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FUTURE PROSPECTIVE SCENARIOS FOR THE USE OF ENERGY IN TRANSPORTATION IN BRAZIL AND GHG EMISSIONS BUSINESS AS USUAL (BAU) SCENARIO - 2050

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Future prospective scenarios for the use of energy in transportation in Brazil and GHG emissions

Business as Usual (BAU) scenario - 2050

Final Report

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Acronyms

ABRACICLO: Brazilian Association of Manufactures of Motorcycles, Mopeds, Scooters, Bicycles and Similar Vehicles.

ANAC: National Civil Aviation Agency.

ANFAVEA: National Association of Automotive Vehicle Manufacturers.

ANTAQ: National Agency for Waterways Transport.

ANTT: National Agency for Land Transport.

ASI: Shift, Improve and Avoid.

ASIF: Activity, structure, intensity and fuel.

B8: 8% of biodiesel added to petroleum diesel

BAU*: Business as Usual.*

BEN: National energy balance.

BEV: *Battery electric vehicle.*

BRT: Bus Rapid Transit.

BX: Percentage of biodiesel added to petroleum diesel.

CEC: Scenario elaboration committee.

COP: Conference of The Parties.

of The United Nations Framework Convention on Climate Change.

EPE: Energy Research Company.

FBMC: Brazilian Climate Change Forum.

GHG: greenhouse gases.

Gg: Gigagram.

CNG: Compressed Natural Gas.

HDV: Heavy-duty vehicles.

IBGE: Brazilian Institute of Geography and Statistics.

ICCT: The International Council on Clean Transportation.

iNDCs: Intended Nationally Determined Contributions.

IPCC: Intergovernamental Panel on Climate Change.

IEA: International Energy Agency.

LDV: Light-duty vehicles.

LTC: Cargo Transport Laboratory.

NDC: Nationally Determined Contributions.

WHO: World Health Organization.

PBMC: Brazilian Panel on Climate Change.

TGW: Total gross weight.

PDE: Brazilian 10-Year Energy Plan.

GDP: gross domestic product.

PNE: National Energy Plan.

SFC: Smart Freight Centre.

TOE: Ton of Oil Equivalent

TOD: Transit-oriented development.

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PRESENTATION

The study entitled "Future prospective scenarios for the use of energy in transportation in Brazil and GHG emissions" is a publication developed by the Cargo Transport Laboratory (LTC) of the Transport Engineering Program (PET) of the Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (COPPE) of the Federal University of Rio de Janeiro (UFRJ), edited and published by the Brazilian Institute of Sustainable Transportation (IBTS).

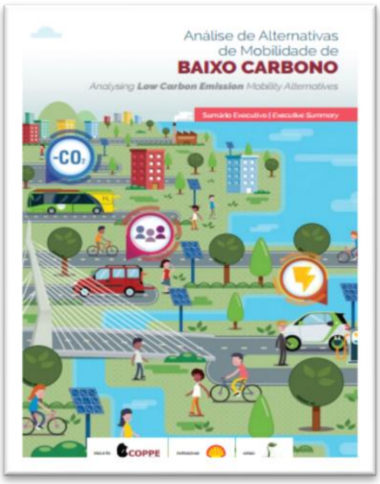
This first edition, which introduces a series of publications, presents the *Business as Usual* (BAU) Scenario of the transportation sector, which involves passenger and freight transportation, considering only the Brazilian domestic trips. The next editions will introduce new scenarios.

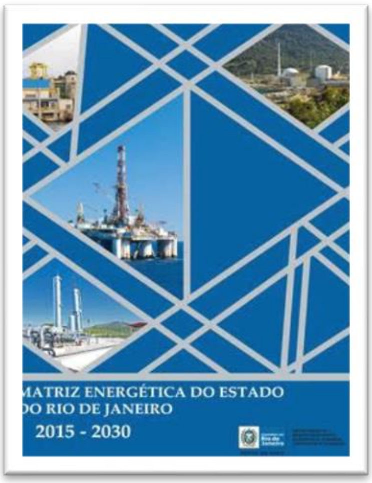
The study aims to illustrate the effect of the development trend of the transportation sector on energy demand, particularly regarding fossil fuels and, consequently, Greenhouse Gas (GHG) Emissions. It, therefore, intends to support decision-making concerning strategies to mitigate GHG emissions. It is an instrument of fundamental importance in developing guidelines for actions in the energy sector covering economic, financial, social, environmental, institutional, technological and human resources aspects and the interconnection between them.

The study was coordinated by Prof. Márcio D'Agosto, who participated in several studies related to the theme, among them: item 3.3 – Transports in Chapter 3 – Paths to Climate Change Mitigation of Volume 3 – Climate Change Mitigation Report of the Brazilian Panel on Climate Change (PBMC) (2011), Inventory of Atmospheric Emissions by Automotive Vehicles in the State of Rio de Janeiro (2011); two editions of *Energy Revolution* published by Greenpeace (2013 and 2015); Chapter 8 of the Analysis Report 5 -*Mitigation of Climate Change* of Workgroup III of the *Intergovernmental Panel on Climate Change* (IPCC) (2014); Analysis of Alternatives of Low Carbon Mobility (2015); Energy Matrix of the State of Rio de Janeiro (2016) and GHG emission – 2050: Economic and Social Implications of the Governmental Plan Scenario (2016).

The participation in the production of the above-mentioned studies and in the meetings of the Thematic Chamber of the transportation sector of the Brazilian Climate Change Forum (FBMC) allowed the identification of assumptions, parameters and variables that are present in the BAU Scenario and are based on a participatory process of scenario creation, which mobilized the sectors of the Brazilian society presented in Annex I.

RECENT WORKS RELATED TO THE THEME





1. Introduction

According to the International Energy Agency (IEA, 2013), transportation sector is the largest consumer of petroleum fuels, with a participation of 93% of global non-renewable energy consumption. Thus, it is one of the agents that most contribute to the emission of greenhouse gases (GEE) (7.1Gt CO_2eq in 2013 with an increase of 2.3 times in the last 40 years). Their increased concentration in the atmosphere is responsible for global warming, humanity's greatest environmental challenge for the 21st century. Considering the above, the challenge of mitigating GHG emissions in the transportation sector is reflected in international commitments, being present in 77% of the Intended Nationally Determined Contributions (iNDCs) submitted in the Paris climate agreement at the end of 2015 (Gout *et al.*, 2015).

Moreover, about 54% of the world population currently lives in urban areas and this trend is growing in the 21st century (*United Nations*, 2014). Ensuring sustainability for the mobility of people and freight in cities is another equally important challenge for the next decades. According to the World Health Organization (WHO), transportation is the largest source of atmospheric pollutants in cities and is responsible for significant social losses arising from respiratory, cardiovascular and neurological diseases, stress, injuries and deaths caused by accidents. In Brazil, as well as worldwide, there is a strong correlation between the transportation of people and freight and the gross domestic product (GDP), as a whole or *per capita*. In the period between 2006 and 2015, the passenger and freight transportation moments increased 58% and 31%, respectively, while GDP increased 120% and the population, 9% (Gonçalves and D'Agosto, 2017).

On the other hand, the energy demand of the transportation sector in Brazil grew around 64% in the period between 2005 and 2014, increasing its relevance in final energy consumption, with 32% of participation and corresponding to 69% of the consumption of petroleum and natural gas, fossil fuels, and 13.8% of GHG emissions, ranking behind enteric fermentation and the deforestation of Amazonia, which correspond to about 18.4% and 14.1% of GHG emissions, respectively (MCTI, 2016).

The search for sustainable scenarios presents the sectors (ANNEX I) responsible for most of the GHG emissions in the country with new challenges, which must be recognized and discussed for the improvement of sectoral planning under the perspective of the government, the private initiative and the organized civil society.

The Future Prospective Scenarios technique is a tool that enables the identification and responses regarding the economic, environmental and social impacts of the application of different sets of GHG emissions mitigation measures in Brazil until 2050.

The present study aims to find out a trending scenario (*Business as Usual* – BAU) of evolution of the energy matrix for transportation in Brazil until 2050, considering energy consumption and GHG emissions. This study seeks to provide decision-makers, from the government and the private initiative, with an estimate on how Brazil can increase the offered service level and reduce transportation costs through assumptions oriented to a low-carbon economy.

After this introduction, this study is divided into four other sections: in section two, the methodology used to produce the estimates is described. Section three describes the assumptions considered for each transportation mode and activity type. In section four, the results will be presented and analyzed. Section five presents the final considerations, limitations and recommendations for future studies.

2. Methodology

Taking into consideration the objectives of this study, a combination of exploratory and explanatory research was carried out, which is considered by Freitas and Jabbour (2011) as a robust way of producing knowledge. These two types of research were chosen considering that an exploratory research can provide greater familiarity with the problem and an explanatory research seeks to identify factors that contribute to the occurrence of the phenomenon, besides explaining the reason for the events (GIL, 2008).

To analyze the facts and confront them, under the theoretical and practical point of view, it is necessary to draw a conceptual and operational model of the research. This model refers to the research planning in its broader dimension, with emphasis on the research approach, be it qualitative and/or quantitative, and on the methods and procedures for collecting and analyzing data (GIL, 2008).

The approach taken in this work led to the option for a quantitative research defining the parameters and variables to obtain an accurate evaluation of the components of the addressed problem and a qualitative research with the purpose of verifying the phenomenon through its study (Kirk and Miller, 1986).

The procedures for collecting data included a bibliographical research based on scientific books and articles and a documentary research based on reports and technical documents. Both researches aimed to raise historical and current data about the Brazilian transportation sector, to identify national and international scenario projection studies conducted by public and/or private entities, to raise information about energy efficiency for the transportation sector, to identify the possibility of changing transportation users' behavior, among other kinds of information.

Furthermore, surveys were conducted with specialists in the area of transportation and energy with the purpose of ratifying the assumptions adopted in other studies conducted by the team.

In order to analyze the data gathered from books, scientific articles, reports and technical documents, mathematical and statistical tools were used to establish the relationship between the variables considered in the construction of the scenarios. The results obtained were compared to each other in order to verify the need for adjustment or calibration.

It is important to emphasize that, in light of the broad projection horizon (2016-2050) and due to the large amount of variables in the model, the results reflect the assumptions chosen to arrive at them; assumptions which may be changed depending on unforeseeable situations that will eventually occur in the future, making it necessary to periodically revise this work.

Considering that the energy consumption projections vary depending on the projected payload (in t.km or pass.km), the quantitative approach of this study was based on projections related to the GDP for freight transportation, considering the behavior presented in Figure 1, and the population and GDP *per capita* for passenger transportation (Façanha *et al*., 2012; EPE, 2016a; Vanek *et al*., 2014).

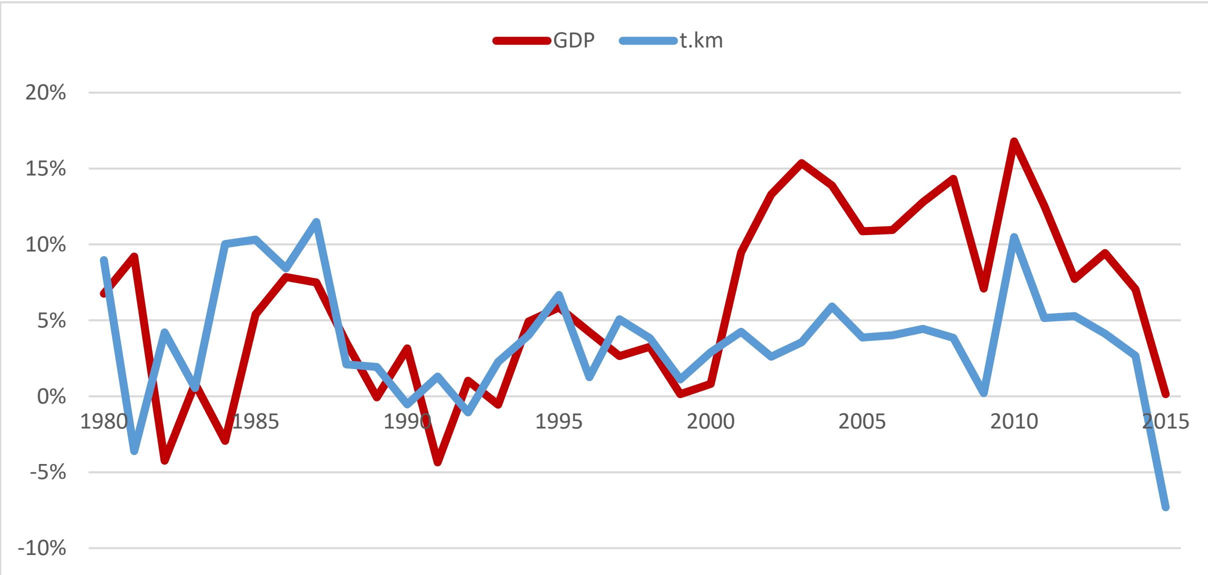


Figure 1. Annual variation – t.km vs. GDP

Source: Made by the authors.

Payload is understood as a measurement of passenger-kilometer (pass.km) transported, in the case of passenger transportation, and ton-kilometer (t.km) transported, in the case of freight transportation. Passenger-kilometer is a unit that measures the effort related to the movement of one passenger for a distance of one kilometer. Similarly, ton-kilometer is a unit that measures the effort related to the movement of one ton for a distance of one kilometer (EPE, 2012).

2.1. Qualitative approach

The qualitative approach used the ASIF method, which was introduced by the Intergovernmental Panel on Climate Change (IPCC – *Intergovernmental Panel on Climate Change*) in its first report in 1991 and considers 4 lines of action to reduce fossil energy consumption in transportation and, consequently, the emission of GHG, in addition to the emission of atmospheric pollutants, promoting environmental benefits and indirect social benefits. These lines of action are: reduction in transportation activity (A-"*activity*"), offer of infrastructure (S-"*structure*"), reduction in energy intensity (I-"*intensity*") and choice of low-carbon energy sources (F-"*fuel*") (Schipper *et al.*, 2000).

Figure 2 introduces the major steps of the method. The reduction in transportation activity and the increase in infrastructure offer are usually better related to a change in behavior regarding the choice for freight and passenger transportation modes. While the lines of action that consist in the decrease in energy intensity and the choice of low-carbon energy sources depend more directly on the use of technology.

