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Feasibility study of the insertion of electric vehicles in the Brazilian fleet: economic and environmental impacts from a Brazil 2050 perspective

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Orientador: Prof. Dr. José Antônio Perrella Balestieri

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SOFIA GLYNIADAKIS

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“As above, so below. As within, so without.”

Hermes Trismegistus

ABSTRACT

The world energy matrix is in a clear process of transition from a notable fossil base to a new condition in which the presence of renewable energy sources is markedly dominant. The implementation of electric vehicles in the passenger mode generates a wide level of discussion when considering the source used to generate electricity. Brazil's propensity for structuring a sustainable electric matrix, combined with a significantly large automotive fleet, indicates a good scenario for the insertion of electric vehicles, but the issue of using ethanol increases the complexity of the issue. There is then a scenario in which the Brazilian automotive fleet presents a growing trend, in contrast to the objective of decarbonization. It is, therefore, necessary to modify the technology used, in a scenario in which, with a greater absolute number of vehicles, fewer greenhouse gases are emitted than in the linear scenario without considering electric vehicles. The motivation for this process is compliance with environmental protocols to reduce the greenhouse effect. In this research, an analysis of the long-term planning of the Brazilian energy matrix is developed, with the possible inclusion of electric vehicles in the road modal, considering the need to maintain an expansion of the system on a renewable basis. However, some important research questions concern the renewability of electricity generation and its impacts on the countries' electricity matrix, a fact that becomes more relevant in the Brazilian case due to the availability of ethanol in a successful program of more than four decades and that cannot be disregarded. The present work presents perspectives regarding the insertion of electric vehicles and the use of ethanol as an energy source in internal combustion vehicles. To determine the best condition in a Brazil 2050 perspective, an optimization model was developed, whose objective function is to minimize emissions in the transport sector, from 2019 to 2050, considering as variables determined by the model the distribution of vehicles in their types, and subject to technical variables. From the analysis of the results obtained by the model, it was possible to conclude that Brazil has a good perspective for the insertion of electric vehicles, reaching the threshold of 10%, showing resilience even in pessimistic conditions of the evolution of the electric matrix. However, the use of ethanol proved to be an essential option for achieving the decarbonization target, and for the scenario without considering the modification of the growth line, Brazil presents an increase of 34.67% in CO2 emissions for the year 2050, while adopting sustainable policies for the insertion of electric vehicles allied to the use of ethanol, 59% of decarbonization was achieved, with the stipulated target of 58%. When considering the modification of consumer behavior, increasing the average distance traveled per year, the decarbonization for the year 2050 was 22.44%, highlighting the importance of the user’s mode of the vehicle by the consumer, in addition to the technology used.

KEYWORDS: Electric mobility. Brazilian automotive fleet. Automotive energy planning. Renewable resources. Road transport in Brazil.

RESUMO

A matriz energética mundial encontra-se em franco processo de transição de uma base eminentemente fóssil para uma nova condição em que a presença de fontes renováveis de energia seja marcadamente dominante. A implementação de veículos elétricos no modal de passageiros gera um amplo nível de discussão quando se considera a fonte utilizada para gerar a energia elétrica. A propensão do Brasil à estruturação de uma matriz elétrica sustentável, aliada a uma frota automotiva significativamente grande, indica um bom cenário para a inserção de veículos elétricos, mas a questão do uso do etanol aumenta a complexidade da questão. Tem-se, então, um cenário no qual a frota automotiva brasileira apresenta uma tendência crescente, em contrapartida ao objetivo de descarbonização. Desse modo, faz-se necessária uma modificação na tecnologia empregada, em um cenário no qual, com um número absoluto maior de veículos, sejam emitidos menos gases do efeito estufa do que o cenário linear sem considerar veículos elétricos. A motivação para esse processo é o atendimento aos protocolos ambientais com vistas à redução do efeito estufa. Nesta pesquisa é desenvolvida uma análise do planejamento de longo prazo da matriz energética brasileira com a possível inclusão de veículos elétricos no modal rodoviário, considerando-se a necessidade de se manter uma expansão do sistema em bases renováveis. Entretanto, algumas questões de pesquisa importantes dizem respeito à renovabilidade da geração elétrica e seus impactos na matriz elétrica dos países, fato que se torna mais relevante no caso brasileiro devido à disponibilidade de etanol em um bem-sucedido programa de mais de quatro décadas e que não pode ser desconsiderado. O presente trabalho apresenta perspectivas em relação à inserção de veículos elétricos e o uso de etanol como fonte de energia em veículos de combustão interna. Para determinar a melhor condição em uma perspectiva Brasil 2050 foi desenvolvido um modelo de otimização, cuja função objetivo visa a minimização das emissões no setor de transporte, de 2019 a 2050, considerando como variáveis determinadas pelo modelo a distribuição dos veículos em seus tipos, e sujeitas a variáveis técnicas. A partir da análise dos resultados obtidos pelo modelo, foi possível concluir que o Brasil possui uma boa perspectiva para a inserção de veículos elétricos, atingindo o patamar limite de 10%, apresentando resiliência mesmo em condições pessimistas de evolução da matriz elétrica. Entretanto, o uso do etanol revelou-se uma opção imprescindível para que fosse possível atingir a meta de descarbonização, sendo que para o cenário sem considerar a modificação da linha de crescimento o Brasil apresenta um aumento de 34,67% das emissões de CO_2 para o ano de 2050, enquanto que, ao adotar políticas sustentáveis de inserção de veículos elétricos aliada ao uso do etanol, atingiu-se 59% de descarbonização, sendo a meta estipulada de 58%. Quando considerada a modificação do comportamento do consumidor, aumentando a distância média percorrida ao ano, a descarbonização para o ano de 2050 foi de 22,44%, alertando para a importância com relação à forma de uso do veículo por parte do consumidor, bem como da tecnologia empregada.

PALAVRAS-CHAVE: Mobilidade elétrica. Frota automotiva brasileira. Planejamento energético automotivo. Fontes renováveis. Transporte rodoviário no Brasil.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANP	National Agency of Petroleum, Natural Gas and Biofuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, in Portuguese)
ARMA	Autoregressive Moving Average
BEN	National Energy Balance (Balanço Energético Nacional, in Portuguese)
CIMA	Interministerial Council for Sugar and Alcohol (Conselho Interministerial do Açúcar e do Álcool, in Portuguese)
EV	Electric Vehicles
EPE	Energy research company (Empresa de Pesquisa Energética, in Portuguese)
FENABRAVE	National Federation of Motor Vehicle Distribution (Federação Nacional da Distribuição de Veículos Automotores, in Portuguese)
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel of Climate Change
ICEV	Internal Combustion Engine Vehicle
ICDP	International Car Distribution Program
IPI	Tax on Industrialized Products (Imposto sobre os Produtos Industrializados, in Portuguese)
LCA	Life Cycle Assessment
PBE	Brazilian Labeling Program (Programa Brasileiro de Etiquetagem, in Portuguese)
PE 2040	Petrobras Strategic Plan (Plano Estratégico Petrobras, in Portuguese)
SUV	Sport Utility Vehicle
C2050	2050 Calculator (Calculadora 2050, C2050, in Portuguese)

SUMMARY

1 INTRODUCTION

Brazil presents a dependence in its transportation of the road sector, which represents a significant portion of greenhouse gas emissions. This introduction aims to raise the relevant facts of the issue, guiding the reader to the present work.

1.1 CONTEXTUALIZATION AND RESEARCH QUESTIONS

According to Zioni; Freitas (2015), an essential condition for economic development is the issue of transportation, which encompasses both the implementation of technology and the environmental aspect. However, the continued consumption of vehicles has led to serious climate problems. For the Intergovernmental Panel on Climate Change (IPCC), 75% of CO_2 emissions in the last 20 years come from burning fossil fuels. The idea of using the electric vehicle aims to promote the replacement of oil by renewable and non-polluting sources of energy, which would offer a higher quality of life to cities. The whole world has been making efforts in this direction (De; Do, 2013).

Electric car technology is gaining prominence around the world since 2005 when automakers began to heavily invest in the diffusion of this technology (Dijk; Orsato, 2013). The main barriers since then are the source of this electric power that powers the car, and the consequent carbon emission policies. In a country like Brazil, where the electric energy mix is essentially renewable, the insertion of large-scale electric mobility is largely amenable to analysis.

Pereira; Lessa (2011) highlight the importance of road transport development policies in Brazil, especially due to the nation's continental dimensions and the high logistic dependence that several strategic industrial areas have on the road modal. In the referred approach, there is the development of road and industrial infrastructure to meet the demand for vehicles, the need for the energy source to make this intrinsic system operate sustainably. Issues about the price of fossil fuels are complex and can lead to crises in the country, as in 2018[1].

The growth of the Brazilian automotive market in the 2000s is highlighted by the Ministério da Economia (2020) as a reflection of the recovery of the economy after the international financial crisis of the 1990s. The reduction in unemployment and the consequent increase in worker income associated with economic maneuvers such as the extension of the

[1] In the year 2018, the constant increase in diesel prices has generated a general strike of truck drivers, and dependence on the entire industrial sector in the road distribution of products, entailing in crises in the industry, including food supply.

financing terms for acquiring new vehicles and the reduction of taxes, in general, were striking in this resumption in sales. However, this resumption was associated with an increase in sales of imported vehicles. In 2011, the Brazilian Federal Government and representatives of the sector were concerned with global effects to come and established the need to create a plan that valued the national industry to suppress the effects of international exchange.

Welch et al. (2019) evaluated the Big Data study methodologies in the transport sector, highlighting the importance of the creation of strategic plans and detailed assessment of the sector, the combination being most frequently pointed out by regression estimation.

The high level of emissions of the Brazilian automotive fleet counteracts the decarbonization targets established for the year 2050. According to the IPCC (2018), the concern with the climate has increased, and the changes are being led by the three largest emitters in the world (China, United States, and European Union). In addition to analyzing the impacts, the report suggests strategies to limit emissions, among which we highlight the change in energy sources, which are renewable and zero-emission.

Considering the previous statements, it was created a detailed database of the Brazilian automotive fleet and use regression, self-correlation, and forecasting assessment methods to assess the influence of Brazilian automotive sector policies. Given the macroeconomic points of Brazil, which can be modified by the optimization model, and the possible factors of technological disruption, there is the proposition of a hybrid method of planning the Brazilian highway modal.

1.2 OBJECTIVE

This research has as objective to develop a model for evaluating the economic viability of the large-scale insertion of electric vehicles in the Brazilian market by 2050, taking into account the perspectives of technological improvement of such technology and considering it as a function of decarbonization goals. Based on this, it will be determined the economic and environmental consequences of the change in the Brazilian energy mix and the logistical systems of energy supply, both at a national and regional level.

1.3 DISSERTATION ORGANIZATION

This dissertation is organized into four chapters, the first being an introduction to the ideas that motivated its realization. The second chapter concerns the theoretical basis, addressing both the technical factors related to electric vehicles, a review of fossil fuels and electricity generation in Brazil, as well as mathematical aspects. Chapter three presents the material and method used, the fourth projection results, considering the sensitivity factors, and the fifth the conclusions obtained from the analysis of the insertion of electric vehicles in Brazil.

2 LITERATURE REVIEW AND THEORETICAL BASEMENT

This chapter presents the main theoretical factors that support this dissertation, being segmented in related areas in the scope of energy planning in the automotive sector. As part of a better understanding of the theoretical basis used, a brief explanation of the correlation between the factors included in the optimization model is necessary.

It was analyzed the insertion of electric vehicles in the Brazilian automotive modal, through an economic purchase criterion and with an objective function of minimizing emissions. It was necessary, then, to research data in two directions: the energy mix and the discretization of the automotive fleet.

In the energy branch, in addition to economic data and emissions from electricity generation, the fossil fuels side is presented, to compare and create decision-making criteria. On the side of the automotive fleet, there were two approaches: in segmentation of categories and manufacturers – both of them allowed, in addition to refining the emission parameters, the possibility of creating an economic criterion.

Besides the issues raised regarding the insertion of electric vehicles in other countries, Brazil presents the peculiarity of the widespread use of ethanol. It was then necessary to review government programs in the Brazilian automotive sector to understand this dynamic and consider it in the algorithm, that aims the insertion analysis, the objective of this work.

2.1 BRAZILIAN ENERGY MIX

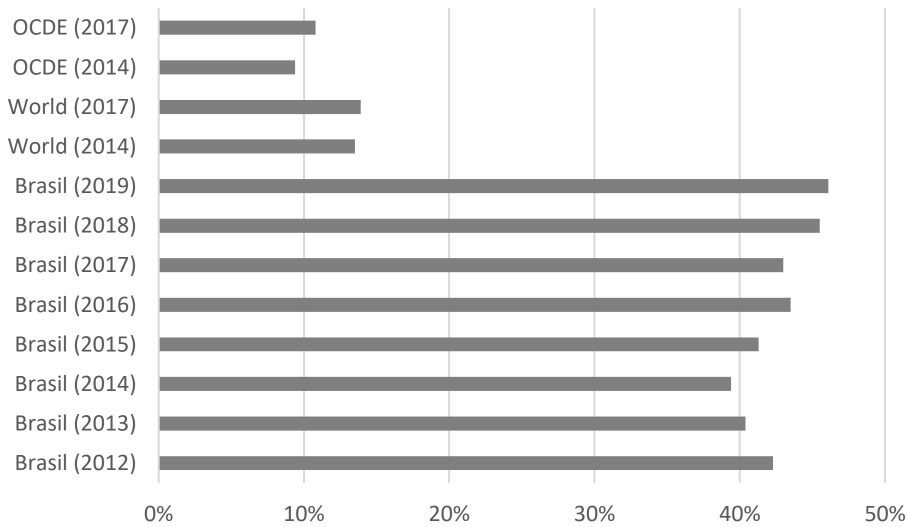
To analyze the feasibility of the insertion of electric vehicles in the Brazilian energy mix, it is necessary to know the electric mix of the country in detail since it is the energy source for the circulation of this kind of technology (CARDOSO CHRISPIM *et al*. 2019). Woo, Choi, Ahn (2017) considered the energy generation mix of each country and analyzed the environmental effects of the expansion of Electric Vehicles (E-V) use in 70 countries. These authors concluded that Battery Electric Vehicle (BEV) had lower greenhouse gases (GHG) emissions than Internal Combustion Engine (ICE) vehicles in most countries and regions, which confirms the necessity of the discrimination of the energy mix.

Garcia et al. (2017) consider that it is necessary to discuss the origin of the electricity used, which is not necessarily renewable and free of pollutant emissions. As an example, Buchal et al. (2019) studied that E-V in Germany emits more carbon dioxide than diesel vehicles compared the CO_2 emissions of a Tesla Model 3 (electric) and a Mercedes C220d (diesel), and when considering the production chain as a whole (battery manufacture and source of electricity), and a diesel vehicle emitted less CO_2 (141 grams per kilometer, compared to a range between 156 and 181 grams of the electric vehicle). On the other hand, France, for having a nuclear base to produce electric energy, does not present the same contradiction in the use of electric vehicles.

According to Piecyk; McKinnon (2010), the carbon footprint, a measure of the equivalent carbon emission in the atmosphere, when applied to the road transport sector has factors that influence the environmental impact that can be divided into base groups: structural, commercial, operational, functional and external. This last group can then be explained as government regulations and tax policy, wider macro-economic trends, market dynamics, and advances in technology. For emission forecasts, it is necessary to consider at least three scenarios: business-as-usual, optimistic and pessimistic, with a focus on external trends.

The Brazilian Energy Research Agency (Empresa de Pesquisa Energética, EPE, in Portuguese), responsible for the data collection of Energy in Brazil, prepares and publishes the National Energy Report (Balanço Energético Nacional, BEN, in Portuguese) annually, accounting for the energy supply and consumption in Brazil Empresa de Pesquisa Energética (2020). It is essential, then, to understand the current state of the energy production sector, to account for the emission that will come from electric vehicles. Figure 1 compares the participation of renewable sources in the generation of electricity between Brazil and the world.

Figure 1 – Participation of renewables in the Brazilian Energy Mix



Source: Adapted from Empresa de Pesquisa Energética (2020).

It can be inferred from the analysis of Figure 1 the growth in the share of renewable energies in the Brazilian mix, which includes sugarcane biomass (18.00%), hydraulic (72.40%), firewood, and charcoal (8.7%) and bleach and other renewables (7.00%) in 2020. Comparing to the 2014 data, Brazil surpasses the world by more than 3 times the share of renewable sources. The favorable focus on the use of renewables remained, and although global data for 2018 and 2019 were not available in BEN, Brazil showed an increasing trend in the use of renewable energy sources. In 2017 the first positive indicator to be considered regarding the implementation of electric vehicles, as argued by White et al. (2013) on the importance of using renewable sources and consequent government policies for the sustainability of industries.

2.1.1 Renewable sources sharing

In 2017, the last year of a global comparison, the Empresa de Pesquisa Energética (2017) considered that 32.40% of energy use was destined to the transport sector, essentially comprising ethanol, diesel oil, and gasoline. Of these, only the first, which represents 5.60% of the total amount, is a renewable source and considered clean; thus, only 20.00% of energy consumption in transport is renewable, according to its mix.

In 2019, according to Empresa de Pesquisa Energética (2020), the share of energy use for transportation reached 32.70%, maintaining the growing trend. In 2018, the share of renewables reached 24.00% and in 2019, in a constant increase, it reached 25.00%, highlighting the increase in the share of ethanol (anhydrous + hydrated) in the light vehicle market.

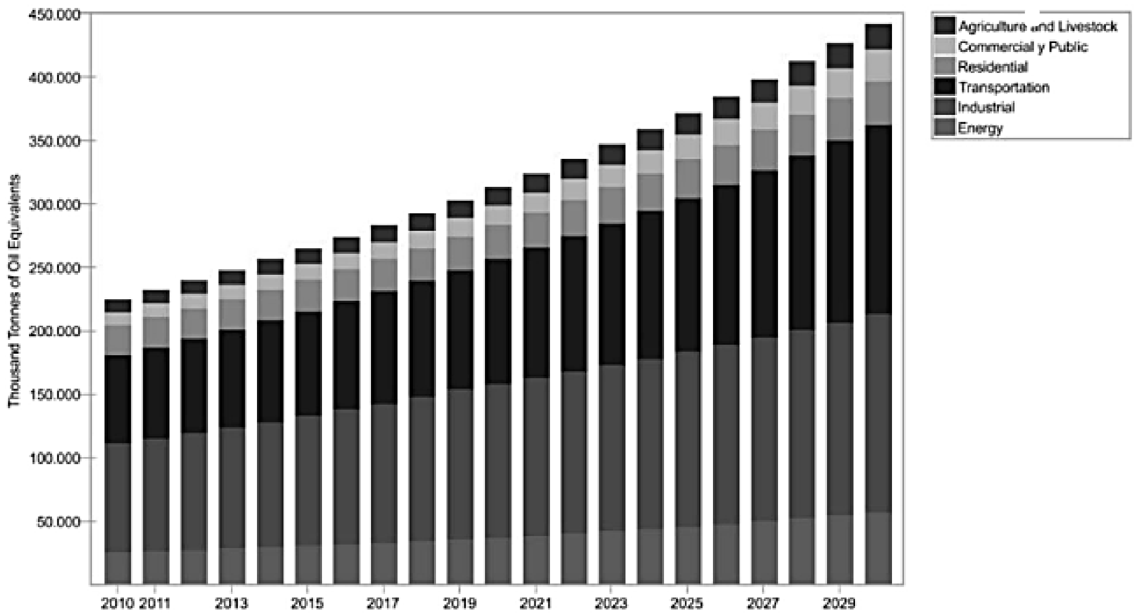
According to the Empresa de Pesquisa Energética (2020), Brazilian electricity in 2017 had a total of 81.70% participation of renewable sources, mainly due to the drop in the share of thermoelectric plants and the increase in the use of wind and hydraulic generation. On the other hand, on a similar date, the world uses only 22.00% and OCDE 26.00% of renewable sources in the generation of electricity. The share of renewables in Brazil in 2018 and 2019 was 83.30% and 83.00%, respectively. No global comparative data were presented in these years, but EPE pointed out that although electricity consumption increased by 2.30%, it was possible to decrease electricity imports by 28.60% while maintaining a high share of renewables in the electrical mix due to strategies for increasing wind and photovoltaic generation, increased hydro generation and via natural gas associated with the decline in the use of petroleum products as a source, thus consolidating the Brazilian electric mix essentially renewable.

2.1.2 Energy consumption in transports

According to Cardoso Chrispim et al. (2019), with a low carbon policy in mind, transport is considered a key sector in a global context; In 2014, 14% of global CO_2 emissions came from this segment, and the IPCC has already positioned itself favorably on both hybrid and battery electric vehicle insertion policies combined with renewable energy generation strategies.

Pereira; Lessa (2011) highlights the importance of policies for the development of road transportation in Brazil, especially due to the nation's continental dimensions and the high logistical dependence that several strategic industrial areas have on the road modal. In this approach, in addition to the development of road and industrial infrastructure, it is also necessary to evaluate the energy sources for the supply of vehicles' demand to make this intrinsic system operate sustainably. Issues such as the price of fossil fuels are already complex and can lead to crises in the country, as well as in the year 2018. De Andrade Guerra et al. (2015) consider the consumption and energy supply scenarios for the main sectors of Brazil in a 2030 perspective, represented in Figure 2.

Figure 2 – Evolution of Transports Demand



Source: De Andrade Guerra et al. (2015).

Figure 2 illustrates the increase in energy demand in the transport sector, and the reduction in emissions associated with such an increase is still a barrier to be overcome, since the only planning policy studied is the use of sugarcane ethanol, highlighting the intrinsic system of the RenovaBio program to operate sustainably.

2.1.3 Energy mix projection for the year 2050

A synthesis of the perspectives of the Ministry of Mines and Energy (Ministério de Minas e Energia, MME, in Portuguese) for the year 2050 is presented, to conceptualize the emission indicators regarding Electricity used in the model.

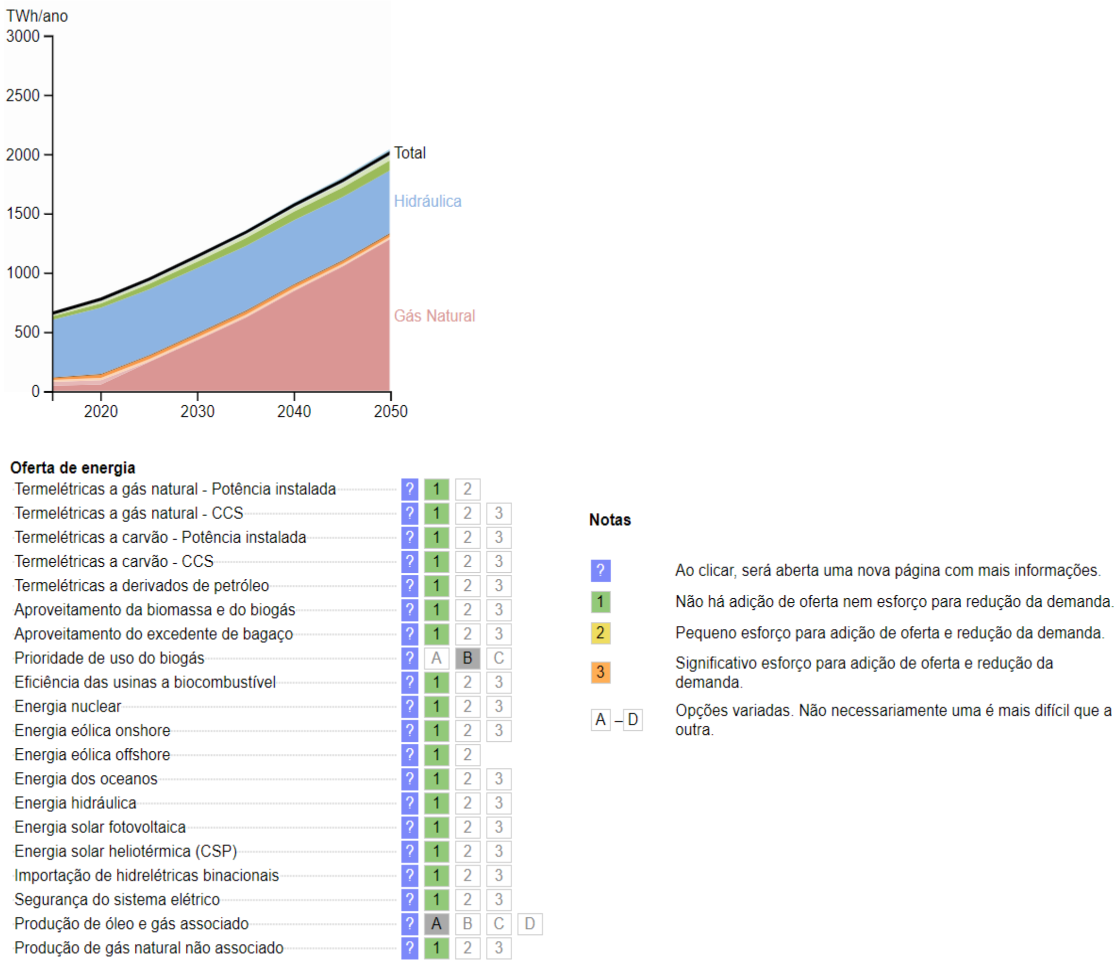
Lap et al. (2020) presented a forecast of electricity generation for the year 2050 through the shooting of eight scenarios. An endogenous factor considered was an additional demand for electric vehicles. It was found that the incorporation of electric vehicles has influences in addition to economic, but related to factors such as charging facilities, which were not considered in the simulation.[2]

Given the focus on electric energy emissions to obtain a parameter to be considered by the developed program, the internal electric energy supply was discussed, as shown in Figure 3, which generates the emission factor presented in Figure 4 as a consequence. The respective figures are presented in Portuguese as they are on a Brazilian basis, the terms used in the text are translated into English to adjust the understanding and described in Appendix F (composition of the internal energy supply) for explaining the factors and values considered in each level.

From the composition of the internal energy supply, it is observed that for the composition of the Brazilian electric mix, each factor has at least two levels, where 1 represents the minimum interference of energy policies. There are intermediate levels that can be considered to one decimal place, thus generating a considerably large number of possible scenarios.

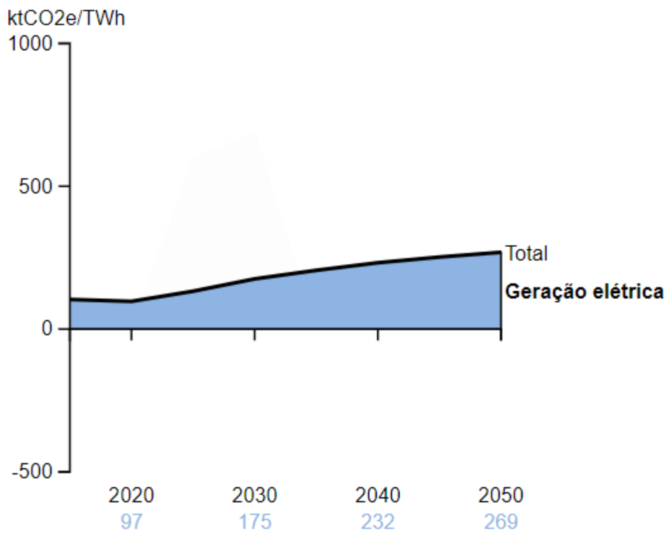
[2] As the present work aims to analyze the impacts of electric vehicles themselves and expose the complexity of a simulation of electric power generation forecast, it was decided to adopt the relative factors of electric emission as those predicted by the MME, in the public domain through the 2050 Calculator (Calculadora 2050, C2050, in Portuguese). In the chapter on materials and methods, the specifications of the emissions bases used are presented, but an understanding of the general electrical panorama is presented in this section, to understand the composition of the Brazilian electrical mix.

Figure 3 – Internal Energy Supply



Source: Empresa de Pesquisa Energética (2020).

Figure 4 – Electricity Emission Intensity



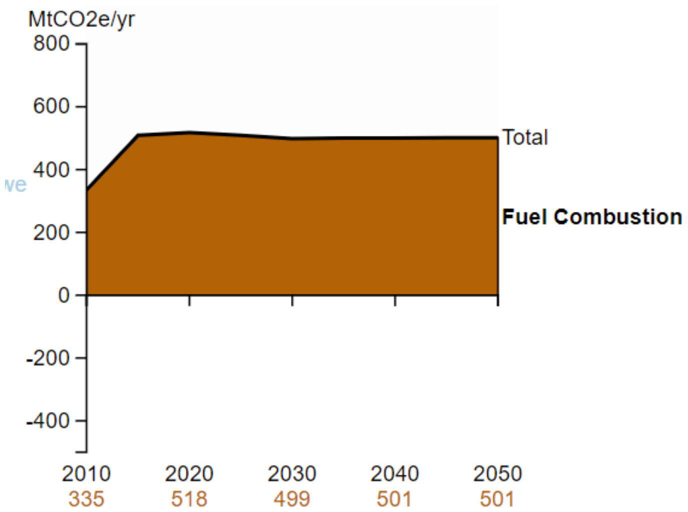
Source: Empresa de Pesquisa Energética (2020).

In Chapter 3 (material and method), the emission levels considered for this work are broken down; however, the review aims to make the reader aware of the possible electric energy scenarios in Brazil, making it clear at this point that, in addition to the scenario of the insertion of electric vehicles, this is related to national energy segmentation policies, summarized by C2050.

2.1.4 Major economies energy mix

In this subsection, a comparative synthesis of the energy mix is presented, highlighting countries in Europe and Japan for being the main powers in the technological development of the automotive industry. The scope of such a comparison permeates the issue of emissions related to electric vehicles, these coming from the energy mix of the country studied. The countries listed are exponents in the issue of insertion of electric vehicles, and in Figures 5, 6, and 7 the emissions of electrical generation are presented respectively by the 2050 calculator from Japan, the United Kingdom, and Europe.

Figure 5 – Electricity Emission Intensity in Japan



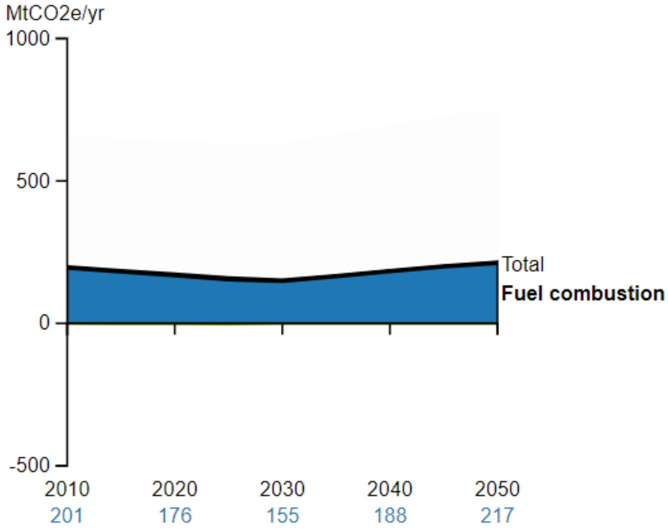
Source: Japan Low Carbon Navigator (2021).

According to Japan Low Carb Navigator (2021), Figure 5 sets out the baseline scenario by 2050 to help policymakers, energy producers and the public understand energy choices and their emissions. For 2050, an electricity demand of 1070 TWh/year is considered for Japan. Electricity emissions reach a constant but not sustainable level due to the electric mix being composed of 87% of carbon-based sources. Comparing the emission levels on the same basis, for Brazil, in 2050, an emission level is projected to reach 473 Mt_{CO2}/year, with a final consumption of electricity of 1760 TWh/year, and the emission intensity of 269 kt_{CO2}/year. For

Japan, there is an emission level of 501 Mt_{CO2}/year, final consumption of electricity of 1070 TWh/year and emission intensity of 468 kt_{CO2}/TWh. Comparing the forecasts for the base scenarios of the two countries, the emission level has a variation of 5.58%; however, the intensity of emissions is equivalent to 57.4% lower for Brazil relatively to Japan, which confirms Brazil as the owner of a low-emission electrical perspective. This fact encourages the study of the insertion of electric vehicles, while Japan, even with a greater intensity of emissions, has such technology inserted in the policies to reduce emissions.

United Kingdom department of energy & climate change (2021) has the electricity supply base policy of decommissioning several modes, such as nuclear, solar, and waves, being in 2050 composed of conventional forms of energy, that is, burning fossil fuels. In Figure 6 there is an articulation in the decreasing curve, becoming increasing in 2030, the date foreseen for the disarticulation of several renewable sources. In 2050, United Kingdom presents a final consumption of electricity of 2490 TWh/year, even though it is a significantly smaller country. The intensity of emissions of 87 kt_{CO2}/TWh for the year 2050 represents a percentage of 32% concerning the intensity predicted for Brazil in the year 2050. With this, Brazil falls into an intermediate level of emissions between Japan and the United Kingdom, and both have electric vehicle insertion policies.

Figure 6 – Electricity Scenario in the United Kingdom

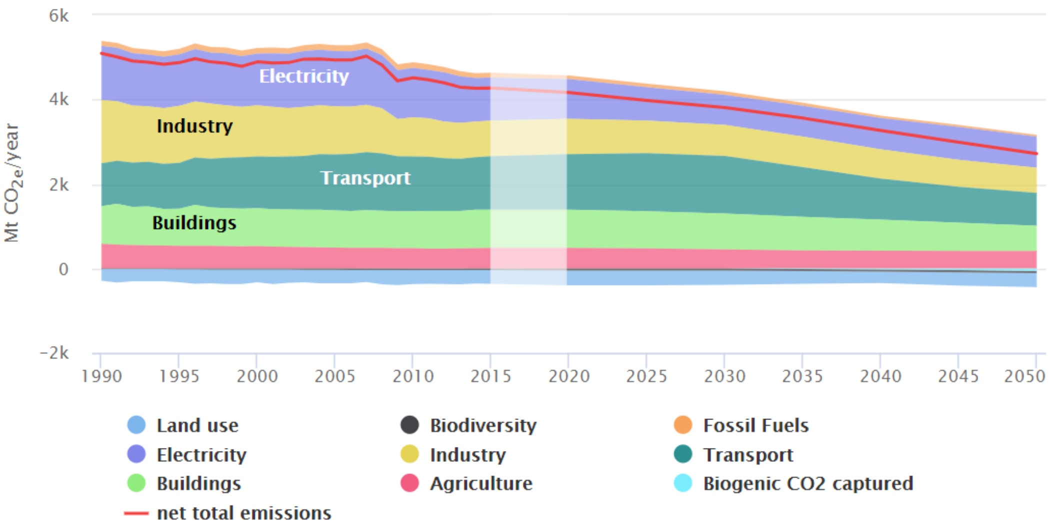


Source: United Kingdom department of energy & climate change (2021).

