Emergence and exploration of new business and markets (E).	Consumer avoid to buy EV because resale value (E); Brazilian government investments in oil and ethanol (E); Inexistence or inefficient regulation to EV market (P); Highest tax burden on EV (PE).
Innovation(I)-Environmental(V)- factors	
Reduction of environmental pollution (V); Insertion of the country into a new sustainable transport technology (I); Climate change mitigation due to the less carbon footprint of the EV (V); Enhancing the use of renewable energies (I); Possibility of charging the EV by self-production of electricity (VI).	None

CHAPTER 6 | GENERAL DISCUSSION AND CONCLUSIONS

6.1 Answering research questions

The research presented in this thesis was developed around four questions aiming to contribute to the deployment and expansion of electric mobility in Brazil, particularly to deliver mobility for private passenger cars. Major motivations for this research include the need to look for a sustainable option to support an increasing mobility demand in the country without harming the climate system, while taking the advantages from the new electric vehicles technology in terms of new businesses, energy efficiency and greenhouse gas mitigation. A wide range of methods was applied to come out with information and knowledge covering different aspects, to answer the research questions.

This chapter is mostly devoted to answering the research questions stated at the beginning of the research program, and also presents some limitations encountered during the research work and proposes selected ideas for future research.

6.1.1 RQ#1: What is the most appropriate technology for the purpose of climate mitigation and energy consumption reduction in the case of Sao Paulo: electric or ethanol vehicle?

The approach taken was supported by the municipality of Sao Paulo (SP) case study, due to its importance as a mega city that may serve as a leader to mobility shift for others to follow. Although SP is a huge biofuel producer and adopts large-scale ethanol as fuel for passengers' mobility, the CO_2 emissions from transport have been increasing due to increased demand for transport. Sao Paulo city has been living with an increasing level of emissions from the road transportation system.

In the first decade of 2000, the growth of the road vehicle fleet was around 50 percent (bus growth around 35 percent), and CO_2 emissions increased almost 40 percent in SP. To reduce about a quarter of the CO_2 emissions from road transport, some options were assessed (Costa et al. 2014): (1) replace 25 percent of fossil fuel passenger cars by EVs, by the year 2030; or (2) replace 25 percent of gasoline and ethanol passenger cars by PEVs (in the proportion of 30 percent BEVs and 70 percent PHEVs) by the year 2030. Others options may also include (3) doubling of the ethanol consumption, which may be not feasible because large parts of the current fleet in circulation use diesel, (4) improving sustainable public transportation, for which EV can be the feasible option, to limit individual private fossil fuel-based vehicles.

The last two options may allow the reduction of at least 15 percent of energy consumption in road transportation. Additionally, SP has much to gain if the mass-market adoption of new technology PHEV models supplied by ethanol and electricity options (PHEV by ethanol and electricity is not available to the market) should occur. If ethanol and electric flex-fuel technology will become available, a good option to reduce a quarter of the current CO_2 emissions from passenger cars (around 75 percent of SP's fleet) until 2030, should be to replace gasoline cars by PEV in proportion of 30 percent EV and 70 percent PHEV supplied by ethanol and electricity. Moreover, this replacement would lead to a decrease of energy consumption of around 15 percent in the LDV transport sector, with gasoline reducing around five times the consumption in the base year and electricity increasing by six percent.

From the environmental perspective, our study revealed that, for SP, EV is more advantageous to SP than models powered by ethanol, mainly if one takes into consideration the WTW approach for CO_2 emissions estimation. Assessing the interplay between ethanol and EV also considers emission coefficients from life cycle analysis showing that EV will have a higher environment positive impact than ethanol, once on average EV generates around three times less CO_2 emission than ethanol LDV.