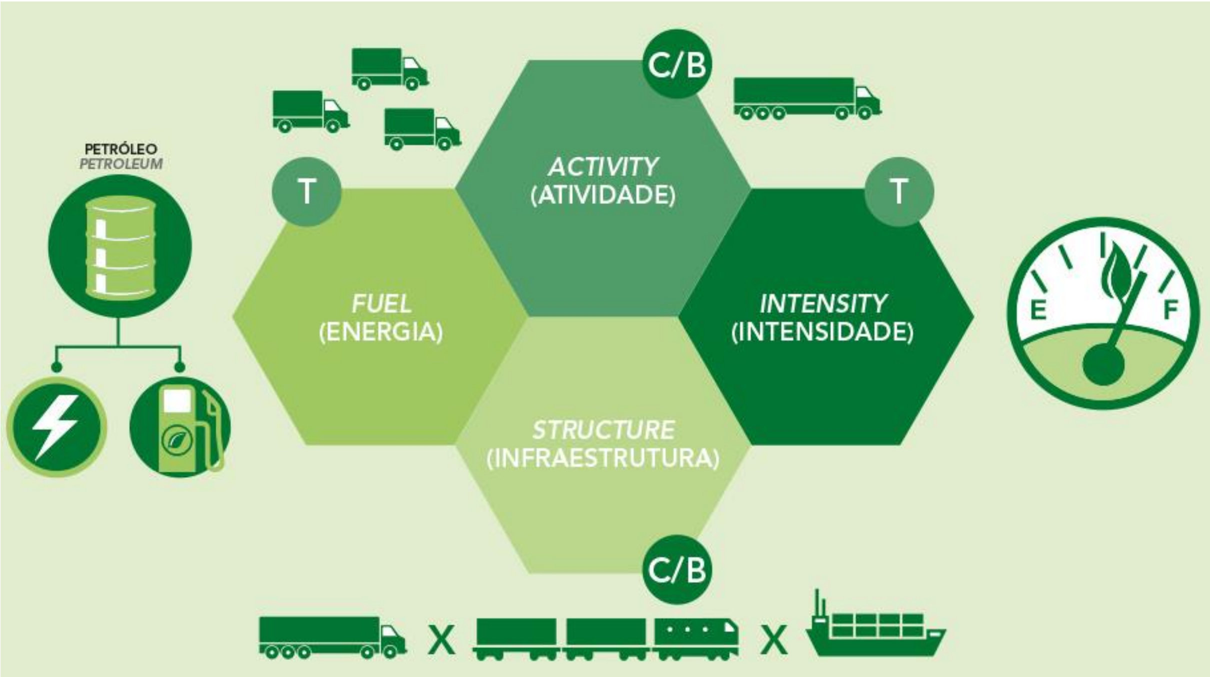


Figure 2. ASIF method.

Note: *C/B – Comportamento/Behavior *T – Tecnologia/Technology.

Source: Oliveira and D'Agosto (2017).

The ASIF method is consistent with the measures aimed at developing more efficient and sustainable transportation systems in the future, such as the Shift, Improve and Avoid (ASI) method used in the Transportation-Oriented Development (TOD) approach and the approach adopted by the Smart Freight Centre (SFC). The ASIF method was used in the Greenpeace *Energy Revolution* Report (Greenpeace International *et al.*, 2015), in the study developed by the *International Council on Clean*

Transportation (ICCT) (Façanha *et al*., 2012) and in the study Economic and Social Implications of the Governmental Plan Scenario (D'Agosto, Gonçalves and Oliveira, 2016).

2.2. Quantitative approach

Considering that the projections of energy consumption and GHG emissions vary depending on the projections of payload (in t.km or pass.km), the quantitative approach of this study was based on projections related to the GDP for freight transportation and GDP *per capita* for passenger transportation.

Practices adopted by the specialized literature and the sensitivity analysis conducted pointed to the possibility of estimating the passenger payload by means of GDP *per capita* (GDP and population ratio), considering that passenger trips are not only related to the quantity of people, but also to their purchasing power.

Due to the availability of useful data and the lower level of complexity in relation to vehicle types, energy efficiency and scrappage curve, the isolated top-down methodology was chosen in order to estimate the energy consumption and GHG emission for railway, waterways, pipelines and aerial modes of transport.

The top-down and bottom-up methodologies were used jointly in the case of the road mode. In this context, the results of the application of the top-down methodology were used to adjust the evolution of payload and energy consumption.

2.2.1. Top-down Methodology

The top-down methodology aims to identify and quantify energy consumption as a whole, enabling only a widespread view of the use of each energy source. Thus, the calculations of energy demand are made based on four main data sets for each transportation mode: (1) payload; (2) modal split; (3) energy efficiency; and (4) grouping per fuel type.

The procedure used to estimate energy consumption and GHG emissions through the top-down methodology is synthesized in Figure 3.

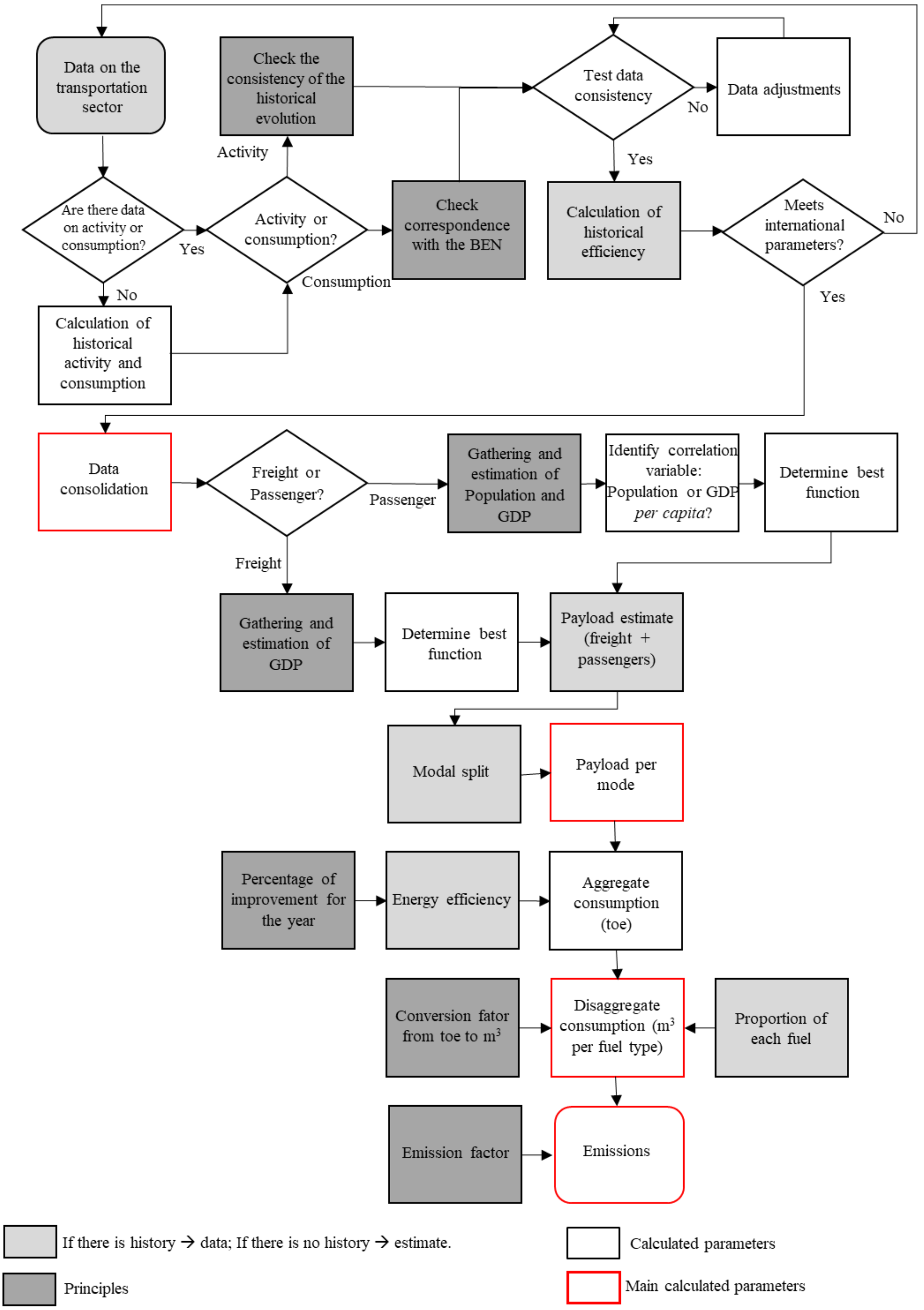


Figure 3. Procedure adopted to estimate energy consumption using the *top-down methodology*.

Note: BEN – National Energy Balance

Source: Made by the authors.

This methodology was chosen for railway, waterways, pipeline and air transportation modes, both for cargo and passenger transportation, because these modes present a smaller variety of types of energy sources and due to the limitation of consistent and reliable sources of information about their intensity of use, circulating fleet and energy performance. In this case, what followed were the procedures and the assumptions of the Study Associated with the 10-Year Energy Plan, PDE 2021, Consolidation of Databases of the Transportation Sector, 1970-2010 (EPE, 2012); the energy consumption was measured based on reports of the National Energy Balance. Additionally, this methodology was also adopted for the road mode, for the calibration of the results achieved by applying the *bottom-up* methodology.

2.2.1.1. Data collection

Initially, the data deemed indispensable for the application of the *top-down* methodology was raised. The data consists of historical values per mode and type of activity, which are: (1) movement, (2) mileage traveled, (3) percentage of useful mileage, (4) energy efficiency, (5) energy consumption by fuel type, (6) future perspectives of investment, efficiency improvements and introduction of new technologies.

After gathering the data from yearbooks of the sector, emission inventories and/or directly from the concessionaires, the payload and its respective energy consumption were calculated.

2.2.1.2. Data consistency analysis

After calculating the payload and its respective energy consumption, it was observed that the transport activity follows a logical historical sequence, with values that are close to those found in the Executive Group for the Implementation of Transport Policy (GEIPOT) yearbooks and the PDE 2021 study. Moreover, the consumption was compared to the values presented in the National Energy Balance (BEN).

In cases where the verifications pointed out divergences, the payload was adjusted. In some cases, in which this adjustment was not possible, a new data collection was performed.

2.2.1.3. Calculation of energy efficiency

After the verification and the adjustments, energy efficiency was calculated by the relationship between energy consumption in Joules and payload. Then, these energy efficiency values were compared to the values found in the literature (national and international), which consisted in a second reliability check of the historical data, since these are the main *inputs* of the model.

For the cases in which the efficiency values obtained were not between the minimum and maximum values found in the literature, a new data collection was carried out.

2.2.1.4. Data consolidation

After having finished the step of verification and adjustment of historical data for all modes and types of activity, these were consolidated by type of activity (passenger and cargo) and then the modal split was assessed over the years considering the payload participation of each mode in the total payload of a given year.

2.2.1.5. Gathering and estimates about population and GDP

In this step, historical data about population and GDP were gathered in addition to their respective future estimates, followed by the calculation of the GDP *per capita*.

2.2.1.6. Adjustment of curves

After obtaining the data about GDP, population and GDP *per capita*, the curves were adjusted with the purpose of verifying the relationship between the transport activity [t.km or pass.km] and the data about GDP, population and GDP per capita (national and state). This correlation was assessed using the adjusted correlation coefficient (R^2).

After identifying the independent variables, a sensitivity analysis was conducted to verify the function that best adjusted to the historical data.

2.2.1.7. Modal split estimate

In order to identify transportation infrastructure investments and their respective impacts in modal split, the long-term governmental plans were analyzed.

Once the modal split projections and the total payload value were established, the payload projection for each mode was established based on the estimated modal split percentages.

2.2.1.8. *Energy efficiency estimate*

Once the average historical energy efficiency was calculated until the base year, the percentage of annual improvement that should be applied to the current efficiency was identified in the literature. Thenceforth, it was observed that the values obtained are consistent with those identified in the consulted sources.

2.2.1.9. *Calculation of fuel consumption*

The energy consumption (fuel) was calculated based on the payload and on the energy efficiency of each transport mode. Energy consumption values for the past years were raised in the first phase and were used to refine the proposed model. For subsequent years, the calculation was carried out considering the relationship between the payload and the energy efficiency of each mode.

After the calculation of energy consumption, it was distributed by the different energy sources (fuel types) according to the premises found in the literature. Then, the fuel consumption was calculated, measured in energy (Joules) and volume measurement units (m^3 or l), using conversion factors.

2.2.2. Bottom-up Methodology

One characteristic of the *bottom-up* methodology is that it quantifies and identifies energy consumption considering disaggregate data, enabling the individualized management of the use of each energy source. For the calculation of energy consumption, four main data sets must be identified: (1) circulating fleet considering the year, model, age and energy source for each vehicle type; (2) use intensity by vehicle type and fuel type and (3) consumption by energy source. The procedure used to estimate energy consumption and GHG emissions through the top-down methodology is synthesized in Figure 4.