Even with an electrical base with high emissions and based on fossil combustion, in its transport policy, the United Kingdom Department of Energy & Climate Change (2021) considers level 1 (base scenario) 20% plug-in vehicles. The level 4 mode, which would be as sustainable as possible, assumes the totalization of the electrification/hydrogenation of the fleet. At intermediate levels, it considers the participation of zero-emission vehicles powered by biofuels. The latter type is relevant in the present work since Brazil already has an automotive fleet capable of running almost entirely with ethanol.

According to EUCalc (2021), the tool designed comprises an aid to answer the question of the feasibility of decarbonization in Europe, and which are the routes fast enough to comply with the Paris Agreement. Figure 7 exposes GHG emissions from the various sectors. In the base scenario, there is the prospect of a decrease in all sectors, however, the transport sector is the most significant. As a result, it was necessary to further explore the tool to find out how the reduction in emissions related to transport occurs. Figure 8 represents the evolution of the distance traveled per passenger and Figure 9 the technological distribution of light vehicles, the scope of the present work. The fading of Figures 7, 8 and 9 are related to the period in which the calculator already existed, however, since it comprises a time already past, such data were updated according to the existing real values.

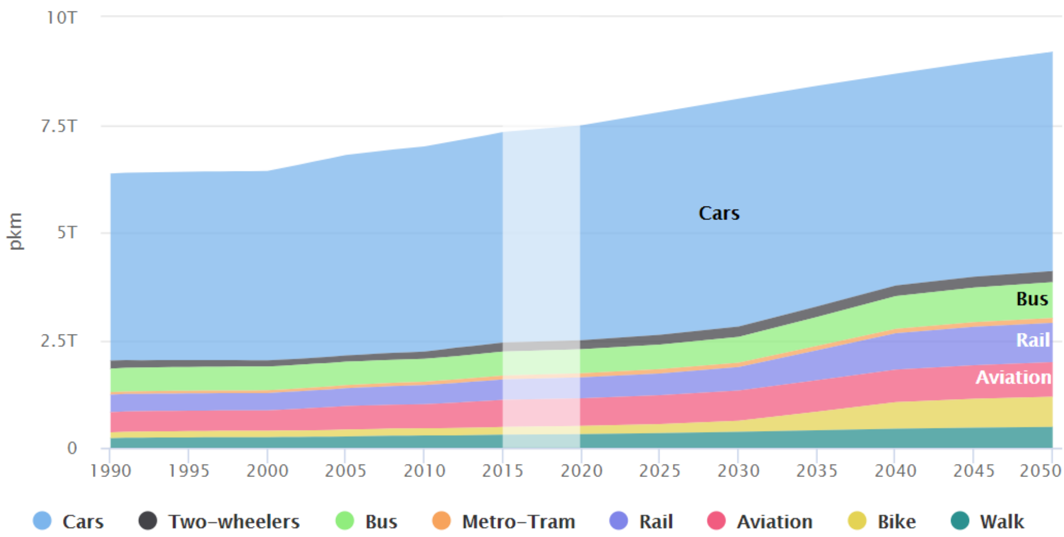
Figure 7 – Emissions Scenario in Europe



Source: EUCalc (2021).

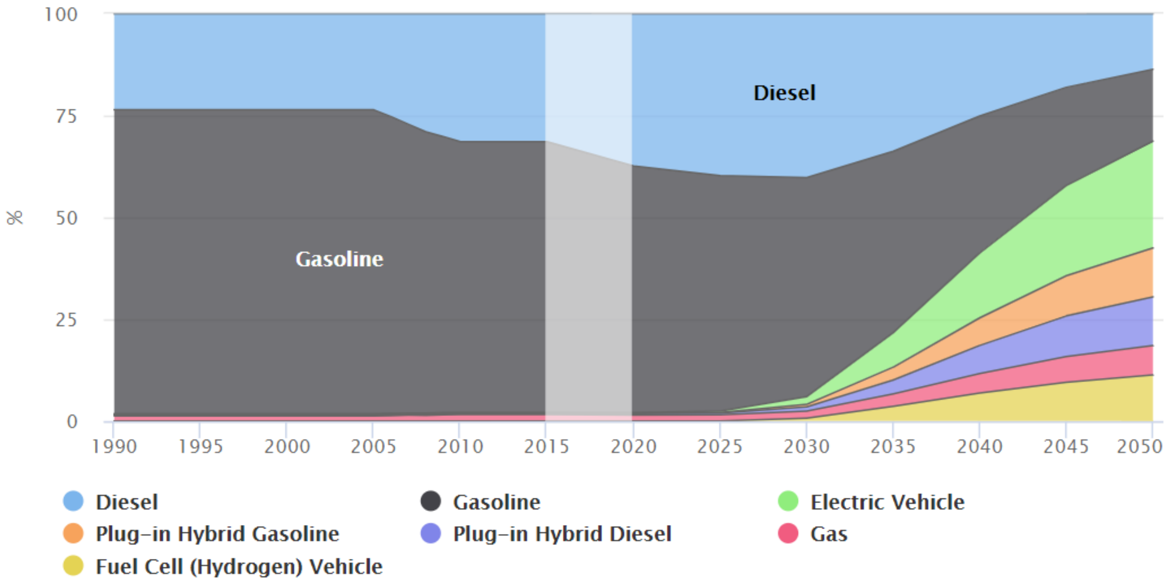
When analyzing Figures 8 and 9 together, it is realized that Europe adopts as an emission reduction strategy the use of electric vehicles, considering an effective insertion from the year 2025. According to EUCalc (2021), such considerations take into account the perspectives of large-scale production assemblers associated with the implementation of refueling stations. However, the use of biofuels such as ethanol is not considered, even though European automakers have mastered this technology.

Figure 8 –Passenger distance per mode in Europe



Source: EUCalc (2021).

Figure 9 –Car's technology share in Europe



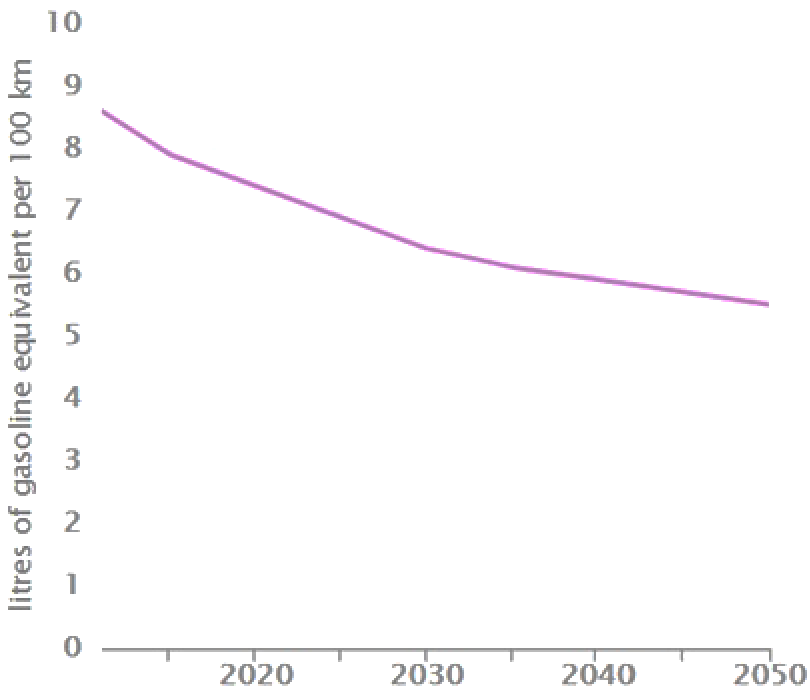
Source: EUCalc (2021).

It is noteworthy that this strategy, considering the emissions exposed in Figure 7, which are much higher than the emissions in Brazil exposed in Figure 4, creates a favorable perspective for the insertion of vehicles in the Brazilian scenario.

According to The Global calculator (2021), The Global Calculator 2050 is a tool developed to analyze the global energy iteration, aiming at reaching the sustainable scenario agreed by the Paris Agreement. In addition to the energy scenarios, it is possible to create pathways for land and food. For the present work, data referring to the electricity and transport base perspectives are used. Figure 10, Figure 11, Figure 12, and Figure 13 expose the forecasts for the global emissions, the number of rolling vehicles, their efficiency, and the distribution of the source of the used fuel.

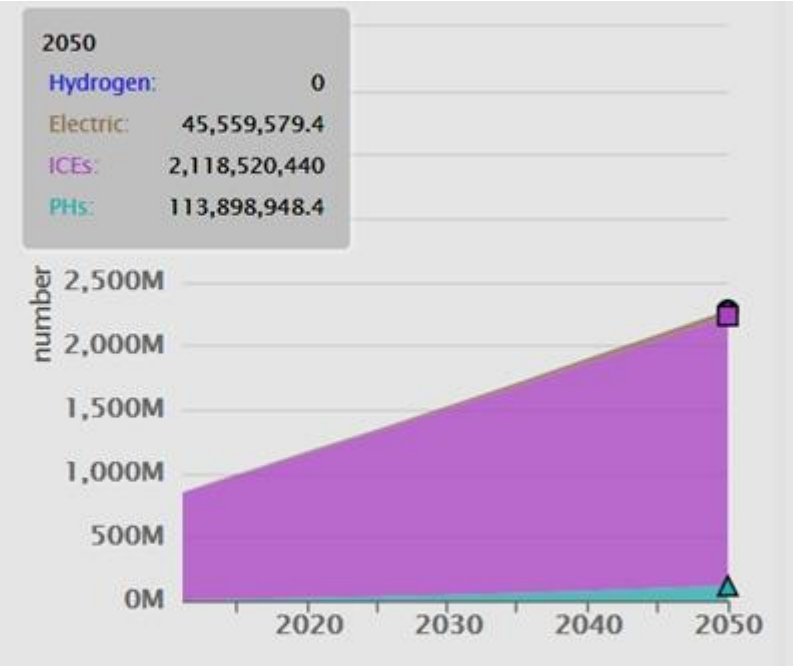
From Figure 10, it could be deduced that there are good prospects for improving the efficiency of vehicles, which is already favorable to the reduction of emissions from the transport sector. However, from Figure 11 it may be seen a 100% growth when comparing the year 2020 with 2050, which requires a change in the emissions profile, in addition to the efficiency of the vehicles. It is also observed in Figure 11 the insertion of electric vehicles in a global perspective, with prospects for a more sustainable worldwide electric mix consistent with Figure 12. Figure 13 shows the fuel source specification for the more than 2 billion vehicles expected by 2050, and for internal combustion vehicles only hydrocarbons, liquids, and gases are considered. Thus, the present work explores this gap: the fact that until 2050 the participation of ICE is significant globally, and the consideration of the possibility of using biofuels.

Figure 10 – Average efficiency of cars on road: Global



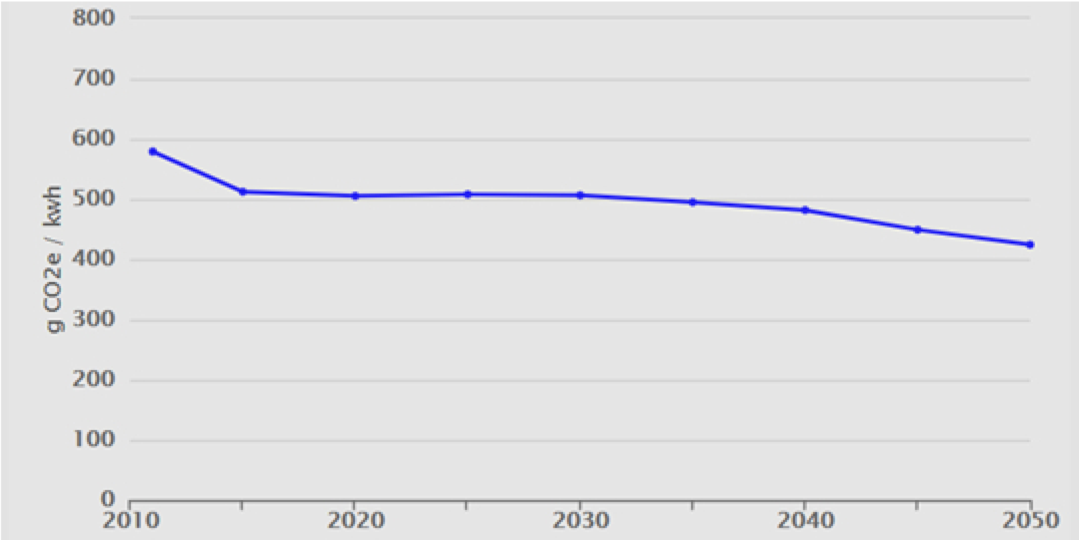
Source: Adapted from The Global calculator (2021).

Figure 11 – Number of cars on road: Global



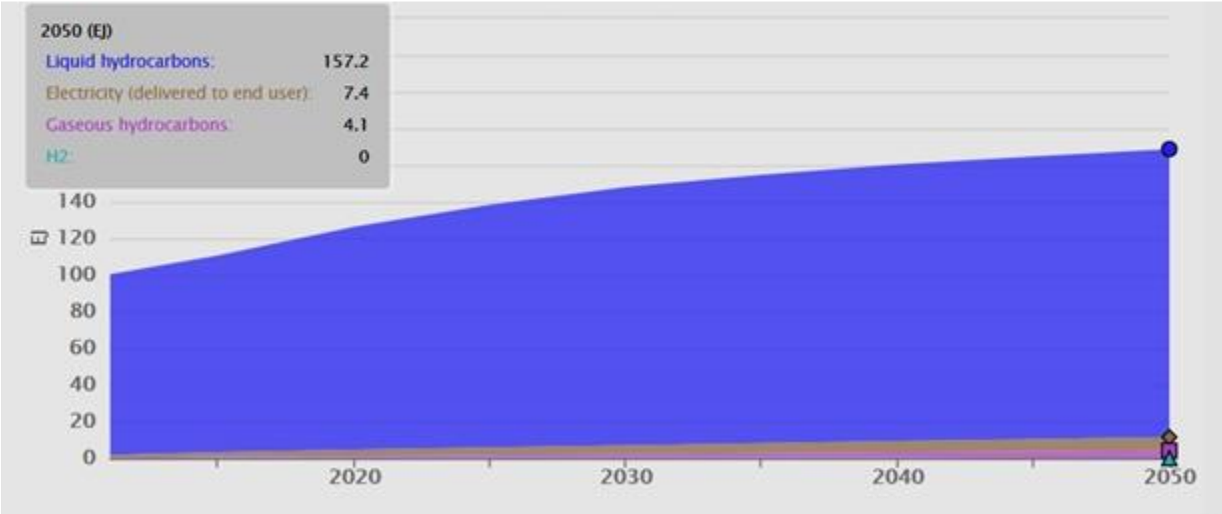
Source: Adapted from The Global calculator (2021).

Figure 12 – Electricity Global emissions



Source: Adapted from The Global calculator (2021).

Figure 13 – Transport by fuel Type: Global



Source: The Global calculator (2021).

2.1.5 Fossil fuel and ethanol prices

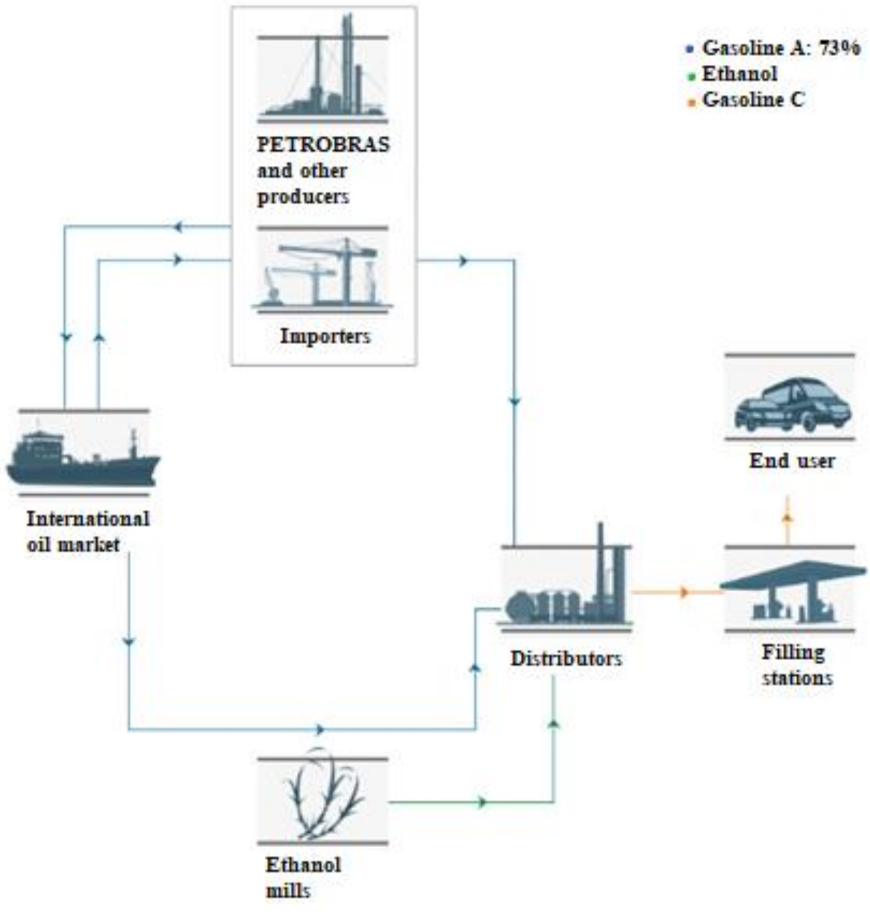
According to Dantas; Bell (2011), Petrobras is a Brazilian oil company, having led off its offshore activities in the late 1960s, and until the early 2000s underwent a massive transformation, having associated, in addition to equipment, operational knowledge. This last period can be divided into two parts: the first passive learning, in which there were several partnerships with other oil and gas exploration companies; the second part, active learning, where even through trial and error there has already been the production of the technology itself. Finally, the company is about to create innovative and strategic techniques, highlighting the exploration of deep-water submerged oil.

Today, Petrobras is a publicly held corporation operating in an integrated manner in the oil, natural gas, and energy industry. Due to its wide range of activities, it relates to a variety of importers by participating in bidding procedures conducted by the National Agency of Petroleum, Natural Gas and Biofuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, ANP, in Portuguese). In 2018, it had an annual average and production of 1.133 million barrels of oil per day, which compared to 2008, when the pre-salt exploration began, more than 400 thousand times, a fact that states the change in the national scenario and the importance of the national company. Gasoline alone already accounted for sales volume in 2018 of 545,000 barrels per day, with the market share in the service station segment accounting for 23.9%, thus underlining the great importance of automotive vehicles in the use of oil products.

According to PETROBRAS (2018), in 2018, about 60% of cars in Brazil were gasoline-fueled, the focus of the present study. Its price is regulated by the ANP and Federal Law 9.478/97 (Petroleum Law), easing the monopoly hitherto exercised by Petrobras. The Interministerial Council for Sugar and Alcohol (Conselho Interministerial do Açúcar e do Álcool, CIMA in Portuguese) regulates the ratio between Anhydrous Ethanol and "A" Gasoline (produced in refineries) for the formulation of "C" Gasoline (passed on to consumers at resale points). Ethanol's share varies between 18% and 27%. Figure 14 illustrates the dynamics in the gasoline commerce in Brazil.

From Figure 14, the main parts of gasoline price composition in Brazil are inferred: realization of the producer or importer (29%), which is directly influenced by the international derivatives market; the share of production in ethanol plants (13%); these two first followed by the margins practiced by both the distributors and the retailers themselves (12%); and finally by both state (30%) and federal (16%) taxes - thus, the price of gasoline depends on several linked factors.

Figure 14 – Dynamics in the gasoline commerce in Brazil



Source: Adapted from PETROBRAS (2018).

2.1.6 Electricity distribution and pricing

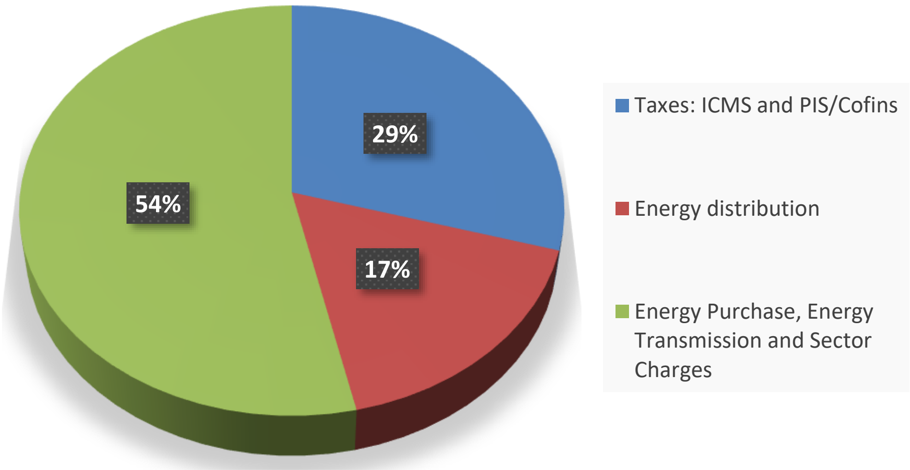
In 2005, Brazil was going through an intense process of privatization of electric energy distribution concessionaires. Rocha et al. (2007) established a fundamental metric of financial evaluation, concluding that the inversion of the capital return curve occurred in the year 2003, being only then profitable in the electric sector. It is considered a milestone, because it was when Law 8987, enacted February 13, 1995 (Concessions Act) can finally guarantee a stable distribution sector, an essential fact for considering the insertion of electric vehicles.

In addition to a stable distribution scenario, for the effective consideration of the insertion of electric vehicles, it is necessary to obtain an electric energy pricing. Kayo et al. (2020) emphasize the importance of pricing not only for the investor but also for the consumer, an element considered by the authors to be important is the calculation of the cost of equity, using the traditional capital asset pricing model (CAPM). However, volatile variables make the consumer/investor relationship too complex, and in their work, an alternative procedure for the context of electricity transmission in Brazil was proposed. With this, the authors proposed an alternative model to that of National Electric Energy Agency (Agência Nacional de Energia Elétrica, em português, ANEEL), providing new insights. In the present work, it was considered a factor of energy variation of 26.00%, identified by the authors' analysis.

The Brazilian electric energy sector is regulated by ANEEL. the According to ANEEL (2021), the pricing of electricity tariffs aims to regulate a price that covers the costs of generation, transportation of energy to consumer units, and sector charges. In addition to the energy auctions that began in 2004, it aims to provide the consumer with the fairest possible price. Nevertheless, social charges are not determined by ANEEL but are instituted by governmental laws. Figure 15 shows the participation of each sector in determining the price of electricity and Figure 16 exposes the electricity flow in the year 2020.

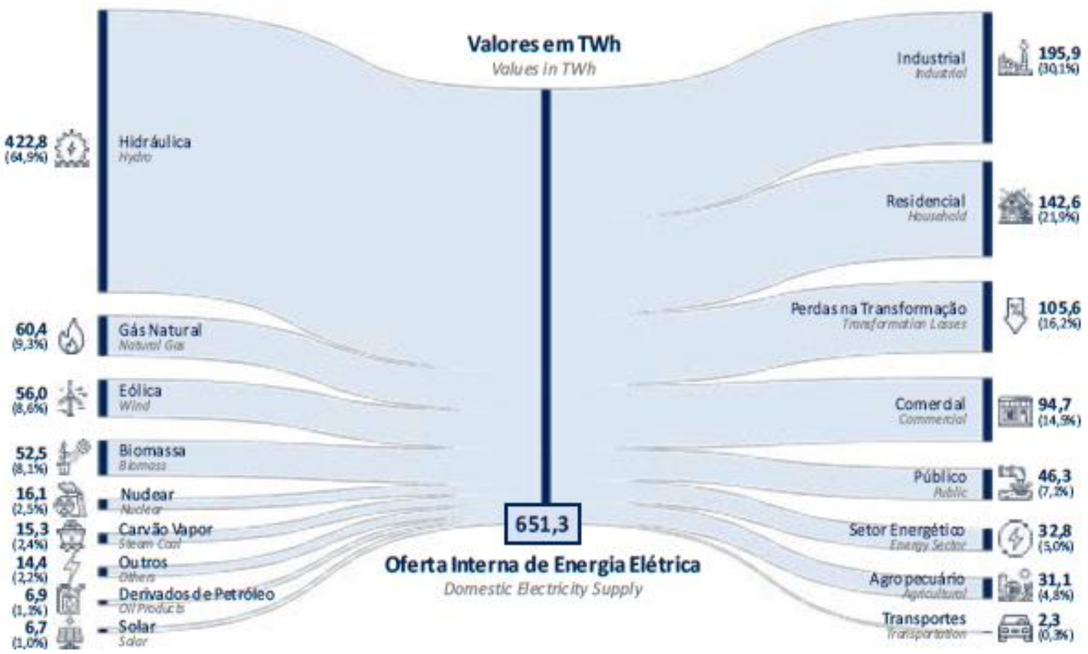
From Figure 15 and Figure 16, it is inferred that the taxes that make up the value of electricity are the Tax on Circulation of Goods and Services (ICMS), the Contribution to the cost of public lighting (CIP/COSIP), the Emergency Capacity Charge (ECE), the Social Integration Program (PIS) and the Contribution to the Financing of Social Security (COFINS). PIS and COFINS are fees charged to legal entities by the federal government, which may vary from one month to another according to Technical Note No. 115/2005-SFF / SER / ANEEL of 04/18/05, ratified by Homologatory Resolution No. 227 of 18 / 5/10. The CIP/COSIP, on the other hand, is determined by the prefectures of each municipality, thus varying throughout the State. The ECE was determined by Resolution 71, of 02/07/2002, edited by ANEEL, corresponding to 0.35% of consumption. Thus, it is not possible to determine a national electric energy value, being thus chosen as the base value for the present work of the State of São Paulo. Finally, the ICMS which is determined by the Regional Government, and the São Paulo State taxes are presented in Table 1, focusing on residential consumption.

Figure 15 – Final Value of Electricity



Source: Adapted from ANEEL (2021).

Figure 16 – Electricity Flow in 2020



Source: Adapted from BEN (2020).

Having the variations determined by Table 1, it was then necessary to determine a value for the year 2021, in which the price variation factor was placed. The value per kWh according to Companhia Paulista de Força e Luz (2020) was around 0.92 R$/kWh for the residential tariff and 0.86 R$/kWh for the commercial tariff.

Table 1 - ICMS in the State of São Paulo

CLASSES	CONSUMPTION RANGE (kWh)	RATE OF ICMS
Residential	0 to 90	Isenta
	91 to 200	12%
	Over 200	25%
Public power and state authorities	any consumption	EXEMPT
Public power and municipal authorities	any consumption	18%
Other classes	any consumption	18%

Source: Secretaria da Fazenda do Estado de São Paulo (2020).

2.2 AUTOMOTIVE TECHNOLOGIES

This section conceptualizes and presents the passengers' automotive technologies currently present on the market. The technologies used in the planning project in this section are defined. According to Cardoso Chrispim et al. (2019), electric vehicles have been considered a direction to be taken for decades to come considering current energy challenges. One of the main relevant questions regarding the issue of purchasing electric vehicles is their high cost compared to conventional vehicles, which can reach up to 2.5 times the value of the initial investment. To consider the possible scenarios, it is essential to discriminate, within the present scenario, the available technologies to consider their future projections.

Developing a regional optimization model, Noori et al. (2015) considered the United States automotive fleet not only the division between ICEV and E-V but also five categories, exposed in Frame 1. From Frame1, it is necessary to emphasize that the designation of such categories was applied to an analysis in the USA, and the Brazilian scenario has some particularities. Therefore, the categories HEV, BEV, and ICEV were considered with one particularity: the existence of a Flex automotive fleet, that is, using gasoline or ethanol as fuel.

EV's use electrical energy as a source of energy for the operation of the car and the ICE 61851 standard, which serves as an international standard for charging systems. In Brazil, ABNT NBR ICE 61851-1 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2013,

p. 47) addresses the operating characteristics of the recharging and connection systems for EV's, has been in force since 2013. This standard defines 4 charging modes and three types of connectors.

Frame 1 – Vehicles definition

ICEV (Internal Combustion Engine Vehicle)	A vehicle powered by an internal combustion engine, whose energy comes from combustion in the pistons. Its fuel source can be diesel or gasoline.
HEV (Gasoline Hybrid Electric Vehicle)	A vehicle that endues a battery, that is preliminarily used and especially in hard acceleration conditions, the gasoline engine facilitates driving the vehicle.
PHEV (Gasoline Plug-in Hybrid Electric Vehicle)	A particular type of hybrid vehicle in which the battery can be recharged
EREV (Gasoline Extended Range Electric Vehicle)	A type of PHEV with a larger battery that powers the vehicle until depleted, at which point the vehicle switches to gasoline power.
BEV (All electric vehicle)	A vehicle powered exclusively by an electric motor powered by a battery. It has charging devices for kinetic energy, but its main source of energy is the connection to the power grid.

Source: adapted from Noori et al. (2015).

According to Noori et al. (2015), recharge mode 1 is the simplest mode, in which the EV is connected to the standard alternating current outlet that does not exceed 16 A, with the protective power and ground conductors. Recharge mode 2 is connected to the standard alternating current socket that does not exceed 32 A, the connection is made through grounding conductors and protection systems, in a control box integrated with the cable. Recharge mode 3 uses a control box permanently connected to the integrated AC network, and charging mode 4 is the fast-charging mode, which uses an external charger connected to the integrated network, and the pilot function extends to the permanently connected devices.

In this standard, three types of connectors are specified to perform EV recharging, cases A, B, and C. Case A uses power cables and a plug is permanently attached to the EV. Case B uses a detachable power cable between a mobile socket on the EV and an alternating current supply system. In the case of C, a power cable and a mobile EV outlet permanently connected to the power system are used. This last case is the only one that can be used for recharge mode 4.

Garcia et al. (2017) presented a detailed analysis of batteries, an issue that precedes this theme, and the current barrier to implementing E-V on a large scale. Consequently, a factor of great weight in the scenarios to be analyzed is how big will be the improvement of technological development that the batteries will have reached in 2050.

According to Cardoso Chrispim et al. (2019), the autonomy of E-V is directly influenced by its battery and its respective weight, so studies are moving towards obtaining electrodes with greater stability, using nanotechnology. The lithium battery is a high-cost raw material, mainly because it is scarce on the Earth's surface, evaluating the possibility of its replacement by aluminium, for example, which is promising.

2.2.1 Brazilian automotive fleet

The Federação Nacional da Distribuição de Veículos Automotores (FENABRAVE), the Brazilian private association of automobile distribution, brings together 51 Automobile Vehicle Brand Associations from different segments, seeking to defend sector interests, including exchanging information with other countries. In addition to promoting congresses that guide the future of the Brazilian market, it carries out a series of studies and research on the sector, from international spheres in partnership with the International Car Distribution Program (ICDP) to the Indices and Numbers of the Brazilian automotive fleet (FENABRAVE – 2020). Its annual reports since 2004 are in the public domain, systematizing data from the Brazilian automotive sector.

In addition to statistics per se, in the annuals, a summary of the sector's assessment by FENABRAVE (2020) is reported. From 2004 to October 2008, an impulse in the sector was reported, related to an implemented policy of reducing interest rates and innovations in the credit sector. To ease the effects of the crisis, the Government then employed a policy to reduce the IPI, which is essential for the sustainability of the sector in 2009. In 2010, the end of the IPI reduction did not cause major impacts, thanks to the confidence resulting from the increase in jobs and real wage growth. 2011 was marked by the beginning of a phase of defaults, and a consequent gradual reduction in credits. There were successive years of declining sales in the sector, until 2016, which was the worst recession in history. In 2017, the economy began to recover, and 2018 was highlighted by the large participation of Rental Companies, as loans from individuals remained restricted.

On the official FENABRAVE website, FENABRAVE (2020), semi-annual balance sheets and annual reports since 2004 are available and freely accessible, systematizing relevant data on automotive distribution in Brazil and the comparison of the main countries of the world

For ANP (2020), in its predefined scenarios and simulation of the impact from the RenovaBio program, consumption of the Otto Cycle is an intrinsic variable. Three main branches are active: fuel pricing, real income per capita, and the automotive fleet itself, the latter being related to the sale of new cars and their scrap curve. This item describes the behavior of the light car fleet, taking into account the finding of the effects of predecessor automotive policies and the need for a neglected database aiming at relevant economical assessments and inspection of the most comprehensive niches and consequently of greater national impact.

Rodrigues; Bacchi (2017) correlated the inelasticity of fuel prices to income in the short run, limiting more significantly to the fleet in operation. Table 2 gathers the data from the Brazilian automotive fleet and its average age from the years 2004 to 2018, discriminating against the distribution of the five major Brazilian geographic regions.

2.2.1.1 Flex vehicles

Rodrigues; Bacchi (2017) proposed in their work, a model for analyzing the elasticities of demand for each type of fuel in Brazil, taking into account the peculiarity of ethanol, diverging from global analyzes that take gasoline pricing as input variables. Flex vehicles (defined as being able to burn ethanol, gasoline, or a mixture of both), which were introduced in the Brazilian market in 2003, are, therefore, a comprehensive correlation specification factor, since their consumption permeates the fluctuation of the fuel market. Du; Carriquiry (2013) focused on the dynamics of ethanol and gasoline prices to implicate the development of ethanol markets abroad and concluded that Flex Fuel vehicles share allow consumers to arbitrage in the substitution, so establishing higher ethanol blends its essential encompassing Flex technology.

De Souza Nascimento et al. (2012) signalize Volkswagen and General Motors as the predecessor of the Flex Fuel technology, even not expecting great success, as it happened in Brazil. In both cases, they shared the strategy of monitoring the market, to decide the perfect timing to launch a car. The introduction of the electronic injection system started a period of innovations for all manufacturers; Table 2 allows an analysis of flex-fuel insertion over time.

Table 2 – Flex Vehicles Evolution

	Percentage of flex vehicles sold by the manufacturer (%)								
Year	VW	Fiat	GM	Ford	Renault	Honda	Toyota	Nissan	Hyundai
2004	34	23	22	07	02	0	0	No data	No data
2005	82	69	49	25	37	0	0	No data	No data
2006	97	99	97	41	81	03	0	No data	No data
2007	98	98	100	72	81	47	55	0	No data
2008	97	98	100	92	94	81	93	0	No data
2009	98	99	100	80	97	98	77	No data	0
2010	99	99	100	95	88	99	98	No data	0
2011	99	99	099	96	100	100	No data	100	0
2012	98	99	100	98	100	100	100	100	35
2013	97	99	100	97	100	100	100	100	93
2014	95	98	99	96	100	100	87	99	81
2015	94	98	99	97	91	93	92	99	97
2016	93	99	99	98	100	98	91	100	98
2017	95	100	99	98	100	96	91	100	97
2018	97	100	98	97	100	95	89	100	97

Source: the Author – Compilation of FENABRAVE's Yearbooks.