Table 6.1 Comparison of LDV average CO_2 emissions between ethanol versus EV

Ethanol	EV
Average hydrous ethanol consumption = 1 L/ 10 km (Inmetro 2019)	Consumption (24 kWh/135 km) = 0.178 kWh/km (USDE 2019)
Emissions per unit of energy = 0.409 kg CO_2/L (Leite 2016)	Emissions per unit of energy = 0.0740 kgCO_2/kWh (MCTIC 2019)
Emissions per unit distance = 0.0409 kg CO_2/km	Emissions per unit distance = 0,01316 kgCO_2/km

Several studies have questioned the environmental advantages of ethanol as fuel for vehicles, mainly due to environmental damages, including deforestation and risks associated with the food chain (broadly explored in our studies). In addition, Brazil does not have the productive capacity to supply the whole fleet of vehicles with ethanol.

In conclusion, considering energy and CO_2 emissions, the most adequate passenger mobility option for SP, taking ethanol cars versus EV cars, is electric mobility. However, it should be highlighted that EV and ethanol vehicles are not mutually exclusive, but complementary technologies that must coexist together in the future. EV is environmentally more favorable to Brazil than other technologies such as the LVD driven by ethanol or fossil fuel, mainly because EV is more efficient and the country's energy matrix is predominantly suitable.

6.1.2 RQ#2: What will be the expected impacts of the likely expansion of electric mobility in Sao Paulo municipality, in terms of CO_2 emissions and energy consumption and how effective are current public policies in place to promote such expansion?

The answer to this question was tackled in two parts (Costa et al. 2017, Costa et al. 2018): a) by assessing if the adoption of the electric passenger car to mitigate air pollution and climate change is a myth or a reality for SP, and b) by analyzing if current public policies have been sufficient to prevent the growth of CO_2 emissions.

Regarding the first part, the research indicated a reduction of about 11 MTCO_2 (representing more than 10 percent compared with the total emissions from the fleet of gasoline-powered cars) by the year 2030, compared with 2015, considering a scenario of EV adoption (around 360 thousand units) to replace LDV by a proportion of 20 percent. In this scenario, we only evaluated the penetration of EV. I did other scenarios by admitting the penetration of other car models such as PHEV and ethanol-based ICEV.

Regarding the additional indirect emissions due to the growth of electricity consumption to attend the considered increase of EV penetration, the research revealed a growth of 13 tCO_2 by the year 2030, which can be considered not significant when compared with a saving of about 11 MTCO_2 emissions of SP scenario by the year 2030.

In that scenario, replacing 20 percent of the ICE gasoline cars by EVs, SP could save around US$6,200 billion in 2030 with energy. Therefore, I may conclude that the adoption of electric mobility has significant advantages for SP in terms of energy, environmental and economic perspectives.

These results are aligned with the majority of current studies confirming that EV emits less CO_2 than fossil fuel vehicles, which is why EV should be prioritized as a GHG emission-mitigating option. Even in places where EV does not reveal environmental benefits, it should be prioritized because EV has no end-of-pipeline emissions and helps to reduce local pollution.

To reduce CO_2 emissions, SP would have to replace carbon intensive vehicles with carbon-free alternatives such as EV, considering that the level of EV emissions will depend on the level of the emissions from power-generation sources, on the way EV is charged, and on the management of the charging process. Improving ICEV's efficiency, replacing old vehicles by low emission vehicles and other green mobility options, and discouraging the adoption of fossil fuel-based vehicles, require strong and coherent public policies.

Regarding current public policies, our analysis revealed they have been not sufficient to prevent the growth of CO_2 emissions. In this context, Brazil could benefit from the accumulated knowledge of the international community, associated with the increase of R&D in the country involving several areas of knowledge, from socio-techno-economic to public policies. Herein, we list two main aspects regarding public policies that could support the transition towards low carbon mobility in Brazil.

Incentives for the diffusion of EV: electric mobility in Brazil is in its incipient phase – few projects focused on isolated initiatives, mostly for education proposals or demonstration projects – with no clear indications of national interests in developing it in the short term. For the diffusion of EV, the country will have to implement adequate public policies, including subsidies and incentives such as those that occur in other countries that support the diffusion of EV.