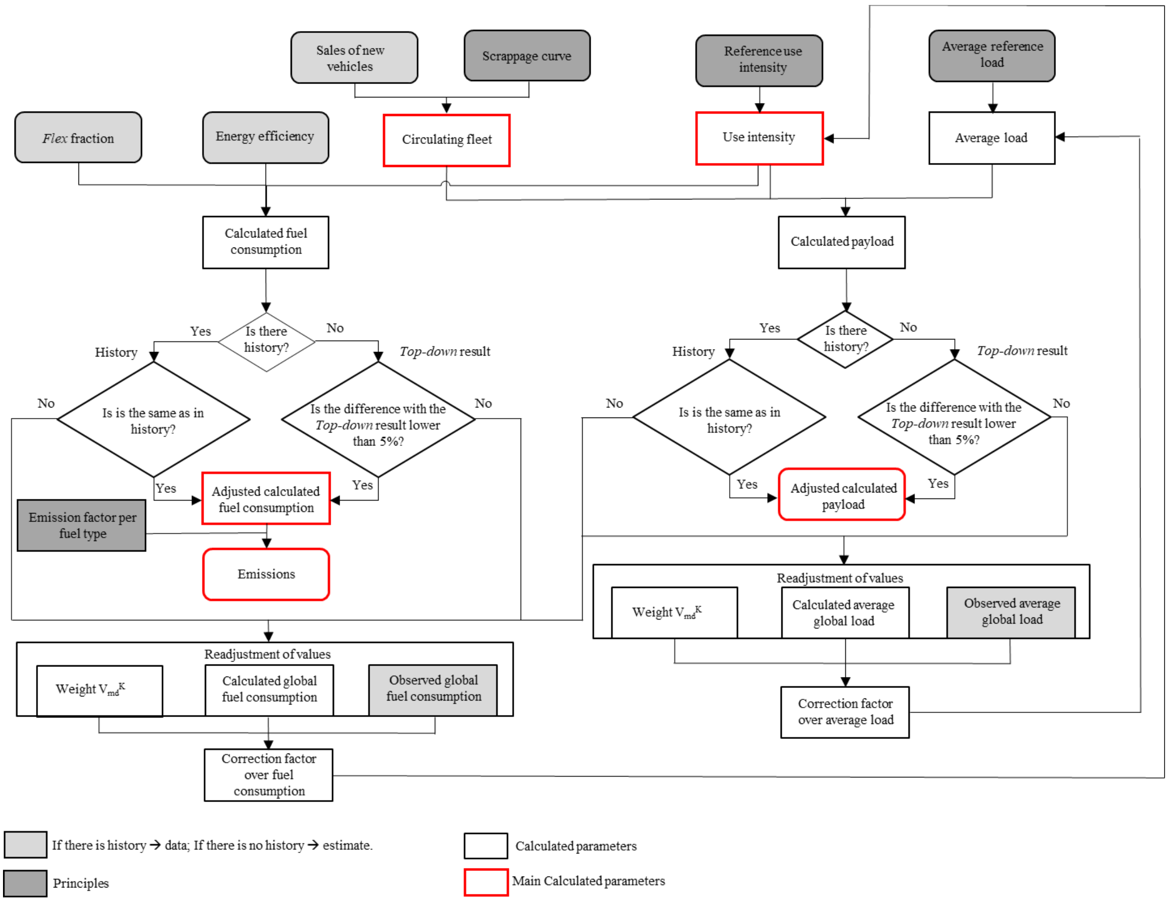


Figure 4. Procedure adopted to estimate energy consumption using the *bottom-up* methodology.

Source: Made by the authors.

This methodology was chosen for the road mode to calculate the circulating fleet, fuel use intensity and fuel consumption, following the procedures and assumptions adopted in the national Inventory of Atmospheric Emissions by Road Vehicles, 2013 (MMA, 2013) and in the Inventory of Atmospheric Emissions by Automotive Vehicles of the State of Rio de Janeiro (D'Agosto *et al*., 2011). The payload was calibrated according to the study of Gonçalves and D'Agosto (2017), for years before 2016. For the years from 2016 to 2050, the results were compared with the results obtained through the *top-down* methodology.

Road transportation has greater diversity of vehicles, energy sources and operational complexity, which leads to the need of greater detailing for the quantification of energy consumption. In the case of road passenger mode in Brazil, according to the Second National Inventory of Automotive Vehicle Emissions 2013 (MMA, 2013), there is a "subdivision" consisting of cars, light commercial vehicles, motorcycles and public transportation vehicles (buses). Many of these still use a variety of energy sources, as is the case of cars, which can run with gasoline, ethanol, electricity and/or CNG. Public transportation vehicles are divided as follows: urban buses, micro-buses and road buses.

In the case of freight transport, in Brazilian inventories for energy, there is also a division by vehicle types according to their total gross weight (TGW) into: light commercial vehicles (diesel cycle), semi-light, light, medium, semi-heavy and heavy trucks.

Both for passengers and for freight, road vehicles have biofuels in the final fuel mixture. Anhydrous ethanol is mixed with gasoline A to obtain gasoline C. The same happens with diesel; biodiesel is mixed with mineral diesel. Therefore, the fraction of biofuels in the current mixture (base year) should be identified along with its future predictions of increase or decrease.

In the case of road transportation, the quantification of the energy consumed and GHG emissions is a data-intensive activity and, in an optimal situation, data on fleet, use intensity and emission factors should be observed/measured in the field. However, the experience mentioned by the team that prepared the Second National Inventory of Automotive Vehicle Emissions 2013 (MMA, 2013) shows that this ideal situation is impracticable due to the limitations of material, human and time resources, being usual and acceptable to estimate these data by means of a given procedure.

2.2.2.1. Procedure for calculating the circulating fleet

The calculation of the circulating fleet was based on sales estimate and scrappage curves for the different types of vehicles. The sale history of new vehicles marketed until the first semester of 2017 used in this study was based on the National Association of Automotive Vehicle Manufacturers (ANFAVEA, 2016), the Brazilian Association of Manufacturers of Motorcycles, Mopeds, Scooters, Bicycles and Similar Vehicles (ABRACICLO, 2017) (motorcycles) and the National Bank of Economic and Social Development (BNDES), Vaz *et al*.; (2015) (hybrid and electric cars).

The estimate of future sales was based on the sales history of new vehicles, on GDP estimates (Figure 7) and on studies in the automotive sector. The scrappage curve was obtained from the Reference Report on Greenhouse Gases in the Energy Sector by Mobile Sources, from the Second Brazilian Inventory of Anthropic Greenhouse Gas Emissions (MCT 2010) and from the study of the Brazilian Circulating Fleet, SINDIPEÇAS (2009).

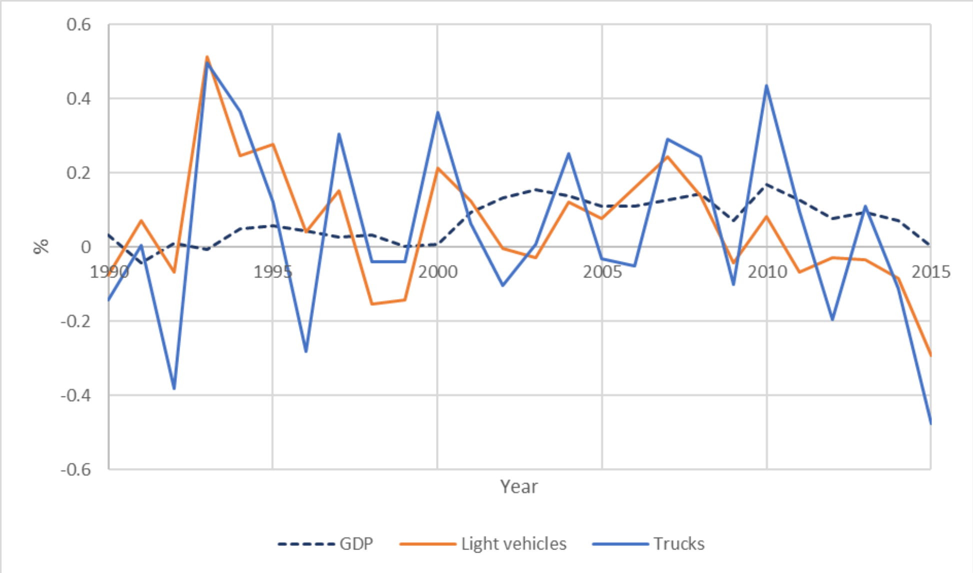


Figure 5. Annual variation – Vehicle sales (light and trucks) vs. GDP.
Source: Made by the authors.

The scrappage curves adopted for cars and light commercial vehicles (except for the diesel cycle ones) are the ones used by the PETROBRAS Planning Service, calibrated by the data of the National Household Sample Survey (PNAD) (MME, 2013 *apud* PNAD, 1988). The resulting scrappage function is a *Gompertz* function (MMA, 2013).

For the diesel cycle light commercial vehicles, buses and trucks, the scrappage curves (logistic function) were calibrated based on average age and total fleet data of 1997 provided by DENATRAN (MMA, 2013).

For motorcycles, the scrappage curve used was the one adopted by SINDIPEÇAS (2009) in the Brazilian Circulating Fleet Study, in the first and second National Inventories of Atmospheric Emissions by Road Vehicles (MMA, 2011 and MMA, 2013), whose annual scrappage rates for motorcycles up to 200cc are: 4% in the first five years; 5% from the 6th to the 10th year; 6% from the 11th to the 15th year; and 8% from the 16th year on.

2.2.2.2. Procedure for calculating use intensity

The calculation of use intensity first considered a reference of use intensity based on the National Inventory of Atmospheric Emissions by Road Vehicles, 2013 (MMA, 2013). If the fuel consumption calculated by means of the estimated use intensity does not conform to that observed through the history (until the base year) or the one estimated using the *top-down* methodology, the use intensity should be calibrated. An adjustment coefficient of use intensity for each fuel must be calculated by the difference between the observed and the calculated fuel volumes. After calculating this coefficient , the adjusted use intensity is obtained by means of a multiplication.

If the payload does not conform to the one observed through the history (up to the base year) or the one estimated by means of the *top-down* methodology, the use intensity should be re-calibrated, but without the consumption exceeding the difference of 5% of the observed/estimated.

2.2.2.3. *Procedure for calculating fuel consumption*

Fuel consumption is calculated based on energy efficiency, on the circulating fleet, on use intensity and on the *flex* fraction (percentage of *flexible-fuel* vehicles) that uses each type of fuel (gasoline and ethanol).

The calculation of fuel consumption from automotive vehicles considered the ratio of the fleet, its respective use intensity (adjusted) and its average energy efficiency, for each type of vehicle and fuel considered.

2.2.2.4. *Procedure for estimating payload*

After defining and adjusting use intensity, the payload for freight (t.km) and passenger (pass.km) transportation is determined by means of the relationship between fleet, use intensity and its average occupation.

In case the calculated freight payload is higher than the one estimated by the *top-down* methodology, the value was corrected by adjusting the occupancy rate of trucks and light commercial vehicles, preferably from the ones of smallest capacity to those with the highest capacity, so that the calculated payload was equal to the observed one. If the calculated value is lower than the observed or estimated payload, the value was corrected by adjusting the occupancy rate of the vehicles of higher capacity to the ones of lower capacity, so that the calculated payload was equal to the observed one.

Now for the case in which the calculated passenger payload was higher than the one estimated by the *top-down* methodology, the correction was made by adjusting the occupancy rate of buses (urban, road and micro) so that the calculated payload was equal to the one that was observed or estimated. If the estimate was lower than the observed payload, the correction was made by adjusting the occupancy rate of the buses (urban, road and micro) and the cars so that the calculated payload was equal to the one observed or estimated. For both cases (freight and passengers), besides the adjustment in the average occupation, the adjustment in use intensity may be necessary, respecting the calibration of consumption. The estimated loads of vehicles were defined according to the historical national behavior observed until 2015.

2.2.2.5. Procedure for calculating CO_2 emissions

For the calculation of CO_2 emissions, the consumption of each fuel is multiplied by its respective emission factor (Table 1).

Table 1. CO_2 emission factor by fuel type.

Fuel	CO_2 emission	Unit
Gasoline A	2.21	kg/l
Anhydrous Ethanol	1.46	
Hydrous Ethanol	1.53	
Biodiesel	2.43	
Mineral Diesel	2.60	
Fuel oil	3.10	
Maritime diesel	3.10	
Aviation kerosene	2.49	
Aviation gasoline	2.23	
CNG	1.999	Kg/m³

Source: Made by the authors based on MMA (2013).

2.2.2.6. Procedure for vehicles converted for CNG use

The methodology for estimating CO_2 emissions by vehicles converted to use CNG was the same adopted in the last two National Inventories of Automotive Vehicle Emissions (MMA, 2011; 2013), through the *top-down* methodology, where the emission factors in $g_{pollutant}/m^3_{fuel}$ are directly applied directly to the fuel consumption reported in the National Energetic Balance (EPE, 2014b).

For the conversion of emission factors in g/km to g/m^3, the average performance value of 12 km/m^3 was used, as it was in both above-mentioned National Inventories (MMA 2011; 2013). Regarding CO_2 emissions, the procedures and values adopted are the same ones presented in the previous subsection.

The vehicles considered to be converted to CNG were withdrawn from the fleet they originally belonged and were named the CNG fleet in order to avoid double counting.

3. Assumptions

This section will present the assumptions related to passenger and freight transportation.

3.1.1. Macroeconomic data

In Brazil, as well as worldwide, there is a strong correlation between the transportation of people and freight and GDP, be it total or per capita. In the last 10 years (2006 to 2015), the passenger and freight payload has grown 58% and 31%, respectively, while GDP grew 120% and population grew 9%.

Considering that the energy consumption projections vary depending on the projected payload (in t.km or pass.km), the quantitative approach of this study was based on projections related to the GDP for freight transportation, and related to the population and GDP *per capita* for passenger transportation (Façanha et al., 2012; EPE, 2016a; Vanek et al., 2014).

For this, a survey of GDP projections was conducted, as can be observed in Figure 6.

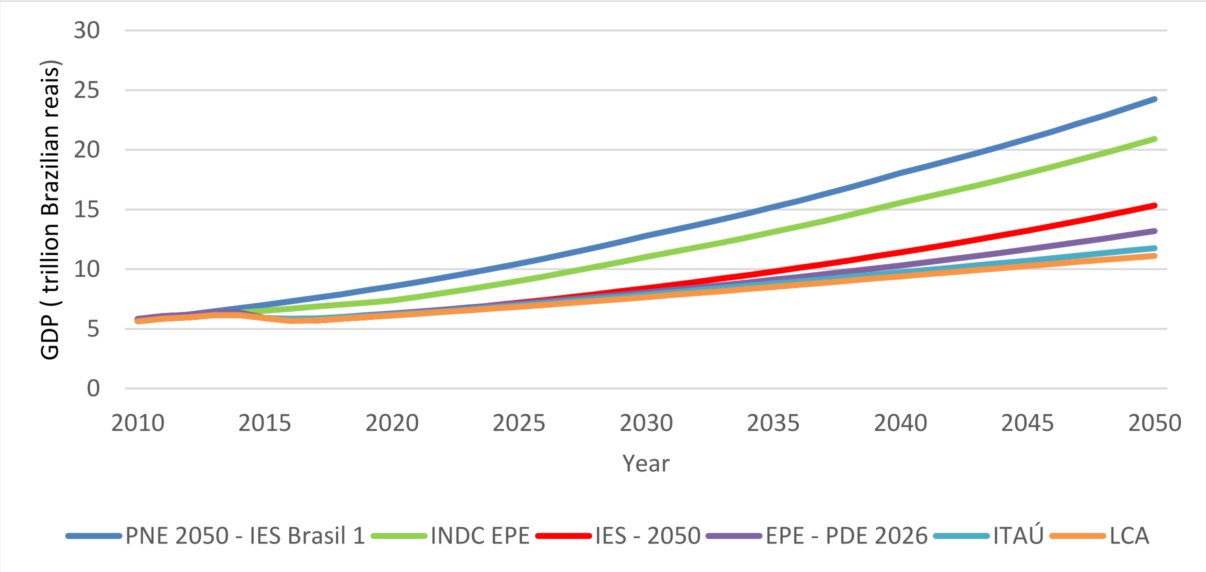


Figure 6. Brazilian GDP projections.