From Table 2 it can be inferred that, from the year 2008, fuel-flex technology was already widespread among sales of new vehicles, and FENABRAVE (2020) points out that in the categorization of light vehicles, diesel utility vehicles are included, whose technology does not allow the implementation of Flex vehicles. FENABRAVE admits the average useful life of a vehicle in Brazil as 13 years, so from the year 2021, it is possible to consider the Brazilian automotive fleet as essentially fuel-flex, an assumption made by RenovaBio (2019), where the use of ethanol or Gasoline is solely a function of consumer choice, not technological issues.

2.3 GOVERNMENT ENERGY PLANNING POLICIES IN BRAZIL

The historical description of the energy planning policies of the automobile sector and the perspectives for related sectors, of direct influence in the sector, to have a national level in the sector is presented to understand the evolution of the automotive sector and its peculiarities.

2.3.1 Automobiles

Bastin et al. (2010) denote that since the first concepts of policies for the insertion of new technologies, the process can be divided into three major phases: the invention of the technology itself, the complete development, and finally the diffusion for general use. In the specific case of energy technologies, there is an intrinsic relationship with market needs and vehicles, being energy consumers, and having their demand correlated with the pricing of the fuels used, that must coexist with the relevant technological capabilities.

Considering Brazil's dependence on the road network and the consequent expression of the share of vehicle sales in its economy, this subsection presents a retrospective of Brazil’s automobile sector, relating it to recently implemented public policies, from a recent past and still in force.

2.3.1.1 Promotion of Brazilian ethanol-powered vehicle

Bastin et al. (2010) presented an overview of the National Alcohol Program, having as its main predecessor motivation for its effective application the reduction of dependence on the import of fuel fuels. In a first step, it was proposed to mix anhydrous ethanol with gasoline, and the pure use of hydrated ethanol was decided upon in a subsequent step, which was divided into three phases:

I) 1979-1981: first ethanol vehicles were launched, presenting technical problems regarding the development of the main manufacturers;

II) 1982-1983: a combination of technological solutions to a better situation in the national market;

III) 1983-1985: characterized by mass dissemination of the ethanol-powered vehicle, mixing the conversion of the existing fleet and encouraging manufacturers to use such technology.

2.3.1.2 Brazilian Labeling Program (PBE, Programa Brasileiro de Etiquetagem)

In 2008, the National Vehicle Labeling Program was instituted, whose tabulation of approved models is available from 2009 to this day, at the National Institute of Metrology, Quality and Technology (Instituto Nacional de Metrologia, Qualidade e Tecnologia, Inmetro, in Portuguese) website, the autarchy responsible for classification. According to INMETRO (2020), the purpose of this voluntary membership program is to allow the consumer easy access to vehicle energy efficiency data, thus facilitating conscious consumer’s decision making, and consequently favoring the market to automatically tend towards a more efficient vehicle within the same category. In real operating conditions, several factors interfere with the efficiency of the vehicle, both mechanical and in use (driver's way of driving, traffic patterns, climate, among many others). The laboratory data obtained by a series of tests disclosed that 90% of the cases are within a gap of 20% of the actual declared consumption.

Bastin et al. (2010) noticed, at the beginning of the PBE, an important step on the path of Brazilian energy efficiency due to the simplicity of the label design and consequently a wide range of population reach, but pointed out a disadvantage in comparative labeling. A vehicle of a higher category can present a better efficiency, even if its consumption is greater than that of a given vehicle of a lower category, which deceptively discourages downsizing from larger to smaller vehicles. Table 3 exposes the evolution of labeling in the middle of the 2010s.

According to the Ministério da Economia (2020), the full participation in the National scope in the PBE only started to have a full adhesion of the manufactures when fiscal incentives were significant, and its label became a standard of measuring the parameter of efficiency. 2017 culminated in total adherence to the consolidation of General Motors.

Table 3 - Effectiveness of the National Vehicle Labeling Program

Year	Labeled Vehicles
2013	36%
2014	49%
2015	64%
2016	81%
2017	100%

Source: Ministério da Economia (2020).

2.3.1.3 INOVAR AUTO

According to Ministério da Economia (2020), the *Programa de Incentivo á Inovação Tecnológica e Adensamento da Cadeia Produtiva de Veículos Automotores* (Inovar-Auto) was a program implemented by the government between 2013 and 2017 aiming to increase the productivity in the automotive industry, looking for systematic efficiency gains at the production chain, from manufacturing to servicing and marketing network. The program was divided into two major actions: the first one, incentives during the current period, with benefits of Taxes on Industrialized Products (Imposto sobre os Produtos Industrializados, IPI, in Portuguese) up to 30%. In the second one, in 2017, when vehicles manufactured in Brazilian achieving a reduction of 15.46% in fuel expenditure, it was entitled to a reduction of 1% in the IPI tax, and those that reached the target of 18.84% were entitled to 2%.

At the end of the current period, Inovar-Auto (2019), through the Program Monitoring Group, prepared an evaluation report, in the public domain, aiming to detail the efficiency and results, impacted indicators in the national industry to expose the aggregation value obtained and encourage manufacturers to take part to subsequent public policies. The program was based on a retrospective study carried out by the Brazilian Industrial Development Agency (Agência Brasileira de Desenvolvimento Industrial, ABDI, in Portuguese), a Brazilian agency for encouraging industrial development, thus the analysis of the measures taken reflected in the reflections of what currently establishes the current program.

2.3.1.4 ROTA 2030

According to Cirilo, Clark e Corrêa (2020), Federal Law No. 13,755/2018, known as Rota-2030, was established in 2018 and had been celebrated by the automotive industry sector for making clear the objective of increasing the sector's competitiveness, aiming at a global insertion of the Brazilian industry. The program currently in force differs from its predecessor, Inovar-Auto, in that it does not have an incentive, but it did require participation in issues of energy labeling corresponding to efficiency and assistive driving technologies (such as the ABS brake). At this stage in the country's development, largely because of the economic crisis scenario in which the targets were established, tax incentives are not associated with large investments in research and development (R&D), as in the decade of 2010 there was already a mass migration from factories to Brazil. The focus in the 2020s is to add knowledge, from researching materials (including applicable fuel sources, such as biofuels) to automate the manufacturing process, logistically improving the efficiency of the production chain.

Considering the automotive sector as fluctuating in the unstable global economy, within the scope of the Rota-2030 program, the publication of an annual report reported by Ministério da Economia (2020), prepared by its respective Monitoring Group, is already foreseen. The factors of production, employment, investments, innovation, and value-added were listed as annual comparative measures to even assert the goals established in 2018 to assert the dynamics of the economy.

2.3.1.5 RenovaBio

ANP (2020), the Brazilian regulatory agency for fossil and renewable fuels, describes the National Biofuels Policy in force, established by Law 13.576 / 2017, RenovaBio. It aims to contribute to the fulfillment of the Paris Agreement commitments by expanding the participation of biofuels in the energy mix. It has a great focus on the dynamics of the national hydrated ethanol markets, based on macro-econometric studies in conjunction with automotive technologies to determine CBio, a cost associated with the reversal of the necessary subsidy to find the convergence between pricing and gasoline pumps. This aimed to guarantee to the consumer the viability of using ethanol and to the automotive manufacturer the resilience of the market for the flex vehicle.

2.3.2 Future perspectives

In the sector of strategic business and management planning, Petrobras (2018) considers that technological innovation and the adoption of new government strategies are factors that point to a period of the energy transition towards a low carbon economy, thus simultaneously presenting to the company the importance of its resilience and the development of new sectors, such as the production of biofuels. In this uncertain scenario, then, the company developed the year 2040 as a date for long-term analysis, thus creating the Petrobras Strategic Plan (PE 2040).

According to Petrobras (2018), PE 2040 focuses on the exploration and production of oil and natural gas; pre-salt being the main source of value generation, with prospects for greater aggregation in the use of natural gas, including global perspectives through partnerships. In this long-time aspect, opportunities for using renewable energies that have synergy with the current fields of Petrobras are incorporated, focusing on wind and solar sources in Brazil. For the 2019-2023 Business and Management Plan, the operational planning and distribution of the investment portfolio have already been detailed, and of the 84.1 billion dollars, 0.5% will be used in renewable technologies. Even though it is essentially an oil and gas company, the outlook for the next distributions of the portfolio is favorable to the increase in the share of renewables.

Earth has changed its ecosystem due to human interference. In Ipcc (2019) report, it is exposed that from a quarter to a third of the production potential has been exploited to supply the chain of needs, including energy production. Since the 1960s, such exploration has been intensified, causing a big growth in greenhouse gas (GHG) emissions, and consequently in climate changes. Global warming has been altering several characteristics of ecosystems, such as the desertification of lands, thus expanding arid lands and contracting the polar caps. Several living beings, animals and plants, experienced changes in characteristics, abundance, and seasonality of habits. It is noteworthy that plantations and animal breeding for slaughter were also compromised, directly altering the food supply chain on which humanity is dependent.

Increasing the consequences of global warming, the Intergovernmental Panel of Climate Change (IPCC) created GHG emission scenarios for the second half of the 21st century, considering medium and high levels, to assess the impact on different climatic zones.

Cardoso Chrispim et al. (2019), in a primary analysis regarding the comparative use of ICE vehicles and E-V ones, inferred that the first ones pollute the atmosphere, especially with CO_2 from combustion and the second has zero emissions during its use. An issue preceding this theme is the discussion about the origin of electric energy, which is not necessarily renewable and free of pollutant emissions. As an example, the IER- Institute for Energy Research concluded that Electric Vehicles in Germany emit more Carbon Dioxide than Diesel Vehicles, comparing the CO_2 emissions of a Tesla Model 3 and a Mercedes C220d when considering the production chain (battery manufacture and source of electricity); 141 grams per kilometer, compared to a range between 156 and 181 grams of the electric vehicle.

Cardoso Chrispim et al. (2019) through an LCA study it was found that, on average, an E-V generates half of the GHG emissions when considering the steps from production to its useful life. This potential for reducing and adapting to decarbonization goals can then be exploited, especially when the electricity is from renewable sources. A fact that deserves attention is that at the beginning of the cycle evaluation (manufacturing stage), the GHG emissions of an E-V are higher, requiring a minimum of 7884 km traveled to be more environmentally advantageous.

According to Cardoso Chrispim et al. (2019), the most relevant difference when comparing the disposal of ICE vehicles and E-V is in the battery itself, whereas other components are essentially the same. Currently, it is considered that when reaching the level of 75% of the original charge, the battery must be discarded, however, there are reuse options, such as storing wind and solar energy. The improvement regarding the recycling techniques is considered to minimize the option of the landfill and consequently the generation of solid and polluting residues.

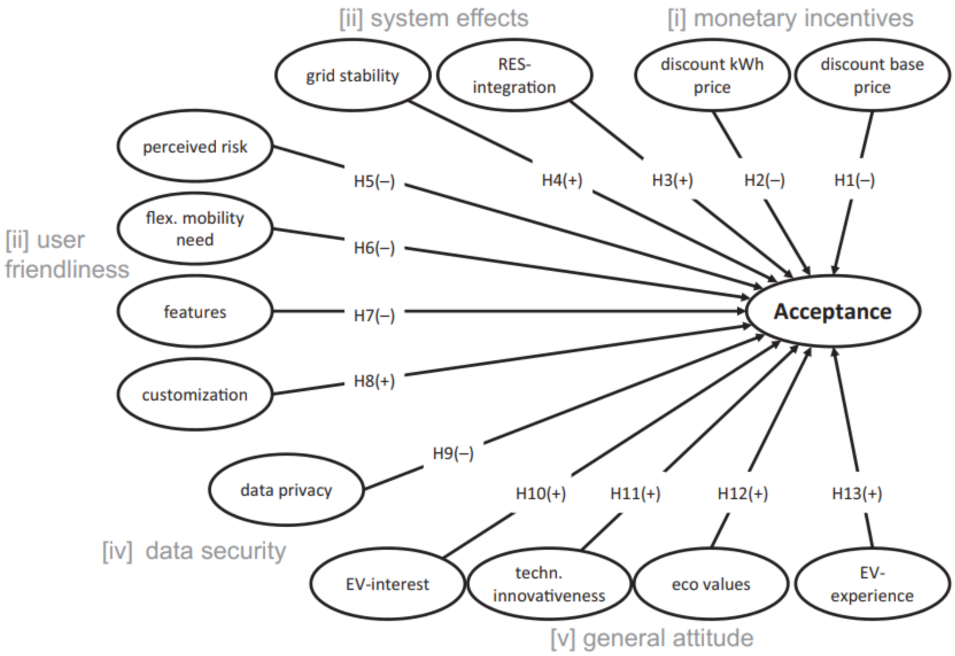
2.3.3 Technology acceptance

When it comes to inserting a new technology, the cost aspect is of great importance in the purchase decision by the consumer. The comparison factors considered by the model proposed in the economic view are listed.

According to Cardoso Chrispim et al. (2019), one of the main issues to be considered when replacing conventional vehicles - internal combustion engine (ICE) with electric vehicles (E-V) is the Life Cycle Assessment (LCA). This is not a trivial task, as it is necessary to consider all stages from extraction to destination. Will; Schuller (2016), in their preliminary review work, discussed the influencing factors for the acceptance of electric vehicles. Figure 17 exposes the survey design and the respective hypothesis addressed.

In this way, the authors discussed the hypotheses formulated in terms of E-V acceptance, as exposed in Figure 17. With this, the main influences for the question of the technology acceptance of E-Vs were determined. As a summary of all the hypothesis tests carried out by Will; Schuller (2016), the importance of grid stability is emphasized, both in terms of pricing and in terms of stability. Contrary to previous studies, the authors concluded that the higher initial cost of EVs does not have a negative influence, while the hypothesis of long-term compensation for recharge prices was considered. The main influencing factor for the acceptance of the technology was the existence of a renewable electrical mix, as Brazil fits, and the other hypotheses were considered of little relevance for the technological acceptance factor. It is noteworthy that it was of great importance to expose such sustainable issues for the final consumer.

Figure 17 – E-V acceptance hypothesis



Source: Will; Schuller (2016).

2.4 STATISTICAL AND SIMULATION METHODS

It was necessary to apply statistical and simulation methodologies. The theoretical basis used is presented in this subsection.

Welch et al. (2019) in their study to review the methodology used in the creation of public policies in the transport sector, identified that one of the frequent studies using the concept of consumer behavior and Big Data is related to the feasibility of inserting E-V's in the modals.

The data sources vary from Automated Data to Web Data from governmental databases, but, in all cases, it is necessary to create a method for processing this data to apply them properly to the projections. From 2016 onwards, most incident applications are estimated by regression and are descriptive by data visualization. Thus, as the aim of the present work was to simulate through a program of minimization of emissions by the software Lingo, it was necessary to carry out treatments of the past data obtained by governmental bases. From such treatments, projections were then made. An explanation is made of the most appropriate statistical methods for government data.

Karpušenkaite et al. (2018) proved the best accuracy of the mathematical application of a hybrid model of time series for the determination of automotive residues. The application of the integrated moving average autoregressive model (ARIMA) stands out due to its greater adaptability to issues of sensitivity and temporal variance. In this way, for each analyzed variable, it was possible to create the model that best adapted.

According to Chauhan; Singh (2017), ARIMA model was developed in 1970 by Box and Jenkins, being an expansion of the ARMA method, in which their considerations allow a better forecast of linear variables. The biggest challenge of the ARIMA method is to define the most appropriate model, starting with the determination of whether the model is stationary or not. Subsequently, the evaluation criteria are analyzed, comparing the developed series. Therefore, to carry out projections using the ARIMA method, some simulations, and a later choice of the best methodology by analyzing the smallest residues are necessary.

Box; Jenkins (1970) developed an approach for the construction of parametric models for univariate time series. As a first definition, a time series consists of observations ordered in time so that the sample presents a crucial dependence between the observations, it is the realization of a stochastic process. Two main aspects of the study of a time series were defined:

1. Analysis and modeling: describe the series through the adequacy of a mathematical model, defining the serial dependence between series values. For this, it is necessary to adapt the descriptive parameters.
2. Series forecast from past values to find good forecasts of future values, indicating a forecast horizon and its respective confidence interval. Future models are thus divided into univariate, in which the series is predicted by its past or causal values, in which there is dependence on external values. The model discussed is univariate, so its construction strategy is based on an iterative cycle.

The method developed by Box; Jenkins (1970) consists of four steps for the formation of the iterative cycle. The first (specification) considers a general class of models, where it is expected that they represent the adequacy of the theoretical representation that is still unknown and will be confirmed in the future by the subsequent steps. The second step (identification) thus determines the p, q, and k values of the ARIMA function (p,q,k). The identification still consists of auto-correlation processes in the lag of actual past values and those estimated through the p and q values adopted in the process. The past series is associated with a confidence interval for the answers, as in other statistical processes.

The third step is the estimation, in which predictions are made for the given time horizon. A method is then adopted, the verisimilitude being the most recommended for parameter estimation. Finally, the diagnostic criteria for the series obtained are arrived at, with the Akaike criterion and the Schwarz criterion represented by equations (1) and (2). Profillidis e Botzoris (2019) defined the log likelihood function, represented by equation (3).

$$AIC = -2\frac{l}{T} + 2\frac{k}{T} \tag{1}$$

$$SIC = -2\frac{l}{T} + k\frac{\log(T)}{T} \tag{2}$$

$$l = -\frac{n}{2}(1 + \ln(2\pi) + \ln(\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2)) \tag{3}$$

in which:

log – log-verisimilitude;

l – the log likelihood function (assuming normally distributed errors), which is computed by the equation;

T – number of observations;

k – number of estimated parameters.

The Akaike criterion represented by equation (1) analyzes the divergence between the obtained model and the model said to be real. The Schwartz Criterion represented by equation 2 operates in the diagnosis as a measurement of existing noises, thus, the complete diagnosis is the set of analysis of these criteria, and it is expected that they are as small as possible, combined with the highest R^2. The proposal of the ARIMA method then consists of the cyclical repetition of the steps presented, until the moment when the diagnosis is considered with low noise or white noise.

3 MATERIAL AND METHOD

According to Ruse (2012), Karl Popper defined the hypothetical-deductive method as the process in which a provisional solution is offered, followed by criticism, thus generating a self-renewal of the scientific method. In this way, decisions have to agree with a procedure defined by rules, and the stopping points are testable statements, of acceptance or rejection, guiding the researcher to assign added values to these rules.

Starting from the method explained by Popper, the present work is based on previous knowledge, these being the set of policies of the automotive sector, the present criteria for the insertion of vehicles adopted, and the decarbonization goals, creating as a conjecture the insertion in the electric vehicle modal through an economic criterion, followed by the falsification phase that includes variations in the standard input parameters, assessing their impacts.

This research is classified, according to Mello; Turrioni (2007), as applied research by nature, considering that the results of this analysis may be relevant for defining transportation public policies in the national sense. The objectives of this research are descriptive relatively to the collection and systematization of several databases, as well as exploratory in terms of the proposition of possible scenarios considering economic and environmental aspects. The problem is then treated quantitatively by modeling and simulation techniques related to statistics and mathematical programming.

The Lingo software (LINDO SYSTEMS, 2006) was used to create and compile the model to adhere to the proposed optimization. The input data for the model were obtained from relevant government databases, highlighting the Ministry of Mines and Energy and The Ministry of Economy. Such data were treated econometrically in the EViews software (EVIEWS 11, 2020), even used by the current automobile planning program, to obtain parity of analysis for the forecasts. Finally, Microsoft Excel software (MICROSOFT EXCEL, 2019) was used as an interface between the others, even allowing the inference of scenario conditions.

Frame 2 correlates the variables and their explicit meanings. The variables exposed in Frame 2 are related by equations 4 to 18.

Frame 2 – Control variables and explicit meanings

$BAF_{\_X}$	total Brazilian automotive fleet in the year X	[1]
$BAF_{\_C\_X}$	fraction of Brazilian automotive fleet ICE vehicles in the year X	[1]
$BAF_{\_C\_GAS\_X}$	fraction of Brazilian automotive fleet ICE vehicles burning gasoline in the year X	[1]
$BAF_{\_C\_ETHANOL\_X}$	fraction of Brazilian automotive fleet ICE vehicles burning ethanol in the year X	[1]
$BAF_{\_E\_HEV\_X}$	fraction of Brazilian automotive fleet hybrid electric in the year X	[1]
$BAF_{\_E\_PEV\_X}$	fraction of Brazilian automotive fleet electric vehicles in the year X	[1]
$CC_{\_esp\_auto\_X}$	specific autonomy of internal combustion vehicles burning gasoline as a fuel source	km/l
$Dist_{\_x}$	average distance traveled by a vehicle in the year X	km
$EMI_{\_BAF\_X}$	emissions of Brazilian automotive fleet vehicles in the year X	10^6kg CO_2/year
$EMI_{\_BAF\_C\_X}$	emissions of Brazilian automotive fleet ICE vehicles in the year X	10^6kg CO_2/year
$EMI_{\_BAF\_C\_ETHANOL\_X}$	emissions of Brazilian automotive fleet ICE vehicles burning ethanol in the year X	10^6kg CO_2/year
$EMI_{\_BAF\_C\_GAS\_X}$	emissions of Brazilian automotive fleet ICE vehicles burning gasoline in the year X	10^6kg CO_2/year
$EMI_{\_BAF\_E\_HEV\_X}$	emissions of Brazilian automotive fleet hybrid electric vehicles in the year X	10^6kg CO_2/year
$EMI_{\_BAF\_E\_PEV\_X}$	emissions of Brazilian automotive fleet electric vehicles in the year X	10^6kg CO_2/year
$EMI_{\_EE\_X}$	emissions of Brazilian electric mix in the year X	10^6kg CO_2/year
$PEV_{\_ELE\_consumption\_X}$	electricity consumption by the per fleet in the year X	kWh
$PEV_{\_esp\_auto\_X}$	ratio mileage traveled by a per vehicle per electricity consumption	km/kWh

Source: the Author.

Equation (4) presents the system minimization objective function, which corresponds to the sum of the emissions of the years considered in the system (2020 to 2050); the emission of the Brazilian automotive fleet in a given year X, described in terms of the ICE vehicles, hybrid vehicles, and electric vehicles Brazilian automotive fleet, is represented by equation (5).

$$\text{OF: MIN} \sum_{x=2020}^{2050} EMI_{\_BAF\_X} \quad (4)$$

$$EMI_{\_BAF\_X} = EMI_{\_BAF\_C\_X} + EMI_{\_BAF\_E\_PEV\_X} + EMI_{\_BAF\_E\_HEV\_X} \quad (5)$$

For the plug-in vehicles, the specific autonomy data related to the battery's electric energy and the corresponding emission factor of the Brazilian Mix was used (see Appendix E). For hybrid and conventional vehicles, it was necessary to relate their specific range in km/L of the given fuel to its equivalent emission. Due to the peculiarity of Brazil in the use of ethanol and the consequent existence of flex vehicles, it was necessary to segment this relationship in equation (6). Equations (7) and (8) are related to the numbers corresponding to each vehicle category in a year, which is determined by the program with the relationship exposed by equation (5). The objective function is subjected to equations (6) to (21)

$$EMI_{\_BAF\_C\_X} = EMI_{\_BAF\_C\_ETHANOL} + EMI_{\_BAF\_C\_GAS} \quad (6)$$

$$BAF_{\_X} = BAF_{\_C\_X} + BAF_{\_E\_HEV\_X} + BAF_{\_E\_PEV\_X} \quad (7)$$

$$BAF_{\_C\_X} = BAF_{\_C\_ETHANOL\_X} + BAF_{\_C\_GAS\_X} \quad (8)$$

$$BAF_{\_Y\_(X+1)} = BAF_{\_Y\_X} * growth_{\_Y\_X} \quad (9)$$

$$BAF_{\_c\_gas\_(X+1)} >= BAF_{\_c\_gas\_X} - BAF_{\_X}*BAF_{\_growth\_(X+1)} \quad (10)$$

$$BAF_{\_c\_etanol\_(X+1)} >= BAF_{\_c\_etanol\_X} - BAF_{\_X}*BAF_{\_growth\_(X+1)} \quad (11)$$

$$BAF_{\_e\_hev\_(X+1)} >= BAF_{\_e\_hev\_X} - BAF_{\_X}*BAF_{\_growth\_(X+1)} \quad (12)$$

$$BAF_{\_e\_pev\_(X+1)} >= BAF_{\_e\_pev\_X} - BAF_{\_X}*BAF_{\_growth\_(X+1)} \quad (13)$$

$$EMI_{\_BAF\_c\_gas\_X} = EMI_{\_gas} * BAF_{\_c\_gas\_X} * (Dist_{\_X}/CC_{\_esp\_auto\_X}) \quad (14)$$

$$EMI_{\_BAF\_c\_etanol\_X} = EMI_{\_etanol} * BAF_{\_c\_etanol\_X} * Yeld_{\_etanol\_X} * (Dist_{\_X}/CC_{\_esp\_auto\_X}) \quad (15)$$

$$EMI_{\_BAF\_c\_X} = EMI_{\_BAF\_c\_gas\_X} + EMI_{\_BAF\_c\_etanol\_X} \quad (16)$$

$$EMI_{\_BAF\_e\_hev\_X} = EMI_{\_gas} * BAF_{\_e\_hev\_X} * (Dist_{\_X}/HEV\_BAF_{\_esp\_auto\_X}) \quad (17)$$

$$EMI_{\_BAF\_e\_pev\_X} = EMI_{\_EE\_X} * BAF_{\_e\_pev\_X} * (Dist_{\_X}/PEV\_BAF_{\_esp\_auto\_X}) \quad (18)$$

$$EMI_{\_BAF\_X} = EMI\_{}_{BAF\_c\_X} + EMI\_{}_{BAF\_e\_hev\_X} + EMI_{\_BAF\_e\_pev\_X} \quad (19)$$

$$PEV_{\_E\_Consumption\_X} = BAF_{\_e\_pev\_X} * (Dist_{\_X}/PEV\_BAF_{\_esp\_auto\_X} \quad (20)$$

$$BAF_{\_e\_pev\_X <=} BAF_{\_X}*(0.10) \quad (21)$$

In equation (9), y corresponds to the categories conventional, hybrid, and plug-in, and x to time. Growth is the variable determined by EViews prediction. Thus, the program determines by the growth of the automotive fleet, which will be the fleet in year X + 1 by equation (4). Returning to equation 6, the program distributes the fleet in its divisions: conventional, hybrid, and pure electric.

Equations (10), (11), (12), and (13) represent restrictions on the continuity of the automotive fleet in its sectoral division. Thus, the maximum variation of a category from one year to the other is restricted to the variation of the automotive fleet in the given year, preventing the program from inadvertently modifying the automotive fleet. In the initial year, 2018, the distribution of technical vehicle categories is an input in subsequent years, this was obtained by the program, and as a use in the annual calculation, the one from the previous year was used, obviated by the restrictions of the program, explicated by equations (7) and (8).

Equations (14) to (19) are associated with the calculation of emissions related to each portion of the Brazilian automotive fleet, in a given year X. Therefore, the sum of all years is the accumulated emission, an objective function of the optimization program. The emission of the automotive fleet was segmented into three sectors analyzed: respective to conventional vehicles, hybrid vehicles and purely electric vehicles, due to the determination of their emissions to be different. The average distance traveled during the year was 12,900 km, according to Fenabrave (2019), in the preliminary moment. In a later stage, the global consideration shown in Figure 8 was inserted, with the distance covered according to the global growth trend. The specific autonomy in the preliminary moment was adopted as 11km/l and this specific autonomy value was later refined with the values from the PBE tables.

Equation (20) represents the electrical energy consumption of pure electric vehicles. The accumulated analysis of electric energy consumption as a function of the insertion of electric vehicles represented by equation (20) aims, in the spiral construction step of the electric mix sensitivity analysis model, to permeate the effect of change when considering the electric supply directly from large stations generators, not considering distributed solar generation stations. Equation (21) presents the limitation imposed by the consideration of C2050 regarding the insertion of electric vehicles.

3.1 BRAZILIAN AUTOMOTIVE FLEET DATABASE

To make predictions and forecasts about the Brazilian automotive fleet, a survey was carried out based on Fenabrave yearbooks, discriminating the automotive route in different approaches. Table 4 shows the evolution of the automotive fleet and its regional distribution.

Table 4 – Brazilian Automotive Fleet Evolution and Regionalization

	Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Brazil	Fleet [10^3]	24,731	25,955	27,465	28,550	31,778	34,032	36,601	39,150	41,893	44,529	49,403	51,195	52,750	54,466	56,455
	Age [years]	13.00	13.40	12.70	13.30	12.70	12.80	12.80	12.90	12.90	13.10	12.90	13.40	13.90	14.40	14.80
Midwest	Fleet [10^3]	1,858	1,925	2,059	2,156	2,459	2,676	2,924	3,165	3,434	3,698	4,142	4,314	4,460	4,618	4,809
	Age [years]	12.00	12.60	11.80	12.30	11.60	11.50	11.40	11.50	11.50	11.60	11.50	12.00	12.50	13.00	13.50
Northeast	Fleet [10^3]	2,578	2,641	2,843	2,988	3,389	3,694	4,078	4,460	4,897	5,317	6,070	6,390	6,655	6,941	7,248
	Age [years]	11.00	11.40	10.50	11.10	10.40	10.40	10.30	10.40	10.40	10.50	10.40	10.90	11.40	11.90	12.40
North	Fleet [10^3]	561	596	667	709	823	912	1,019	1,119	1,227	1,334	1,520	1,602	1,664	1,732	1,817
	Age [years]	10.00	10.40	9.30	9.80	9.10	9.10	9.00	9.00	9.10	9.30	9.30	9.80	10.40	10.90	11.30
Southeast	Fleet [10^3]	14,226	15,105	15,918	16,489	18,238	19,411	20,716	22,002	23,342	24,613	27,070	27,932	28,714	29,583	30,585
	Age [years]	14.00	13.70	13.00	13.60	13.10	13.20	13.30	13.40	13.50	13.70	13.60	14.10	14.60	15.10	15.50
South	Fleet [10^3]	5,508	5,686	5,977	6,207	6,866	7,337	7,862	8,403	8,991	9,566	10,599	10,956	11,255	11,590	11,994
	Age [years]	14.00	14.30	13.60	14.30	13.70	13.80	13.80	13.90	13.90	14.00	13.80	14.20	14.80	15.30	15.70

Source: the Author – Compilation of FENABRAVE’s Yearbooks.

In the Yearbooks, there are sales data from the most significant automakers. From 2004 to 2009, the 8 most significant ones are shown, 12 are shown in 2012, and 10 in the other years leading to 2018. The data provided by FENABRAVE (2020) can be seen in Table 5 and Table 6.

Table 5 – Brazilian Manufacturers Market Share

	Unit sales values by the manufacturer								
Year	VW	Fiat	GM	Ford	Renault	Honda	Toyota	Nissan	Hyundai
2004	294,908	304,811	325,230	114,006	50,247	50,403	42,371	No data	No data
2005	323,407	344,939	329,558	133,954	43,878	56,517	44,000	No data	No data
2006	371,848	405,763	374,012	141,453	47,906	66,693	44,432	No data	No data
2007	489,712	523,512	444,849	175,105	69,907	83,878	43,683	6,879	No data
2008	526,051	557,994	468,378	191,578	110,796	109,634	49,378	10,210	No data
2009	626,127	619,639	502,242	235,028	113,622	114,610	68,184	No data	20,984
2010	601,490	612,101	561,686	265,061	154,482	107,676	55,732	No data	44,017
2011	586,104	597,223	529,139	244,029	174,366	76,597	No data	53,536	62,328
2012	651,231	679,976	535,621	255,420	180,698	120,036	63,576	87,188	62,965
2013	539,059	605,003	540,545	238,226	170,861	130,990	116,691	62,215	174,776
2014	471,424	505,433	492,186	282,784	219,879	137,884	152,062	60,767	228,433
2015	290,434	316,319	330,976	236,672	166,351	153,367	142,862	55,457	198,464
2016	185,314	190,398	304,541	164,402	127,536	122,541	146,337	57,300	193,540
2017	217,696	172,454	348,786	188,893	148,480	131,085	155,188	74,760	197,914
2018	302,155	183,343	389,485	205,844	193,040	131,592	160,800	91,180	202,355

Source: the Author – Compilation of FENABRAVE’s Yearbooks.

Table 6 expose the relationship between the hole sales per year and the participation of the top 10 manufacturers in the way to conduce to a reduced but valid sample to study the parameters of the Brazilian automotive fleet.

The year 2014 stands out in Table 6. Although it was a year of low sales, FENABRAVE started to classify Sport Utility Vehicle (SUV) vehicles as light vehicles instead of light commercial vehicles. Such adherence was justified by the Federation in consonance with the effective use of such vehicles. The 10 manufacturers listed as most expressive in the country have at least 87% of market share, attesting that for market analysis, the monitoring of these allows adequate general visibility. Honda is highlighted in Table 5 for the year 2011, with its substandard sales below average, due to climatic problems that occurred in Japan.

Table 6 – Brazilian Manufacturers Percentual Participation.

Year	**BRAZIL** (Vehicles [1])	**Percentage of Top 10** (%)	**Growth** (%)
2004	1,252,821	94.3451618	-
2005	1,369,093	93.2188683	4.951
2006	1,557,244	93.2485211	5.818
2007	1,977,135	92.9387725	3.952
2008	2,195,425	92.1925823	11.304
2009	2,479,245	92.787764	7.093
2010	2,651,799	90.5892566	7.550
2011	2,645,597	87.8184395	6.965
2012	2,841,882	92.7804532	7.005
2013	2,755,063	93.5864625	6.294
2014	2,795,147	91.2600303	10.944
2015	2,122,657	89.0818441	3.628
2016	1,688,149	88.3754337	3.038
2017	1,855,870	88.1126372	3.253
2018	2,101,837	88.4842164	3.651

Source: the Author – Compilation of FENABRAVE’s Yearbooks.

Table 7 exposes the participation of each segment of Brazil’s Market Share in the automotive sector. The data is a compilation of FENABRAVE's yearbooks (2020). For each yearbook, the value of the year and its four predecessors are shown and according to the institution, the data disagreement is due to the deadlines for closing the manufacturers' reports, so the most recent data has always been adopted. In the 2014 yearbook, SUV vehicles were classified as light cars, so there has been a reclassification from 2010, which is considered in the present work.