For example, the lack of government resources to subsidize electric mobility, the country could increase the tax burden on ICEV, on fossil fuels and use the funds raised to subsidize EV. In summary, the governments might encourage the purchase of EV through taxation policy since tax payments or tax advantages have a stronger influence on consumer choice without affecting the public budget.

To reach a more advanced level in electric mobility, Brazil will have to contemplate within public policies the development of internal competences (e.g. investments in research) in order to reach the level of knowledge of other countries where electric mobility is under development. Unfortunately, the Program for the Brazilian automobile industry ROTA 2030 does not appear to be sufficient to achieve this stage of development. Indeed, the gains will be higher for countries that encourage electric mobility and produce vehicles such as China, Japan, UK, and Germany. Brazil has one of the largest auto industries in the world and has a predominantly renewable energy mix, thus bringing together basic conditions to reach a position among the major players in global electric mobility.

Although renewable energy dominates the country's energy mix, Brazil must include in its public policies incentives to expand the share of clean electricity, especially photovoltaic-based due to its synergy with electric mobility – Brazil is among the countries with the highest sun time – and ensure that the expansion of EV could be fueled by renewable energy such as wind power.

The country should encourage research to assess the impacts of EV in the electricity distribution network (such as peak consumption hours), adequately evaluating the necessary investments and the public policies to be adopted to regulate the electric system considering the expansion of EV. After all, utilities are strategic and operational agents in the diffusion of EV in Brazil.

Public incentive policies should also recognize the main stakeholders, considering the reduction of the purchase value of the vehicle, create facilities for the use of EV, and lower total cost of ownership (TCO) in relation to ICEV once these are basic conditions that favor the mass diffusion of EV (e.g. Norway). Moreover, the country should implement incentives (and regulatory powers) to eliminate the proliferation of different plugs and communication protocols for DC fast chargers, for establishing state-of-the-art business models for EVSE network and EV. Besides that, public policies should contemplate incentives so that the users can charge their vehicles and pay at all public charging stations using a universally accepted payment method.

The government could implement subsidies by starting with fleet companies that usually have large fleets in the country (including the government itself) in a way that ensures that the user of the vehicle is benefited; i.e. the employee who has the benefit of the car as part of their benefit package should receive part of the benefit if they opt for EV. Also, the country may adopt taxation schemes providing incentives for consumers to buy EV and restrict the use of vehicles with higher emissions.

Brazil should develop electric mobility in a structured way to ensure maximum socio-techno-economic-environmental benefits for the country; i.e. production of the vehicle and its components locally, in order to generate jobs, avoid increasing imports, reduce energy dependence from oil sources, reduce GHG emissions and mitigate climate change. Public policies should include mechanisms to ensure that manufacturers, utilities and dealers' networks do not hinder the expansion of EV.

6.1.3 RQ#3: How to overcome the barriers regarding the deployment of the charging infrastructure at the municipality level, in the case of Sao Paulo, Rio de Janeiro and Belo Horizonte?

The research on the development to EVSE network installation revealed some common features to the investigated municipalities, like the concentration of EVSE in a small part of the territory, as well as common barriers, such as the non-urbanized areas (e.g. subnormal agglomerate) or risk areas as flooding places. Three municipalities in Brazil were analyzed, resulting in favorable points to develop the EVSE network, as the case of small distance between the boundaries of the municipality, and of sustainable energy mix (Brazilian electricity matrix uses 82 percent of renewables). The main results for each municipality are:

a) **Rio de Janeiro** – Taking the scenario for 2025, with a demand for EVSE that could be around 2,000 charging points to charge 1 percent passenger cars, our research shows that (i) around 12 percent of the districts in the municipality would hold 85 percent of the suitable locations for the installation of EVSE_L1 (domestic equipment level 1); (ii) around 60 percent of suitable locations for the installation EVSE_L2 (slow charging equipment level 2); and (iii) around 20 percent of districts in the municipality hold 51 percent of the suitable locations for the installation of EVSE_L3 (fast charging equipment level 3). The largest distance of the municipality's boundaries is 70 kilometers.