Source: Made by the authors based on La Rovere *et al.* (2016), EPE (2017), Itaú (2016) and LCA (2017).

Note: IES-2050 – estimated GDP used in the study of La Rovere (2016); EPE-PDE 2026 – estimate of GDP used in the study PDE 2026 (EPE, 2016); ITAÚ-GDP estimated by Itaú Banking (Itaú, 2016); LCA GDP estimated by the economic consultancy company (LCA, 2017)

The estimate of Itaú-BBA was chosen based on the social interactions that took place in several workshops (ANNEX II) related to the theme, in which there was a consensus between the representatives of the Scenario Elaboration Committee (CEC) that the estimate varies between the

PDE 2026 and LCA scenario. Thus, as the scenario of Itaú-BBA is among the ones mentioned, it has been chosen.

Considering the above, for the aggregate projections of freight payload (t.km), the GDP estimated from the percentages of variation provided by Itaú-BBA considering the period from 2000 to 2050 was used. For the aggregate projections of passenger payload (pass.km) the same GDP was used in composition with population data, provided by IBGE (2013), in the form of GDP per capita, as can be seen in Figure 7.

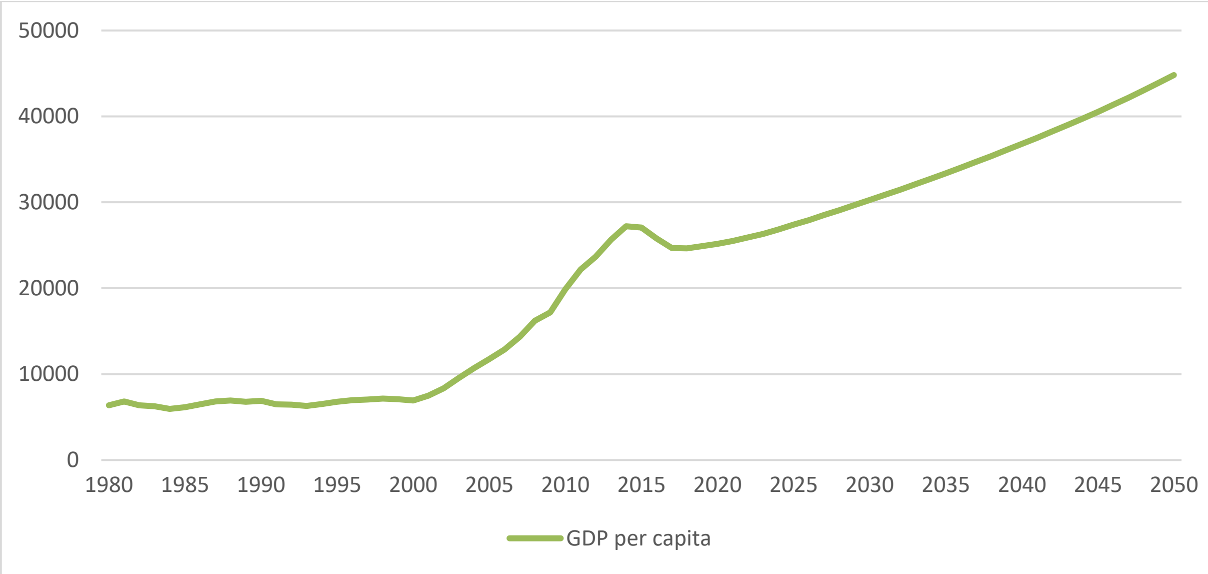


Figure 7. Brazilian GDP per capita projection for 2050.

Source: Made by the authors based on IBGE (2013) and Itaú (2016).

3.1.2. Conventional energy sources

What follows below is a list of the conventional energy sources considered.

- Diesel: it will be considered for the road (freight and passenger), rail (freight), inland waterways (freight and passengers) and passenger maritime modes.
- Gasoline C: it will be considered for the road mode (passenger);
- Heavy oil: it will be considered for maritime cabotage transportation;
- Aviation kerosene: it will be considered for the air mode (freight and passenger);
- Aviation gasoline: it will be considered for air mode for passengers.

It is worth pointing out that in the case of the railway mode, due to the insignificant representativeness of passenger transport with diesel-powered vehicles, all the energy spent on this fuel was allocated to freight transport.

In the case of the air mode, all aviation gasoline was allocated for passenger transport, since this type of fuel is used by small aircrafts, models used for crop spraying and special passenger transport, all of which do not have the capacity to carry a relevant quantity of freight. Aviation kerosene was allocated for both freight and passenger transportation, since most of the aircraft fleet carries passengers and freight on the same flight.

3.1.3. Alternative sources

Below is the list of the alternative energy sources considered.

- Compressed Natural Gas (CNG): it will be considered for the road mode with cars and light commercial vehicles adapted to use CNG in the biofuel form, being allocated mainly for the fleet of taxis;
- Biodiesel: it will be considered for the road and rail modes, regarded that this biofuel will be considered with the addition of petroleum diesel. The participation of biodiesel in petroleum diesel (BX) considered will be of B8 (8% biodiesel and 92% petroleum diesel) in 2017, this percentage will be elevated to 9% and 10% every 12 subsequent months, so in March 2019 it will be B10 (Law n ° 13,033 of 2014). A participation of 12% was considered from 2030 to 2040, then going to 15% and remaining so until 2050, an assumption adopted considering the commitment made by the Brazilian Government during COP 21 and the submitted NDC. After 2025, this same type, with the same operating addition, will be considered for inland waterways freight and passenger transportation.
- Anhydrous ethanol: it will be considered for the road mode with the addition of up to 27% gasoline in the form of anhydrous ethanol;
- Hydrous ethanol: it will be considered for the road mode, for cars and flexible-fuel light commercial vehicles, hybrids and the residual ethanol-only fleet.
- Electricity: it will be considered for the road and rail (passengers) modes.

- Biokerosene, Bio-oil, sugarcane diesel and hydrogen: these were not considered in the BAU scenario. They will be considered in the alternative scenarios to be published.

The choice of fuel type for flexible-fuel vehicles and for hybrid light vehicles (cars and light commercial vehicles), until the year 2016, was based on historical data. From then on the use was linearly adjusted until reaching the percentage of 50% for hydrous ethanol in 2030 and remaining so until 2050. This assumption was based on the Brazilian NDC that aims to increase the consumption of biofuels in the Brazilian energy matrix until 2030, increasing the offer of ethanol even through the increase in the proportion of advanced biofuels (second generation).

The percentage of 50% was calculated based on the evolution of the road passenger mode, on the displacement of the prediction of the National Climate Change Policy (PNMC) on the use of ethanol to replace gasoline and in a conservative view of the estimate declared in the Brazilian NDC, of the production of ethanol in 2025 and 2030 of 45 and 54 billion liters, respectively.

3.1.4. Energy efficiency

In order to determine the improvement in energy efficiency, a theoretical reference was chosen to balance the values that will be used. This study used the 5th Analysis Report of the Intergovernmental Panel on Climate Change Chapter 8, made by the *Inter-governmental Panel on Climate Change* (IPCC), (Sims, R *et al*., 2014) and the study published by the U.*S. Department of Energy* (Vyas *et al*., 2013). Therefore, the reference values were adopted according to the level of energy efficiency established for each mode, as well as the year in which such efficiency is achieved, as illustrated in Table 2the.

Table 2. Potential for improvements in energy efficiency of all transportation modes.

Mode	Actions	Potential for improvements in energy efficiency	
		2030	2050
Air	Improvements in the design and construction of aircrafts, such as weight reduction, aerodynamic resistance, introduction of winglets and riblets and improvement in engine performance.	20% to 40%	23% to 65%
	Operational improvements through the use of satellite navigation systems, reducing congestion and fuel consumption.		
Waterways	Better ship designs for weight reduction; efficient transmission engines and systems; heat recovery systems; auxiliary systems for energy generation and reduction of aerodynamic and hydrodynamic resistance.	Up to 15% (maritime)	Up to 30% (maritime)

Mode	Actions	Potential for improvements in energy efficiency	
		2030	2050
	Adoption of measures for optimum operating conditions and cruise speed control.		
	Adoption of measures related to the renovations and improvements of ship maintenance.	Up to 5% (inland waterways)	Up to 20% (inland waterways)
Rail	Use of higher efficiency propulsion systems and regenerative braking, as well as improvements in the diesel engine.	15% to 17%	30% to 35%
	Aerodynamic improvements and weight reduction of compositions.		
	Use of electronically controlled pneumatic brakes (ECP) and PTC control system (positive train control) that can reduce congestion and the time of operation in neutral gear, which would result in an increase in energy efficiency.		
	Infrastructure modernization of the railway system, with the same intention as the previous item.		
	Use of hybrid locomotives and Genset.		
Road	Vehicles weight reduction, aerodynamic resistance reduction, use of low rolling resistance tires and/or radial tires and accessories electrification.	20% to 30% (HDV) Up to 25% (LDV)	25% to 50% (HDV) Up to 50% (LDV) Motorcycles: 10% and 20%
	Technological improvements in engines and use of heat recovery technologies, such as the use of engines with energy recovery by coupled turbine and flat thermodynamic cycle, the use of engine fan with intermittent drive, and intake and discharge valves with variable valve actuation (VVA), in addition to turbo powered engines.		
	Use of exhaust gas post-treatment system with advanced cooling, which generates better fuel burning and promotes increased energy efficiency.		
	Reduction of friction losses in the propulsion system, use of automatic transmission and improvements in turbo compressor.		
	Improvements in maintenance and adoption of vehicle conservation programs.		
	Eco-driving, reduction of low gear use, and better traffic management and routes choice.		
	Travel monitoring (with goals and financial incentives to drivers), and the adoption of projects aimed at reducing fuel consumption.		
	Use of hybrid vehicles (diesel-electric)	20% to 30% (HDV) Up to 35% (LDV)	
Pipeline	Increased capacity and improved use.	Up to 7.5%	Up to 17.5%

Source: made by the authors based on the Analysis Report of the Intergovernmental Panel on Climate Change – Chapter 8 (Sims, R *et al*., 2014), *The International Council on Clean Transportation* (ICCT), Façanha *et al*., (2012) and Vyas *et al*. (2013).

Based on the results obtained from the application of the top-down methodology, there was a noticeable improvement of achieved efficiency and estimated consumption, which was followed by a comparison of the overall efficiency improvement with the energy efficiency presented in the assumptions adopted for the road mode. The estimated consumption was compared to the consumption obtained by the procedure for calculating fuel consumption for the road mode in the bottom-up methodology. Based on the comparisons made, on the technical knowledge of the team involved in the study and on the estimate presented in the Energy Demand Study 2050 (EPE, 2016), the efficiency improvement was adjusted.

3.1.5. Passenger transportation

This subsection will present the assumptions related to passenger transportation.

3.1.5.1. Modal Split

In order establish the passenger transportation modal split, the values considered in the study of Gonçalves and D'Agosto (2017), which aimed to consolidate the transportation sector database, considering activity (payload) and energy usage. As an estimate, a certain growth trend was adopted for the modal split of transportation modes, as can be seen in Table 3. These assumptions are close to the predictions of the passenger transportation modal split estimated by the Energy Demand Study 2050 (EPE, 2016).

Table 3. Modal Split for Passenger transportation.

Year	Air	Waterways	Rail	Road
2015	6.20%	0.06%	1.83%	91.91%
2020	6.32%	0.07%	2.18%	91.44%
2030	6.55%	0.08%	2.87%	90.50%
2040	6.79%	0.09%	3.57%	89.55%
2050	7.00%	0.10%	4.20%	88.70%

Source: Made by the authors.

3.1.5.2. Road mode

This subsection will present the assumptions related to passenger transportation for the road mode.

3.1.5.2.1. Fleet

The passenger road vehicles fleet division was made based on sales history information found in reports from the National Association of Automotive Vehicle Manufacturers (ANFAVEA, 2016) from 1957 to 2016 and from the Brazilian Association of Manufacturers of Motorcycles, Mopeds, Scooters, Bicycles and The Similar (ABRACICLO, 2016), for motorcycle sales.

Sales were estimated based on GDP estimates and the results obtained with the *top-down model.* The penetration of new technologies was based on the discussions set out in the various Workshops and on the authors' experience.

- As for light vehicles (cars and light commercial vehicles), the average sales rate of light commercial vehicles was of 3.2% per year, from 2018 to 2050. For motorcycles, the rate considered was of 2.8% per year up to 2050;
- For conventional vehicles of collective use, the average sales rate of collective transportation vehicles urban bus, road bus and micro-bus was of 5.0% per year up to 2039 and 1% per year until 2050. By increasing the share of urban buses (from 68% to 82%) and reducing road (10% to 8%) and micro buses (23% to 10%) shares. The decreased share of road buses is due to the increase in the share of air mode in modal split. As for the micro-bus, it follows the historical decrease.