Table 7 – Vehicles Categories Share

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Entrance	0.4804	0.4484	0.4285	0.4089	0.4	0.3829	0.3664	0.3272	0.3131	0.2589	0.2507	0.2347	0.2068	0.2043	0.1736
Hatch Small	0	0.1552	0.1525	0.1478	0.1437	0.1424	0.1759	0.1719	0.1997	0.2504	0.2463	0.236	0.2644	0.2695	0.2859
Hatch Medium	0.0516	0.0475	0.0441	0.0543	0.0687	0.066	0.0744	0.0665	0.0529	0.0457	0.0356	0.029	0.0195	0.011	0.0063
Sedan Small	0.1323	0.1426	0.1463	0.1676	0.1666	0.1948	0.1862	0.1508	0.1391	0.1659	0.1741	0.1721	0.1683	0.1486	0.1399
Sedan Compact	0.0314	0.0226	0.0207	0.0227	0.0185	0.0263	0.0357	0.0308	0.0471	0.0391	0.0346	0.0286	0.0242	0.0217	0.0446
Sedan Medium	0.0555	0.0544	0.0759	0.082	0.0925	0.078	0.0665	0.072	0.0819	0.0761	0.0854	0.0895	0.0869	0.0825	0.0675
Sedan Big	0.0047	0.0054	0.0061	0.0042	0.0061	0.007	0.0072	0.0106	0.0057	0.0065	0.006	0.0079	0.0058	0.0049	0.0049
SW Medium	0.0307	0.0365	0.0426	0.0405	0.0379	0.0371	0.0238	0.0197	0.0179	0.0136	0.0102	0.0084	0.0058	0.003	0.0042
SW Big	0.0048	0.0064	0.0062	0.0082	0.0045	0.0018	0.0017	0.0041	0.0036	0.0002	0.0001	0.0006	0.0007	0.0005	0.0004
Mono Cabinet	0.0503	0.052	0.0607	0.0497	0.0479	0.0524	0.0521	0.0423	0.0388	0.0325	0.0344	0.0304	0.0229	0.0169	0.0157
Grand Cabinet	0.028	0.0234	0.0157	0.0132	0.0125	0.0105	0.0087	0.0073	0.01	0.015	0.014	0.0132	0.0139	0.0137	0.0123
Sport	0.0004	0.0005	0.0007	0.0007	0.0008	0.0009	0.0012	0.0017	0.0009	0.0012	0.001	0.001	0.0011	0.0007	0.0011
SUV	0	0	0	0	0	0	0.0763	0.0949	0.0892	0.0949	0.1077	0.1487	0.1798	0.2227	0.2438

Source: the Author – Compilation of FENABRAVE’s Yearbooks.

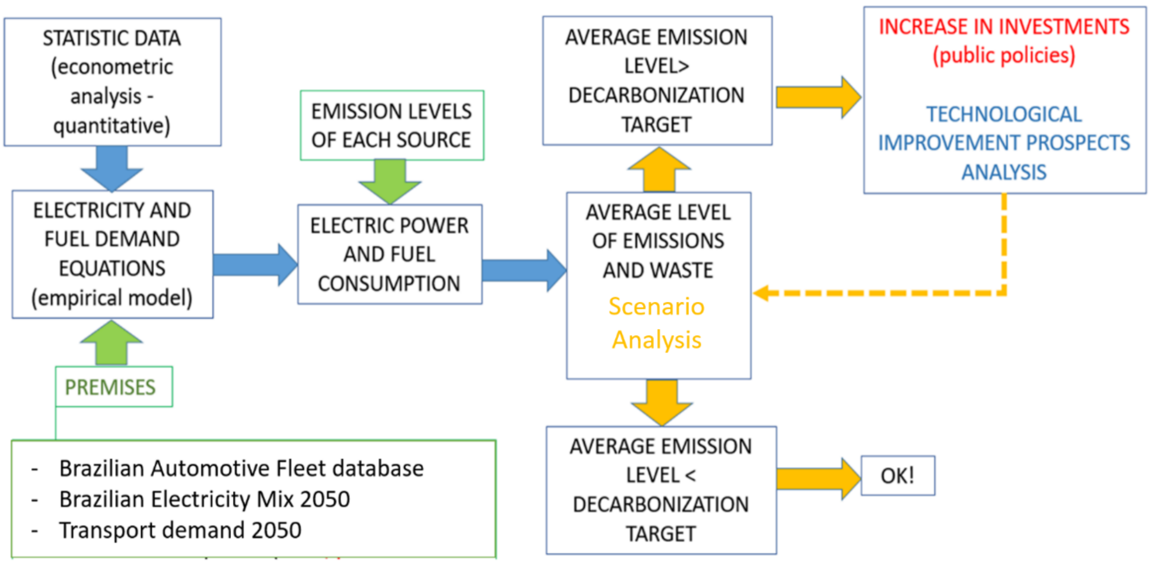
3.2 EMPIRICAL MODELING

The proposed model incorporates data from both macroeconomic relationships and technological aspects, conceptualized respectively as Top-Down and Bottom-Up approaches. Consequently, the model is defined as a hybrid model. Given the overall concept of the analysis, we can segment the system power variables as:

- Top-Down: the ones analyzed by econometrics quantification. Brazilian Electric Mix (considering the participation of each energy source and their respective costs), taxes (regional and federal taxes for fuels, purchase, and maintenance of automobiles), Brazilian Automotive Fleet evolution, segmenting it in manufacturers and vehicles categories.
- Bottom-Up: technological improvement of Electric-Vehicles (efficiency, autonomy, and recycling batteries).
- General Data: Emissions levels of each source and decarbonization target.

Considering such input data, it is possible to determine emission levels in a standard, optimistic and pessimistic scenario. In addition, the arbitrary consideration of technological improvement and public policy investments allows for system feedback to create alternative scenarios to achieve targets. The proposed connection between the data is shown in Figure 18.

Figure 18 – Empirical Model Concept

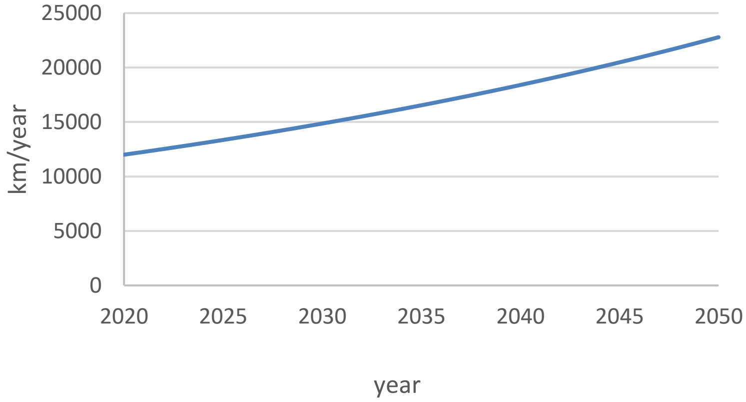


Source: the Author.

With the analysis of Figure 18, it is possible to understand the logical path of model design in the Lingo Software. The blue path establishes the basic design of the model, susceptible to the influences of the input variables, indicated by the green arrows. From the level of emissions indicated, it is possible to start from two conditions (as indicated in yellow) of adherence to the decarbonization target or not. In the event of failure, two aspects of the premises – public policies, and inspection of technological improvements – are modified. The investment aspect was chosen as a possibility for direct government action in pricing and infrastructure to achieve decarbonization goals. The technological aspect, on the other hand, intends to cover the possibilities of technological disruptions, considering research in electric automobiles that favor its implementation.

The assumptions of the system are presented in each row step of the system implementation process, as they present variable econometric characteristics, such as trend, seasonality, cycle, and random term. Section 3.1 detailed the database regarding the Brazilian automotive fleet. For the emissions from each source, the PBE data presented was used. Section 2.14 presented the form of detailing the emissions related to the Electric Mix, and the results related to the considered scenarios are presented in Section 4.4. Figure 8 represents the distance survey used to calculate emissions as a function of the number of vehicles. The Brazilian calculator does not have a section aimed at the transport sector, like the European one. The Brazilian Government adopts the value of 12,000 km/year as a calculation base, a value considered in the simulation stages up to the sensitivity analysis stage of the electrical mix projection. Based on the same growth factor adopted by the European Union, the value of 12,000 km up to the year 2050 was extrapolated to the Brazilian scenario, as represented by Figure 19.

Figure 19 – Average distance forecast



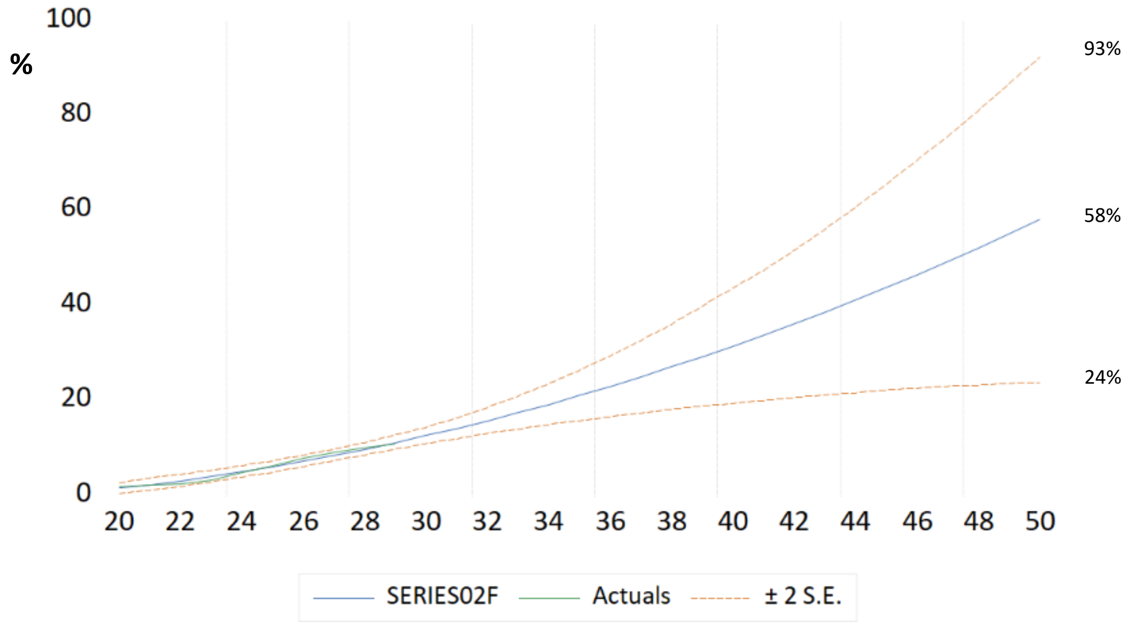
Source: the Author.

According to Neves (2014), when considering the emission factors when in its complete chain, gasoline emits 2.31 kg_{CO2}/l and ethanol 0.355 kg_{CO2}/l, unlike the RenovaBio program, which considers the emission factor for ethanol to be null. This approach was chosen in the present work to approach a more realistic consideration.

As a metric for verifying the effectiveness of the emission reductions program, the Ministério de Minas e Energia (2017) defined a decarbonization target of 11% concerning the year 2017 for the year 2029. The intermediate annual values are in the public domain, and from such data, it was forecasted a projection for the year 2050 by adopting the ARMA method to obtain a level of comparison following the current biofuels program, as shown in Figure 20. Figure 21 shows the stats of the obtained forecast adopting the autoregressive–moving-average (ARMA) method.

From Figure 20 in the ARMA analysis, 'SERIES02F' represents the projection of the achieved decarbonization target, and 'Actuals' are the values stipulated by RenovaBio considering the Standard Error (+- 2 S.E.), a regression that fits the R-squared value of 0.99. The decarbonization target of 58% for 2050 was obtained, with a range of 93% and 24% (confidence interval). So, this is the target and consequently the control value of the model. From Figure 21 we have the Adjusted R-squared as 0.98, thus attesting the forecast made by the least-squares method as adequate.

Figure 20 – Decarbonization target, in % (from 2020 to 2050)



Source: the Author, database Ministério de Minas e Energia (2017) - Eviews software.

Figure 21 –Decarbonization target – Stats

Dependent Variable: SERIES02
Method: ARMA Maximum Likelihood (OPG - BHHH)
Date: 08/10/20 Time: 03:35
Sample: 2019 2029
Included observations: 11
Convergence achieved after 25 iterations
Coefficient covariance computed using outer product of gradients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.898146	1.387021	0.647536	0.5413
@TREND	0.645601	0.393552	1.640445	0.1520
@TREND^2	0.038804	0.028712	1.351473	0.2253
AR(1)	0.565680	0.342450	1.651865	0.1497
SIGMASQ	0.112780	0.117043	0.963575	0.3725

R-squared	0.990308	Mean dependent var	5.500000
Adjusted R-squared	0.983847	S.D. dependent var	3.577709
S.E. of regression	0.454712	Akaike info criterion	1.599710
Sum squared resid	1.240579	Schwarz criterion	1.780572
Log likelihood	-3.798407	Hannan-Quinn criter.	1.485702
F-statistic	153.2665	Durbin-Watson stat	0.939087
Prob(F-statistic)	0.000004		

Inverted AR Roots	.57

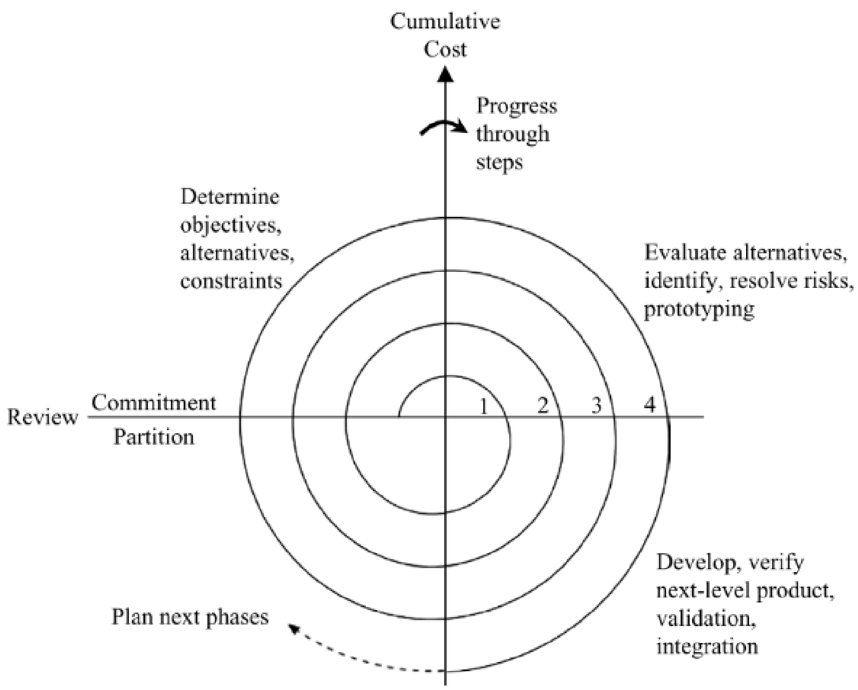
Source: the Author – Eviews software.

3.2.1 Model validation

Boehm et al. (1987) proposed a software development methodology in improvement to the incremental model used until then, the so-called spiral model, thus symbolizing its line of reasoning that comprises a spiral, represented by Figure 22 passing successively through the stages of Definition of Objectives, Assessment and Risk Reduction, Implementation and Validation, and Planning and Specification.

Nilsson; Wilson (2012), in the analysis regarding the application of the model established by Boehm, found advantages in staged modeling. It is noteworthy that when going through verification points, greater reliability of answers is obtained, and the existence of versatility in the process, since in each verification step, in addition to diagnosing problems, it is possible to create alternative solutions, often not seen at the beginning of the design process.

Figure 22 –Boehm Spiral Model



Source: Nilsson; Wilson (2012).

For establishing the algorithm, the concept of spiral growth of the model was used, which is segmented in the main steps described.

4 RESULTS AND DISCUSSION

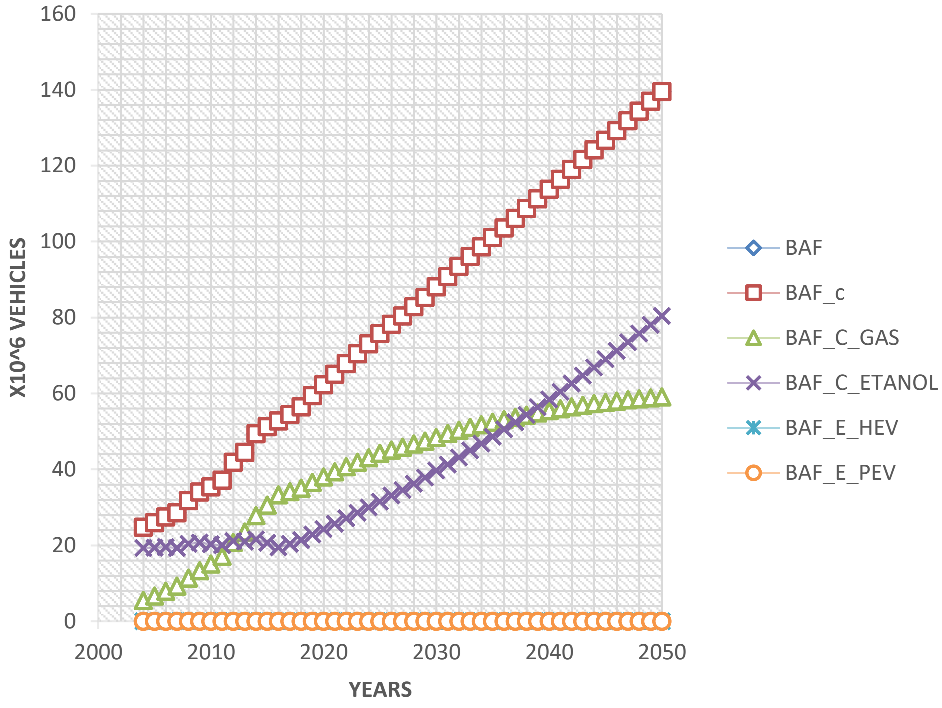
Is listed the feedback factors for the algorithm described in Figure 18 to meet decarbonization targets. The base modeling starts from the statistical data, and only then the sensitivity scenarios of +-30%, according to the premises of Ministério de Minas e Energia (2020) (see Appendix F) and the other possibilities highlighted in Figure 18 in red and blue are inserted.

4.1 MODEL VALIDATION

In the first step of the model's concept, it was adopted a one-year's validation, aiming to ensure the program logic and emissions values were correct. The design of the model is the minimization of emissions, programmed in the Lingo software, and for better visualization of the results obtained, the interaction with the Microsoft Excel software was necessary. As it is not a pre-established code, it was necessary to validate it, and for this, it was initially simulated the calculation of growth forecast and consequent emission for the years 2017-2018 to obtain the convergence between the emission result obtained by the model and the actual emissions in the period according to FENABRAVE (2020). An absolute number of the automotive fleet equal between the simulated and the database was obtained. The error obtained between the actual emission ($84.5x10^9$ kg_{CO2}/year according to RenovaBio (2019)) value and the one calculated with the algorithm (83.0 $x10^9$ kg_{CO2}/year) was 1.78%. This value validates the logic of the program, especially considering that the emission values of each source were approximated at this stage.

In a retroactive validation, it was sought to confirm the growth algorithm of the Brazilian automotive fleet. The absolute values of the retroactive Brazilian automotive fleet were obtained (FENABRAVE, 2020), and the participation of gasoline and ethanol as fuels referring to the analysis of the RenovaBio program. At this stage, a maximum limit of 10% participation of electric vehicles in the total modal was arbitrated, as represented by Equation (20). Driscoll (2013) presents the insertion values predicted for the forecast models to meet the Paris Agreement: the maximum target considered is 10%, this being the massive insertion. Values from 1 to 5% are considered as expected insertions, with 10% being the maximum level adopted by European governments. Figures 23 and 24 represent, respectively, the Brazilian automotive fleet predicted by RenovaBio and Fenabrave and the simulated one. About Lingo 10 API version 4.1.1.190 Stats the model class adopted was Linear Program, 13 variables, 281 constraints, generator memory used of 570K anda elapsed runtime of 9 seconds in a I7(8th gen) 16GB Ram machine.

Figure 23 – Data Prediction of Brazilian Automotive Fleet



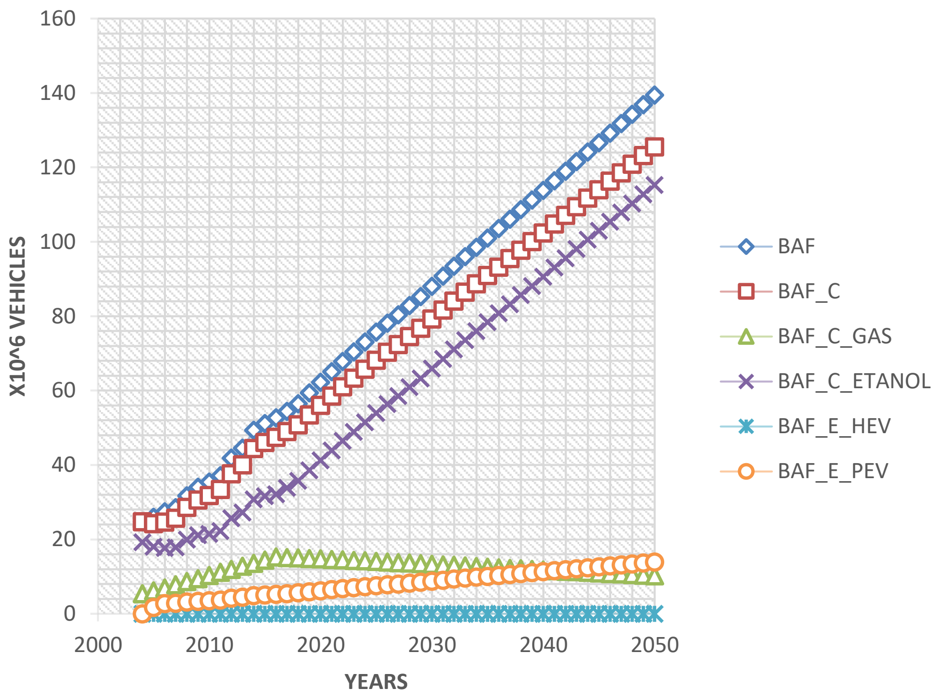
Source: compilation of Fenabrave (2020) and RenovaBio (2019).

Figure 23 represents a compilation between data obtained by Fenabrave (2020) and RenovaBio (2019), where the absolute value of the automotive fleet (BAF) is referred to Fenabrave, and the distribution between the use of ethanol (BAF_C_ethanol) and gasoline (BAF_c_gas) is given by RenovaBio's participation perspectives. The RenovaBio Program is set to a date in the year 2030; thus, the trend of participation of each fuel was explored until the year 2050 and represented in the graph to contemplate the same time level. It is noteworthy that as the mass insertion of electric and hybrid vehicles is not considered in the current Brazilian scenario, these segments (BAF_e_hev and BAF_e_pev) are considered null. Therefore, BAF and BAF_c are superimposed on the graph, meaning that the total of the Brazilian automotive fleet is composed of ICEV vehicles.

When the predictions of the model adopted by RenovaBio until the year 2050 are exploited following the growth patterns of Fenabrave; in the year 2036, the share of ethanol vehicles surpasses gasoline vehicles, being a first indicator of the importance of the use of ethanol in a sustainable transport scenario.

RenovaBio considered the growth of the automotive fleet, but in the simulation represented by Figure 24, the optimization algorithm developed in the Lingo software aiming the minimization of emissions related to the Brazilian automotive fleet as a whole describes the best scenario, the vehicle's technology distribution, according to the decarbonization target adopted. Thus, the objective function is to minimize total emissions over the period from 2004 to 2050, in the sum of emissions in tons of carbon dioxide per year.

Figure 24 – Model Validation Simulation



Source: the Author.

In Figure 24, which represents the validation of the model, the objective was to verify that the entire automotive fleet (BAF) converged with that represented in Figure 23, noting that the program had its growth parity in order with the perspectives of the institutions consulted. It was also allowed that the program had degrees of freedom to determine the distribution of vehicle categories since 2004 for verifying the correct trend in choosing the modal to minimize emissions. It is noteworthy that this step does not represent reality, as it is only possible to modify the distribution of the modal of vehicles from the year 2019. There is already a trend towards the insertion of electric vehicles allied to the use of ethanol in flex vehicles, thus providing a good perspective of analysis for the subsequent steps.

The annual carbon dioxide (CO_2) emission is a function of the Brazilian automotive fleet of each segment to its specific performance, the average distance traveled, and emissions from each source of energy relative to the listed segment. At this stage, both the specific yields and the average distances were considered constant, to permeate the system sensitivity, and only later to insert issues of technological temporal implementation in the fully validated model. The maximum value of insertion of E-V was 10% at this moment, considering existing models, and later this value will be self-determined by the simulator, with economic conditions.

4.2 PRELIMINARY PREVIEW

To fully validate the model of emissions minimization, a regression analysis was performed in terms of correlated emissions, as shown in Figures 24 and 25. At this point of validation, we can highlight the divergence of emission factors associated with sources, such as biomass. However, the linearity of the system ensures the robustness of the algorithm, being necessary only in the next step the refining of the associated emission factors.

In the total period (30 years), the cumulative emission of CO_2 without electric vehicles was 3,124,589.35 (10^6 kg_{CO2}) while when considering the insertion of electric vehicles was 2,424,986.03 ($10^6 kg_{CO2}$).

4.2.1 Insertion from 2019 to 2050

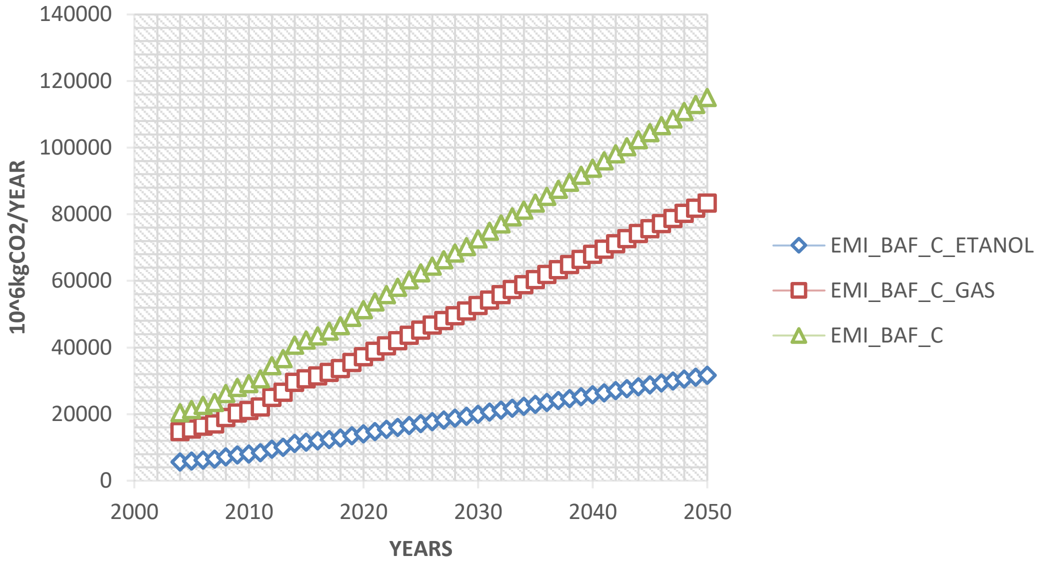
After proving the concomitance between the simulation and the real values of the Brazilian automotive fleet, a more realistic simulation was performed considering the insertion of electric vehicles from 2019, representing the proposed emission reduction policy. Results are exposed in Figures 26 and 27.

The simulation from 2019 presents a breaking point between the retroactive, from 2004 to 2018, and the moment of insertion of the low emission policy, showing already how the current Brazilian automotive scenario is not ecologically aligned but has very promising prospects of deeper studies.

Comparing Figure 25 to Figure 26, Brazil presents excellent perspectives on emission reductions when electric vehicles are implemented, mainly due to its Electric Energy Mix being of low CO_2 emission (see Appendix E). It remains in the evolution of the model the application of economic bias boundary conditions. With the steps completed so far, it was possible to check the validity of the model created, thus enabling the project follow-up to determine the possible scenarios until the year 2050 and its inherent public policies.

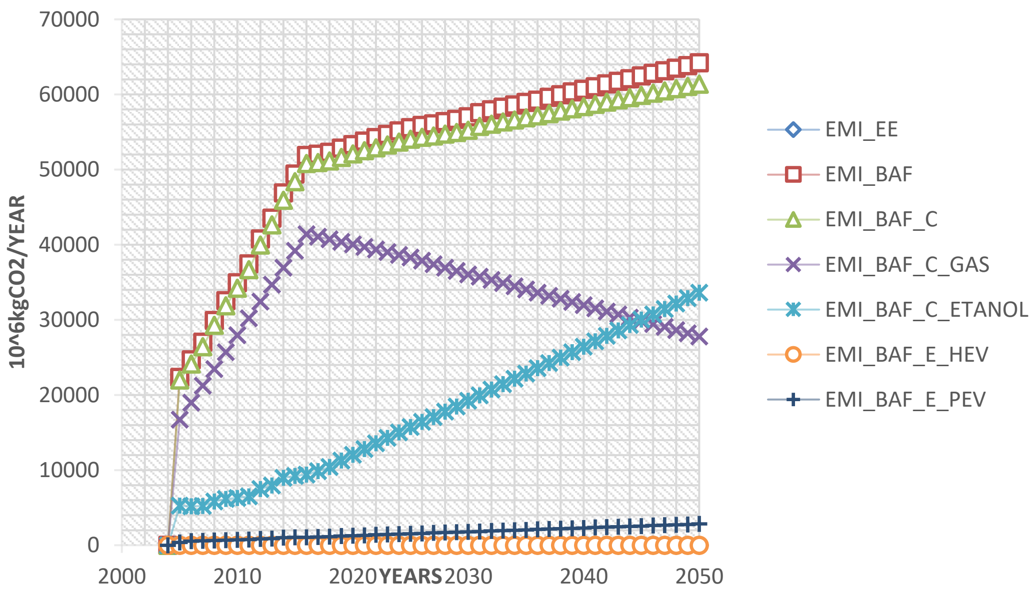
It is important to highlight that the already validated model can now be implemented in its proper forecasting period (2020-2050) and the preliminary simulation (2019-2050) that combined with an aggregate econometric assessment will bring the proposed perspectives within the project scope.

Figure 25 – Preliminary emissions without insertion of E-V



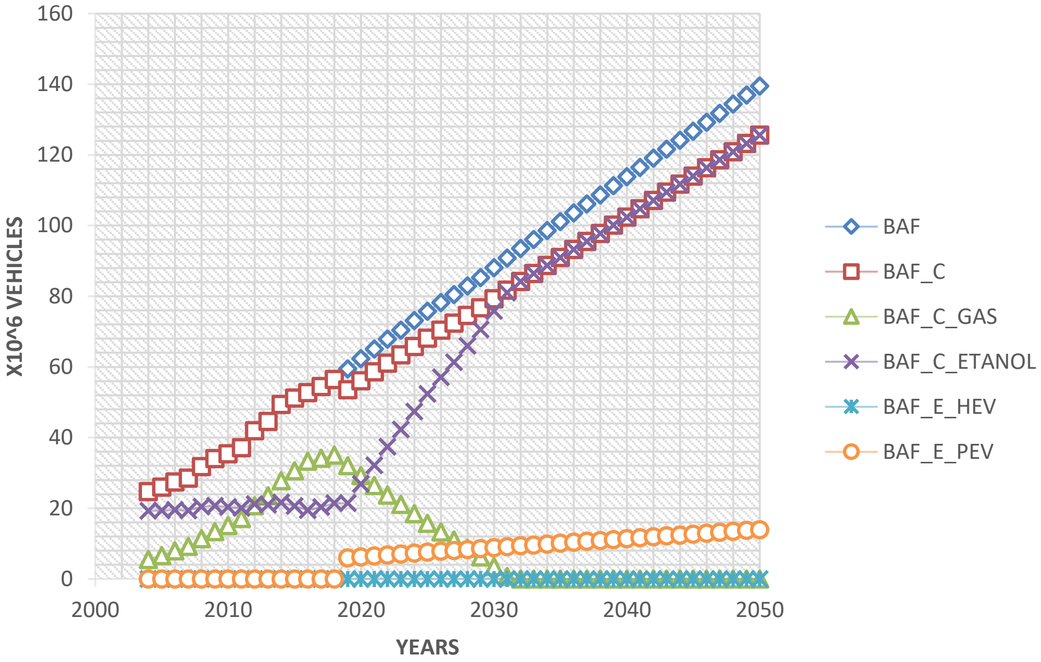
Source: the Author.

Figure 26 – Simulated emissions considering insertion of E-V since 2004



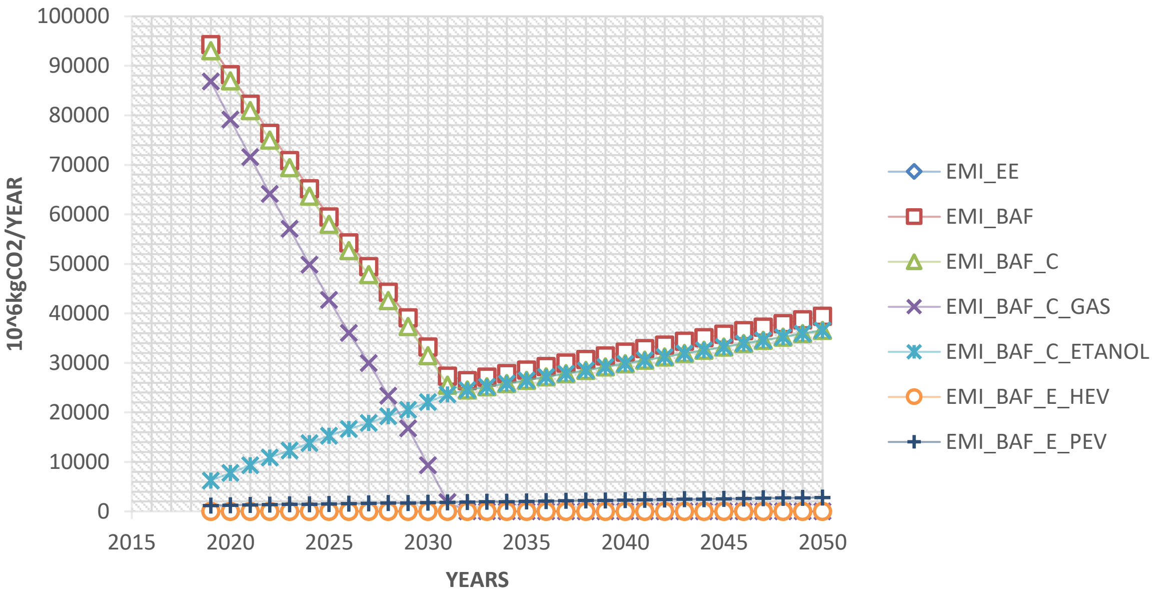
Source: the Author.

Figure 27 – Brazilian Automotive Fleet Simulation considering insertion of E-V from 2019 to 2050



Source: the Author.

Figure 28 – Simulated Emissions considering insertion of E-V from 2019 to 2050.



Source: the Author.