b) **Belo Horizonte** – for 2025, the demand for EVSE could be around 1,200 charging points to charge 1 percent passenger cars in a very small geographic space, being the largest distance of the municipality's boundaries is 40 kilometers, distributed as follows; (i) about 65 percent of the recommended EVSE_L1 installations were located in 10 neighborhoods (less than 5 percent); (ii) all of EVSE_L2 is concentrated in 45 percent of the area; and (iii) around 40 percent of the recommended EVSE_L3 installations were located in around 10 neighborhoods.

c) **Sao Paulo** – for 2025, assuming the need for around 3,300 charging points stations to support a penetration of 1 percent of EV in the urban private cars. EVSE is ideally situated in a small area of the municipality of Sao Paulo: (i) almost 70 percent of EVSE_L1 is concentrated in around 11 percent of the municipality of Sao Paulo; (ii) EVSE_L2 and almost all EVSE_L3 are likely located in 57 percent of the Sao Paulo municipality. The largest distance of the municipality's boundaries is 50 kilometers.

The customization of the charging infrastructure network for EV must follow global standards as well as local characteristics. Developing countries have different characteristics among them and not infrequently socio-techno-economic factors are significantly different from developed countries. The importance of attributes to guide the installation of charging station may be identified for each city or municipality. For example, in Brazil one may consider the attribute of shopping centers (where people spend a lot of time because the space is equipped with large leisure areas and vast parking lots) as an ideal location for EVSE_L2, whereas European countries – where there is not much space available for shopping malls with large parking lots and leisure areas – may consider the shopping center more suitable locations for EVSE_L3 (active shopping centers with little parking lots should offer fast charging options). Therefore, the experience developed by the electric mobility of the international community may need to be customized to be implemented in Brazil.

Moreover, this research revealed that some local characteristics had not been identified by other nations. For example, it was found that socio-economic issues are preponderant for the optimized implementation of the EVSE network. For example, areas with significant rates of violence can compromise the safety of the charging infrastructure, and the vehicles and their occupants during the charging time, which require adjustments to the methods to identify the best locations for the installation of an EVSE network as well as a new business model able to overcome specific characteristics of each region. Therefore, unsafe areas – derived from the inability of the state to provide personal and patrimonial public security – as well as areas subject to environmental risks (e.g. flooding) or geographic factors (e.g. large areas without urbanization issue as subnormal agglomerate) require research and adequate public policies to support the diffusion of EV. This assessment may apply to many megacities in developing countries that may become an important barrier to the diffusion of electric mobility worldwide.

6.1.4 RQ#4: What are the main perceived challenges and opportunities from the mass penetration of electric mobility in Brazil?

The opportunities for EV to have rapid market diffusion depends on the evolution of techno-economical and innovation-environmental issues. From a large survey conducted over a wide set of Brazilian mobility related stakeholders, we can take the following conclusions:

i. The consumers and society will benefit most from the expansion of EV due to low emissions and Total Cost of Ownership (TCO).
ii. Opportunities and priorities for EV to have rapid market penetration were led by innovation-environmental factors; the biggest risks in the expansion of EV are due to political-economic aspects, as the country has clear priorities for the development of ethanol as a fuel.
iii. EV diffusion requires the development of various aspects, such as proper charging infrastructure, fast charging time of by the 60 minutes, battery range of around 300 kilometers, and speeds of 120 kilometers/hour.
iv. The diffusion of EV would take place mostly in Southeastern Brazil (71 percent) and penetration from 2 to 10 percent by 2030.
v. The ethanol sector and oil industry are important barriers to the mass diffusion of EV in Brazil.
vi. Socio-economic issues dominate the benefits of EV, as techno-economic issues dominate EV barriers. Overall, the diffusion of EV in Brazil as offering more opportunities than threats.