Regarding the participation in sales of each type of technology until the year 2050, the following were considered:

- As for gasoline dedicated cars, there was a 3.8% participation in sales in 2016. Then, there was a linear decrease until 2030, when this technology shall no longer be marketed;
- As for ethanol-dedicated cars, these are no longer marketed since 2013;
- Flexible-fuel cars showed a 96.2% participation in sales in 2016, maintaining its participation up to 2030. Then, there was a linear decrease until 2050, reaching 50% of the participation;
- As for hybrid cars, there was a 0.05% participation in sales in 2016. Then, there was a growth trend until 2030, reaching 4% of participation. After that, there was linear growth until 2050, reaching 40% of the participation;
- As for electric cars, there was a 0.001% participation in sales in 2016. Then, there was a linear growth until 2030, when the participation will reach 2%. From 2030 to 2050, there was a linear growth in sales participation and this technology will reach 10% of the participation in 2050;
- As for the gasoline-dedicated light commercial vehicles, there was a participation of 13% in sales in 2016 (only considering Otto cycle). Then, there was a linear decrease until 2030, when this technology shall no longer be marketed;
- The ethanol-dedicated light commercial vehicles are no longer marketed since 2012;
- As for flexible-fuel light commercial vehicles, there was a participation of 87% stake in sales in 2016. Then, there was a linear decrease until 2040, when it reaches 67% of sales. After that, there was a more intense decrease until 2050, reaching a share of 50%;
- The hybrid light commercial vehicles begin to be marketed in 2020, with a 2% share. A linear growth was considered until 2030, reaching 20% of the share, and exponentially up to 2050, reaching 50%;

- As for electric light commercial vehicles, these will not be considered in this study;
- As for motorcycles, the sale of electric motorcycles in introduced in 2018 based on replacing gasoline-dedicated motorcycles and part of *flexible-fuels*, reaching a share of 20% for electric motorcycles in 2050 (up to 200cc), 75% *flexible-fuel* and 5% gasoline-dedicated;
- Regarding conventional collective-use vehicles (diesel cycle), conventional urban and micro-buses, their share in sales, will decrease from the current 99.3% in 2016 to 94% in 2050, and will remain with that participation until 2050;
    - Micro-buses will be progressively replaced by electric plug-in buses, starting with 0.5% of participation in 2016 and reaching a 6% participation in 2050;
    - As for the alternative collective use vehicles (hybrid and electrical), the sales rate of collective transportation vehicles (alternative, diesel-electric hybrids; and electric plug-in) of the type urban bus increased, arriving at a 3.5% share for diesel-electric hybrids and 2.5% for electric plug-in vehicles in 2050.
- As for hybrid and electric road buses, these will not be considered in this study.

Table 4 introduces the road vehicles fleet for the base year.

Table 4. Types and percentages of passenger road vehicles in 2015.

Vehicle Type	Share percentage
Gasoline vehicle (dedicated) (1)	30.63%
Ethanol vehicle (dedicated)	2.61%
Flexible-Fuel *vehicle*	65.39%
CNG vehicle	1.36%
Flex-electric hybrid vehicle	0.01%
Plug-in electric vehicle	0.0001%
Gasoline motorcycle (dedicated)	81.1%
Flexible-Fuel *Motorcycle*	19.9%
Gasoline light commercial vehicle (dedicated)	34.85%
Ethanol light commercial vehicle (dedicated)	1.74%
Light *flexible-fuel* commercial vehicle	61.77%
CNG light commercial vehicle	1.63%
Urban diesel bus (B8)	100%
Micro-bus diesel (B8)	100%
Diesel road bus (B8)	100%

Note: (1) light commercial diesel-cycle vehicles were considered only for freight transportation.

Source: Made by the authors.

3.1.5.2.2. Use intensity

The determination of the reference use intensity of passenger road vehicles that will be operating until 2050 was based on information supplied by MMA (2013) in the form of the average annual distance traveled by vehicles (km/year), as may be observed in the Table 5. The necessary adjustments for determining use intensity were based on the energy consumption obtained by the *top-down* methodology.

Table 5. Reference use intensity adopted by type of passenger vehicles.

Vehicle Type	Use intensity (km/year)
Gasoline vehicle (dedicated) [(1)]	20,000
Ethanol vehicle (dedicated)	
Flexible-Fuel *vehicle*	
CNG vehicle	30,000
Flex-electric hybrid vehicle	20,000
Plug-in electric vehicle	
Gasoline motorcycle (dedicated)	12,000
Flexible-Fuel *Motorcycle*	
Gasoline light commercial vehicle (dedicated)	
Ethanol light commercial vehicle (dedicated)	20,000
Flexible-fuel light commercial vehicle	
CNG light commercial vehicle	30,000
Urban diesel bus (B8)	91,994
Micro-bus diesel (B8)	
Diesel road bus (B8)	118,094

Note: (1) the light commercial diesel cycle vehicles were considered only in freight transport; (2) variations in use intensity in proportion to vehicle age follow the same systematics provided by the National Inventory of Atmospheric Emissions by Road Vehicles 2013 (MMA, 2013).

Source: Made by the authors.

Use intensity will vary over the years due to several factors. Among them, the development of information technology and connectivity between services can be highlighted. In this context, private companies have already begun to develop innovative ways to enter the passenger transportation market either individually, an activity that was restricted to taxis, or in small groups, which in many places ended up occurring informally in a market that was already considered mature.

Such kind of transportation has in its essence a lucrative model, leading to the consequent existence of a more competitive environment, which can reduce fee values and therefore will attract more users by removing cars from the streets.

According to the technical note No. 06013/16 of the Office for Economic Monitoring, the rental services of private vehicles, classification of the organ in which competing companies in the taxi fit into, have generated strong rivalry in the individual transportation market dominated by taxi drivers.

Competing companies have already been operating since 2012 in several cities, such as London and New York. In 2014 the first Brazilian city to receive a new competitor in this type of service was Rio de Janeiro (CANCIAN, 2016).

Analyzing New York City's database (NYC, 2016), it is observed that in less than a year the fleet of new players surpassed conventional taxis, and together they have a larger fleet by about 103%.

Another item that tends to grow is *carsharing*, which, according to Britton (2000), emerged in Europe almost 30 years ago, with pioneering and important experiences in Switzerland, in 1987, and Germany, more specifically in Berlin, in 1988. In North America, the programs emerged in the 1990s in the United States, originating from *station cars*, and in Canada.

Recent North American studies show that each shared car removes between 9 and 13 private cars from the streets (Shaheen and Chan, 2015).

The growing demand for this kind of service has raised the interest of transportation operators and stakeholders in this business, causing many private entities and government agencies to provide financial resources to promote the shared use of vehicles (Shaheen and Cohen, 2015). Another important factor is the participation of vehicle manufacturers in the innovation of carsharing, providing similar services.

Two Brazilian cities have this kind of service: Recife and São Paulo. In Recife, the service is provided by only one company. In São Paulo, the service is offered by three companies.

3.1.5.3. Payload

The average occupation per km of road, urban and micro buses was 45.50 and 13 passengers, respectively. This value is based on the study by Gonçalves and D'Agosto (2017). The study was used in conjunction with the top-down model (projection) for the adjustment of the calculated payload.

3.1.5.4. Efficiency

The identification of current efficiency of conventional road vehicles was based on information provided by the National Atmospheric Emissions Inventory by road motor Vehicles 2013 (MMA, 2013). For hybrid and electric vehicles, the values were based on the studies made by the *Intergovernmental Panel on Climate Change* (IPCC) (Sims, R *et al*., 2014), by the C40 *Cities Climate Leader Group* and the *Inter-American Development Bank* (IDB) (C40 and IDB, 2013) and on manuals of vehicles currently available in the world market (Nissan, 2016 and BYD, 2017).

The improvement in energy efficiency of these vehicles was determined based on the studies conducted by the *International Council on Clean Transportation* (ICCT) (Façanha *et al.*, 2012), the IPCC (Sims, R *et al.*, 2014) and the *U.S. Department of Energy,* Vyas *et al.*, (2013), according to Table 6,Table 7 and Table 8.

Table 6. Efficiency and improved energy efficiency of passenger road vehicles (otto cycle).

Vehicle	Efficiency [km/l]	Efficiency Improvement (1)
Gasoline vehicle (dedicated) (1)	11.3	It will not be considered
Ethanol vehicle (dedicated)	6.9	It will not be considered
Flexible-fuel vehicle (gasoline)	12.2	25% until 2050
Flexible-fuel vehicle (ethanol)	8.5	25% until 2050
Gasoline motorcycle (dedicated)	37.19	10% until 2050
Flexible-fuel motorcycle (gasoline)	43.2	10% until 2050
Flexible-fuel motorcycle (ethanol)	29.30	10% until 2050
Gasoline light commercial vehicle (dedicated)	9.9	10% until 2050
Ethanol light commercial vehicle (dedicated)	6.9	It will not be considered
Flexible-fuel light commercial vehicle (gasoline)	9.1	25% until 2050
Flexible-fuel light commercial vehicle (ethanol)	6.2	25% until 2050
Urban diesel bus (BX)	2.3	25% reduction, depending on fleet conversion to type *Padron* and BRT's, both with air conditioning (D'Agosto *et al.*, 2016)
Micro-bus diesel (BX)	6.9	5% until 2050
Road diesel bus (BX)	3.1	5% until 2050

Note: BX - biodiesel percentage added to petroleum diesel.
Notes: (1) in relation to 2012.
Source: Made by the authors.

Table 7. Energy efficiency of passenger road vehicles (CNG).

Vehicle	Efficiency [km/m3]	Efficiency improvement
CNG vehicle	12	It will not be considered
CNG light commercial vehicle	12	

Source: Made by the authors.

Table 8. Energy efficiency of passenger road vehicles.

Vehicle	Efficiency	Efficiency improvement
Flex-electric hybrid vehicle (ethanol)	11.6 km/l	25% until 2050
Flex-electric hybrid vehicle (gasoline)	16.6 km/L	25% until 2050
Plug-in electric vehicle	3.5 km/kwh	25% until 2050
Hybrid diesel-electric urban bus	3.25 km/l	15% until 2050
Plug-in electric urban bus	1 km/kwh	15% until 2050

Source: Made by the authors.

The comparison and adjustment of global efficiency improvements was made based on the energy efficiency presented in Table 2 obtained from the 5th Analysis Report of the Intergovernmental Panel on Climate Change – Chapter 8, made by the IPCC (Sims, R *et al.*, 2014), on the studies conducted by the ICCT (Façanha *et al*., 2012), in the studies of the *U.S. Department of Energy (*Vyas *et al*., 2013), on the experience of the researchers who prepared this report and on the Rota 2030 Program, which will succeed the Inovar-Auto Program, which ceases operation on December 31, 2017.

3.1.5.5. Other modes

For the further passenger transportation modes (air, waterways and rail), the current energy efficiency (kJ/pass.km) of the modes was considered based on the payload and energy consumption information related to the historical evolution of modes (1980-2015), provided by the study of Gonçalves and D'Agosto (2017), while the energy demand was updated according to the BEN (EPE, 2017).

To determine the improvement in energy efficiency, a theoretical reference was used to balance the values that will be used. This was done based on the 5th Analysis Report of the Intergovernmental Panel on Climate Change Chapter 8, made by the IPCC, (Sims, R *et al*., 2014 and the *U.S. Department of Energy (*Vyas *et al*., 2013). Therefore, the reference values were established according to the level of energy efficiency established for each mode, as well as the year in which such efficiency was reached (Table 9).

Table 9. Evolution of energy efficiency by transportation mode, in kJ/pass.km.

Year	Air	Rail	Road	Waterways
2015	1,041	197	1,059	1,982
2030	937	192	1,017	1,883
2050	833	187	900	1,784

Note: (1). Inland waterways and Maritime.

Source: Made by the authors.

3.1.6. Freight transportation

This subsection presents the assumptions related to cargo transportation.

3.1.6.1. Modal Split

As a starting point for freight transportation modal split, the modal split of 2014 was used, since the split of 2015 was historically atypical due to the decline of GDP. The projection of the modal split attempted to take into consideration the infrastructure predicted by the government, in the National Logistics and Transportation Plan (PNLT, 2011), for the year of 2031. However, considering the non-completion of rail and waterway projects within the predicted deadlines, a schedule adjustment was made, considering that what was predicted for 2015 would be accomplished only in the year 2025, postponing modal split for the following years until the year 2050. Still, the resulting modal split led to a high proportion of modal shift to the railway mode (36.41%), which would lead to high investments, seemingly incompatible with the moderate GDP evolution that was used to predict the grouped freight payload. Considering the above, the modal split of cargo transportation was made based on the study developed by the ICCT (Façanha *et al.*, 2012), for railway mode. Moreover, the trending evolution was used for pipeline, air and waterways modes (divided into maritime cabotage and inland waterways) leaving the remainder for the road mode (Table 10). These assumptions approximate the prediction of freight transportation modal split estimated by the Energy Demand Study PNE2050 (EPE, 2016) and at the discussion during the workshops conducted (ANNEX II).

Table 10. Modal Split predicted/adjusted in t.km

Year	Pipeline	Air	Waterways	Rail	Road
2014	2.53%	0.12%	15.52%	23.22%	58.61%
2015	2.71%	0.13%	9.49%	27.04%	60.64%
2020	2.51%	0.13%	15.68%	23.47%	58.21%
2030	2.33%	0.15%	17.22%	26,02%	54.27%
2040	2.16%	0.18%	18.76%	28.57%	50.33%
2050	2.00%	0.20%	20.15%	30.87%	46.78%

Source: Made by the authors.

3.1.6.2. Road mode

This section will present the assumptions related to freight transportation for the road mode.

3.1.6.2.1. Fleet

The road freight vehicles fleet division was made based on sales history information found in reports from the National Association of Automotive Vehicle Manufacturers (ANFAVEA, 2017) from 1957 until 2016. The future sales estimate was based on the correlation between the sales history of trucks with the GDP, and on the projected road transportation activity, being:

- For conventional vehicles (diesel cycle), the sales rate considered for light commercial vehicles and light, semi-light and medium trucks was of 3.3% per year from 2018 to 2025 and with 1.6% per year from 2026 until 2050;
- For semi-heavy and heavy vehicles, the rate considered was of 3.3% per year from 2018 to 2025 and of 0.7% per year from 2026 until 2050, as a result of the modal shift of freight transportation from road to rail mode. Considering the assumption of modal split presented in Table 3, these rates were obtained based on the results of energy consumption and payload found using the top-down methodology.

3.1.6.2.2. *Use intensity*

The use intensity of road vehicles was adjusted based on the average annual distance traveled (km/year) (MMA, 2013), as can be seen in Table 11, according to the energy demand estimated with the *top-down* methodology and the assumptions adopted.