4.2.2 Spiral Remodeling

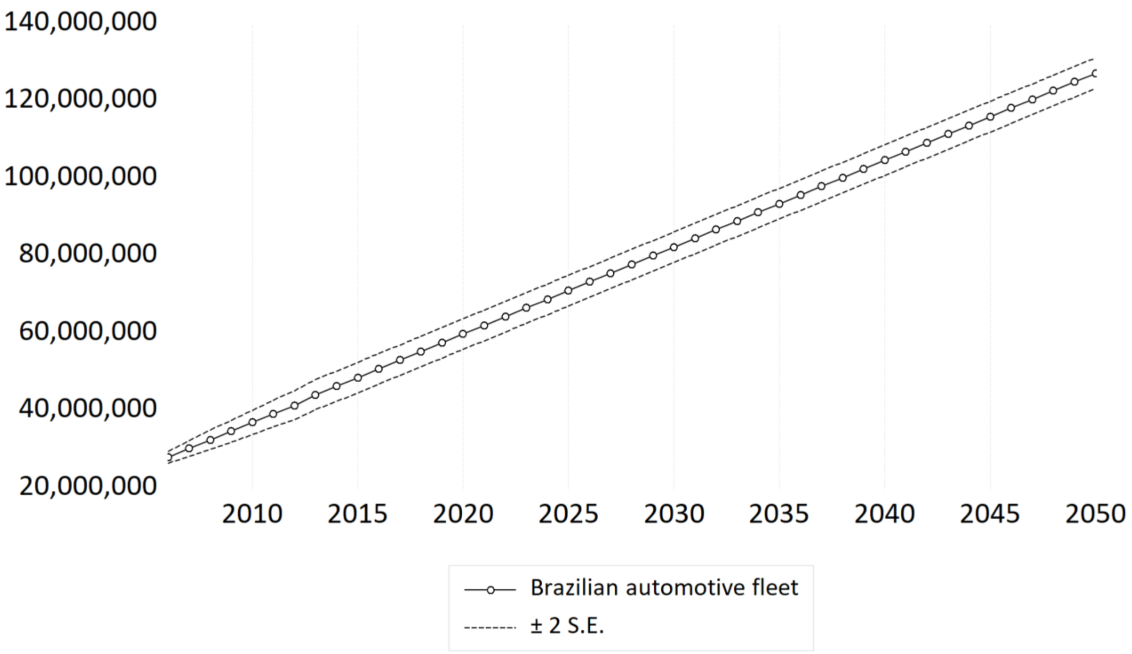
The analysis itself is dependent on macroeconomic values, highlighting the cost of electricity and the use of fossil fuels. Up to now, the values considered were forecasts obtained by third parties. The last step foresees these values with the Eviews 11 SVLite econometric software, and besides improving the model accuracy, it allows an interaction between the annual model forecasts and their consequences on the feedback economy itself, concluding so the approach of a hybrid prevision model.

In this stage of the model development, a refining of the input data is implemented. For the validation of the model, a base value of specific autonomy was used, now the data are obtained through a compilation of the yearbooks by FENABRAVE and PBE, through two different approaches.

Karpušenkaite et al. (2018) from an automotive waste analysis, demonstrated the relevance of mathematical models not based on a simple time series, attesting to the greater accuracy of hybrid modeling. Chauhan; Singh (2017) applied an autoregressive integrated moving average (ARIMA) model, explaining the need for testing autocorrelation indexes and lags to obtain a reliable forecast. From the repercussions proposed by Contreras et al. (2017) regarding risks, the ARIMA series (1.1.1), (1.1.8), (8.1.8), and (8.1.8) were applied, being selected for home prediction the most assertive option was selected according to with Correlogram D (segment) and the Least Squares method. The criteria for choosing the best method are, in order, the lowest volatility, the highest r-square, the lowest Akaike Info Criterion, and the lowest Schwartz Criterion. For the growth of the automotive fleet as a whole, the retroactive data from Table 2 was used, and the forecast is shown in Figure 29. From Figure 29, it is possible to infer a substantial expected growth of the auto fleet, however, it considers the fleet. Thus, in the next stages, such a fleet will be sub-segmented to meet the inherent peculiarities.

In Figure 29, in addition to the forecast by the EViews software be identical to the data obtained by RenovaBio, the confidence interval (+- 2 S.E. – Standard Error) was small, attesting to a linear and valid time series to be used as an objective value for the composition of the fleet automotive until the year 2050.

Figure 29 – Brazilian automotive fleet forecast from 2019 to 2050



Source: the Author.

4.3 ELECTRICITY MIX PROJECTION

As the focus is not the responsibility of the electric power generation but the effect of emissions in favoring the insertion of electric vehicles, three scenarios were listed, and their levels are shown in Frame 3. Frame 3 exposes the composition of the considered scenarios: Base Scenario (SC1), Emission Maximization Scenario (SC2), and Emission Minimization Scenario (SC3) (see Appendix E for details of Electricity Mix composition)

In the first scenario, all factors remained at the lower level, that is, disregarding policy influences, thus being the basic trend in electricity emissions. In SC2, the factors were chosen to tend the electric mix to maximize emissions, the less sustainable base and consequently which less favors the insertion of electric vehicles. In contrast, SC3 considers the most environmentally sustainable choices to be the best scenario for E-V. Between SC2 and SC3 the possible emission scenarios are understood, and consequently covering the countless possible scenarios.

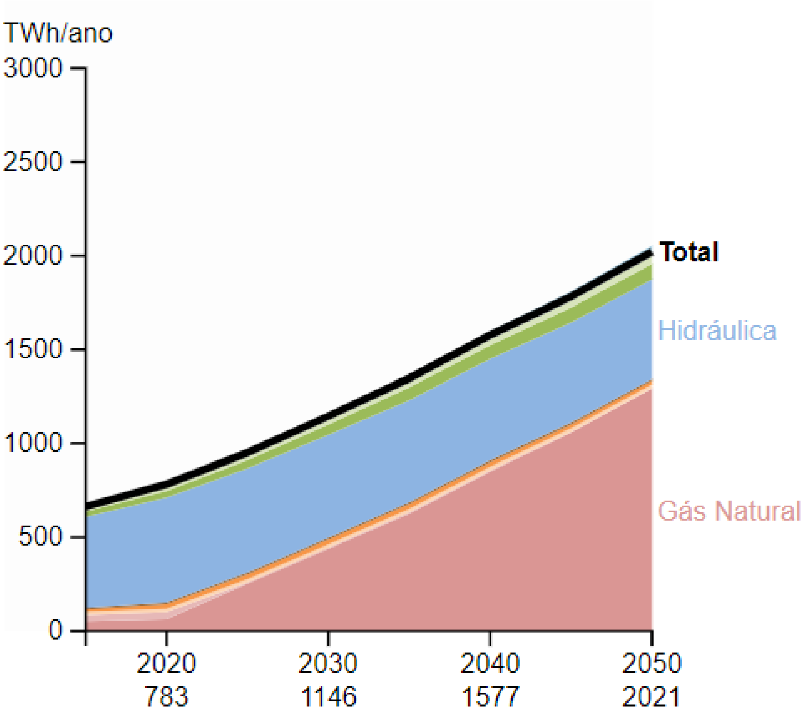
Frame 3 - Internal energy supply scenarios

Factor	Base Scenario (SC1)	Max Emissions Scenario (SC2)	Min Emissions Scenario (SC3)
Natural gas power generation – installed capacity	1	1	2
Natural gas power generation – Carbon Capture and Storage	1	1	3
Coal-fired power stations - installed capacity	1	3	1
Coal-fired power stations - Carbon Capture and Storage	1	1	3
Fossil fuel power station	1	3	1
Utilization of biomass and biogas	1	1	3
Use of surplus sugarcane bagasse	1	1	3
Priority of biogas use	A	A	C
Efficiency of biofuel plants	1	1	3
Nuclear energy	1	1	3
Onshore wind energy	1	1	3
Offshore wind energy	1	1	2
Ocean Energy	1	1	3
Hydraulic energy	1	1	3
Photovoltaic solar energy	1	1	3
Heliothermic solar energy	1	1	3
Binational hydroelectric plants importing	1	1	3
Electrical system security	1	1	3
Oil and associated gas production	A	A	D
Unassociated natural gas production	1	1	3

Source: the Author.

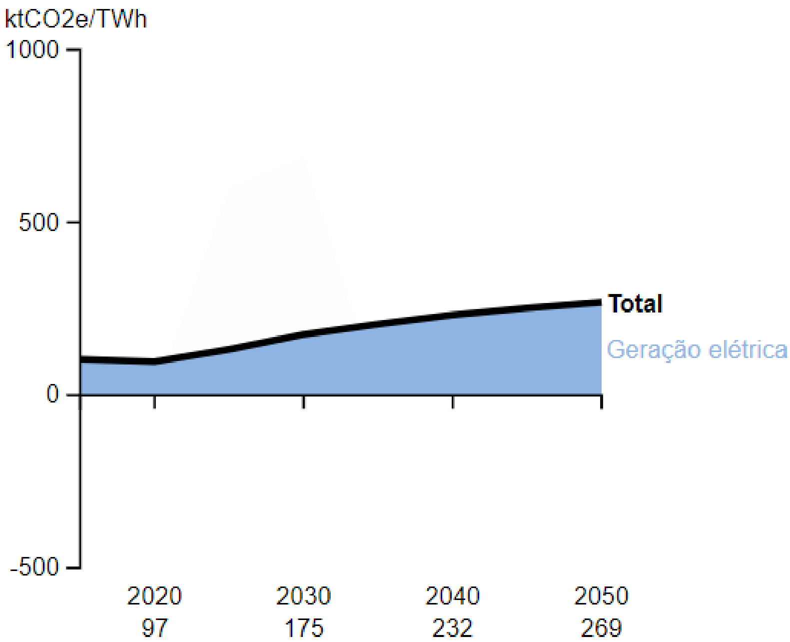
Figures 30 to 35 expose the elucidated scenarios. The first pair relates to the base scenario, the second to the scenario of maximizing emissions, and the third pair to the scenario of minimizing emissions.

Figure 30 – Internal energy supply in Scenario1



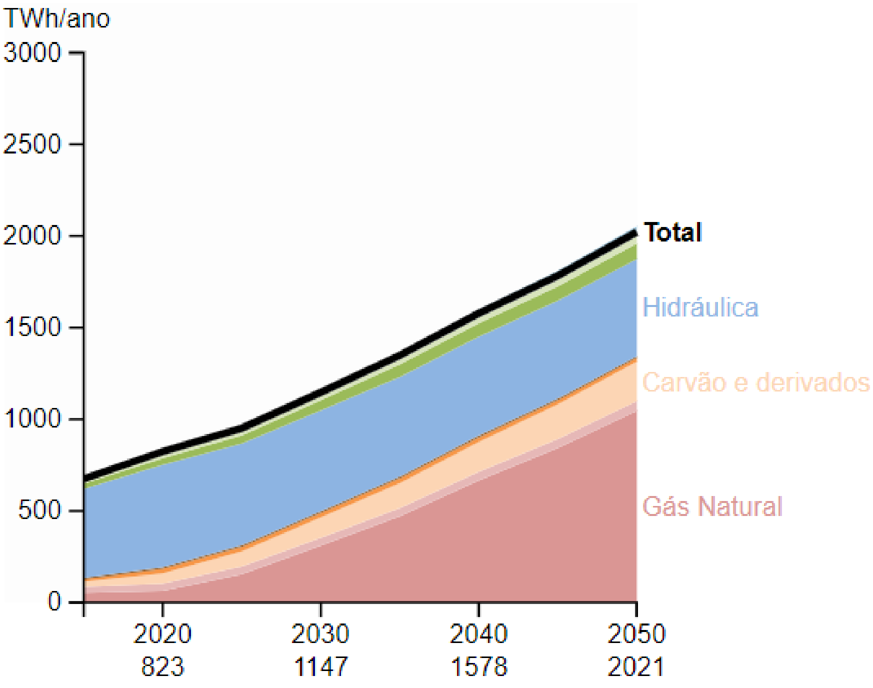
Source: the Author – using Calculator2050 (2021).

Figure 31 – Intensity of electricity emissions in Scenario 1



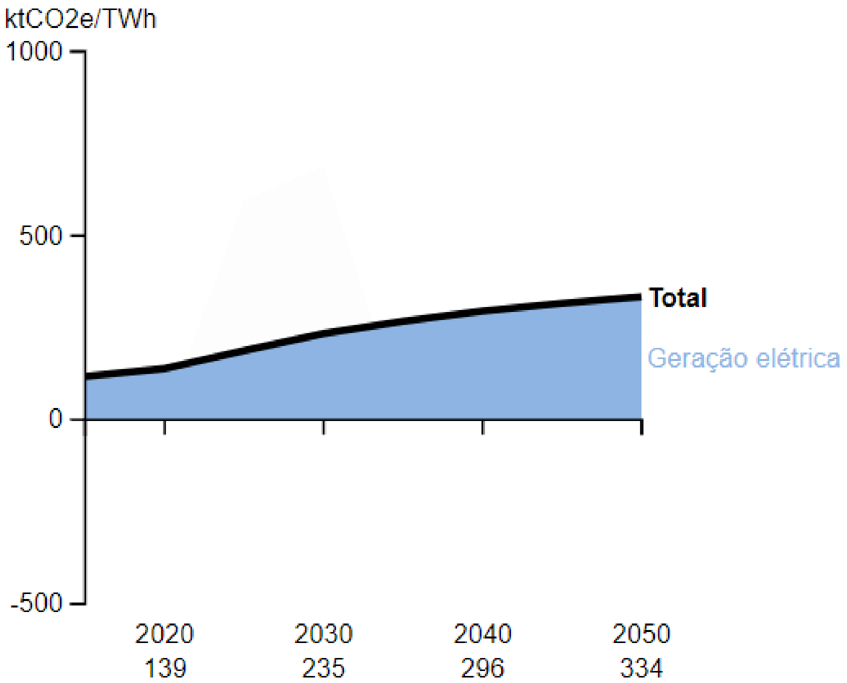
Source: the Author – using Calculator2050 (2021).

Figure 32 – Internal energy supply in Scenario 2



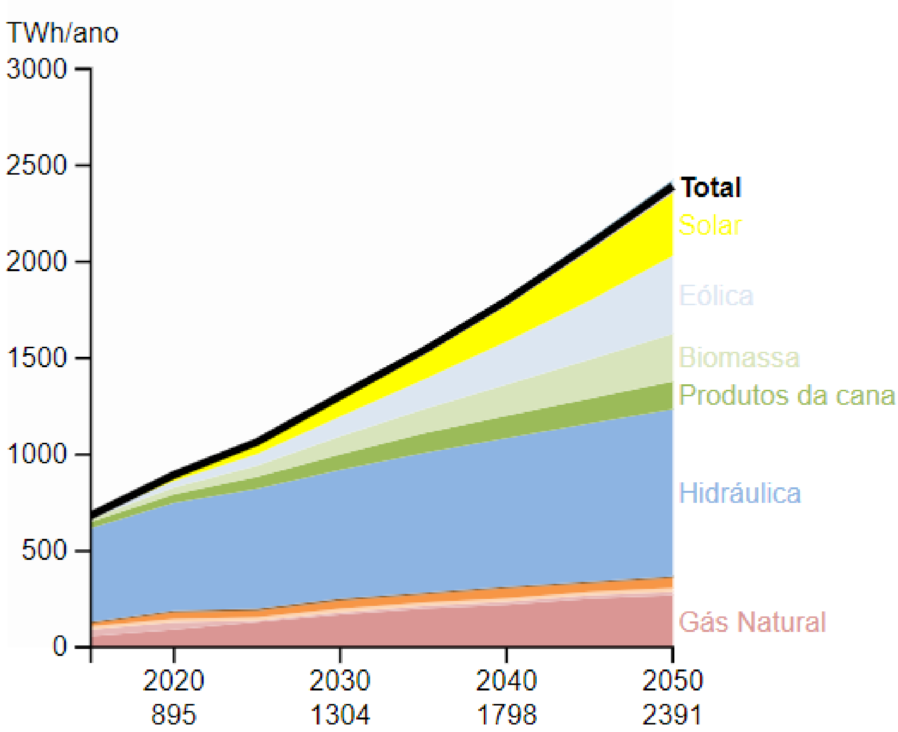
Source: the Author – using Calculator2050 (2021).

Figure 33 – Intensity of electricity emissions in Scenario 2



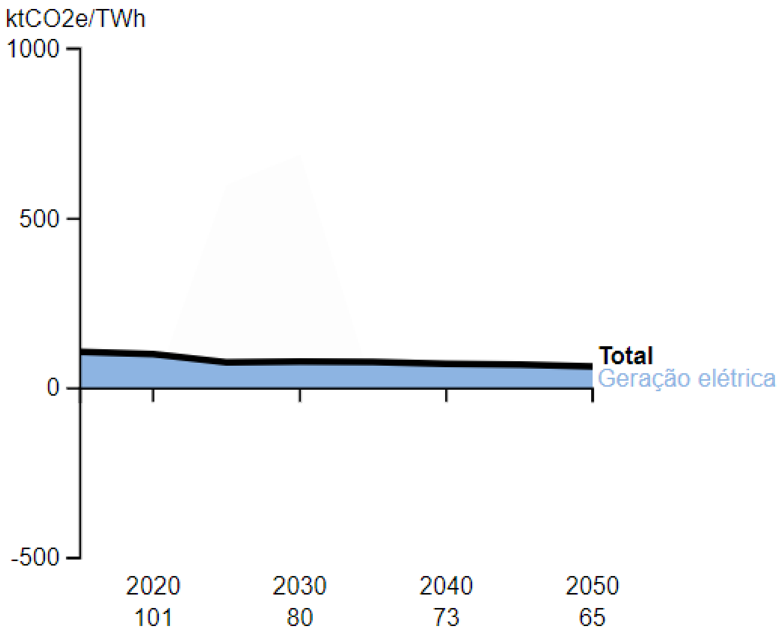
Source: the Author – using Calculator2050 (2021).

Figure 34 – Internal energy supply in Scenario 3



Source: the Author – using Calculator2050 (2021).

Figure 35 – Intensity of electricity emissions in Scenario 3



Source: the Author – using Calculator2050 (2021).

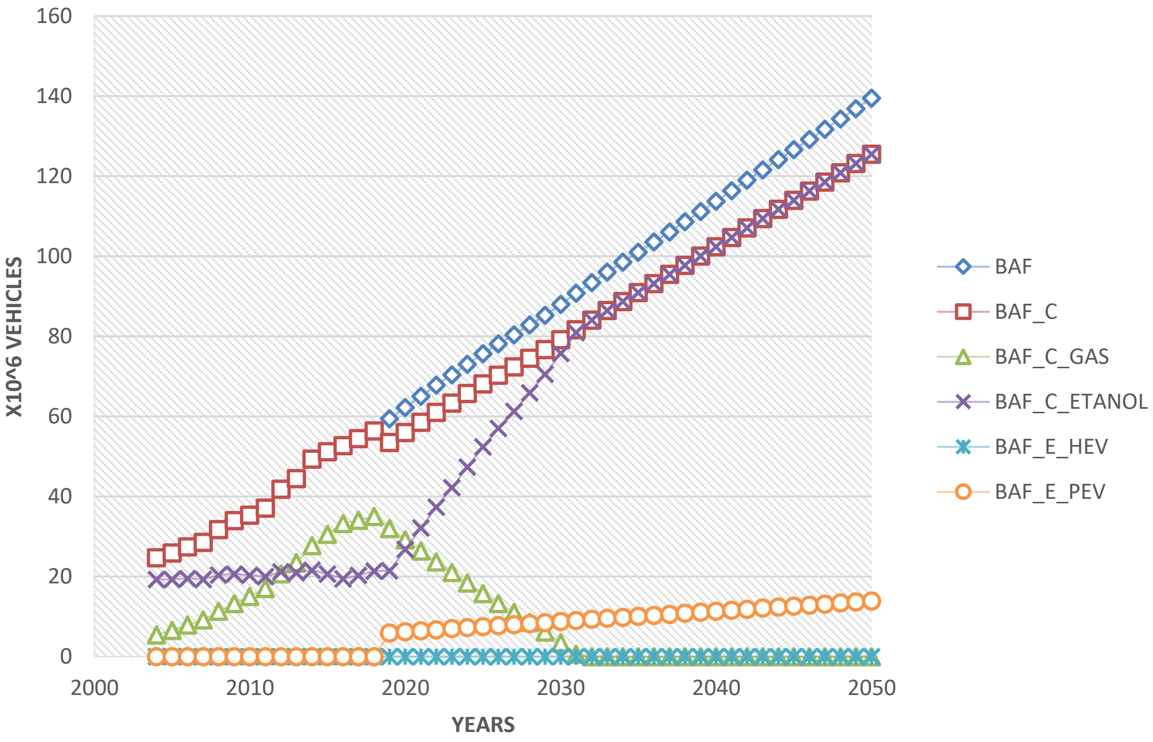
The detailed emission results for each scenario are contained in Appendix E – Detailed Emissions of Brazilian Mix, which are used as data year by year for the program scope of the present work. Comparing Figure 30 and Figure 32, it is observed that the internal supply of energy between the base scenario and the scenario of maximization of emissions is similar, in the respective figure to the scenario of minimization of emissions, there is an increase of 370 TWh/year, an important fact to measure that the insertion of electric vehicles requires a change in the Brazilian mix and consequently requires such an increase in the internal supply of electric energy. The comparison between Figure 31, Figure 33, and Figure 35 highlight the objective of the scenarios created, with the repercussion of Mix emissions within the insertion of electric vehicles one of the objectives of the present work.

To analyze the impact of the insertion of electric vehicles in the Brazilian Electricity Mix, in addition to analyzing the emissions coming from it, an electric energy consumption variable, represented by equation 21, was added.

The meaning of variables adopted in equation 21 is explicit in Frame 2. Figure 36 exposes the Brazilian automotive fleet distribution considering Mix base scenario 1 and Figure 37 exposes the respective emission, Figure 38 exposes the Brazilian automotive fleet distribution considering Mix emissions' maximization scenario 2 and Figure 39 exposes the respective emissions and Figure 40 exposes the Brazilian automotive fleet distribution considering Mix emissions' minimization scenario 3 and Figure 41 exposes the respective emissions.

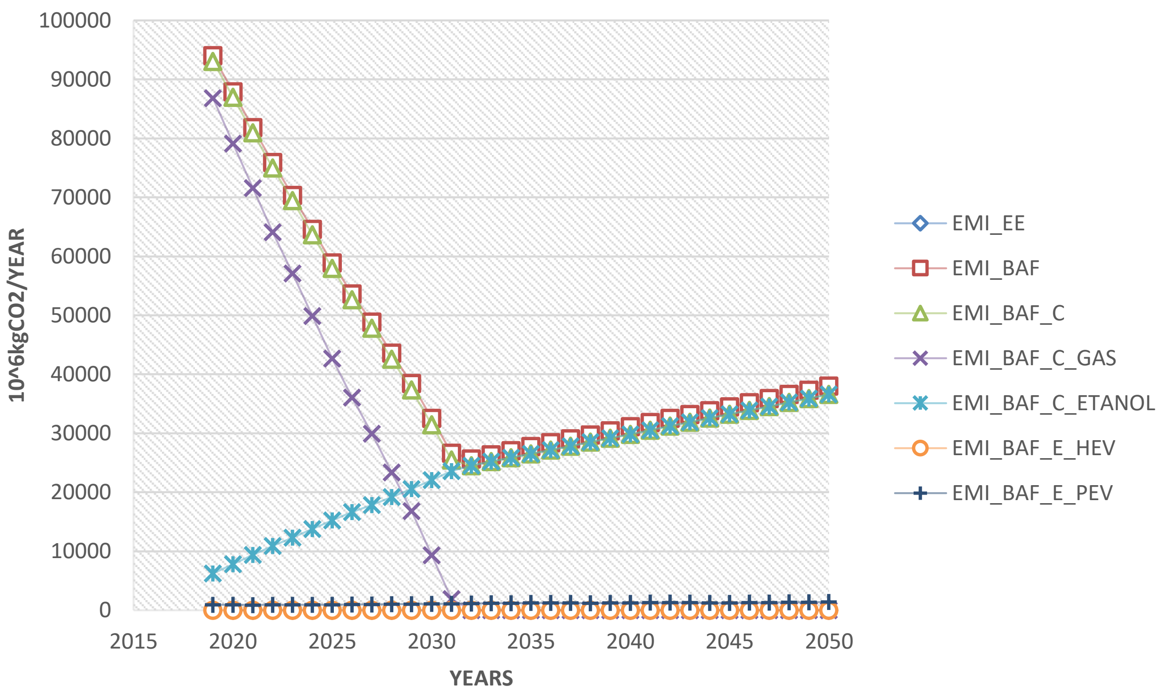
In terms of emissions, there is a difference between the three compared scenarios shown in Figures 37, 39, and 41. However, when comparing Figures 36, 38, and 40, corresponding to the growth of each automotive category until the year 2050, the result was equal. This fact attests that even in a scenario of unsustainable electricity generation, the system's response is resilient, confirming the viable proposal for the insertion of electric vehicles combined with the use of ethanol in conventional vehicles.

Figure 36 – Brazilian Automotive Fleet Simulation considering Mix scenario 1



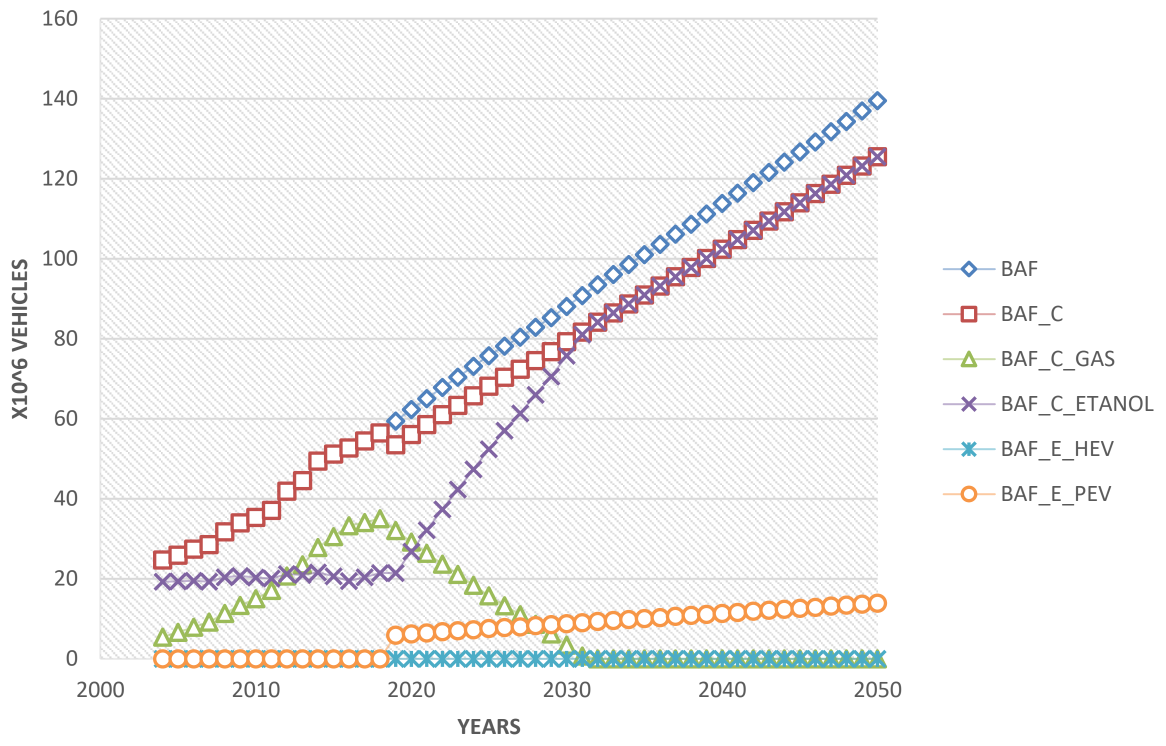
Source: the Author.

Figure 37 – Simulated emissions considering Mix scenario 1



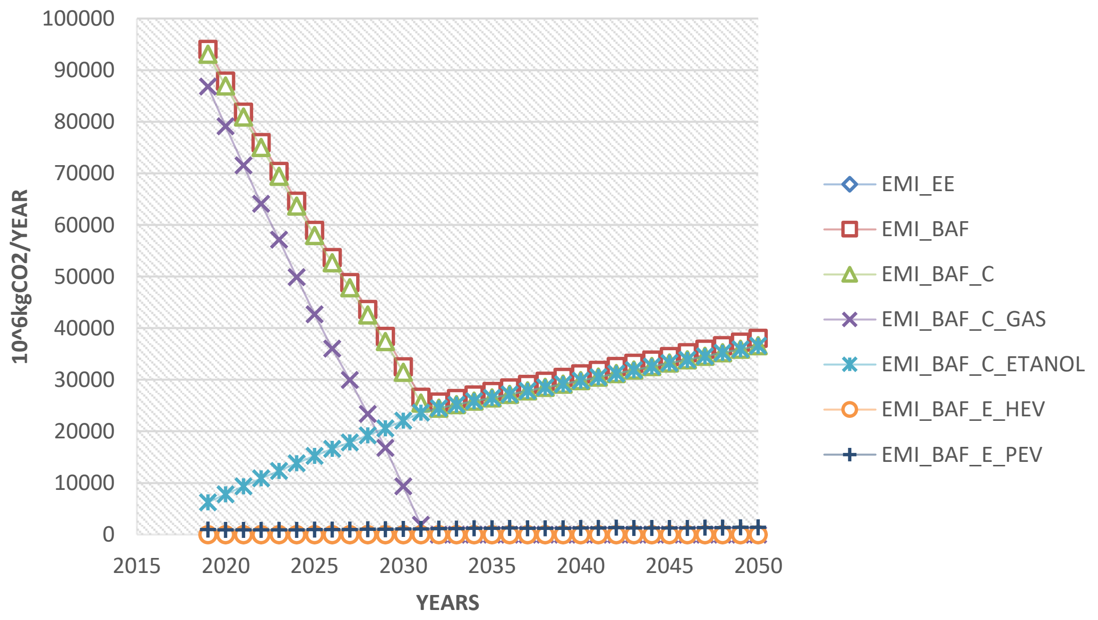
Source: the Author.

Figure 38 – Brazilian Automotive Fleet Simulation considering Mix scenario 2



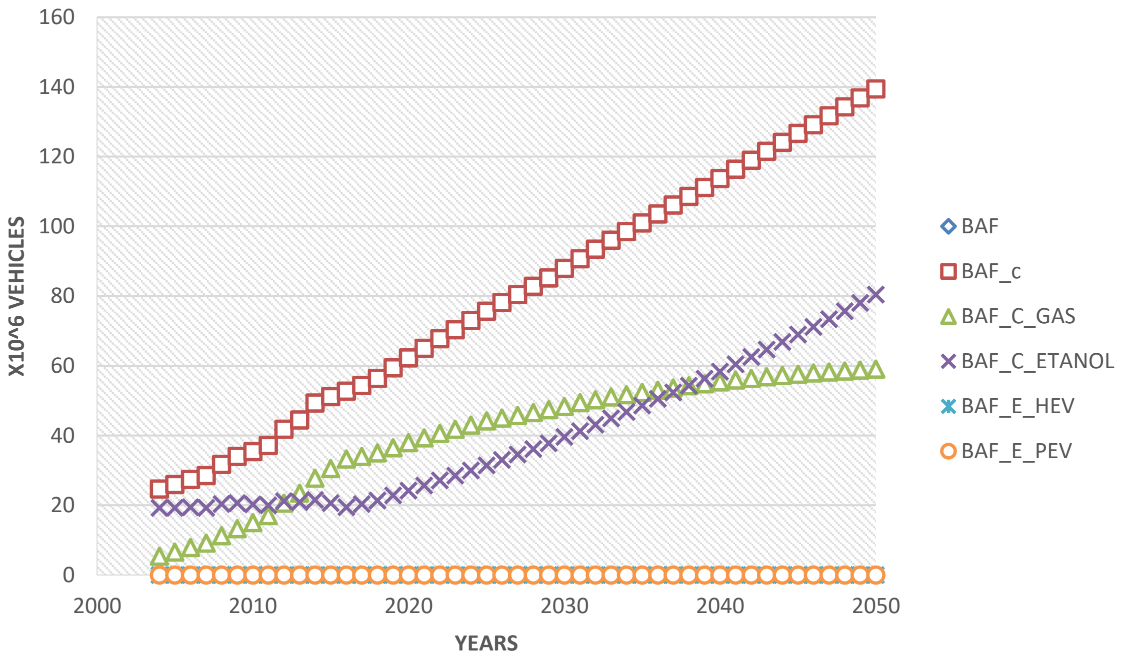
Source: the Author.

Figure 39 – Simulated emissions considering Mix scenario 2



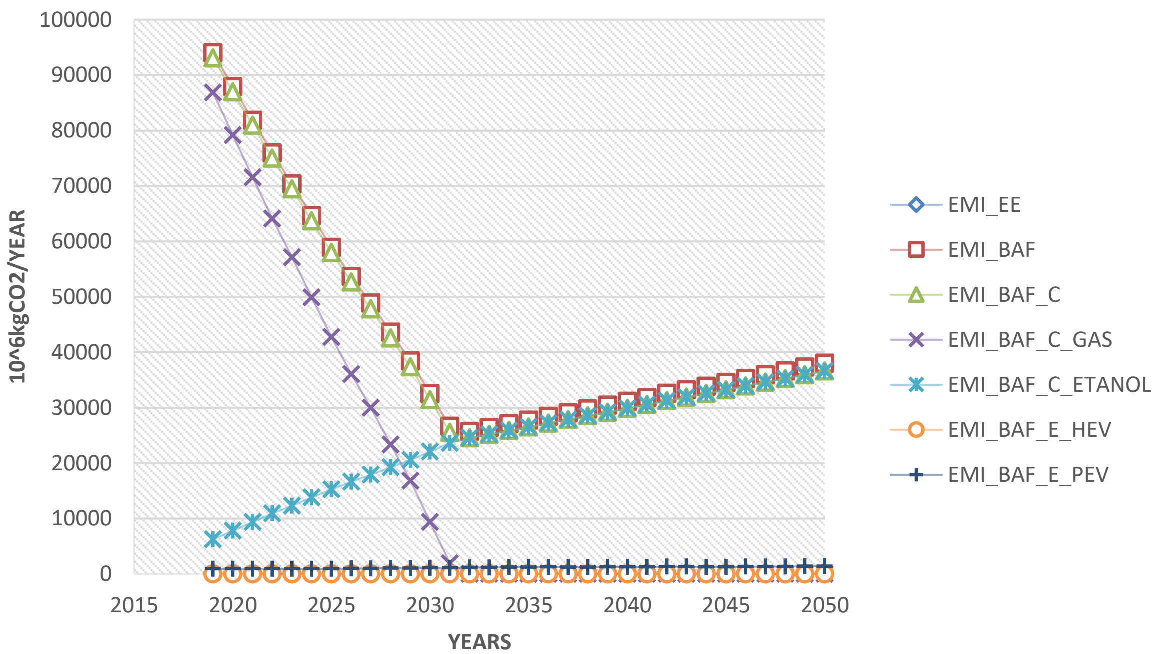
Source: the Author.

Figure 40 – Brazilian Automotive Fleet Simulation considering Mix scenario 3



Source: the Author.