6.2 Limitations and future work

The development of the present research was facing some limitations that deserve to be acknowledged. Real-live driving such CO_2 emissions or energy consumption from the fleet, were not available over the three-year period, preventing the use of the data for comparative purposes. The lack of control over the types of vehicles in circulation did not allow the identification of the exact quantity of vehicle by type (EV, PHEV or HEV). It is not possible to adequately quantify energy consumption and GHG emissions by category of electric vehicles.

The difficulty of access to stakeholders, especially government leaders, such as ministers and secretaries, and private initiative, such as CEOs of organizations, limited the participation of top leaders and the size of the sample. The low number of electric mobility experts in Brazil limited the size of the survey sample to identify the best location for the electric vehicle infrastructure.

The firewall system and control of e-mail (spam) of large organizations and the Brazilian government made it difficult or impossible to submit the research questionnaires (about 30 percent of the questionnaires did not reach the recipients) thus limiting the sample size.

To complement this study, future work may be developed, namely: i) an evaluation of impacts and investments in the grid with the diffusion of EV, in order to quantify the investments necessary for the functioning of the network with the expansion of EV; ii) other electric vehicles such as commercial vehicles, microbuses, buses, trucks, and motorcycles as well as diesel fuel should be incorporated in future investigations, because they are high carbon intensive; iii) impacts of the biofuel crops area (deforestation) to meet the growing demand for ethanol, namely the increasing competition of land use for energy, food production, and for biodiversity degradation, would improve the knowledge the sustainability of ethanol as a mobility fuel, with implications on its future use, and iv) evaluate the energy, environmental and economic impacts with the introduction of the EV considering fleet of the companies and private property.

6.3 Final remarks

The present thesis reveals fundamental elements about the expansion of EV in Brazil, explaining for the first time a technology of a lighter environmental footprint than the ethanol vehicle. With large-scale adoption of EV, Brazil will be opening up new possibilities for the sustainability of transport and reducing dependence on oil. The present dissertation contemplating different stakeholders from society, government and diverse areas of economy and business revealed new information and knowledge to advance the diffusion of the EV in Brazil. In addition to the results produced by the thesis, it was possible to collect some valuable information from other studies.

i. Environmental and energy issues should cause EV to continue to expand in developed countries where they may have a dominant presence (e.g. Norway). However, globally the EV probably will not be the dominant share by the year 2040 (IEA 2018) – except in some European countries or China, where electric mobility is progressing consistently. However, in regions such as Europe, and North and East Asia ICEV is expected to gradually lose market share to EV. Governments around the world (especially European) are announcing restrictive measures to fossil fuel vehicles and encouraging environmentally more positive technologies such the EV.
ii. The technological advancement of EV's battery providing higher energy density of the battery, smaller and lighter battery, and lower energy storage cost could be key to the mass expansion of electric mobility. The evolutions mentioned are already occurring and new types of batteries are under development. Therefore, new battery options – more efficient than the lithium-ion – and ion batteries more efficient may not be slow to reach the market, thus facilitating the global diffusion of EV.
iii. The evolution and diffusion of charging equipment is occurring quickly. With the offering of super-fast chargers – capable of delivering 200 kilometers of range in 10 minutes as is the case with the 800-volt charging system launched for the Porsche Taycan – there is not so much need for a long-range battery. Thus, there may be cars with smaller batteries and therefore lighter – thus generating more autonomy – and with more competitive prices thus contributing to the rapid

diffusion of EV.

iv. The trend of mobilization of policy makers, stakeholders and governments for the development and diffusion of heavy electric vehicles should also support the expansion of passenger EV, as there may be synergy of the electric infrastructure. As heavy vehicles pollute much more – e.g. buses and trucks – they are being deployed primarily for those who serve urban centers or smaller sections involving a logistics process. The segment such as off-road heavy-duty vehicles already has a significant EV market share – e.g. airport vehicles, manufactory yards, large organizations, sports such as golf, and soccer, and hotels – and they should further increase the market share since there are benefits for these types of EV.