Table 11. Reference use intensity adopted by type of freight vehicles.

Vehicle Type	Use intensity in the year of vehicle acquisition (km/year)
Diesel light commercial vehicle (B8)	20,000
Diesel light truck (B8)	64,580
Diesel semi-light truck (B8)	64,580
Diesel medium truck (B8)	112,310
Diesel semi-heavy truck (B8)	117,904
Diesel heavy truck (B8)	117,904

Note: (1) variations in use intensity as the age of the vehicle increases follow the same systematics provided by the National Inventory of Atmospheric Emissions by Road Vehicles 2013 (MMA, 2013).
Source: Made by the authors based on MMA (2013).

3.1.6.2.3. *Payload*

The average occupation of the trucks was conservatively adopted based on the experience of the authors who prepared this report with the average value of 35% of occupation [1], considering that the vehicles return from the trips empty and that not the entire fleet is in operation.

The calculated payload was compared and adjusted according to the consumption obtained with the top-down method (projection for the road mode) and to the historical data, obtained through the study of Gonçalves and D'Agosto (2017).

3.1.6.2.4. *Efficiency*

The identification of the current average efficiency of freight road vehicles was based on information supplied by the MMA (2013). The determination of the improvement in energy efficiency of these vehicles used values based on the studies made by Façanha *et al*. (2012), Sims *et al*. (2014) and Vyas *et al*. (2013), according to Table 12.

[1] The value differs between the types of trucks, being higher for heavy trucks (road transport) and lower for light trucks (urban transport).

Table 12. Efficiency and improvement in energy efficiency of passenger road vehicles (diesel cycle).

Vehicle	Efficiency [km/l]	Efficiency Improvement [(1)]
Diesel light commercial vehicle (B8)	10.5	No changes
Diesel light truck (B8)	5.6	15% until 2050
Diesel semi-light truck (B8)	9.1	
Diesel medium truck (B8)	5.6	
Diesel semi-heavy truck (B8)	3.4	
Diesel heavy truck (B8)	3.4	

Notes: (1) in relation to 2012; (2) the otto cycle light commercial vehicles were considered only for passenger transportation.
Source: Made by the authors.

With the results obtained from the application of the procedure for calculating fuel consumption, the achieved efficiency improvement and the estimated consumption were identified and adjusted.

The calculated fuel consumption was compared and adjusted according to the consumption obtained by the top-down methodology (projection for road mode) and to the historical data, obtained through the National Inventory of Emissions by Road Vehicles 2013 (MMA, 2013).

3.1.6.3. Other modes

For the remaining freight transportation modes (pipeline, air and waterways), the current energy efficiency (kJ/t.km) was considered based on payload and energy consumption information related to the historical evolution of the modes provided by the study of Gonçalves and D'Agosto (2015). The energy demand was updated according to the BEN (EPE, 2017).

To determine the improvement in energy efficiency of these modes, the works of Sims, *et al*. (2014), Façanha *et al*. (2012) and Vyas *et al*. (2013) were also used. Table 12 presents the evolution of energy efficiency by transportation mode.

Table 13. Evolution of energy efficiency by transportation mode, in kJ/t.km.

Year	Air	Maritime cabotage	Inland waterways	Rail	Road	Pipeline
2015	13,566	252	710	123	1,709	121
2030	12,523	233	675	117	1,624	118
2050	10,853	214	639	100	1,538	113

Source: Made by the authors.

4. Results obtained and analyses

This section presents the projections of payload for freight and passenger transportation, their respective energy demand and consequently their CO_2 emissions, considering the assumptions adopted in this study and the results obtained in relation to the projection of the BAU Scenario.

4.1. Payload

Based on the GDP estimates data presented in Figure 6, on the GDP per capita estimate presented in Figure 7, and on the historical data on transportation (1970-2015) obtained in the study of Gonçalves and D'Agosto (2017), the payload projections for freight and passenger transportation were identified.

Based on passenger payload projected and presented in Figure 8, the values of Figure 9 are obtained, with the application of the percentage of participation of each mode (Table 3) in the modal split, according to the assumptions described in section 3.

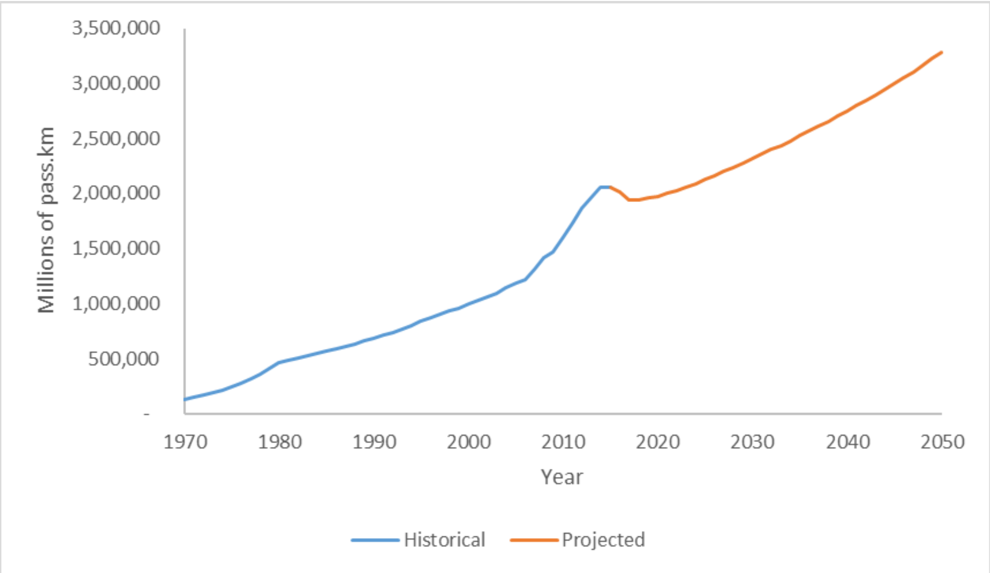


Figure 8. Evolution of passenger payload.
Source: Made by the authors.

Thus, it was observed that passenger payload will reach 3.287 x10^9 pass.km in 2050, with an average growth of 1.7% per year.

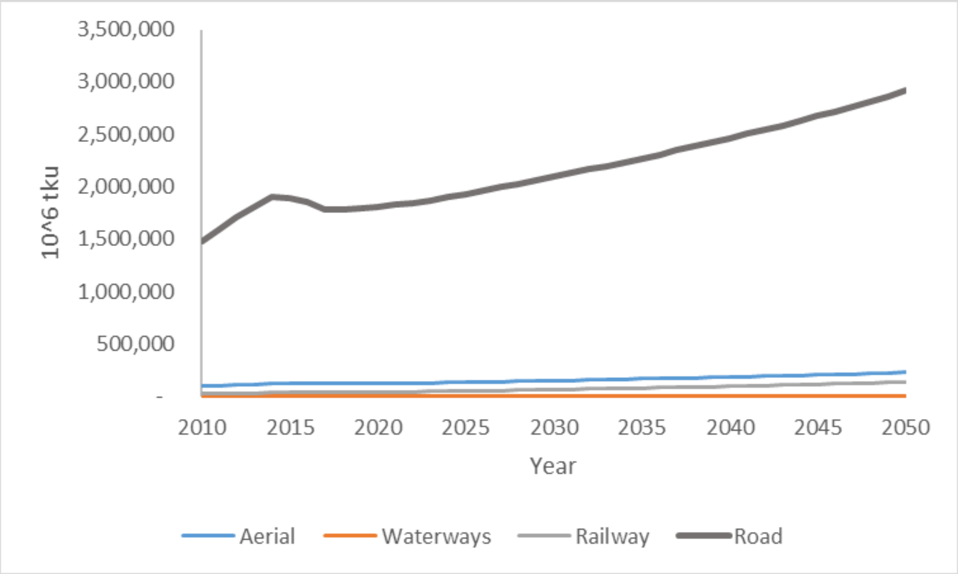


Figure 9. Evolution of passenger payload by mode.

Source: Made by the authors.

With regard to passenger transportation for the road mode, it was observed that since 1970 this is the predominant mode, with an average growth of 6.3% until 2016. An average payload growth of 1.4% is estimated from 2017 to 2050. As for its participation in the modal split, it is estimated a reduction of approximately 3.5%, changing from 91.9% in 2015 to 88.7% in 2050, however, its predominance is estimated to continue.

As for passenger transportation by the air mode, an average payload growth of 8% (1970 to 2015) was observed. As for the period from 2017 to 2050, an average growth of 2% is estimated with its participation in the expanded modal split of approximately 12.9%, changing from 6.2% in 2015 to 7.0% in 2050.

For the waterways mode, there was an average payload growth of 5.8% (1970 to 2015). As for the period of 2016 to 2050, an average growth of 3% is estimated and its participation in the modal split will be expanded by approximately 61%, changing from 0.06% in 2015 to 0.10% in 2050.

For the railways mode, there was an average payload growth of 2.6% (1970 to 2015). As for the period from 2016 to 2050, an average growth of 4% is estimated. Its participation in the modal split will be expanded by approximately 129.8%, changing from 1.8% in 2015 to 4.2% in 2050.

Based on the freight payload projected and presented in Figure 10, the values of Figure 11 are found, with the application of the participation of each mode (Table 10) in the modal split, according to the assumptions described in section 3.

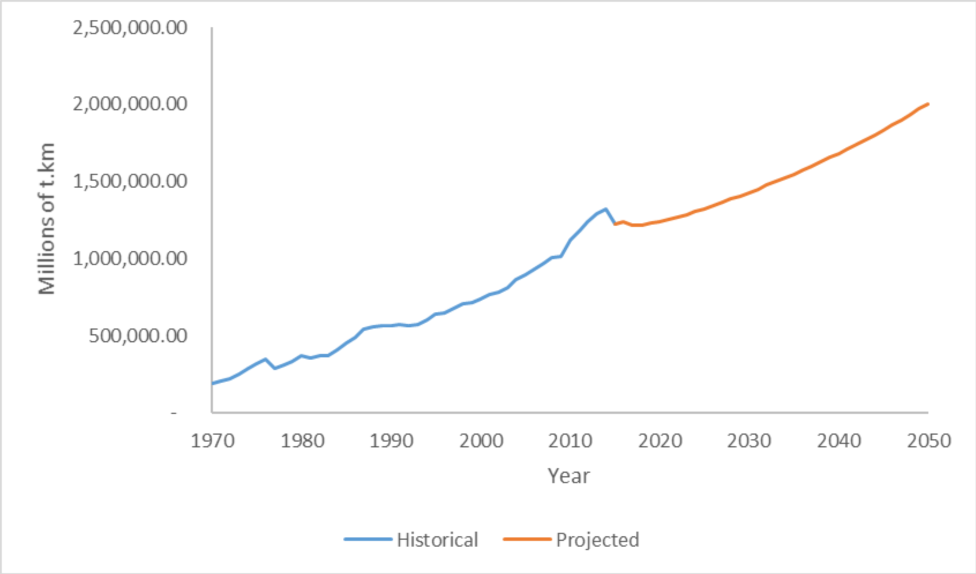


Figure 10. Evolution of freight payload.

Source: Made by the authors.

In the case of freight transport, it will reach 2.006 x10^9 t.km in 2050. With an average growth of 1.5% per year.

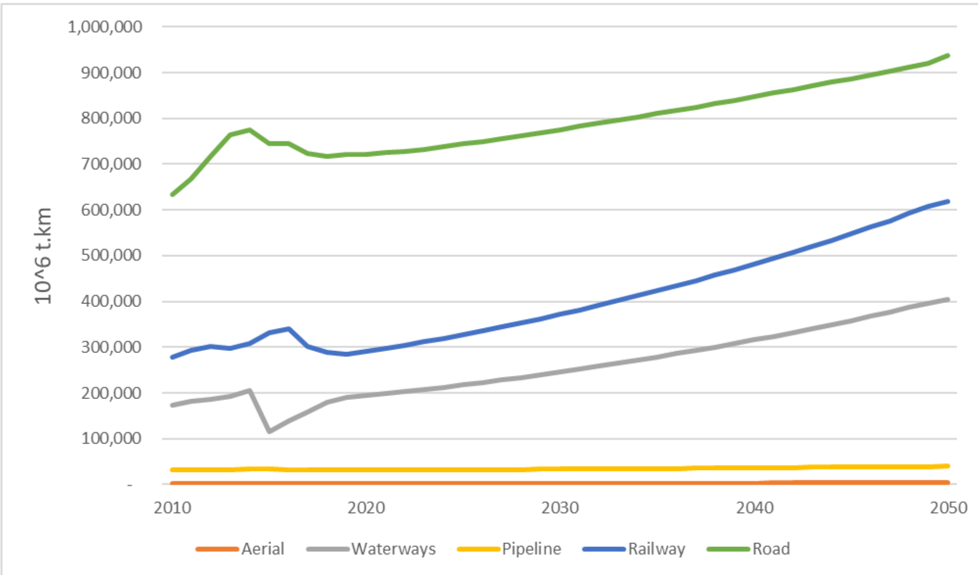


Figure 11. Evolution of freight payload by mode.

Source: Made by the authors.

As for freight transportation through the pipeline mode, there was an average increase in payload of 7% (1970 to 2015). As for the period from 2016 to 2050, an average growth of 1% is estimated. However, its participation in the modal split will be reduced by approximately 26%, changing from 2.71% in 2015 to 2.00% in 2050.

For the air mode, there was an average increase of 7% in payload (1970 to 2015). For the period from 2016 to 2050, an annual average growth of 3% is estimated. Its participation in the modal split will be expanded by approximately 64%, changing from 0,12% in 2015 to 0,20% in 2050.

For maritime cabotage transportation, there was an average growth of 5.5% in payload (1970 to 2015). For the period from 2016 to 2050, an average growth of 2.7% is estimated. Its participation in the modal split will be expanded by approximately 65%, changing from 14.23% in 2014[2] to 16.88% in 2050.

For inland waterways, there was an average increase in payload of 2.6% (1970 to 2015). For the period from 2016 to 2050, an average growth of 5% is estimated. Its participation in the modal split will be expanded by approximately 153%, changing from 1.3% in 2014[1] to 6.27% in 2050.