Figure 41 – Simulated emissions considering Mix scenario 3

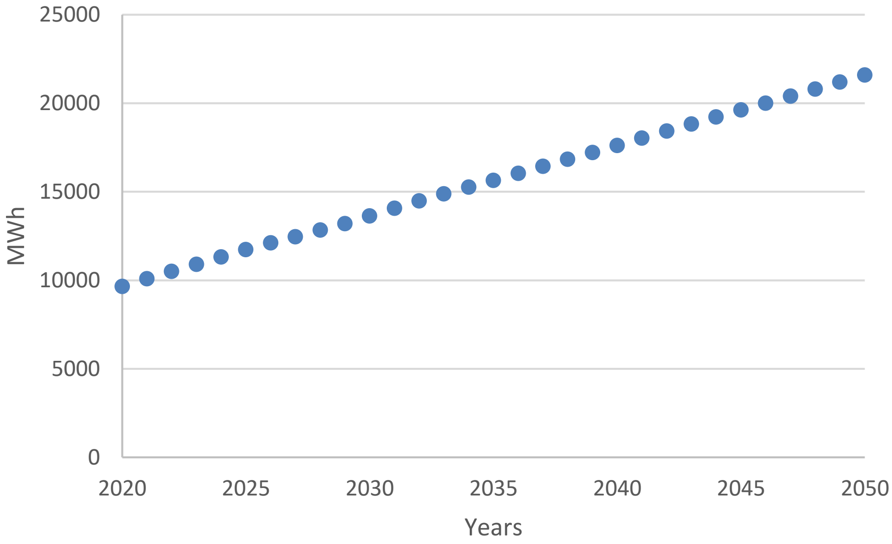


Source: the Author.

Figure 42 shows the consumption of electric vehicles in the simulation and represents the consumption in the three scenarios, while the insertion of electric vehicles was the same regardless of the energy scenario due to the resilience of the electricity mix to the insertion of

E-V. In the year 2050, a level of 22,000 MWh is reached, which when related to the final consumption of electricity forecast for the year 2050 represents a change of only 1.25% when considering the base scenario (SC1). This fact attests to the receptivity of the electric mix concerning the insertion of electric vehicles.

Figure 42 – Electricity consumption of E-V insertion

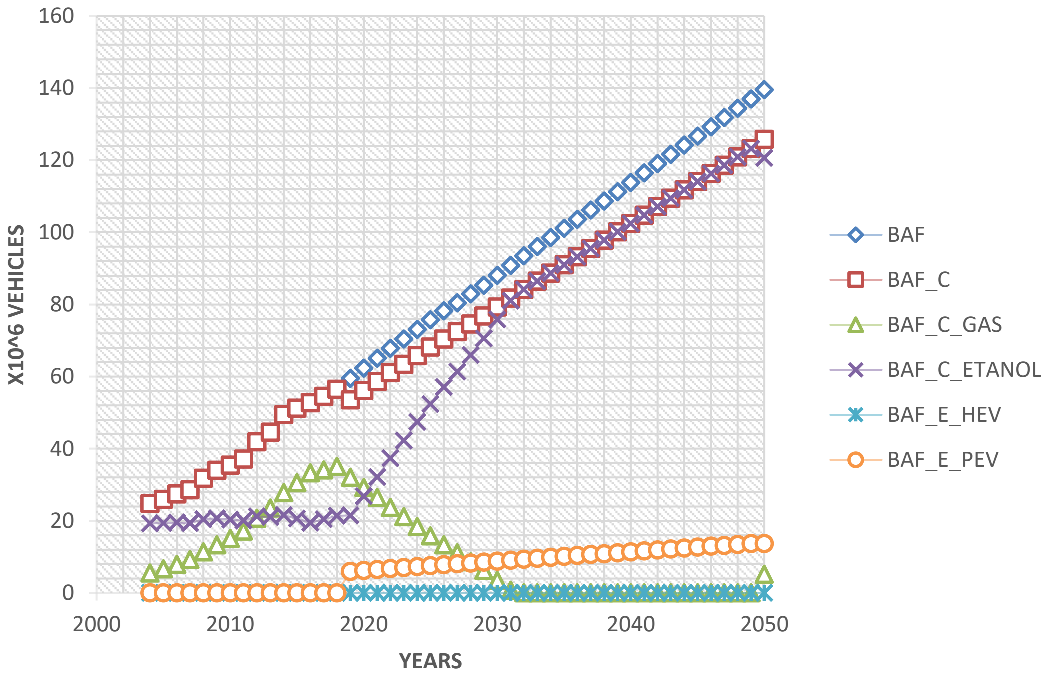


Source: the Author.

4.4 EVALUATION OF THE EFFECTS OF THE AVERAGE DISTANCE COVERED

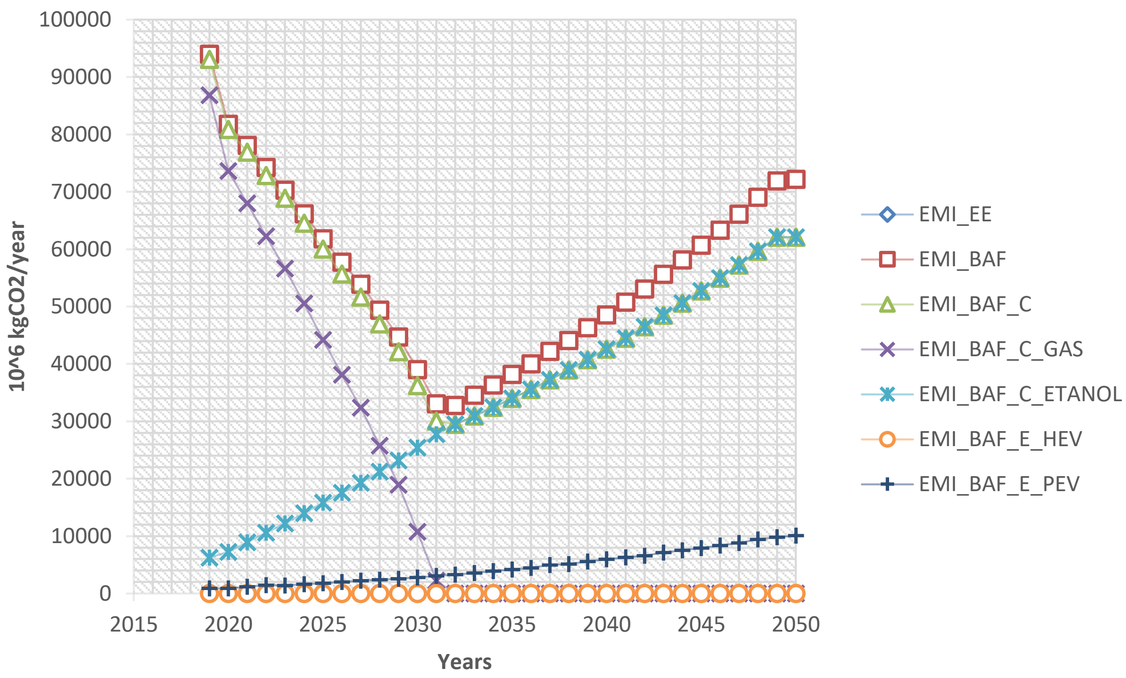
In this evaluation, scenario 1 of electric mix emissions was adopted as the emission standard, represented by Figure 31. After attesting that the insertion of electric vehicles is feasible even in a pessimistic scenario regarding electricity emissions, this step is aimed at evaluating the effect of an increase in the average distance traveled represented by Figure 19. Figure 43 represents the technological distribution of the automotive fleet; Figure 44 presents its respective emission, and Figure 45 presents the electrical consumption of electric vehicles inserted with such consideration.

Figure 43 - Brazilian Automotive Fleet Simulation considering distance increase



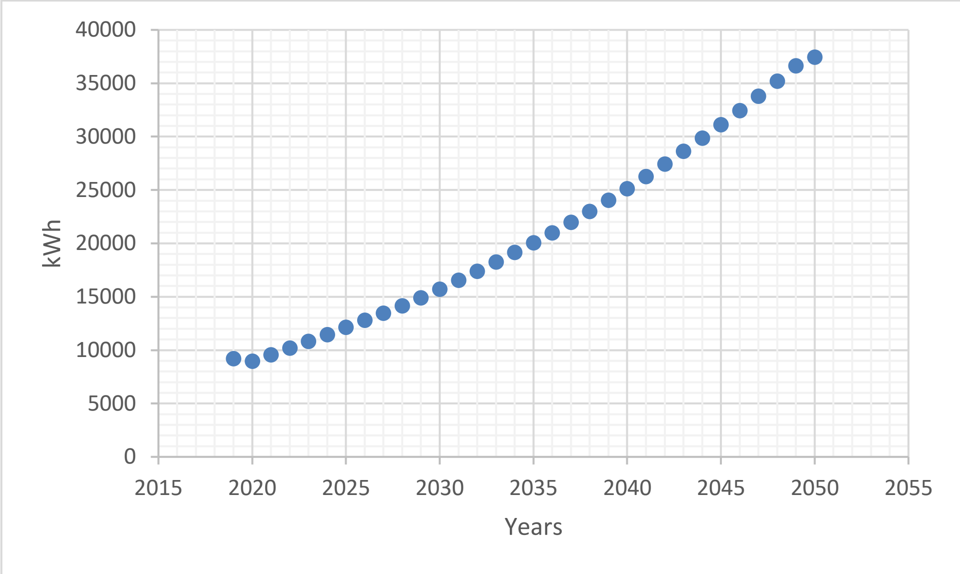
Source: the Author.

Figure 44 – Simulated emissions considering distance increase



Source: the Author.

Figure 45 - Electricity consumption of E-V insertion considering distance increase



Source: the Author.

Figure 43 presents a distribution identical to that of Figure 36, and it is thus verified that even with the increase in the average distance covered, the choice to achieve a sustainable scenario concerning the Brazilian automotive fleet is the maximum insertion of electric vehicles combined with the use of ethanol as a fuel source for internal combustion vehicles. Figure 44, which represents the emission of the automotive fleet with the increase in distance considered, presented an increase of more than 100% compared to Figure 37 (relating to the same scenario of emissions of the electric mix).

As the distance is directly proportional to the emission level, the increase in emissions is an important factor in the analysis of emissions, especially as it is not a technological factor to be considered, but rather a behavioral issue in the use of the car by the consumer. in Figure 45, there was consequently an increase in electricity consumption, reaching a level of 0.0026% change in the electrical mix of scenario 1. This is considered an absorbable value for the Brazilian electrical scenario.

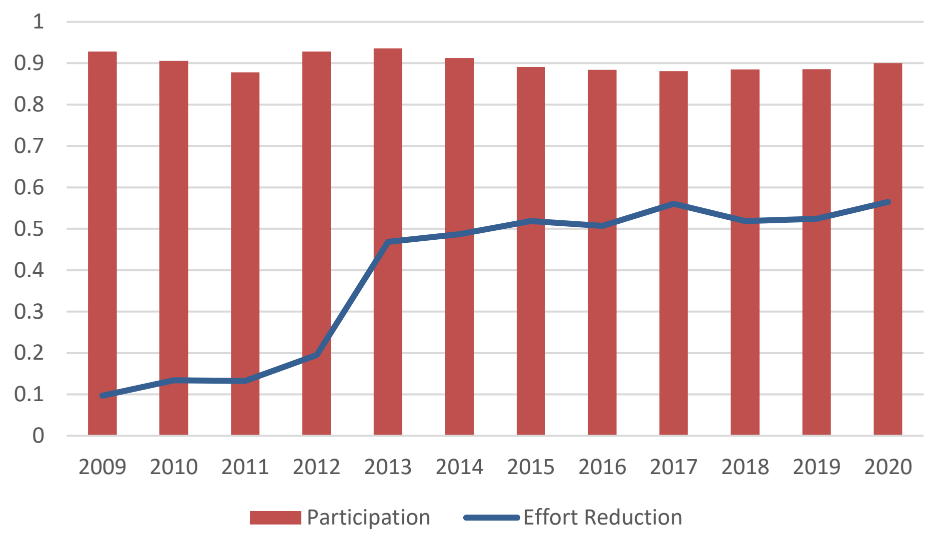
4.5 TECHNOLOGICAL ASPECTS OF VEHICLE SEGMENTS

For the consideration of the segments in the emission minimization code, in addition to the forecast of the variation in participation, their technical characteristics of emissions are necessary. To this end, a retrospective analysis of the PBE was carried out, from 2009 to 2020, and then its emission forecast for each category.

However, there is no direct relationship between the categories adopted and FENABRAVE as already exposed in the present work and the categories considered by PBE, which are Sub-Compact, Compact, Medium, Big, Sport Utility, Off-Road, Mini-Van, Commercial, Charge, and Sport. It was then necessary to regroup the vehicles categorized by the PBE to suit the segments adopted in the present work, the same as those of FENABRAVE.

As it is a manual analysis procedure, vehicle by vehicle, the scope of the top 10 manufacturers exposed in Table 4 was used, thus reducing the necessary manual effort and maintaining the reliability of the technological aspect. Appendix C contains tables with Pareto results in their subdivisions by category to expose the peculiarities adopted in the categorization. Figure 46 exposes the characteristics adopted in the simulation.

Figure 46 - Effort Reduction in analysis considering Top 10 manufacturers



Source: the Author.

In Figure 46, some analyzes were necessary to continue the groupings and projections necessary for the simulation. When considering the obligation of the automakers to submit their vehicles to the PBE emissions analysis only in 2013, the minimum percentage level was reached to allow a labeling analysis. Since the objective of the grouping permeates technical characteristics of emissions, using retroactive data to project with the Eviews software consumption emissions, the years 2013 to 2020 were used as a database.

As for the analysis of Figure 46 itself, it is worth mentioning that the exposed participation is the absolute market share of the top 10 manufacturers listed from Table 3, and the effort reduction competes in the relationship within the PBE Tables (detailed by segment in Appendix C) between the total number of vehicles analyzed by the PBE and the number of vehicles that were analyzed using only the Top 10 manufacturers. Even considering the years before 2013, the brands listed comprise a share of more than 87%.

The reduction in effort became significant as of 2013, just when there was an effective scope of the PBE and consequently the framework of the data used. The next stage consisted of grouping the segments considered by PBE and Fenabrave, exposed in Frame 4, a stage in which the relevance of effort reduction became clearer.

Frame 4 - Segments categorized by PBE and Fenabrave

PBE segments	**Fenabrave segments**
Sub-compact	Entrance
Compact	Hatch Small
Medium	Hatch Medium
Big	Sedan Small
SUV	Sedan Compact
Off-Road	Sedan Medium
Mini-Van	Sedan Big
Comercial	SW Medium
Charge-Pick-up	SW Big
Sport	Mono Cabineti
	Grand Cabinetinet
	Sport
	SUV

Source: the Author.

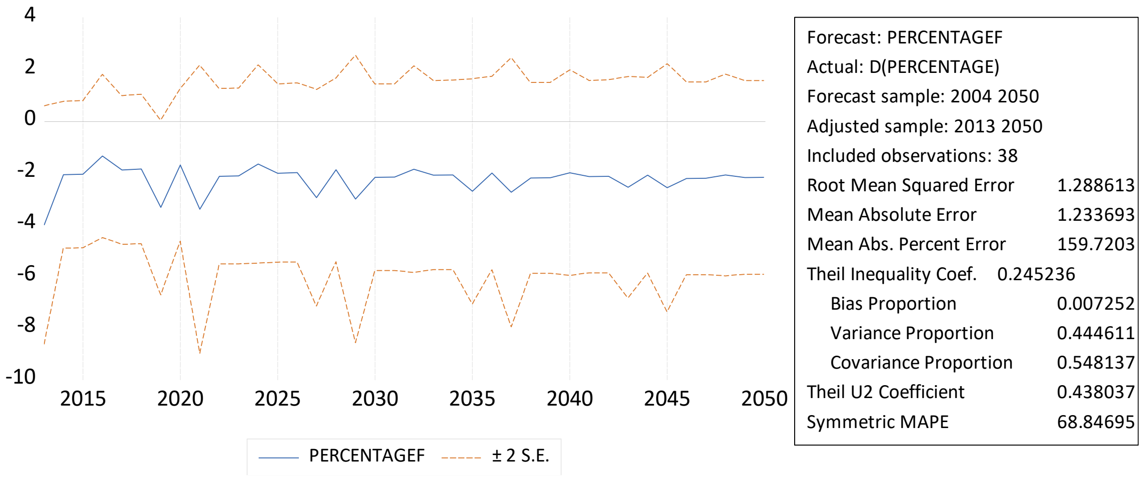
The segments exposed in Frame 4 differ, with PBE focusing on its classification in the passenger area, while Fenabrave addresses marketing issues. It was necessary to create a correlation of the two classifications, while to minimize emissions it was necessary to limit the growth/decrease of each segment associated with each segment. As Fenabrave data is given by category, and PBE data is exposed vehicle by vehicle, it was possible to regroup the vehicles to have an emissions classification for Fenabrave's segments. Apart from the SUV and Sport categories that have a direct relationship, this rearrangement was performed manually. As an example, the PBE segment "Medium" groups the Fenabrave segments "Hatch Medium", "Sedan Medium", and "SW Medium". Adopting the effort reduction shown in Figure 47 between 2013 and 2020, the total of 6,168 vehicles cataloged was reduced to 2,941 vehicles analyzed.

From data exposed in Table 6, for each segment (see Appendix D for extended definitions) was forecast the growth prediction from 2019 to 2050 using the software EViews, and Figure 46 exemplifies the forecast made for each category. The results for segments entrance, hatch small, hatch medium sedan small, sedan compact, sedan medium, sedan big, SW big, Mono Cabinetinet, Grand Cabinet sport, and SUV are exposed in Tables 8 (a,b,c and d), presenting the expected forecast value (FORE), the value presented in its upper and lower confidence limits (respectively FORE+ and FORE-). As these variables are inserted in the minimization algorithm as a percentage variation, their forecast was made using the ARIMA method, according to the same selection criteria used for the automotive fleet as a whole. Appendix B of the present work presents the selection values for each of the analyzed segments.

Thus, the growth of the automotive fleet is considered as an evolution of the share trends of each category combined with the absolute expectations of the fleet. With the proposed analysis methodology, it is possible to visualize technological diversification, and consequently points of the greater impact regarding policies in the automotive sector.

Figure 47 shows as an example the simulation made for the splice subsegment, and that for all other segments was performed and is shown in Appendix B, and the results presented are summarized in Table 8. In the Figure, the blue line represents the expected value (FORE), and the orange dashed lines the expected lower and upper limits.

Figure 47 – Entrance subsegment forecast from 2019 to 2050 adopting ARIMA (8.1.1) method



Source: the Author – Eviews software.

Table 8 – Vehicles subsegments forecasts from 2019 to 2050(a)

Category	**Entrance**			**Hatch Small**			**Hatch Medium**		
Method	ARIMA (8.1.1)			ARIMA (1.1.8)			ARIMA (8.1.8)		
	FORE	FORE-	FORE+	FORE	FORE-	FORE+	FORE	FORE-	FORE+
2019	-3.34	-6.70	0.00	1.20	-3.70	6.10	-0.02	-1.60	1.60
2020	-1.70	-4.70	1.30	1.20	-3.70	6.10	0.25	-1.40	1.90
2021	-3.41	-9.00	2.20	1.20	-3.70	6.10	-0.28	-2.20	1.60
2022	-2.14	-5.50	1.30	1.20	-3.70	6.10	-0.27	-2.20	1.60
2023	-2.12	-5.50	1.30	1.20	-3.70	6.10	-0.21	-2.10	1.70
2024	-1.66	-5.50	2.20	1.20	-3.70	6.10	-0.19	-2.10	1.70
2025	-2.02	-5.50	1.40	1.20	-3.70	6.10	-0.27	-2.20	1.60
2026	-1.99	-5.50	1.50	1.20	-3.70	6.10	-0.22	-2.10	1.70
2027	-2.97	-7.20	1.20	1.20	-3.70	6.10	-0.29	-2.20	1.60
2028	-1.89	-5.40	1.70	1.20	-3.70	6.10	-0.32	-2.20	1.60
2029	-3.01	-8.60	2.50	1.20	-3.70	6.10	-0.27	-2.20	1.60
2030	-2.18	-5.80	1.40	1.20	-3.70	6.10	-0.27	-2.20	1.60
2031	-2.17	-5.80	1.40	1.20	-3.70	6.10	-0.27	-2.20	1.60
2032	-1.87	-5.90	2.10	1.20	-3.70	6.10	-0.28	-2.20	1.60
2033	-2.10	-5.80	1.50	1.20	-3.70	6.10	-0.27	-2.20	1.60
2034	-2.08	-5.80	1.60	1.20	-3.70	6.10	-0.27	-2.20	1.60
2035	-2.71	-7.10	1.60	1.20	-3.70	6.10	-0.27	-2.20	1.60
2036	-2.01	-5.80	1.70	1.20	-3.70	6.10	-0.26	-2.20	1.60
2037	-2.75	-8.00	2.50	1.20	-3.70	6.10	-0.27	-2.20	1.60
2038	-2.20	-5.90	1.50	1.20	-3.70	6.10	-0.27	-2.20	1.60
2039	-2.20	-5.90	1.50	1.20	-3.70	6.10	-0.27	-2.20	1.60
2040	-2.00	-6.00	2.00	1.20	-3.70	6.10	-0.27	-2.20	1.60
2041	-2.15	-5.90	1.60	1.20	-3.70	6.10	-0.27	-2.20	1.60
2042	-2.14	-5.90	1.60	1.20	-3.70	6.10	-0.27	-2.20	1.60
2043	-2.56	-6.80	1.70	1.20	-3.70	6.10	-0.27	-2.20	1.60
2044	-2.10	-5.90	1.70	1.20	-3.70	6.10	-0.27	-2.20	1.60
2045	-2.58	-7.40	2.20	1.20	-3.70	6.10	-0.27	-2.20	1.60
2046	-2.22	-5.90	1.50	1.20	-3.70	6.10	-0.27	-2.20	1.60
2047	-2.22	-5.90	1.50	1.20	-3.70	6.10	-0.27	-2.20	1.60
2048	-2.09	-5.90	1.80	1.20	-3.70	6.10	-0.27	-2.20	1.60
2049	-2.19	-6.00	1.60	1.20	-3.70	6.10	-0.27	-2.20	1.60
2050	-2.18	-5.90	1.60	1.20	-3.70	6.10	-0.27	-2.20	1.60

Source: the Author.- using software Eviews.

Table 8 – Vehicles subsegments forecasts from 2019 to 2050(b)

Category	**Sedan Small**			**Sedan Compact**			**Sedan Medium**		
Method	ARIMA (8.1.8)			ARIMA (8.1.1)			ARIMA (1.1.8)		
	FORE	FORE-	FORE+	FORE	FORE-	FORE+	FORE	FORE-	FORE+
2019	1.40	-1.90	4.80	-0.30	-2.00	1.40	0.10	-2.20	2.40
2020	0.60	-2.70	4.00	1.10	-0.50	2.80	0.10	-2.20	2.40
2021	0.10	-4.00	4.10	-0.50	-2.50	1.50	0.10	-2.20	2.40
2022	0.20	-3.90	4.20	0.00	-2.10	2.00	0.10	-2.20	2.40
2023	0.00	-4.10	4.00	0.20	-1.90	2.20	0.10	-2.20	2.40
2024	0.20	-3.80	4.30	-0.10	-2.20	1.90	0.10	-2.20	2.40
2025	-0.10	-4.20	3.90	0.40	-1.60	2.50	0.10	-2.20	2.40
2026	0.30	-3.50	4.30	0.50	-1.50	2.50	0.10	-2.20	2.40
2027	0.60	-3.70	4.60	-0.20	-2.20	1.90	0.10	-2.20	2.40
2028	0.30	-4.00	4.40	0.80	-1.20	2.80	0.10	-2.20	2.40
2029	0.10	-3.90	4.30	-0.30	-2.50	1.80	0.10	-2.20	2.40
2030	0.20	-4.00	4.30	0.00	-2.20	2.20	0.10	-2.20	2.40
2031	0.10	-3.90	4.20	0.10	-2.00	2.30	0.10	-2.20	2.40
2032	0.20	-4.00	4.30	-0.10	-2.20	2.10	0.10	-2.20	2.40
2033	0.10	-3.90	4.20	0.30	-1.90	2.50	0.10	-2.20	2.40
2034	0.20	-3.90	4.30	0.40	-1.80	2.60	0.10	-2.20	2.40
2035	0.30	-3.80	4.40	-0.10	-2.30	2.10	0.10	-2.20	2.40
2036	0.20	-3.90	4.30	0.60	-1.60	2.80	0.10	-2.20	2.40
2037	0.20	-3.90	4.30	-0.20	-2.40	2.10	0.10	-2.20	2.40
2038	0.20	-3.90	4.30	0.00	-2.20	2.30	0.10	-2.20	2.40
2039	0.20	-3.90	4.30	0.10	-2.10	2.40	0.10	-2.20	2.40
2040	0.20	-3.90	4.30	0.00	-2.20	2.20	0.10	-2.20	2.40
2041	0.20	-3.90	4.30	0.30	-2.00	2.50	0.10	-2.20	2.40
2042	0.20	-3.90	4.30	0.30	-2.00	2.50	0.10	-2.20	2.40
2043	0.20	-3.90	4.30	0.00	-2.30	2.20	0.10	-2.20	2.40
2044	0.20	-3.90	4.30	0.10	-1.80	2.70	0.10	-2.20	2.40
2045	0.20	-3.90	4.30	-0.10	-2.40	2.20	0.10	-2.20	2.40
2046	0.20	-3.90	4.30	0.10	-2.20	2.30	0.10	-2.20	2.40
2047	0.20	-3.90	4.30	0.10	-2.20	2.40	0.10	-2.20	2.40
2048	0.20	-3.90	4.30	0.00	-2.20	2.30	0.10	-2.20	2.40
2049	0.20	-3.90	4.30	0.20	-2.10	2.50	0.10	-2.20	2.40
2050	0.20	-3.90	4.30	0.20	-2.00	2.50	0.10	-2.20	2.40

Source: the Author.- using software Eviews.

Table 8 – Vehicles subsegments forecasts from 2019 to 2050(c)

Category	**Sedan Big**			**SW Medium**			**SW Big**		
Method	ARIMA (8.1.8)			ARIMA (1.1.8)			ARIMA (8.1.1)		
	FORE	FORE-	FORE+	FORE	FORE-	FORE+	FORE	FORE-	FORE+
2019	-0.30	-0.40	-0.21	-0.17	-1.22	0.89	-0.19	-0.62	0.24
2020	0.50	0.41	0.60	-0.17	-1.22	0.89	-0.05	-0.48	0.38
2021	0.07	-0.14	0.27	-0.17	-1.22	0.89	0.01	-0.44	0.46
2022	0.07	-0.14	0.27	-0.17	-1.22	0.89	-0.04	-0.52	0.43
2023	-0.17	-0.38	0.03	-0.17	-1.22	0.89	0.01	-0.47	0.48
2024	0.18	-0.03	0.38	-0.17	-1.22	0.89	-0.12	-0.59	0.35
2025	0.08	-0.12	0.29	-0.17	-1.22	0.89	-0.10	-0.57	0.38
2026	0.02	-0.19	0.23	-0.17	-1.22	0.89	-0.04	-0.52	0.43
2027	0.31	0.11	0.52	-0.17	-1.22	0.89	0.01	-0.46	0.49
2028	-0.45	-0.65	-0.24	-0.17	-1.22	0.89	-0.05	-0.52	0.42
2029	-0.03	-0.30	0.23	-0.17	-1.22	0.89	-0.08	-0.56	0.40
2030	-0.03	-0.30	0.23	-0.17	-1.22	0.89	-0.05	-0.54	0.43
2031	0.19	-0.08	0.46	-0.17	-1.22	0.89	-0.08	-0.56	0.41
2032	-0.14	-0.41	0.13	-0.17	-1.22	0.89	-0.02	-0.50	0.47
2033	-0.05	-0.32	0.22	-0.17	-1.22	0.89	-0.03	-0.51	0.46
2034	0.01	-0.26	0.28	-0.17	-1.22	0.89	-0.05	-0.54	0.43
2035	-0.27	-0.54	0.00	-0.17	-1.22	0.89	-0.08	-0.56	0.40
2036	0.45	0.18	0.72	-0.17	-1.22	0.89	-0.05	-0.53	0.43
2037	0.06	-0.26	0.37	-0.17	-1.22	0.89	-0.04	-0.52	0.45
2038	0.06	-0.26	0.37	-0.17	-1.22	0.89	-0.05	-0.53	0.44
2039	-0.15	-0.47	0.16	-0.17	-1.22	0.89	-0.04	-0.52	0.45
2040	0.16	-0.16	0.47	-0.17	-1.22	0.89	-0.07	-0.55	0.42
2041	0.08	-0.24	0.39	-0.17	-1.22	0.89	-0.06	-0.55	0.43
2042	0.02	-0.30	0.33	-0.17	-1.22	0.89	-0.05	-0.52	0.44
2043	0.28	-0.04	0.59	-0.17	-1.22	0.89	-0.04	-0.54	0.45
2044	-0.40	-0.71	-0.08	-0.17	-1.22	0.89	-0.05	-0.54	0.44
2045	-0.03	-0.38	0.32	-0.17	-1.22	0.89	-0.06	-0.54	0.43
2046	-0.03	-0.38	0.32	-0.17	-1.22	0.89	-0.05	-0.54	0.44
2047	0.17	-0.18	0.52	-0.17	-1.22	0.89	-0.06	-0.53	0.43
2048	-0.12	-0.05	0.23	-0.17	-1.22	0.89	-0.04	-0.53	0.44
2049	-0.04	-0.40	0.31	-0.17	-1.22	0.89	-0.04	-0.53	0.44
2050	0.01	-0.34	0.36	-0.17	-1.22	0.89	-0.05	-0.54	0.44

Source: the Author.- using software Eviews.

Table 8 – Vehicles subsegments forecasts from 2019 to 2050(d)

Category	**Mono Cabinetinet**			**Grand Cabinet**			**Sport**			**SUV**		
Method	ARIMA (1.1.8)			ARIMA (8.1.1)			ARIMA (1.1.8)			ARIMA (1.1.8)		
	FORE	FORE-	FORE+	FORE	FORE-	FORE+	FORE	FORE-	FORE+	FORE	FORE-	FORE+
2019	-0.28	-1.67	1.12	-0.12	-0.77	0.54	0.00	-0.08	0.09	2.00	-1.10	5.10
2020	-0.28	-1.67	1.12	-0.09	-0.75	0.57	0.00	-0.08	0.09	2.00	-2.20	6.30
2021	-0.28	-1.67	1.12	-0.10	-0.76	0.56	0.00	-0.08	0.09	2.10	-2.30	6.40
2022	-0.28	-1.67	1.12	-0.12	-0.78	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2023	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2024	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2025	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2026	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2027	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2028	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2029	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2030	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2031	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2032	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2033	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2034	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2035	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2036	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2037	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2038	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2039	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2040	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2041	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2042	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2043	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2044	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2045	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2046	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2047	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2048	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2049	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40
2050	-0.28	-1.67	1.12	-0.11	-0.77	0.54	0.00	-0.08	0.09	2.10	-2.30	6.40

Source: the Author.- using software Eviews.

From the forecasts of market behavior in the categories listed by Fenabrave, it is highlighted that the Brazilian market has the SUV category as the biggest acquisition trend, followed by Hatch Small and Sedan Small. It is noted that the consumer tends to two extremes: large SUV vehicles with high consumption and small vehicles with low fuel consumption per km, as analyzed according to the PBE labeling.

Table 9 shows, according to Fenabrave (2020), the 10 most affordable electric vehicles in financial matters available in the Brazilian market in 2020. Table 9 shows, in addition to vehicles, their categorization according to Fenabrave, their pricing and the pricing of an ICEV vehicle equivalent in engine power and consumer comfort items. Based on the analysis made of the growth forecast of Fenabrave categories, only the Jac Iev20 and the BMW I3 fit into one of the most exponential categories until 2050. Furthermore, the pricing issue, even with tax incentives, is a big issue, the initial investment being greater than 100% than the equivalent of opting for the conventional one.

Table 9 – E-V available in Brazil (2020)

Vehicle	Category	Price (R$)	Price ICEV (R$)
Jac Iev20	Hatch Small	159,900.00	70,000.00
Novo Renault Zoe E-Tech Zen	Hatch Medium	204,990.00	80,000.00
Jac Iev40	Hatch Medium	225,900.00	80,000.00
Nissan Leaf	Hatch Medium	259,900.00	85,000.00
Jac Iev60	Hatch Medium	259,900.00	85,000.00
Jac Iev330p	Charge	299,900.00	150,000.00
BMW I3	Hatch Small	304,950.00	110,000.00
Jaguar I-Pace	Sedan Big	490,000.00	200,000.00
Audi E-Tron Performance	Sedan Big	559,000.00	200,000.00

Source: adapted from Fenabrave (2020).

4.6 EMISSIONS RESULTS COMPARISON

It is summarized all the emissions results obtained by the simulations to compare them to the decarbonization target for the year 2050, shown in Figure 20. Table 10 shows this synthesis, and for its analysis, the target stipulated for the year 2050 of 58% decarbonized, with a minimum threshold of 24%, is to be followed.

Table 10 – Summary of decarbonization percentage

	DECARBONIZATION (%)
Emissions considering base scenario (Figure 25)	-134.67
Insertion of e-v from 2019 to 2050 (Figure 28)	61.75
Emissions considering mix scenario 1(Figure 37)	59.58
Emissions considering mix scenario 2(Figure 39)	59.14
Emissions considering mix scenario 3(Figure 41)	59.59
Emissions considering distance increase (Figure 44)	22.44

Source: the Author.

From the base scenario, shown in Figure 25, which considers the automotive fleet with the expected growth and following the current trends in the use of ethanol and gasoline in flex vehicles combined with the non-insertion of electric vehicles, negative decarbonization was obtained, an increase in emissions. It is evident that if there is no change in the Brazilian automotive scenario if current trends are maintained, the proposed decarbonization target will not be reached. It is, therefore, necessary that there are changes, and based on the identification of the best sustainable perspectives, that governmental investments be made towards the objective of reducing carbon emissions.

The first analysis of electric vehicle insertion, shown in Figure 28, showed decarbonization of 61.75%, above the established target of 58%. From this good perspective, the model was refined through the analysis of the Brazilian electrical mix, considering the base scenario (Figure 37), pessimistic (Figure 39) and optimistic (Figure 41). The results of these three analyzes were around 59%, thus reaching the proposed decarbonization target.

In the analysis considering the scenario of electrical mix 1 (SC1) combined with the consideration of the increase in distance traveled according to the increase factor defined by EUCalc (2021), the decarbonization target reached the level of 22.44%, below the minimum level of 24% shown in Figure 20. This fact shows that in addition to vehicle technology and associated public policies in the transport sector, it is essential to study consumer behavior and the consequent use that this makes of vehicles.