v. The oil and automotive industries are natural barriers that need to be overcome for the expansion of electric mobility on a global scale. As long as the commercialization of fossil fuel-powered models is more profitable than the EV, the electric mobility won't be mainstream.

vi. Disruptive technologies such CaaS, connectivity, autonomous, and electrification of cars – in line with sustainable development in order to mitigate climate change – could cause profound transformations in the road transportation passenger system. Since around 55 percent of the world’s population lives in urban areas, and the projections reveal that this proportion will increase to around 70 percent by 2050.

vii. An electric motor is more efficient than ICEV. EV has a smaller ecological footprint compared to an ICEV, and much more benefits than ICEV. However, for the mass diffusion, EVs depend on subsidies and incentives from governments.

The thesis revealed that Brazil has much to gain in the economic fields with the generation of new businesses, financial adds with the reduction of fossil fuel burning, and generation of jobs. In the environmental aspects the gain will come with the reduction of GHG emissions from the transport sector, and an effective contribution to the achievement of the Brazilian pledge to the Paris Agreement. Table 6.2 summarizes the key highlights tackled in this thesis, from problem identification, to the advancement of methods to answer the research questions and to the selected insights to policy makers and stakeholders.

The information revealed in this thesis may support Brazil and other developing countries interested in the expansion of structured electric mobility, since the document gathers extensive information on the expansion of EV by other nations. This thesis discloses specific data on the expansion of EV in the Brazilian context, pointing out the critical factors and opportunities for the EV mass-market in developing countries, and discovers attributes not yet reveled by other EV projects. Any country interested in the structured expansion of electric mobility should not ignore or limit itself to exploring the EV international experiences, but rather develop its own research to customize the adoption of a new technology for the sustainability of transportation.

Table 6.2 Dissertation overview: from design problem to advanced knowledge and key insights to policy makers and stakeholders

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Problem Identification	Research Questions	Advancing methods and knowledge	Insights to policy makers and stakeholders
Brazil has a huge ethanol car fleet (in 2017, 2.2 million new light vehicles were licensed), with the participation of flex-fuel technology equivalent to 89 percent of this total. More than half of Brazil's car fleet is flex-fuel technology. Brazil is the world-leading producer of sugarcane ethanol and has a broad ethanol support program, with the government continuously launching policies to encourage the production and consumption of ethanol. EV is expanding around the world, as an option to reduce the transport emissions, if powered by clean electricity. In this context, the problem is to identify what is the best technology to mitigate emissions from passenger cars: ethanol or EV?	RQ#1 - What is the most appropriate technology for the purpose of climate mitigation and energy consumption reduction in the case of Sao Paulo: electric or ethanol vehicle?	To assess the best technology from the climate and energy perspective: ethanol or EV, prospective scenarios were developed supported by the Long-range Energy Alternatives Planning (LEAP) simulation tool, taking a bottom-up and tank-to-wheel approach. Life cycle assessment (LCA) analysis was adopted as well to support the study.	The expansion of appropriate technology (EV) in Brazil should provide opportunities for socio-techno-economic areas, once the diffusion of EV would have higher positive impact on climate change mitigation than the ethanol option. This comes as the second best option for passenger cars in terms of energy and emissions reduction. EV should not be seen as a technology that competes with ethanol, but rather as a complementary alternative option. The production of ethanol as it is structured in Brazil does not prove viable to meet the 100 percent demand of the Brazilian vehicle fleet. Reducing consumption of fossil fuels would bring economic and environmental benefits to the country.
Despite adopting ethanol as fuels, Sao Paulo has experienced rapid growth of emission from the road transportation sector. The public policies adopted by Sao Paulo (and Brazil) have not been sufficient to prevent the advance of transport emissions. Besides, Sao Paulo's vehicle fleet grew almost 60 percent since 2000. In 2011, the transportation sector in Sao Paulo accounted for around 80 percent of the emissions related to the energy sector. Knowing the impacts of the expansion of alternative transportation such EV in terms of energy consumption and CO_2 emissions is a way to help find new ways for the sustainability of Sao Paulo transport.	RQ#2 - What will be the expected impacts of the likely expansion of electric mobility in Sao Paulo municipality, in terms of CO_2 emissions and energy consumption and how effective are current public policies in place to promote such expansion?	This study was carried out on the basis of tabular analysis following top-down guidelines recommended by the IPCC to estimate CO_2 emissions based on fuel consumption from road vehicles. Secondary data analysis was adopted to investigate the public policies in place, as well as the evolution of CO_2 emissions in the period under analysis.	The expansion of EV in Sao Paulo has the potential to provide significant environmental, energy and financial gains. If EV would achieve 20 percent of the LDV market in Sao Paulo by 2030, it would provide a reduction of 11 percent in the CO_2 emissions of passenger cars compared to business as usual growth of LDV fleet, and savings of more than $ 6 billion by saving gasoline. Public policies should focus on the expansion of low carbon transport, giving priority not only to LDEV but also to heavy vehicles (trucks and buses).