Considering that maritime cabotage and inland waterways comprise the waterways mode, it was observed that its share in the modal split will be expanded by approximately 29.83%, from 15.52% in 2014 to 20.15% in 2050.

For the rail mode, there was verified an average growth of 2.6% in payload (1970 to 2015). For the period from 2016 to 2050, an average growth of 2.2% is estimated. Its participation in the modal split will be expanded by approximately 33%, changing from 23.2% in 2014 [1] to 30.9% in 2050.

For the road mode, there was an average increase of 4% in payload (1970 to 2015). As for the period from 2016 to 2050, an average growth of 1% is estimated. Its participation in the modal split will be reduced by approximately 23%, changing from 60.6% in 2015 to 46.8% in 2050.

4.2. Energy demand

Based on the total payload predicted and presented in the previous subsection, in the historical data that were gathered and on the assumptions adopted. The methodology proposed in this study

[2] 2015 was an atypical year for maritime cabotage transportation.

was applied, as described in Section 2. Therefore, Figure 12 presents the energy consumption for freight transportation and passenger transportation.

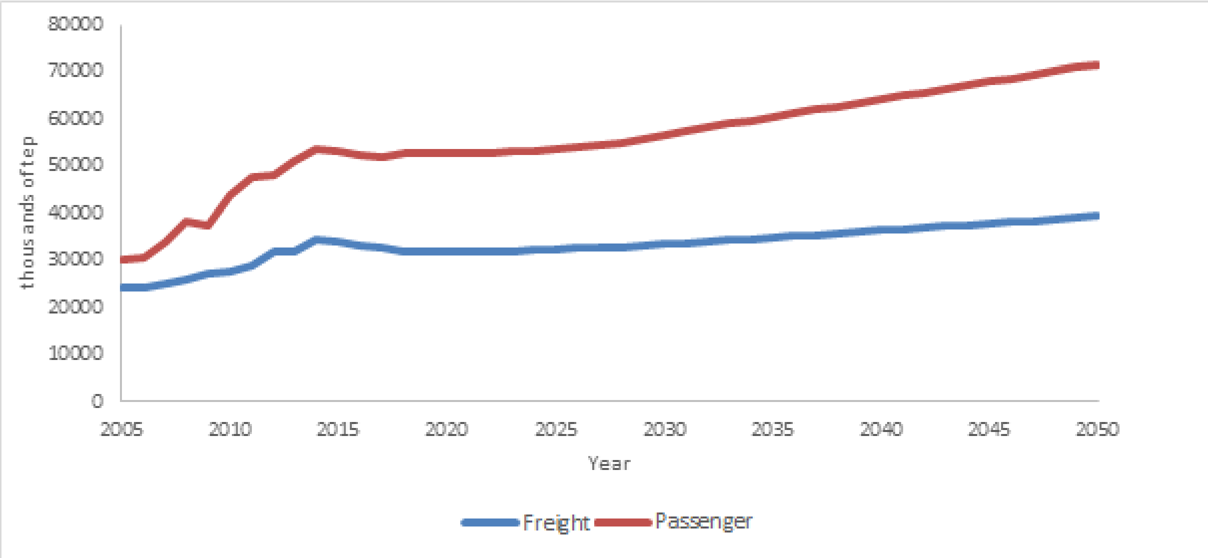


Figure 12. Aggregate energy demand per activity.
Source: Made by the authors.

Analyzing Figure 12, it can be seen that energy demand will increase about 27%, being 35% for passenger transportation and 15% for freight transportation. Therefore, passenger transportation will continue to demand more energy than freight transportation, representing around 61% in 2050.

Considering all transportation modes, it was possible to analyze the consumption by fuel type between years 2015 and 2050, both for passenger transportation (Figure 13) and freight transportation (Figure 14).

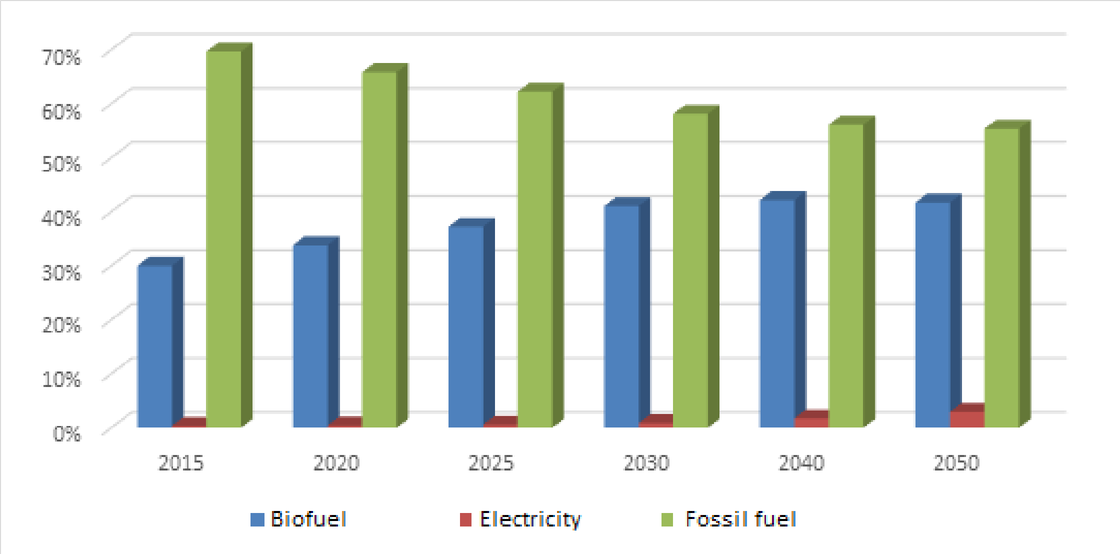


Figure 13. Energy demand by source – Passenger transportation
Source: Made by the authors.

In passenger transportation, there was an increased participation in the demand for biofuels of 39% due to the greater share of biodiesel in diesel and the incentive to use ethanol. The participation of electricity grew by about 7.8 times due to the growth trend of the rail mode and the entering of cars, motorcycles and urban battery electric buses. Given the growing demand for biofuels and electricity, the participation of fossil fuels fell by around 21%.

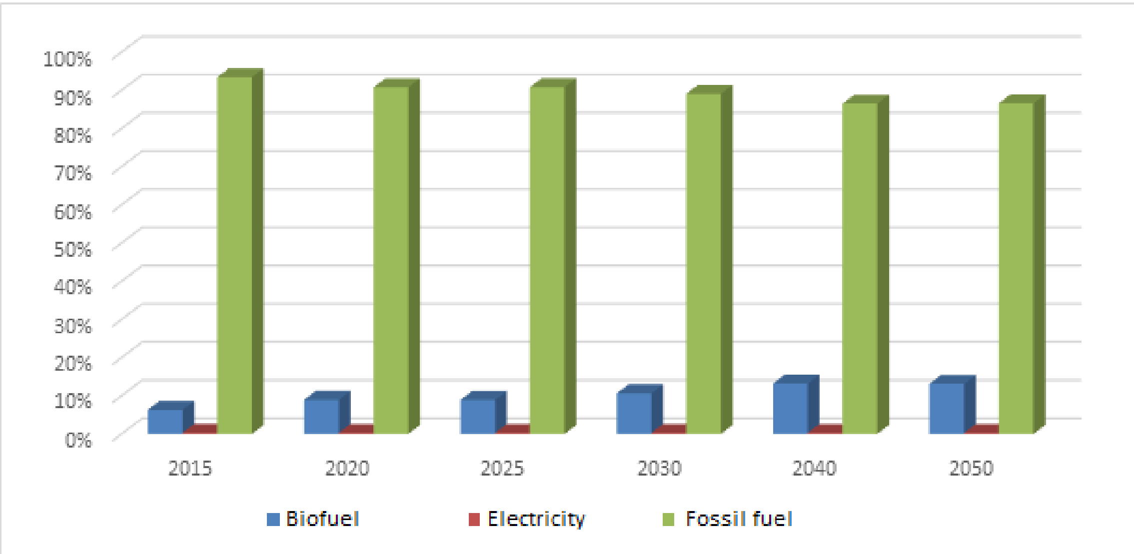


Figure 14. Energy demand by source – Passenger transportation
Source: Made by the authors.

For freight transportation, there was an increase in the participation of the demand for biofuels of 108% due to the greater proportion of biodiesel in diesel and to the introduction of biodiesel in the diesel mixture demanded by inland waterways navigation. The participation of electricity remained the same due to the growth trend of the pipeline mode. Given the growing demand for biofuels, the participation of fossil fuels decreased by around 7%.

4.3. CO_2 emissions

Based on the estimated energy consumption and on the emission factors for each fuel, shown in Table 1, the emission of CO_2 was calculated per transportation mode for passenger transportation (Figure 15) and for freight transportation (Figure 16).

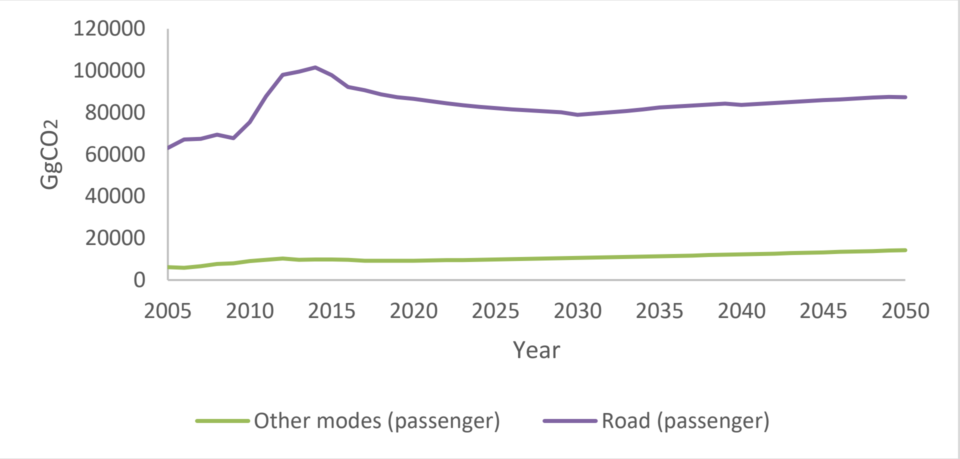


Figure 15. CO_2 emission – passenger transport.

Note: Gg-Gigagram.

Source: Made by the authors.

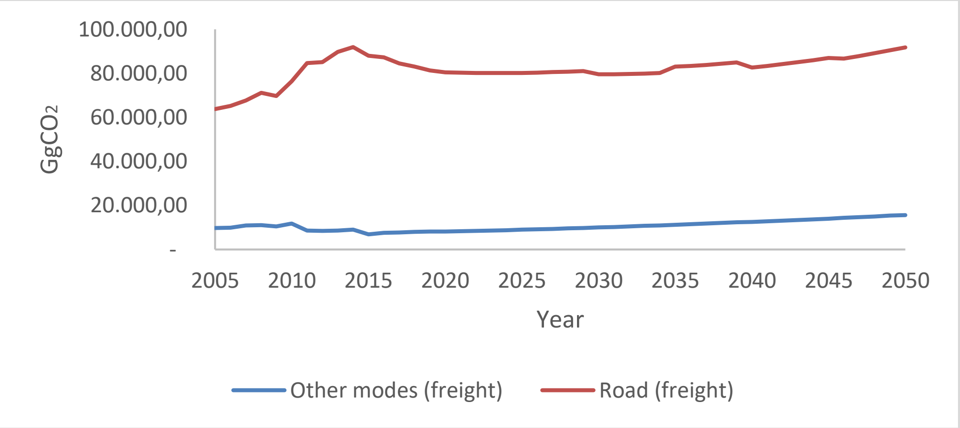


Figure 16. CO_2 emission – freight transportation.

Note: Gg-Gigagram.

Source: Made by the authors.

It was observed that, both for passenger transportation and for freight transportation, there is total predominance of the road mode (2005 to 2050), in relation to CO_2 emissions, compared to other modes.

Analyzing Figure 17, it can be seen that even requiring less energy than passenger transportation, freight transportation will be the greatest responsible for CO_2 emissions in the sector, surpassing passenger transportation in the year 2029. This occurs because the entry of hybrid and electric vehicles was only considered for passenger transportation, besides having one more option of biofuels, the anhydrous ethanol present in gasoline C and the option for hydrated ethanol.

Figure 17. Evolution of CO_2 emissions by transportation type.

Note: Gg-Gigagram.

Source: Made by the authors.

Figure 18 presents the evolution of CO_2 emissions in the transportation sector, considering passenger transportation and freight transportation.

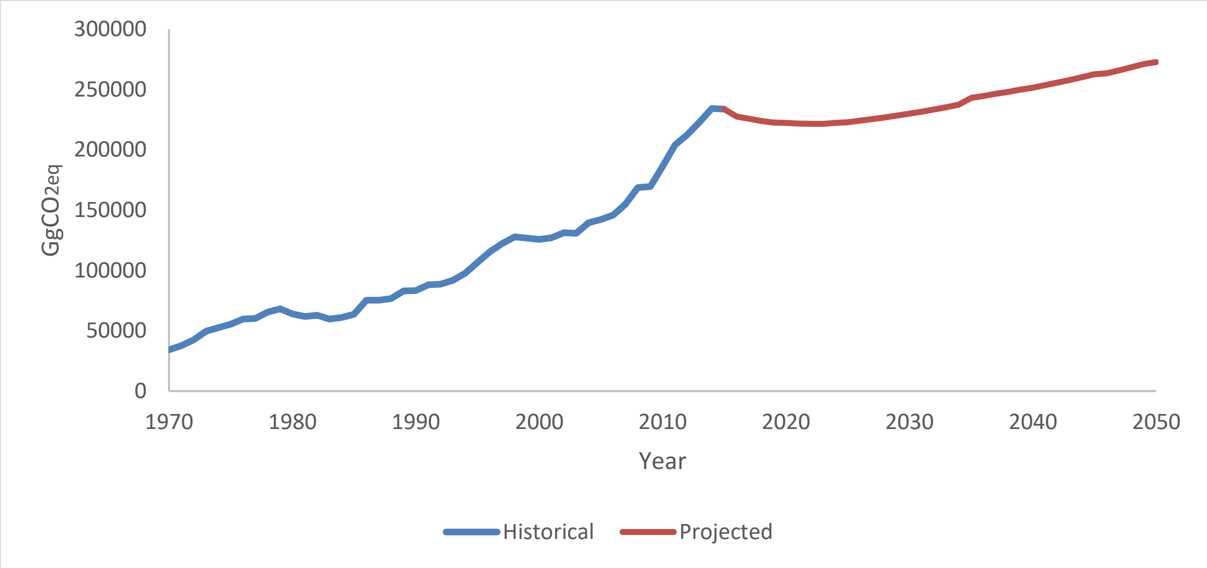


Figure 18. Evolution of CO_2 emissions – transportation sector.