5 CONCLUSIONS

5.1 FLEET REVIEW

Brazil's dependence on the road transport network has the consequence of a considerable impact on national energy supply and economic sectors. The peculiarity of the use of ethanol established in the late 1970s generates consequent peculiarities of Brazil’s automotive scenario concerning other countries, including the headquarters of large multinationals in the automotive industry. Thus, in addition to adapting the international oil market laws, there is a need to create a relationship of trust in Brazil’s sugar cane market. RenovaBio, therefore, considers the variations in cane pricing subsidized by the government to ensure market consistency with gasoline.

The Inovar-Auto program established itself as a milestone in the country’s automotive policy, incorporating the PBE energy efficiency concept but in an active way so that the improvement in efficiency started to trigger fiscal benefits for manufacturers. It also made mandatory the technological development of national industry, in an interdepartmental way, explaining the intrinsic network, which the Brazilian automotive industry is composed, a fact that culminated in the elaboration of the present work: understanding the relationships in the automotive environment for the elaboration of any project within the energy planning of the automotive sector.

The year 2010 was troubled in its macroeconomic issue, creating difficulties for the assemblers to solidly establish their goals in Brazil: in Table 6 when comparing the year in which the project was conceived until 2017, sales growth was at 50%, including SUVs only in the final period. This category even deserves to be highlighted, as it is characterized by large vehicles and large fuel consumption, in dissonance to reduce CO_2 emissions. A detailed analysis of the effects of the gradual increase in the participation of this segment is also necessary.

Analyzing Tables 5 and 6 as one, for a market share of about 90%, it is observed that the hegemony of Volkswagen, Fiat, General Motors, and Ford has been broken in the country (2014), giving great prominence to Japanese automakers. These have been investing in efficient and reliable vehicles, gaining the preference of the Brazilian consumer. In this analysis, the Inovar-Auto program is highlighted in its obligation to bring all manufacturing plants to Brazil.

When considering Rota-2030 associated with RenovaBio, the interdependence of the automotive economy and the ethanol market can be observed, and to achieve the decarbonization goals, which both programs set for the year 2030, the government must guarantee the pricing of ethanol. The factor of great geographical dimension in Brazil generates regional peculiarities as exposed in Table 3, thus highlighting the adherence of specific equations. In this way, the price associated with the policy is not only a subsidy for the maintenance of sugar cane producers but a way to guarantee the decarbonization and industrial and energy independence of Brazil. As it can be observed in Table 2, the flexibility of use of fuels of the Brazilian fleet, in the year 2018, reached a threshold very close to the maximum of Flex Vehicles, highlighting that the percentage that is not comprised SUV vehicles to diesel.

Adding all the considerations, a reliable database of the Brazilian automotive sector is established and more accurate to determine an energy planning analysis than considering the fleet in a generic model.

5.2 STRATEGIES FOR REDUCING CARBON EMISSIONS

From the summary of results presented in section 4.8, it was possible to conclude that Brazil can reach the stipulated decarbonization target, even considering a significant increase in the automotive fleet in absolute numbers. It was identified that, for this fact, the insertion of electric vehicles is favorable, having reached the maximum level of insertion of 10% per year in all simulations.

The issue of the cost of acquisition of electric vehicles and subsequent battery disposal is still decisive for insertion, a fact that even considering state and federal tax incentives, such vehicles are not commercially competitive and, thus, the literature consulted admits 10% a year as the maximum insertion level for this category, allied to the fact that in Tables 8 (a, b, c and d) the most prominent categories in the analysis are the Hatch Small and SUV. With such market analysis, for the most requested categories in the coming years, one of them has no electric vehicles available nowadays, coming to the question of consumer acceptance.

With this work, the use of ethanol as a fuel source was shown to be essential, thus being the most favorable path indicated for sustainable automotive planning in Brazil, exploiting the already program RenovaBio for the year 2050.

5.3 POSSIBLE RESEARCH DEVELOPMENTS

The present work had as objective to analyze the insertion of electric vehicles considering the technologies available in the Brazilian market at the beginning of the year 2019. The hybrid vehicles considered then were analyzed as being their gasoline internal combustion engine. In 2021, hybrid vehicles such as the Toyota Corolla Altis arrived in Brazil, whose hybrid technology is associated with a flex engine. In addition, fuel cell technology is highlighted, with two technologies with perspectives to be analyzed in future works.

The ecological importance of the use of ethanol in the Brazilian scenario was attested; however, economic issues were not addressed as well as the RenovaBio program, with the CBio government input factor. A study is then suggested with the same guidelines as the biofuels program, but with the 2050 time frame, to strategize the Brazilian automotive scenario under electrical and global decarbonization guidelines.

The projection analysis of vehicular sub-segments shown in Tables 8 (a, b, c and d) was important for the market analysis of the Brazilian consumption profile; however, as these categories present technical peculiarities, an analysis of emissions minimization considering the fleet is suggested, i.e, the Brazilian automotive industry not as a whole, but segmented in such segments raised by the present work.

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APPENDIX A - Abbreviations adopted in the analysis

X = index present in the variables representing the year to which it refers. From 2004 to 2018 they are data, from 2019 to 2050 they are predictions even from government programs and obtained from present work.

Dist_X = Average annual distance traveled by the automotive fleet [km]

BAF growth_X = Brazilian Automotive Fleet growth in the respective year [0-1 (%)]

BAF_X = Total Brazilian Automotive Fleet in the respective year [adim]

BAF_age_X = Medium age of rolling vehicles in Brazil in the respective year [years]

BAF_mw_X = Automotive Fleet in region Midwest in the respective year [adim]

BAF_age_mw_X = Medium age of rolling vehicles in region Midwest in the respective year [years]

BAF_ne_X = Automotive Fleet in region Northeast in the respective year [adim]

BAF_age_ne_X = Medium age of rolling vehicles in region Northeast in the respective year [years]

BAF_n_X = Automotive Fleet in region North in the respective year [adim]

BAF_age_n_X= Medium age of rolling vehicles in region North in the respective year [years]

BAF_se_X = Automotive Fleet in region Southeast in the respective year [adim]

BAF_age_se_X = Medium age of rolling vehicles in region Southeast in the respective year [years]

BAF_s_X = Automotive Fleet in region South in the respective year [adim]

BAF_age_s_X = Medium age of rolling vehicles in region South in the respective year [years]

BAF_C_ X = Quantum of Brazilian Automotive Fleet ICE vehicles in the respective year [adim]

BAF_C_GAS_X = Quantum of Brazilian Automotive Fleet ICE vehicles using gasoline as a source of energy in the respective year [adim]

BAF_C_ETANOL_X = Quantum of Brazilian Automotive Fleet ICE vehicles using ethanol as a source of energy in the respective year [adim]

BAF_E_HEV_X = Quantum of Brazilian Automotive Fleet Hybrid Electric in the respective year [adim]

BAF_E_PEV_X = Quantum of Brazilian Automotive Fleet Electric Vehicles in the respective year [adim]

EMI_BAF _X = Emissions of Brazilian Automotive Fleet Vehicles in the respective year [10^6kg CO_2/year]

EMI_BAF_C_X = Emissions of Brazilian Automotive Fleet ICE Vehicles in the respective year [10^6kg CO_2/year]

EMI_BAF_C_ETANOL_X = Emissions of Brazilian Automotive Fleet ICE Vehicles using ethanol as a source of energy in the respective year [10^6kg CO_2/year]

EMI_BAF_C_HEV_X = Emissions of Brazilian Automotive Fleet Hybrid Electric Vehicles in the respective year [10^6kg CO_2/year]

EMI_BAF_C_PEV_X = Emissions of Brazilian Automotive Fleet Electric Vehicles in the respective year [10^6kg CO_2/year]

EMI_EE_X = Emissions of Brazilian Electric Mix in the respective year [10^6kg CO_2/year]

P_c_gas_X = Percentage of use of gasoline in ICE vehicles as a source in the respective year [0-1(%)]

P_c_etanol_X = Percentage of use of ethanol in ICE vehicles as a source in the respective year [0-1(%)]

Car_sale_BR_X = Amount of cars sold in Brazil in the respective years [adim]

Car_sale_USA_X = Amount of cars sold in the USA in the respective years [adim]

Car_sale_CHN_X = Amount of cars sold in China in the respective years [adim]

Car_sale_UE_X = Amount of cars sold in the mores expressive countries of Europe [Top 90 of the year] in the respective years [adim]

Car_Tech_Bi_X = Amount of cars signed that can use even gasoline and ethanol in the respective year [adim]

Car_Tech_gas_X = Amount of cars signed that can use only gasoline in the respective year [adim]

Car_Tech_ ethanol _X = Amount of cars signed that can use only ethanol in the respective year [adim]

Car_Part_pop = Percentage of sells of popular/affordables vehicles in the respective year [0-1(%)]

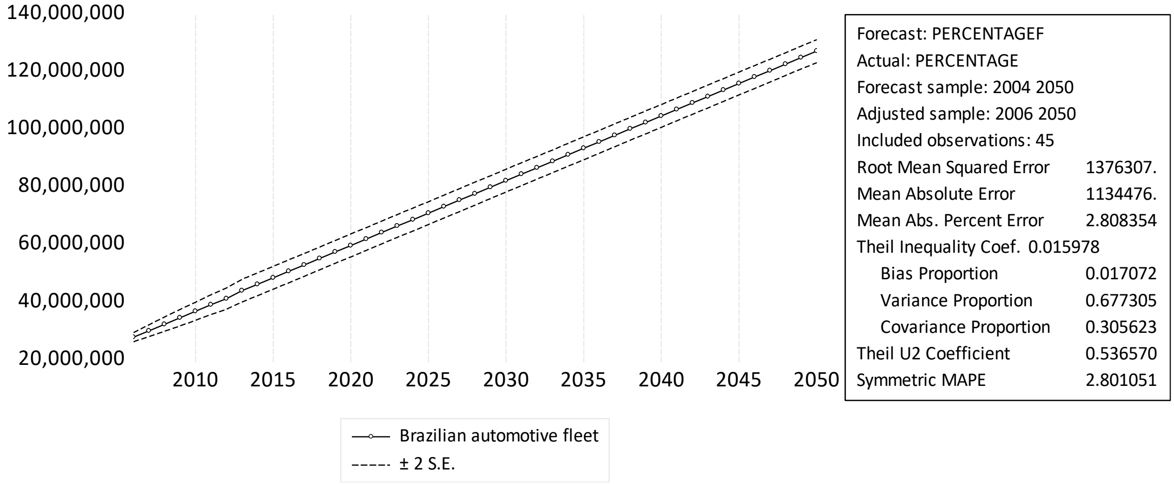
Car_Part_pop = Percentage of sell of popular/affordable vehicles in the respective year [0-1(%)]

Car_Part_unpop = Percentage of sell of unpopular/unaffordable vehicles in the respective year [0-1(%)]

APPENDIX B – Eview's Brazilian automotive fleet forecast analysis

B1 - Brazilian automotive fleet

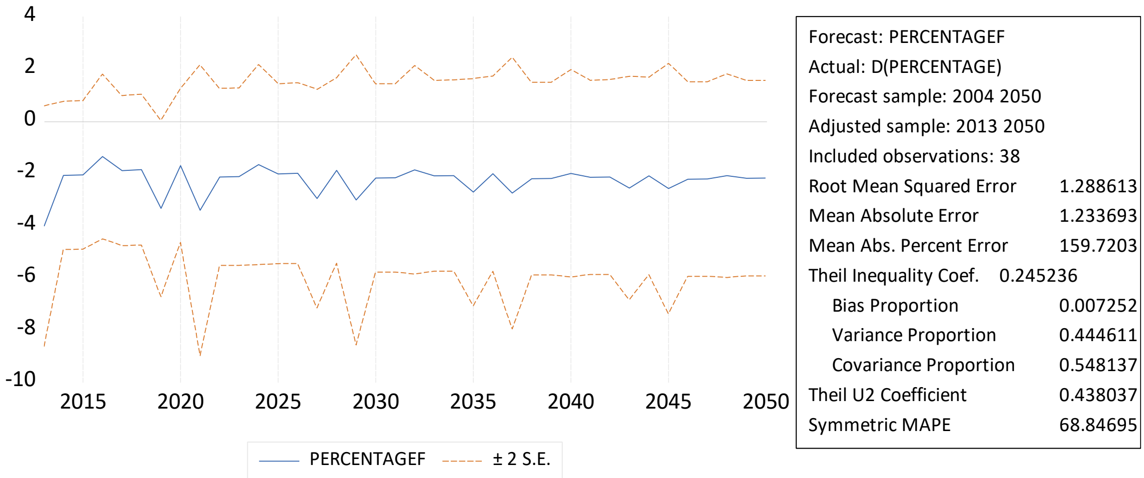
Method	ARIMA (1.1.1)	**ARIMA (1.1.8)**	ARIMA (8.1.1)	ARIMA (8.1.8)
Sigma² (Volatility)	7.89E+11	4.52E+11	6.96E+11	7.30E+11
Adj R^2	-0.155933	0.336804	-0.020704	-0.069753
AIC	30.86904	30.81901	30.82564	30.83409
SBIC	31.05163	31.00160	31.00822	31.01668



Source: the Author.

B2 - Entrance

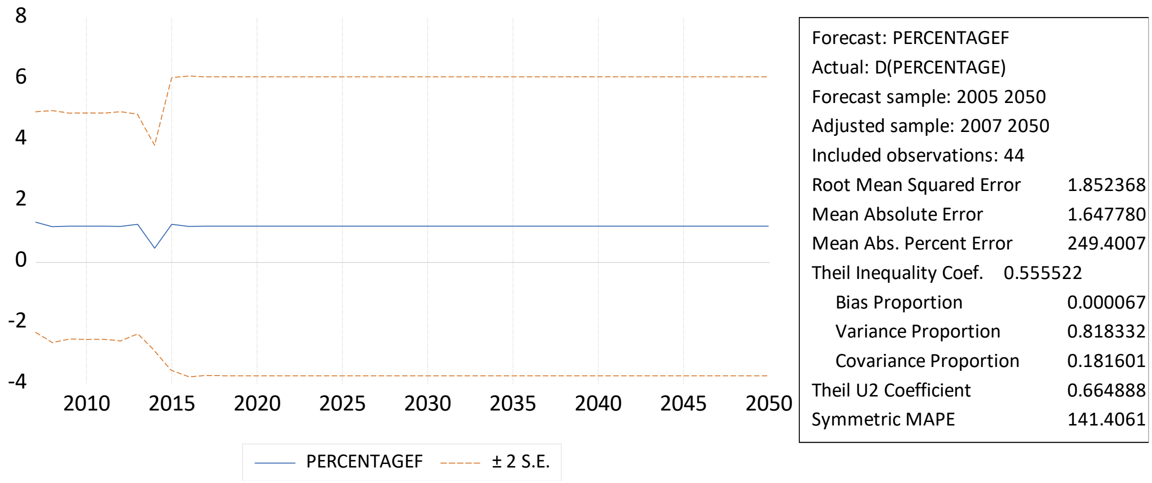
Method	ARIMA (1.1.1)	ARIMA (1.1.8)	**ARIMA (8.1.1)**	ARIMA (8.1.8)
Sigma² (Volatility)	1.381640	0.801994	0.715877	1.224466
Adj R^2	-0.027109	0.403799	0.467818	0.089734
AIC	3.748728	3.632425	3.516419	3.921463



Source: the Author.

B3 - Hatch Small

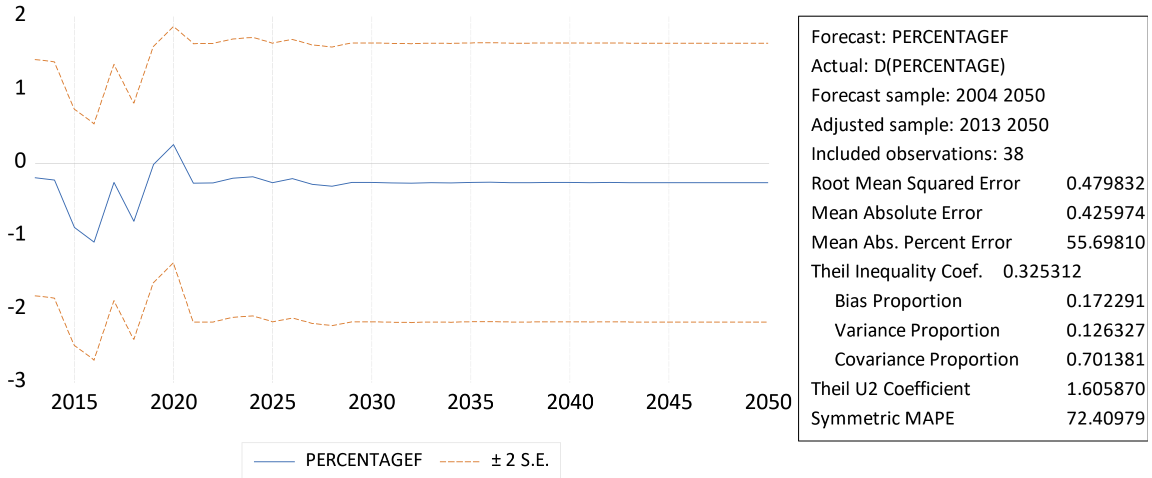
Method	ARIMA (1.1.1)	**ARIMA (1.1.8)**	ARIMA (8.1.1)	ARIMA (8.1.8)
Sigma² (Volatility)	2.732657	1.753945	2.383144	2.109150
Adj R^2	-0.066838	0.315254	0.069612	0.176581
AIC	4.568374	4.598319	4.581465	4.605786
SBIC	4.742205	4.772150	4.755296	4.779616



Source: the Author.

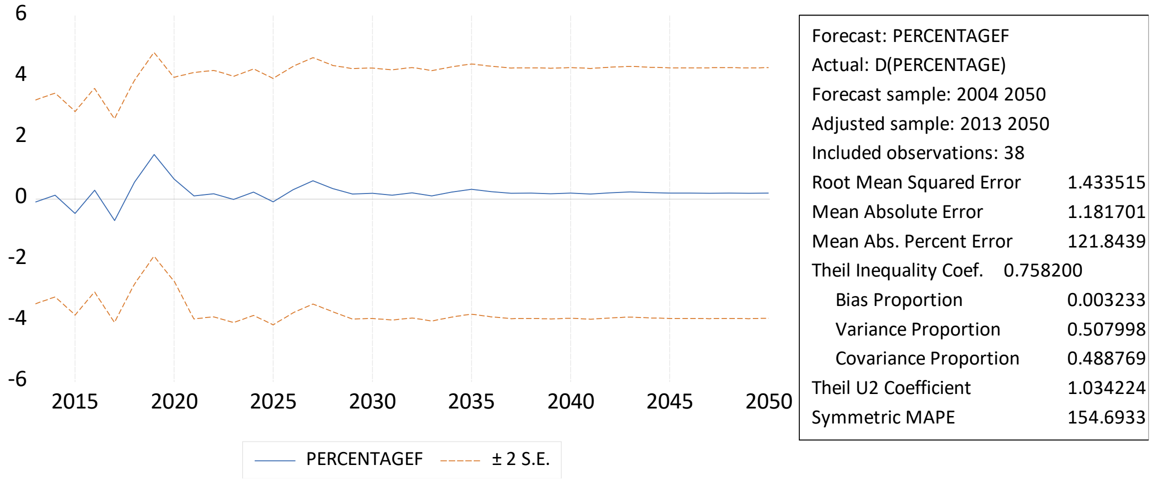
B4 - Hatch Medium

Method	ARIMA (1.1.1)	ARIMA (1.1.8)	ARIMA (8.1.1)	**ARIMA (8.1.8)**
Sigma² (Volatility)	0.513511	0.502951	0.496850	0.465545
Adj R^2	-0.037957	-0.016613	-0.004281	0.058995
AIC	2.756847	2.754556	2.771988	2.866656
SBIC	2.939435	2.937143	2.954576	3.049244



B5 - Sedan Small

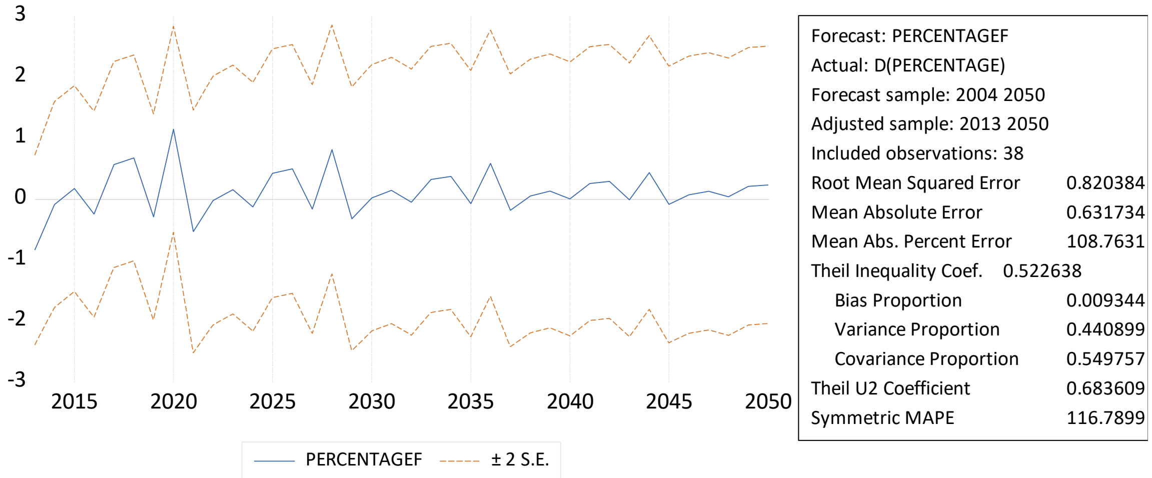
Method	ARIMA (1.1.1)	ARIMA (1.1.8)	ARIMA (8.1.1)	**ARIMA (8.1.8)**
Sigma² (Volatility)	2.747397	2.517084	2.559421	1.994000
Adj R^2	-0.220382	-0.118077	-0.136883	0.114274
AIC	4.425057	4.430871	4.591763	4.644623
SBIC	4.607644	4.613459	4.392274	4.445134



Source: the Author.

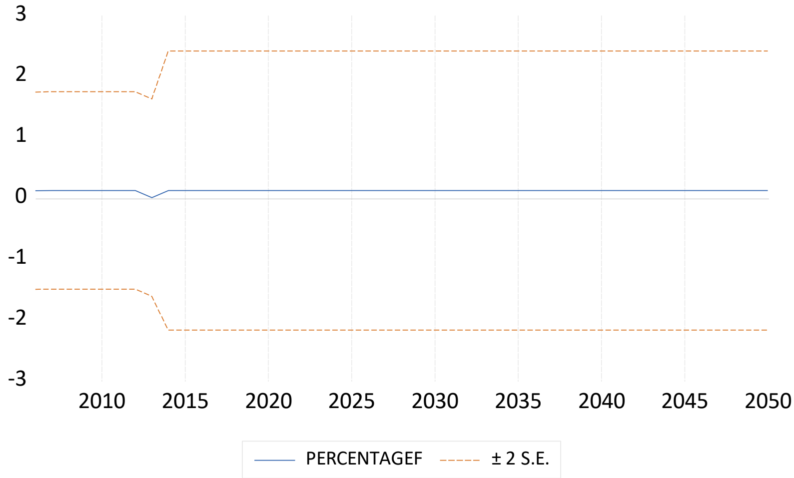
B6 - Sedan Compact

Method	ARIMA (1.1.1)	ARIMA (1.1.8)	**ARIMA (8.1.1)**	ARIMA (8.1.8)
Sigma² (Volatility)	0.603340	0.363313	0.432991	0.472124
Adj R^2	0.084488	0.448706	0.342976	0.283595
AIC	3.040898	2.976266	2.937927	3.049977
SBIC	3.223486	3.158854	3.120515	3.232565



B7 - Sedan Medium

Method	ARIMA (1.1.1)	**ARIMA (1.1.8)**	ARIMA (8.1.1)	ARIMA (8.1.8)
Sigma² (Volatility)	0.861257	0.468531	0.605739	0.484258
Adj R²	-0.074024	0.550556	0.244619	0.396110
AIC	3.361819	3.221041	3.202257	3.202290
SBIC	3.544406	3.403628	3.384845	3.384878

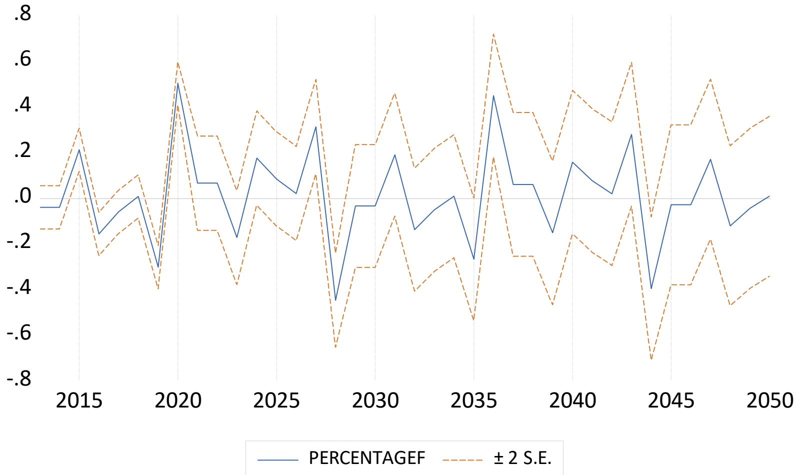


Forecast: PERCENTAGEF	
Actual: D(PERCENTAGE)	
Forecast sample: 2004 2050	
Adjusted sample: 2006 2050	
Included observations: 45	
Root Mean Squared Error	1.053872
Mean Absolute Error	0.910048
Mean Abs. Percent Error	99.14177
Theil Inequality Coef.	0.887871
Bias Proportion	0.000332
Variance Proportion	0.948313
Covariance Proportion	0.051355
Theil U2 Coefficient	1.028538
Symmetric MAPE	169.0139

Source: the Author.

B8 - Sedan Big

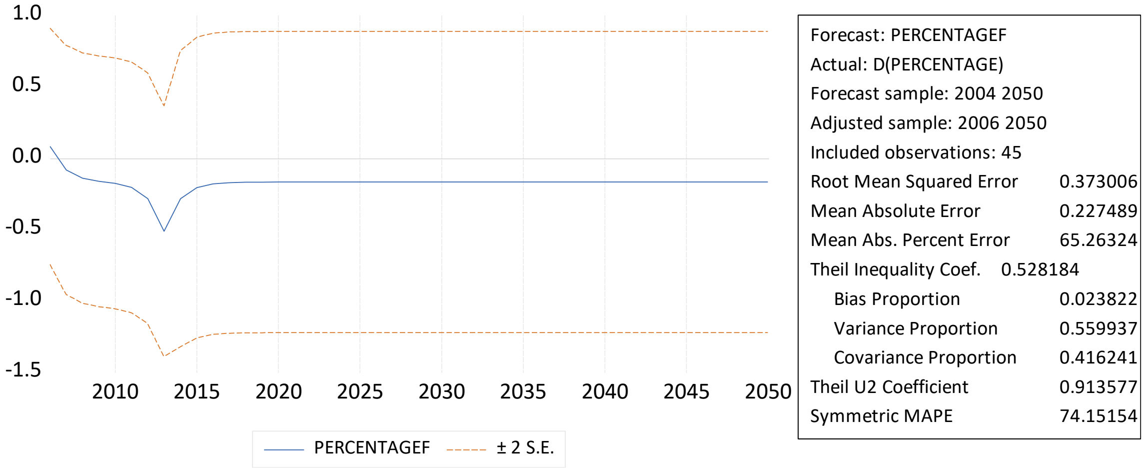
Method	ARIMA (1.1.1)	ARIMA (1.1.8)	ARIMA (8.1.1)	**ARIMA (8.1.8)**
Sigma² (Volatility)	0.024056	0.013534	0.003053	0.001603
Adj R²	0.194260	0.546673	0.897750	0.946323
AIC	-0.158427	-0.306520	-0.882664	-0.711122
SBIC	0.024161	-0.123932	-0.700076	-0.528535



Forecast: PERCENTAGEF	
Actual: D(PERCENTAGE)	
Forecast sample: 2004 2050	
Adjusted sample: 2013 2050	
Included observations: 38	
Root Mean Squared Error	0.056077
Mean Absolute Error	0.040254
Mean Abs. Percent Error	NA
Theil Inequality Coef.	0.233356
Bias Proportion	0.000001
Variance Proportion	0.065453
Covariance Proportion	0.934547
Theil U2 Coefficient	0.098404
Symmetric MAPE	83.14181

B9 - SW Medium

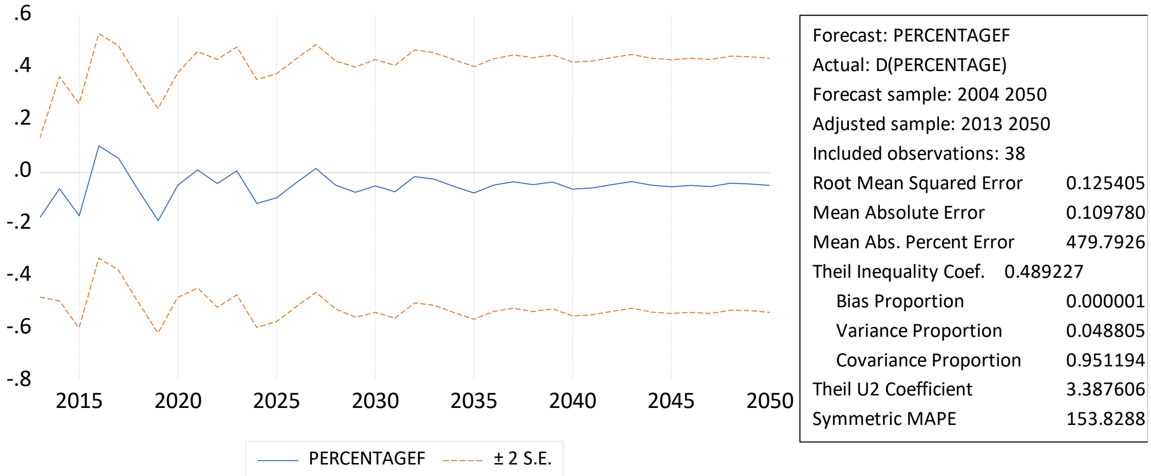
Method	ARIMA (1.1.1)	**ARIMA (1.1.8)**	ARIMA (8.1.1)	ARIMA (8.1.8)
Sigma² (Volatility)	0.173411	0.122239	0.137723	0.152673
Adj R^2	0.132145	0.201936	0.100851	0.003246
AIC	1.674110	1.580470	1.569723	1.678640
SBIC	1.856697	1.763058	1.752311	1.861228



Source: the Author.

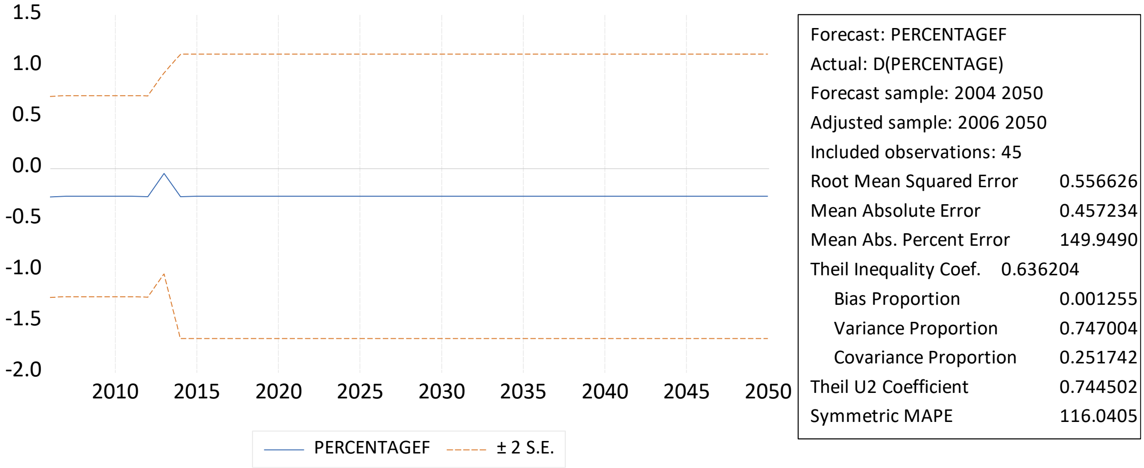
B10 - SW Big

Method	ARIMA (1.1.1)	ARIMA (1.1.8)	**ARIMA (8.1.1)**	ARIMA (8.1.8)
Sigma² (Volatility)	0.020772	0.027728	0.016479	0.024390
Adj R^2	0.142693	-0.144389	0.319872	-0.006635
AIC	-0.316675	-0.092670	-0.335573	-0.092547
SBIC	-0.134087	0.089918	-0.152986	0.090041



B11 - Mono Cabinet

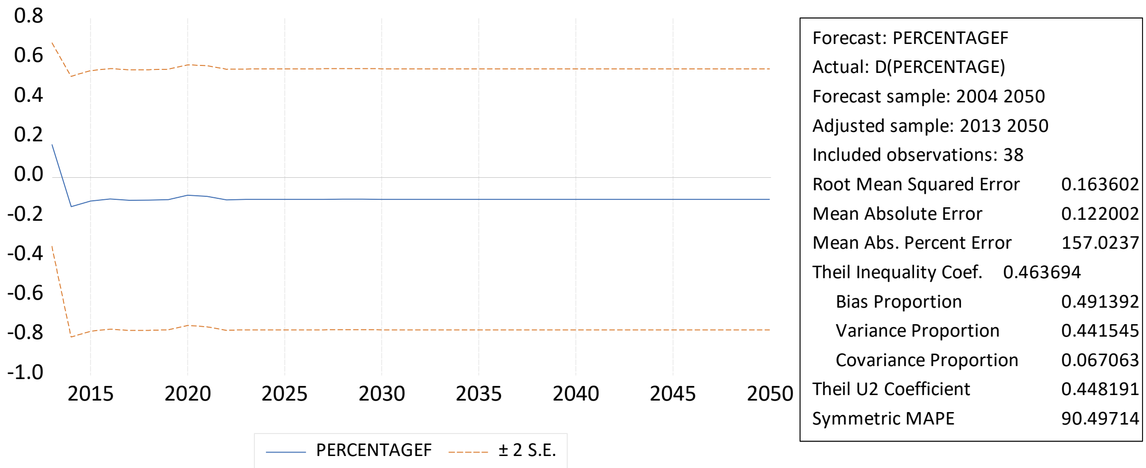
Method	ARIMA (1.1.1)	**ARIMA (1.1.8)**	ARIMA (8.1.1)	ARIMA (8.1.8)
Sigma² (Volatility)	0.230415	0.173278	0.272935	0.284949
Adj R²	-0.051204	0.209466	-0.245191	-0.300000
AIC	2.049623	2.226321	2.118577	2.153861
SBIC	2.232210	2.408909	2.301165	2.336448



Source: the Author.