Problem Identification	Research Questions	Advancing methods and knowledge	Insights to policy makers and stakeholders
Among the main barriers of the EV is the inadequacy of the charging network infrastructure. The charging network is crucial for electric mobility to deliver its main function. The charging infrastructure for EV is complex because it requires knowledge of local characteristics to be properly implemented. The countries that adopt EV are predominantly economically developed and have different social standards in relation to the developing countries. Identifying the key characteristics for the installation of an EV charging network is fundamental for the structured expansion of electric mobility. The three case studies are Brazilian municipalities' leaders (in GDP, vehicle fleet and population) and represent more than 90 percent of the economy of the Brazilian Southeast, which itself is responsible for more than 50 percent of the Brazilian GDP.	RQ#3 - How to overcome the barriers regarding the deployment of the charging infrastructure at the municipality level, in the case of Sao Paulo, Rio de Janeiro and Belo Horizonte?	Multi-criteria Decision Making (MCDM) methodology, the Weighted Linear Combination (WLC) and the Analytical Hierarchy Process and the Geographic Information System (GIS) to process the information were the methods used to assess the suitability of the locations of the charging network.	Together, the three Brazilian municipalities (SP, RJ, BH) would need around 6,500 charging stations, generating new business, expanding employment opportunities, and reducing emissions. With the adoption of EV Brazil would gain experience by being one of the first developing countries to explore the sector of the mobility and could sell know-how e.g. business models for installation of the charging network. In addition, being among the largest players in the automotive industry, the country could take the lead in electric mobility among developing countries, generating economic foreign exchange through the sale of goods and services and international prestige. The EVSE network implementation should require new strategies and new business models, as there are significant limitations due to the existence of non-urbanized areas such as subnormal agglomerate and hazardous such as those subject to flooding.
The diffusion of EV has been restricted to a few developed countries. Little is known about this technology in developing nations. The EV mass-market attempt is recent, requiring research in various areas of knowledge in order to improve the product, support the charging infrastructure and understand how society and governments will interact with the diffusion of EV. Stakeholders' behavior is the backbone of electric mobility claims. Among the largest worldwide economies and with outstanding participation in the global automotive industry, Brazil is naturally an attractive player for EV development. Therefore, knowing the opportunities and challenges of EV expansion in Brazil is of utmost interest to stakeholders.	RQ#4 - What are the main challenges and opportunities associated with the mass penetration of electric mobility in Brazil?	SWOT analysis methodology in conjunction with cross-analysis techniques was used. The statistical SPSS tool and the survey software of Encuestafacil supported the study.	Despite the barriers, the EV should have increased penetration in the coming years in Brazil, especially in the large cities, being more representative in the southeast of the country. With the diffusion of EV, driven by technological innovation and benefiting mainly Brazilian society consumers, new opportunities for investments and gains, especially in battery field and EVSE industry, for stakeholders will emerge. The government needs to be alert to intervene with adequate and timely public policies in the development of EV in Brazil.

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