Note: Gg-Gigagram.

Source: Made by the authors.

Analyzing Figure 18, it can be seen that, considering the trending behavior, CO_2 emissions will increase around 21% until 2050 when compared to the base year (2015). Therefore, the BAU scenario will not meet the NDC goal, since it aims at a reduction of 37% of carbon emissions in 2025 and 43% in 2030. What is estimated in the BAU scenario is an increase in CO_2 emissions by 53% for 2025 and 59% for 2030. It is worth pointing out that the NDC goal considers the reduction of national carbon emissions to be the sum of all sectors. However, it is understood that the transportation sector is a key sector in attaining such goals, since, besides having several mitigation options, it can still provide several simultaneous benefits for the population and the country.

5. Final considerations, limitations and recommendations for future work

Meeting the objectives proposed, this study presented the trending scenario (BAU scenario) of the transportation activity in Brazil, in annual intervals up to the year 2050, considering the evolution of the energy matrix and CO_2 emissions.

This study sought to explore and explain the sector. For that purpose, a qualitative and quantitative approach was chosen in order to establish the model. Also, the following procedures were adopted for data collection: a bibliographic research, a documentary research and a research carried out with specialists in the area of transportation and energy with the purpose of ratifying the assumptions adopted.

The differential of the combined use of the qualitative ASIF methodology with quantitative methodologies, such as *top-down* and *bottom-up*, as well as its mode of data consistency analysis, validation, consolidation and adjustment of *inputs*, in a disaggregate manner, has enabled greater sensitivity for the analyses and the adjustments required.

Based on the gathered historical data concerning energy consumption and payload (passengers and freight), on the values considered for GDP, on the rate of GDP variation and on the population, it was possible to identify the evolution trend of energy use and CO2 emissions for the transportation sector predictions created considering the period until 2050, with 2015 as the base year.

From the application of such methodology, it was verified that freight payload will reach the value of 2.006 $x10^9$ t.km and passenger payload will reach 3.286 $x10^9$ pass.km, both up to 2050.

For the BAU scenario, it is estimated that the road mode will remain predominant both for passenger and freight transportation, although its participation in the modal split was reduced in both cases. The modal split of road passenger transportation would be reduced by 3.5% and that of road freight transportation by 23%, considering the period from 2015 to 2050.

Regarding energy consumption, it was found that the road mode is predominant and will continue to be responsible for the largest share of energy consumption in Brazil in 2050, both for passenger and freight transportation, reaching 90% of participation in the use of all types of energy demanded for the transportation sector. Moreover, it is estimated that the transportation sector will be largely dependent on petroleum-based energy sources (67%), especially regarding petroleum diesel (42%).

Concerning CO_2 emissions in 2050, it is estimated that freight transportation will be responsible for the emission of 51% and passenger transportation for 49%.

The analysis of results shows that, considering the trending behavior, CO_2 emissions will increase around 21% until 2050, when compared to the base year (2015). Therefore, the BAU scenario will not meet the NDC goals, since these goals aim at a reduction of 37% of carbon emissions in 2025 and 43% in 2030. What is estimated in the BAU scenario is an increase in CO_2 emissions of 53% for 2025 and 59% for 2030. It is worth pointing out that the NDC goal considers the aggregate reduction of national carbon emissions for all sectors. Nevertheless, as stated previously, transportation sector is a key sector in attaining such goals, since it has several mitigation options and can provide several benefits on the economic and socio-environmental aspects.

Additionally, it was observed that some assumptions considered in this study were able to provide better results in energy use and reduction of CO_2 emissions. Among them, the following can be highlighted: (1) modal shift, both for freight and passenger transportation, specifically from the road mode to the rail mode; (2) optimization of vehicle capacity, both individually and collectively, directly influencing the average loading of vehicles; (3) reduction of use intensity, i.e., traveling smaller distances; (4) the use of biofuels, mainly ethanol in *flexible fuel* vehicles and biodiesel in buses and trucks; and (5) the greater participation of electric and hybrid vehicles in the road freight and passenger transportation fleet.

With regard to the energy matrix of Brazilian transportation, there was a predominance of fossil fuels (79%), a participation around 20.7% of biofuels and 0.3% of electricity in 2015. In the year 2050, the participation of these energy sources changes to 66% for fossil fuels, 32% for biofuels and 2% for electricity.

The perceived limitations of this study are: (1) the existence of greater uncertainty regarding the historical data on waterways freight transportation; (2) the fact that the historical series of energy consumption begins in 1970, since in previous years the National Energy Balance (BEN) provided by the Ministry of Mines and Energy had not yet been made; (3) the divergence of historical transportation data between the various Brazilian reports for the freight and passenger payload; (4) the dispersion of data from the regulatory agencies in the transportation sector (ANTT, ANTQ and ANAC), which impairs the consolidation and consistency of the information.

Additionally, it is worth highlighting the fact that the assumptions adopted in the study were based primarily on documents of public and private institutions, whose policies can be modified over time, influencing the results. Moreover, there were assumptions based on the current knowledge level regarding the topic in question and which can be modified according to technological and scientific developments.

Another limitation of this study refers to the long deadlines considered for projections of payload, both for cargo and passenger transportation (about 33 years), which increases the possibility of error in estimates.

As recommendations for future work, studies should be carried out focusing on the improvement of road transportation, since this has proved to demand the most energy. Besides, there should also be studies that enable modal shift to modes of higher capacity than road or even non-motorized modes, in the case of passenger transport.

In a future edition of this work, in addition to updating the BAU scenario, there a plan to present an alternative scenario.

Additionally, there should be constant updating of the results achieved, enabling the formation of a database concerning the transportation activity and energy consumption that will enable an improvement and refinement of the information used in this study.

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Annex I – Sectors and their participation in total emissions of CO_{2eq} in 2010 (1.271.399 Gg CO_{2eq})

Sector	Source	Subsector/Activity	%
Energy	Fuel consumption	Transportation	13.8
		Energy	4.8
		Industrial	5.6
		Residential	1.9
		Agriculture	1.4
		Commercial	0.1
		Public	0.1
	Fugitive emissions	Coal mining	0.2
		Extraction and transportation of petroleum and natural gas	1.3
Industrial processes		Cement production	1.7
		Production of pig iron and steel	3.1
		Other industries	2.2
Cattle raising	Enteric fermentation	Bovine cattle	17.8
		Other animals	0.6
	Agricultural soils (Direct emissions)	Grazing animals	4.2
		Synthetic fertilizers	0.9
		Fertilizer Application	0.5
		Agricultural waste	1
		Organic soils	0.4
	Agricultural soils (indirect emissions)	Atmospheric disposition	0.9
		Leaching	3.3
	Rice culture		0.8
	Burning of agricultural waste		0.4
	Animal waste management		1.3
Land use, land use change and forests	Biomass	Amazon	14.1
		Atlantic Forest	6.3
		Cerrado	5.4
		Other biomes	1
	Liming	-	0.8
Waste treatment	Solid waste		2.2
	Effluents		2.1

Source: Adapted from MCTI (2016).

Annex II – Workshops held and participating institutions

<table>
<tr><th>Workshop</th><th>Year</th><th>Location</th><th>City</th><th>State</th></tr>
<tr><td>Energy revolution (1st)</td><td>2015</td><td rowspan="2">Federal University of Rio de Janeiro</td><td rowspan="4">Rio de Janeiro</td><td rowspan="4">RJ</td></tr>
<tr><td>Energy revolution (2nd)</td><td>2016</td></tr>
<tr><td>GHG emissions mitigation technologies in Brazil until 2050</td><td>2016</td><td>Windsor Atlântica Hotel</td></tr>
<tr><td>GHG emissions mitigation scenarios in Brazil until 2050</td><td>2017</td><td>Windsor Florida Hotel</td></tr>
</table>

Institutions	Acronym
National Civil Aviation Agency	ANAC
National Agency of Petroleum, Natural Gas and Biofuels	ANP
Alberto Luiz Coimbra Institute of Graduate Studies and Research in Engineering	COPPE
Brazilian Biodiesel Producers Association	APROBIO
National Association for Transportation Research and Education	ANPET
National Bank of Economic and Social Development	BNDES
Energy Research Company	EPE
Financing of Studies and Projects	FINEP
Greenpeace	
Climate and Society Institute	ICS
Institute of Energy and Environment	IEMA
Institute for Transportation and Development Policy	ITDP
Institute for Transportation and Logistics of the National Transportation Confederation	ITL/CNT
Ministry of Cities	
Campinas State University	UNICAMP
Itajubá Federal University	UNIFEI
World Resources Institute	WRI
World Wide Fund for Nature	WWF

Annex III – Energy Demand Evolution (10^3tep)

	NATURAL GAS	TOTAL PRIMARY	OIL DIESEL	BIODIESEL	OIL FUEL	GASO-LINE	KERO-SENE	ELECTRI-CITY	ALCOHOL (ETHYL)	TOTAL SECOND.	TOTAL
2015											
TRANSPORTATION - TOTAL	1,553	1,553	39,244	-	724	23,306	3,609	273	15,424	82,484	84,037
PIPELINE								96			
ROAD	1,553	1,553	38,033		-	23,257	-	-	15,424	76,714	78,267
RAIL	-	-	971		-	-	-	177	-	1,148	1,148
AIR	-	-	-		-	49	3,609	-	-	3,658	3,658
WATERWAYS	-	-	240		724		-	-	-	965	965
2020											
TRANSPORTATION - TOTAL	1,560	1,560	37,894	3,897	1,041	19,808	3,455	296	16,739	83,038	84,598
PIPELINE								92			
ROAD	1,560	1,560	36,651	3,803	-	19,763	-	3	16,739	76,960	78,520
RAIL	-	-	900	93	-	-	-	201	-	1,194	1,194
AIR	-	-	-		-	45	3,455	-	-	3,500	3,500
WATERWAYS	-	-	343		1,041	-	-	-	-	1,384	1,384

2025

TRANSPORTATION - TOTAL	1,662	1,662	38,814	3,992	1,113	17,395	3,693	393	18,719	84,021	85,683
PIPELINE								98			
ROAD	1,662	1,662	37,480	3,889	-	17,346	-	47	18,719	77,482	79,144
RAIL	-	-	990	103	-	-	-	248	-	1,341	1,341
AIR	-	-	-		-	49	3,693	-	-	3,742	3,742
WATERWAYS	-	-	344		1,113	-	-	-	-	1,457	1,457

2030

TRANSPORTATION - TOTAL	1,905	1,905	39,693	5,059	1,210	15,943	3,998	572	21,749	88,124	90,029
PIPELINE								100			
ROAD	1,905	1,905	38,207	4,866	-	15,892	-	167	21,749	80,881	82,786
RAIL	-	-	1,000	127	-	-	-	305	-	1,432	1,432
AIR	-	-	-		-	51	3,998	-	-	4,049	4,049
WATERWAYS	-	-	486	66	1,210	-	-	-	-	1,762	1,762

2035

TRANSPORTATION - TOTAL	2,103	2,103	41,532	5,287	1,322	16,570	4,349	849	23,833	93,641	95,744
PIPELINE								101			
ROAD	2,103	2,103	39,910	5,083	-	16,515	-	378	23,833	85,719	87,822
RAIL	-	-	1,024	130	-	-	-	370	-	1,524	1,524
AIR	-	-	-		-	55	4,349	-	-	4,404	4,404
WATERWAYS	-	-	598	74	1,322	-	-	-	-	1,994	1,994

2040											
TRANSPORTATION - TOTAL	2,223	2,223	42,403	6,976	1,447	16,929	4,724	1,227	25,147	98,748	100,971
PIPELINE								104			
ROAD	2,223	2,223	40,595	6,691	-	16,870	-	679	25,147	89,981	92,204
RAIL	-	-	1,106	182	-	-	-	444	-	1,732	1,732
AIR	-	-	-		-	59	4,724	-	-	4,783	4,783
WATERWAYS	-	-	702	103	1,447	-	-	-	-	2,252	2,252
2045											
TRANSPORTATION - TOTAL	2,240	2,240	44,491	7,309	1,585	17,412	5,128	1,680	26,379	103,875	106,115
PIPELINE								109			
ROAD	2,240	2,240	42,418	6,991	-	17,348	-	1,042	26,379	94,178	96,418
RAIL	-	-	1,232	203	-	-	-	529	-	1,964	1,964
AIR	-	-	-		-	64	5,128	-	-	5,192	5,192
WATERWAYS	-	-	841	115	1,585	-	-	-	-	2,541	2,541
2050											
TRANSPORTATION - TOTAL	2,156	2,156	46,561	7,632	1,733	17,872	5,551	2,209	27,403	108,848	111,004
PIPELINE								113			
ROAD	2,156	2,156	44,214	7,287	-	17,803	-	1,480	27,403	98,187	100,343
RAIL	-	-	1,365	225	-	-	-	616	-	2,206	2,206
AIR	-	-	-		-	69	5,551	-	-	5,620	5,620
WATERWAYS	-	-	982	120	1,733	-	-	-	-	2,835	2,835

Annex IV – Evolution of passenger (10^6 pass.km) and freight (10^6 t.km) payload

Year	Passenger transportation				Freight Transportation				
	Air	Waterways	Rail	Road	Pipeline	Air	Waterways	Rail	Road
2014	122474	1294	35493	1901099	33469	1646	205445	307304	775741
2015	127533	1279	37603	1891234	33261	1496	116472	331721	743904
2030	151782	1827	66584	2096444	33374	2174	246129	371983	775767
2040	186764	2476	98283	2463980	36356	2986	315990	481259	847655
2050	230073	3287	138044	2915348	40131	4013	404322	619425	938669

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