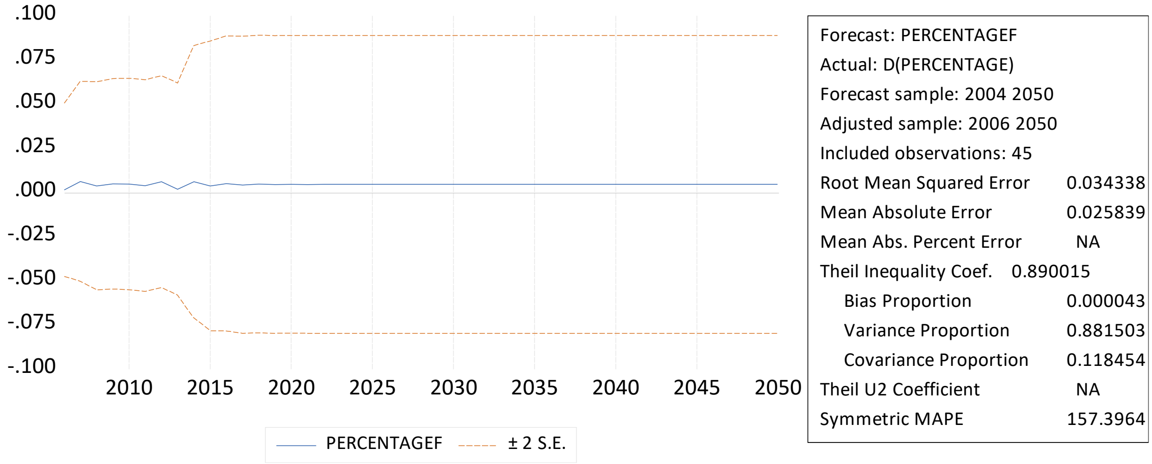
B12 - Grand Cabinet

Method	ARIMA (1.1.1)	ARIMA (1.1.8)	**ARIMA (8.1.1)**	ARIMA (8.1.8)
Sigma² (Volatility)	0.047353	0.059430	0.047167	0.052028
Adj R²	0.251908	0.061111	0.254853	0.178049
AIC	0.429649	0.613100	0.428519	0.996569
SBIC	0.612237	0.795688	0.611107	0.797079



B13 - Sport

Method	ARIMA (1.1.1)	**ARIMA (1.1.8)**	ARIMA (8.1.1)	ARIMA (8.1.8)
Sigma² (Volatility)	0.000781	0.000430	0.000598	0.000464
Adj R^2	0.036068	0.470030	0.262642	0.427832
AIC	-3.724619	3.746369	-3.726306	-3.497534
SBIC	-3.542032	-3.563781	-3.543718	-3.314946



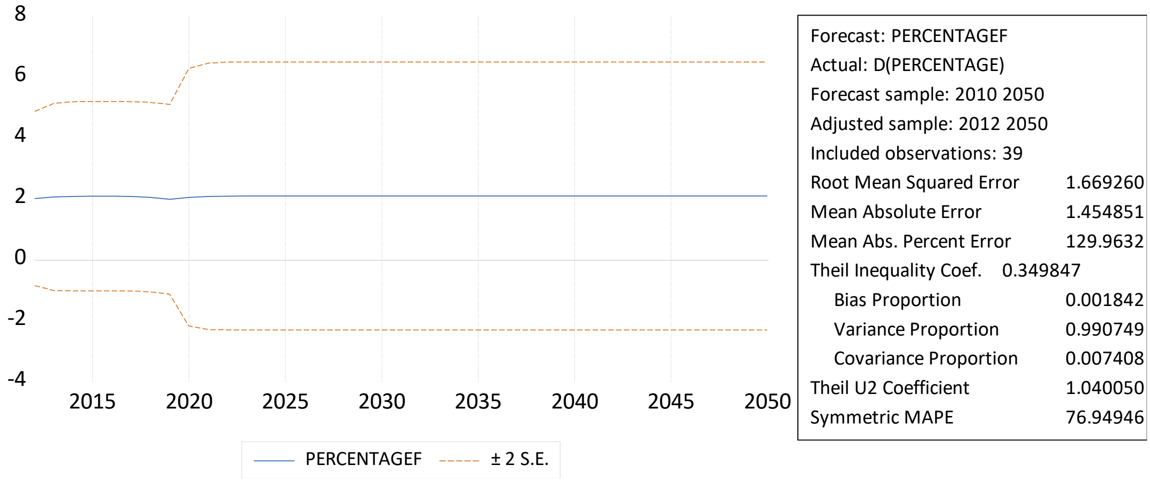
Source: the Author.

B14 - SUV

Method	ARIMA (1.1.1)	**ARIMA (1.1.8)**	ARIMA (8.1.1)	ARIMA (8.1.8)
Sigma² (Volatility)	2.293541	1.021642	9.71E-16	Singular covariance
Adj R^2	-0.604212	0.285415	1.000000	Singular covariance
AIC	4.723741	4.568528	4.620320	Singular covariance
SBIC	4.763462	4.608248	4.660041	Singular covariance

ARIMA (8.1.1) was not suitable for the present analysis because it does not have an applicable SE interval.

Source: the Author.



Source: the Author.

APPENDIX C – Effort Reduction of each segment of PBE

Table C1 – Pareto Analysis for 2020

	2020										
	Sub-Compact	Compact	Medium	Big	SUV	Off-Road	Mini-Van	Comercial	Charge-Pi	Sport	TOTAL
Complete	19.00	78.00	150.00	142.00	265.00	154.00	7.00	30.00	100.00	80.00	1025.00
Top 10	13.00	68.00	135.00	38.00	72.00	7.00	4.00	14.00	91.00	4.00	446.00

2020	
Participation	0.9
Effort Reduction	0.564878049

Source: the Author.

Table C2 – Pareto Analysis for 2019

	2019										
	Sub-Compact	Compact	Medium	Big	SUV	Off-Road	Mini-Van	Comercial	Charge-Pi	Sport	TOTAL
Complete	18.00	62.00	93.00	131.00	151.00	49.00	10.00	22.00	72.00	73.00	681.00
Top 10	15.00	53.00	71.00	41.00	49.00	5.00	4.00	12.00	68.00	6.00	324.00

2019	
Participation	0.885726149
Effort Reduction	0.524229075

Source: the Author.

Table C3 – Pareto Analysis for 2018

	2018										
	Sub-Compact	Compact	Medium	Big	SUV	Off-Road	Mini-Van	Comercial	Charge-Pi	Sport	TOTAL
Complete	20.00	81.00	123.00	154.00	181.00	46.00	11.00	23.00	71.00	80.00	790.00
Top 10	17.00	68.00	93.00	47.00	65.00	2.00	6.00	12.00	66.00	4.00	380.00

2018	
Participation	0.884842164
Effort Reduction	0.518987342

Source: the Author.

Table C4 – Pareto Analysis for 2017

	2017										
	Sub-Compact	Compact	Medium	Big	SUV	Off-Road	Mini-Van	Comercial	Charge-Pi	Sport	TOTAL
Complete	28.00	65.00	90.00	170.00	162.00	55.00	8.00	18.00	65.00	74.00	735.00
Top 10	23.00	58.00	64.00	43.00	62.00	3.00	3.00	8.00	57.00	2.00	323.00

2017	
Participation	0.881126372
Effort Reduction	0.560544218

Source: the Author.

Table C5 – Pareto Analysis for 2016

	2016										
	Sub-Compact	Compact	Medium	Big	SUV	Off-Road	**Mini-Van**	Comercial	Charge-Pi	Sport	TOTAL
Complete	61.00	173.00	174.00	230.00	181.00	93.00	11.00	23.00	71.00	80.00	1097.00
Top 10	46.00	137.00	121.00	74.00	65.00	10.00	6.00	12.00	66.00	4.00	541.00

2016	
Participation	0.883754337
Effort Reduction	0.506836828

Source: the Author.

Table C6 – Analysis for 2015

	2015										
	Sub-Compact	Compact	Medium	Big	SUV	Off-Road	Mini-Van	Comercial	Charge-Pi	Sport	TOTAL
Complete	20.00	81.00	123.00	154.00	181.00	46.00	11.00	23.00	71.00	80.00	790.00
Top 10	17.00	68.00	93.00	47.00	65.00	2.00	6.00	12.00	66.00	4.00	380.00

2015	
Participation	0.890818441
Effort Reduction	0.518987342

Source: the Author.

Table C7 – Analysis for 2014

	2014										
	Sub-Compact	Compact	Medium	Big	SUV	Off-Road	Mini-Van	Comercial	Charge-Pi	Sport	TOTAL
Complete	47.00	119.00	102.00	144.00	66.00	48.00	17.00	19.00	9.00	24.00	595.00
Top 10	37.00	89.00	62.00	59.00	36.00	3.00	6.00	3.00	9.00	1.00	305.00

2014	
Participation	0.912600303
Effort Reduction	0.487394958

Source: the Author.

APPENDIX D – Vehicles Segments Definitions

Frame D1 – Vehicle segments definitions

Fenabrave segments	Definition
Entrance	A term used to identify models that cost less among those offered by brands.
Hatch Small	Abbreviation for the hatchback is a type of car that integrates the trunk to the passenger compartment. Hatch small therefore comprises the hatchback vehicle with a passenger area of less than 7.0m².
Hatch Medium	Abbreviation for a hatchback is a type of car that integrates the trunk to the passenger compartment. Hatch medium, therefore, comprises the hatchback vehicle with a passenger area between 7.0m² and 8.0m².
Sedan Small	Type of car that has a luggage compartment in which it is not integrated with the passenger compartment (nor the rear window). Small refers to a passenger area of less than 6.5 m².
Sedan Compact	Type of car that has a luggage compartment in which it is not integrated with the passenger compartment (nor the rear window). Compact refers to the passenger area between 6.5 m² and 7.0 m².
Sedan Medium	Type of car that has a luggage compartment in which it is not integrated with the passenger compartment (nor the rear window). Medium refers to the passenger area between 7.0 m² and 8.0 m².
Sedan Big	Type of car that has a luggage compartment in which it is not integrated with the passenger compartment (nor the rear window). Big refers to a passenger area larger than 8.0 m².
SW Medium	Known in Brazil by the term station wagon, it is a type of car model that prioritizes the internal space - in several cases, it is a variation of an existing sedan or hatch. It differs from the minivan in that it is generally lower. Medium refers to a passenger area of less than 8.0 m².
SW Big	Known in Brazil by the term station wagon, it is a type of car model that prioritizes the internal space - in several cases, it is a variation of an existing sedan or hatch. It differs from the minivan in that it is generally lower. Large refers to a passenger area larger than 8.0 m².
Mono Cabinetinet	The term is used to designate minivans. In the federation, they are separated in Mono Cabinetinet, the smallest, and Grand Cabinet, the largest, from 7 places.
Grand Cabinetinet	The term is used to designate minivans. In the federation, they are separated in Mono Cabinetinet, the smallest, and Grand Cabinet, the largest, from 7 places.
Sport	Luxury sports vehicles are understood, with high engine power, performance, comfort and cutting edge technological differentials.
SUV	Sport Utility Vehicle, the term used for large sport utility vehicles, with a proposal to run in urban areas and on land.

Source: the Author – adapted from Fenabrave (2020)

PBE segments	Definition
Sub-compact	Vehicles with passenger area to 6.5 m²
Compact	Vehicles with passenger area between 6.5 and 7.0 m²
Medium	Vehicles with passenger area between 7.0 and 8.0 m²
Big	Vehicles with passenger area over 8.0 m²
SUV	Sport Utility Vehicle, the term used for large sport utility vehicles, with a proposal to run in urban areas and on land.
Off-Road	Vehicles designed to drive off the road, with 4x4 traction and which do not fall into the pickup category.
Mini-Van	The name derives from a van, but it is used for private cars that prioritize the interior space and the transport of luggage, hence they are very popular as taxis. They are usually taller than wagons.
Comercial	A term used to designate cargo vehicles (pickup trucks, small trucks) and utility vehicles (vans).
Charge-Pick-up	A vehicle with an open cargo compartment, and because it is a light vehicle, its gross weight cannot exceed 3,500 kg.
Sport	Luxury sports vehicles are understood, with high engine power, performance, comfort, and cutting-edge technological differentials.

Source: the Author – adapted from PBE (2019)

APPENDIX E – Detailed emissions of Brazilian Mix

In this appendix, data referring to the simulations of the Brazilian Mix from the C2050 are presented. To this end, the respective graphs were digitally analyzed using the Engauge software, as the annual levels for each simulation were necessary. Tables X, X, and X refer to SC1, SC2, and SC3, respectively, and the data in bold type are those effectively used in the simulations.

Table E1 – Detailed emissions of Mix Scenario 1

OIE - SC1		**EMI - SC1**		**OIE - SC1**		**EMI - SC1**	
Year	TWh/year	Year	TWh/year	Year	TWh/year	Year	kTCO2e/TWh
2013.915	685.979	2013.714	98.9494	2033.004	1302.22	2033.143	200.84
2014.83	696.959	2014.714	99.1066	2033.919	1334.63	2033.714	200.929
2015.353	718.539	2015.286	99.1964	**2034**	**1336.40387**	**2034**	**203.8836879**
2016.399	729.556	2016.429	99.376	2034.834	1377.75	2034.714	206.9
2017.314	761.964	2017.286	99.6967	**2035**	**1382.690841**	**2035**	**208.5622515**
2018	**771.9982937**	**2018**	**99.76669641**	**2036**	**1423.507473**	**2036**	**212.6393722**
2018.36	783.695	2018.429	99.6902	2036.272	1442.45	2036.857	218.865
2019	**804.4512827**	**2019**	**99.5882042**	**2037**	**1472.593368**	**2037**	**225.2344268**
2019.276	816.103	2019.286	105.639	2037.449	1496.37	2037.857	219.022
2020	**826.9723018**	**2020**	**99.42657325**	**2038**	**1520.365865**	**2038**	**223.7924288**
2020.06	827.044	2020.286	105.796	2038.495	1539.53	2038.714	230.785
2020.845	870.129	2020.571	111.655	**2039**	**1563.363299**	**2039**	**231.1866401**
2021	**878.6685574**	**2021**	**120.4432949**	2039.279	1582.61	2039.571	232.919
2022	**933.5923894**	**2022**	**140.9493848**	**2040**	**1611.74204**	**2040**	**238.1298621**
2022.152	902.65	2022.143	117.716	2040.456	1625.81	2040.571	236.891
2023	**935.0297613**	**2023**	**129.4586682**	**2041**	**1653.724899**	**2041**	**239.7252108**
2023.067	935.058	2023.714	129.591	2041.24	1658.18	2041.143	236.98
2024	**978.263759**	**2024**	**141.2592333**	**2042**	**1689.705974**	**2042**	**240.8929475**
2024.375	978.294	2024.286	141.308	2042.156	1690.59	2042.143	237.137
2025	**1021.462761**	**2025**	**147.1115239**	2042.94	1733.67	2042.857	248.878
2025.551	1021.49	2025.286	147.279	**2043**	**1731.680317**	**2043**	**248.966**
2026	**1064.625765**	**2026**	**159.0216716**	2043.986	1766.12	2043.857	249.035
2026.597	1064.65	2026.857	159.154	**2044**	**1770.238966**	**2044**	**252.5513858**
2027	**1107.822762**	**2027**	**164.9575239**	2044.901	1798.52	2044.571	254.961
2027.774	1107.85	2027.857	165.125	**2045**	**1802.229038**	**2045**	**255.2962299**
2028	**1127.10383**	**2028**	**168.2811529**	2045.686	1830.89	2045.429	255.096
2028.951	1151.05	2028.571	171.051	**2046**	**1840.296343**	**2046**	**258.1650331**
2029	**1154.697665**	**2029**	**173.1177794**	2046.601	1874.02	2046.857	261.134
2029.735	1194.13	2029.714	177.045	**2047**	**1888.203405**	**2047**	**261.0133727**
2030	**1199.003087**	**2030**	**178.990254**	2047.516	1906.42	2047.857	267.105
2030.912	1226.62	2030.714	183.016	**2048**	**1929.717127**	**2048**	**267.136**
2031	**1234.961531**	**2031**	**184.5284691**	2048.17	1938.76	2048.143	267.15
2031.958	1259.06	2031.714	188.987	**2049**	**1970.753947**	**2049**	**267.238**
2032	**1261.261345**	**2032**	**190.5827805**	2049.085	1992.59	2049.143	267.307
2033	**1292.151485**	**2033**	**196.3933677**	**2050**	**2021**	**2050**	**269**

Source: Author – based on MME (2020).

Table E2 – Detailed emissions of Mix Scenario 2

OIE – SC2		**EMI – SC2**		**OIE – SC2**		**EMI – SC2**	
Year	TWh/year	Year	TWh/year	Year	TWh/year	Year	kTCO2e/TWh
2013.567	698.015	2013.534296	119.565	**2033**	**1299.581986**	**2033**	**260.87**
2014.507	719.556	2014.46931	125	2033.704	1324.8	2033.5704	260.87
2015.446	741.097	2015.40433	130.435	**2034**	**1336.730741**	**2034**	**265.2395699**
2016.52	773.508	2016.33935	130.435	2034.51	1357.29	2034.639	271.739
2017.594	795.009	2017.54152	135.87	**2035**	**1377.05092**	**2035**	**274.1872593**
2018	**809.0441386**	**2018**	**138.2014651**	2035.584	1400.61	2035.4404	277.174
2018.533	827.459	2018.61011	141.304	**2036**	**1417.371098**	**2036**	**277.174**
2019	**841.5426692**	**2019**	**146.5921118**	2036.659	1443.93	2036.3755	277.174
2019.607	859.87	2019.41155	152.174	**2037**	**1459.666674**	**2037**	**283.5265414**
2020	**868.8760491**	**2020**	**154.8343773**	2037.599	1487.29	2037.444	288.043
2020.547	881.411	2020.61372	157.609	**2038**	**1505.776679**	**2038**	**290.8708682**
2021	**890.4925067**	**2021**	**162.099254**	2038.539	1530.65	2038.5126	293.478
2021.62	902.913	2021.54874	168.478	**2039**	**1546.552192**	**2039**	**293.478**
2022	**913.0947749**	**2022**	**173.0683445**	2039.479	1563.1	2039.4477	293.478
2022.425	924.494	2022.61733	179.348	**2040**	**1587.111009**	**2040**	**295.9750888**
2023	**936.0039444**	**2023**	**181.942996**	2040.42	1606.46	2040.6498	298.913
2023.499	945.995	2023.4188	184.783	**2041**	**1632.474786**	**2041**	**298.913**
2024	**963.2994379**	**2024**	**190.6945317**	2041.629	1660.65	2041.4513	298.913
2024.439	978.446	2024.4874	195.652	**2042**	**1677.776347**	**2042**	**302.1025021**
2025	**1001.081913**	**2025**	**198.6316588**	2042.569	1704.01	2042.3863	304.348
2025.513	1021.77	2025.4224	201.087	**2043**	**1712.644852**	**2043**	**307.1226939**
2026	**1031.52361**	**2026**	**206.9624557**	2043.642	1725.51	2043.5884	309.783
2026.587	1043.27	2026.491	211.957	**2044**	**1735.095454**	**2044**	**311.8760511**
2027	**1064.13479**	**2027**	**217.8739209**	2044.448	1747.09	2044.657	315.217
2027.641	1096.479	2027.426	222.826	**2045**	**1769.362867**	**2045**	**316.9615302**
2028	**1113.877091**	**2028**	**225.7454179**	2045.791	1801.24	2045.7256	320.652
2028.333	1130.02	2028.4946	228.261	**2046**	**1810.895023**	**2046**	**320.652**
2029	**1150.153065**	**2029**	**233.4015508**	2046.731	1844.6	2046.5271	320.652
2029.407	1162.44	2029.5632	239.13	**2047**	**1857.004382**	**2047**	**320.652**
2030	**1189.01464**	**2030**	**241.3516058**	2047.671	1887.96	2047.5957	320.652
2030.616	1216.62	2030.6318	244.565	**2048**	**1904.543311**	**2048**	**323.3939148**
2031	**1229.878991**	**2031**	**247.0620888**	2048.746	1942.19	2048.3971	326.087
2031.556	1249.07	2031.4332	250	**2049**	**1954.479542**	**2049**	**326.087**
2032	**1264.405983**	**2032**	**255.1265735**	2049.418	1974.72	2049.4657	326.087
2032.496	1281.52	2032.635	260.87	**2050**	**2021**	**2050**	**334**

Source: Author – based on MME (2020).

Table E3– Detailed emissions of Mix Scenario 3

OIE – SC3		**EMI – SC3**		**OIE – SC3**		**EMI – SC3**	
Year	TWh/year	Year	TWh/year	Year	TWh/year	Year	kTCO2e/TWh
2013.51045	697.917	2013.466	111.691	**2033**	**1485.159516**	**2033**	**79.17328**
2014.53103	739.583	2014.622	111.507	2033.5414	1510.42	2033.546	79.0864
2015.55172	781.25	2015.632	105.464	**2034**	**1533.819518**	**2034**	**79.01429**
2016.4448	833.333	2016.644	105.303	2034.5621	1562.5	2034.558	78.9256
2017.4655	864.583	2017.511	105.165	**2035**	**1582.931411**	**2035**	**78.85534**
2018	**883.9779364**	**2018**	**105.0872**	2035.4552	1604.17	2035.714	78.7418
2018.61379	906.25	2018.523	105.004	**2036**	**1626.406081**	**2036**	**78.69636**
2019	**919.763523**	**2019**	**102.1474**	2036.4759	1645.83	2036.437	78.6269
2019.5069	937.5	2019.533	98.9614	**2037**	**1679.114595**	**2037**	**75.25724**
2020	**954.753807**	**2020**	**96.16429**	2037.6241	1718.75	2037.447	72.584
2020.4	968.75	2020.542	92.9185	**2038**	**1734.093358**	**2038**	**72.49601**
2021	**979.6356725**	**2021**	**89.73608**	2038.3897	1750	2038.458	72.4231
2021.54828	989.583	2021.408	86.8986	**2039**	**1777.681958**	**2039**	**72.33702**
2022	**1008.023288**	**2022**	**86.80448**	2039.5379	1802.08	2039.47	72.2623
2022.56897	1031.25	2022.564	86.7148	**2040**	**1830.375532**	**2040**	**72.17808**
2023	**1046.331441**	**2023**	**83.68299**	2040.5586	1864.58	2040.482	72.1015
2023.4621	1062.5	2023.43	80.6948	**2041**	**1885.174713**	**2041**	**72.01912**
2024	**1084.459727**	**2024**	**80.60412**	2041.4517	1906.25	2041.638	71.9177
2024.4828	1104.17	2024.586	80.511	**2042**	**1934.226353**	**2042**	**71.86012**
2025	**1130.562099**	**2025**	**80.44513**	2042.4724	1958.33	2042.65	71.7568
2025.5034	1156.25	2025.453	80.3731	**2043**	**1987.046363**	**2043**	**69.31963**
2026	**1176.523657**	**2026**	**80.28613**	2043.6207	2020.83	2043.515	65.7369
2026.5241	1197.92	2026.609	80.1893	**2044**	**2041.477199**	**2044**	**65.65978**
2027	**1220.119075**	**2027**	**80.12719**	2044.3862	2062.5	2044.527	65.576
2027.4172	1239.58	2027.476	80.0515	**2045**	**2097.579784**	**2045**	**65.50078**
2028	**1263.372766**	**2028**	**79.96825**	2045.6621	2135.42	2045.538	65.4152
2028.4379	1281.25	2028.633	79.8677	**2046**	**2153.809176**	**2046**	**65.3418**
2029	**1306.743484**	**2029**	**79.80925**	2046.4276	2177.08	2046.406	65.2773
2029.5862	1333.33	2029.5	79.7298	**2047**	**2212.129476**	**2047**	**65.18281**
2030	**1354.447705**	**2030**	**79.65023**	2047.4483	2239.58	2047.562	65.0935
2030.6069	1385.42	2030.367	79.5919	**2048**	**2267.73524**	**2048**	**65.02386**
2031	**1401.464426**	**2031**	**79.49125**	2048.469	2291.67	2048.429	64.9557
2031.6276	1427.08	2031.378	79.4311	**2049**	**2320.573937**	**2049**	**65.0715**
2032	**1442.283202**	**2032**	**79.33228**	2049.6172	2354.17	2049.583	65.1898
2032.6483	1468.75	2032.535	79.2473	**2050**	**2391**	**2050**	**65**

Source: Author – based on MME (2020).

APPENDIX F – Composition of the internal energy supply

The table presented in this appendix is a summary of the meaning of the internal energy supply indicators considered by the Ministry of Mines and Energy for the elaboration of possible Brazil 2050 scenarios.

Table F1 – Energy scenarios description

Energy supply possibilities		**Possible scenarios**		
Portuguese Term	English Term	Scenario 1: no addition of supply nor reduction on demand	Scenario 2: small effort for adding supply and reducing demand	Scenario 3: huge effort for adding supply and reducing demand
Termelétricas a gás natural – Potência Instalada	Natural Gas Power Generation – installed capacity	**1 -** Only existing thermoelectric plants, the capacity installed is limited to 13 GW by 2050.	**2 -** Considers the plants currently in operation and the expansion. foreseen in the 10-year plan (PDE 2024), reaching 23 GW in 2050.	
Termelétricas a gás natural – CCS	Natural Gas Power Generation – Carbon Capture and Storage	**1 and 2:** assume that Brazil will not add technologies for carbon capture in natural gas power generation by 2050.	**3 -** considers that the plants built from 2025 will be with CCS.	
Termelétricas a carvão – Potência Instalada	Coal-fired power stations - installed capacity	**1 -** Considers the current plants in operation with coal, the capacity installed would remain constant with 3.2 GW.	**2 -** It includes the operation of plants that are currently under concession. There are three plants of 500 MW on average. The power to be installed is 1.4 GW, totaling 4.6 GW in 2050.	**3 -** Considers that 90% of the reserves of the PNE 2030 “conservative scenario” could be used for thermoelectric generation. Assumes that all plants would be 0.5 GW and average yield 35%. Thus, the installed capacity would reach 40.8 GW.
Termelétricas a carvão – CCS	Coal-fired power stations - Carbon Capture and Storage	**1 and 2:** Brazil will not add any technology for the capture of carbon in coal-fired thermoelectric generation by 2050.	**3 -** Considers that the plants built from 2025 will be with CCS. In this case, there is the installation of 1 GW per year of plants with CCS from 2025, totaling 25 GW in 2050.	
Termelétricas a derivadas de petróleo	Fossil fuel power station	**1 -** Considers that will not be installed new oil derivative plants, and in 2025 all existing plants would be decommissioned. Therefore, the power in 2050 is null.	**2 -** Includes expansion reaching the capacity of 15 GW in 2050.	**3 –** Includes higher expansion reaching the capacity of 17 GW in 2050.
Aproveitamento da biomassa e do biogás	Utilization of biomass and biogas	**1 -** Considers the stagnation of the use of biomass and biogas. In 2050, assumes the valuation of only 0.6% of biomass and 0.2% of biogas.	**2 -** Estimates the utilization for the generation of electric energy of up to 30% of biomass and 10% of biogas in 2050.	**3 -** It foresees the use of 50% of biomass and 20% of biogas for the generation of electric energy.

Energy supply possibilities		Possible scenarios		
Aproveitamento do excedente de bagaço	Use of surplus sugarcane bagasse	**1 -** Assumes maintenance of the current level of bioenergy derived from the use of bagasse for 2050 (37%).	**2 -** It foresees a gradual increase in the use of surplus bagasse up to 50% in 2050.	**3 -** Admits a use of the surplus of bagasse for energy purposes of 70% in 2050
Prioridade de uso do biogás	Priority of biogas use	**A -** It assumes that the totality of the biogas is used as fuel in vehicles.	**B -** Admits that 40% of the biogas is used as fuel and the remainder for electricity generation (60%).	**C -** Considers that biogas is converted into electricity in its entirety
Eficiência das usinas a biocombustível	Efficiency of biofuel plants	**1 –** Considers the maintenance of the park. Conversion efficiency is 18% (20% for bagasse-fed plants), for biogas considers an average conversion efficiency of 25%	**2 -** Conversion efficiency of 24% biomass and bagasse 30%. Estimates an increase in the conversion efficiency of up to 30% in 2050 for biogas.	**3 -** Introduction of boilers high pressure (80 bar), increasing the average biomass conversion efficiency by 30%, bagasse, and biogas by 35%.
Energia nuclear	Nuclear energy	**1 -** Expansion of the Brazilian nuclear park, Angra 1, will be decommissioned in 2045. The total nuclear power installed in the country in 2050 will be equivalent to 2,785 MW.	**2 -** It includes a limited expansion. In addition to the reactors in operation, there will be the implementation of only two new reactors. Thus, the installed capacity totals 4,785MW in 2050.	**3 -** Reflects moderate expansion. Thus, in addition to Angra 2 and 3 (level 1), four new reactors are expected to be installed, making a total of 6,785 MW installed in the country in 2050.
Energia eólica onshore	Onshore wind energy	**1 -** Corresponds to the installed wind park, plus projects under construction and concession. In this conservative scenario, no other projects besides the ones already approved today are considered and the maximum generation capacity is reached between 2015 and 2020.	**2 -** It is based on the scenario of new policies in which the country reaches an installed capacity of 21 GW in 2035. The rate of capacity and generation growth given between 2020 and 2035 was extrapolated to 2050.	**3 -** Considers the premise that intermittent sources can participate in up to 20% of electricity generation in the country without the need for major investments in adapting electricity. infrastructure. Thus, it is assumed that in 2050 onshore wind generation will reach 326 TWh.
Energia eólica offshore	Offshore wind energy	**1 -** Considers the maintenance of the status quo, thus, offshore technology does not is feasible and is not adopted in the country as a source of electrical generation.	**2 -** By 2050, offshore generation will be equivalent to 25% of onshore wind generation.	
Energia dos Oceanos	Ocean Energy	**1 -** Brazil will not add new technology to the harnessing ocean energy up to 2050, only the prototype installed in Pecém / CE, with 100 kW capacity.	**2 -** Consider installing new prototypes in areas that are currently the subject of energy potential studies in oceans (waves and tides). By 2050, the installed capacity reaches 6.5 MW, with an annual generation of 29 GWh / year.	**3 -** Considers the use of minimum technical potential. Thus, by 2050 the installed power is equivalent to 7 GW, and the energy generated is 30 TWh / year.
Energia hidráulica	Hydraulic energy	**1 -** It considers the generation park being implemented and contracted. The power to be installed corresponds to about 19 GW, reaching 105 GW by 2050.	**2 -** Considers hydroelectric expansion planned in PDE 2024. This includes projects with a start-up horizon of 2024, with around 11 GW. The total power is 116 GW.	**3 -** Considers that, by 2050, all the inventoried hydroelectric potential has been implemented. Thus, the installed power reaches 172 GW.

Energy supply possibilities		Possible scenarios		
Energia solar fotovoltaica	Photovoltaic solar energy	**1 -** It includes only existing or under construction projects. The total installed capacity at the end of the period is 127 MWp.	**2 -** The entry of 500 MWp through energy auction. As of 2020, 500 MWp is expected to start operating at 5-year intervals, with an increase to 1,000 MWp from 2035. The power of centralized systems reaches 6.4 GWp. For the distributed generation, we assume the entry of 37 GWp until the end of the period. The total power installed in 2050 is 44 GWp	**3 -** Considers input 2,500 MWp in operation every 5 years with beginning in 2020, with an increase to 10 GWp 2035. Considers great incentives, reaching low-income classes yield, reaching 55 GWp in the sector residential, and 18 GWp in the commercial and industrial sectors. THE total installed capacity at the end of the period is 124 GWp, of which 51 GWp in generation centralized and 73 GWp in GD.
Energia solar heliotérmica	Heliothermic solar energy	**1 -** Until 2050, it only considers the start-up of the Petrolina pilot plant (1 MWe) in 2020. The average capacity factor is 23%.	**2 -** It includes a limited expansion, the implementation of a total of 4,400MW by 2050, of which 70% would be in the region. The capacity factor would evolve with technological advancement, with the increase in heat storage time. In the Northeast region it would go from 41% in 2025 to 61% in 2050, and in other regions from 33% to 54%.	**3 -** It provides for the expansion of solar energy. The installed capacity in 2050 is 30 GW, equivalent to approximately 15% of the Brazilian technical and geographic potential.
Importação de hidrelétricas binacionais	Binational hydroelectric plants importing	**1 -** It assumes a conservative scenario in, the only Binational in operation is Itaipu (14,000 MW).	**2 -** It considers the startup of Binacional Garabi (1,500 MW) in 2025 and Panambi (700 MW) in 2035. It considers that, in the beginning, 50% of Argentine capacity could be available for Brazilian imports. A 75% capacity factor was adopted.	**3 -** Provides maximum effort for the expansion of binational hydroelectric plants. Consider the Binacional Cachoeira Ribeirão entrance (800 MW). It is considered that, in the beginning, 50% of Bolivian capacity could be available for Brazilian imports, with a capacity factor of 68%.
Segurança do sistema elétrico	Electrical system security	**1 -** It does not admit additional effort beyond the current potential. It is assumed that the international interconnections existing and under construction, totaling 3 GW in 2050.	**2** - Supports moderate expansion, totaling 5.7 GW import capacity in 2050. 25% of electricity demand from electric vehicles can be managed.	**3 -** Maximum effort for expansion of international interconnections, totaling 16.7 GW of import capacity in 2050. 50% of electricity demand from electric vehicles can be managed.

Energy supply possibilities		**Possible scenarios**			
Produção de óleo e gás associado	Oil and associated gas production	**A -** Assumes possible depletion of probable reserves - oil production decreases from 1.7 to 0.6 MMbbl / d, and gas production runs out before 2050. It is considered a pre-salt reserve of 30 billion barrels of oil, with reinjection of 40% of the associated gas. Oil production exceeding 4 MMbbl / d is achieved from 2020 for 15 years.	**B -** It is considered a pre-salt reserve of 50 billion barrels of oil, with reinjection of 40% of natural gas. In this way, oil production exceeds 4 MMbbl / d is achieved from 2020 onwards for 25 years.	**C -** Considers the same onshore oil production and level A post-salt offshore and same pre-salt reserve. Differ by assuming a reinjection of 10% of the associated gas due to high methane content.	**D -** It is considered a pre-salt reserve of 100 billion barrels of oil, reinjecting 10% of the gas. A production of 5 MMbbl / d is achieved from 2025, remaining above this level even after 2050.
Produção de gás natural não associado	Unassociated natural gas production	**1 -** It considers that conventional non-associated GN is depleted before 2050. Shale gas production starts in 2050 at a slow pace.	**2 -** The production of shale gas starts in 2045, with the construction of 1 horizontal well in 5 days. Thus, in 2050 the production of non-associated NG reaches 3 MMm³ / d.	**3 -** In 2035, shale gas production begins with the construction of a well horizontal per day. Thus, the production of non-associated NG in 2050 is 15 MMm³ / d.	

Source: Adapted from Ministério de Minas e Energia (2020).