ICAT Brazil Project

CBC – Centro Brasil no Clima

Report 2

GHG Emissions in Brazil up to 2030 under Current Mitigation Policies – Scenario A and under Additional Mitigation Actions – Scenarios B and C

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1. INTRODUCTION

1.1. Background

The Brazilian NDC has an economy-wide goal of 37% GHG emission reduction, in 2025 and an intended 43% reduction, in 2030, compared with 2005 as the base year. In its annex "for clarification purposes," it is specified that these goals translate into an aggregate limit of 1.3 Gt CO_2-eq in 2025 and 1.2 Gt CO_2-eq in 2030 (GWP-100, IPCC AR5).

This annex also presents some quantified sectorial goals in energy, land use and forests, and agriculture:

i) in the energy sector:

- achieving 45% of renewables in the energy mix by 2030, including:
- expanding the use of renewable energy sources other than hydropower in the total energy mix to between 28% and 33% by 2030;
- increasing the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030, by expanding biofuel consumption, increasing ethanol supply, including by increasing the share of advanced biofuels (second generation), and increasing the share of biodiesel in the diesel mix;
- expanding the use of non-fossil fuel energy sources domestically, increasing the share of renewables (other than hydropower) in the power supply to at least 23% by 2030, including by raising the share of wind, biomass and solar;
- achieving 10% efficiency gains in the electricity sector by 2030.

ii) in land use change and forests:

- strengthening policies and measures with a view to achieve, in the Brazilian Amazon region, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030;
- restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes.

iii) in the agriculture sector:

- strengthen the Low Carbon Emission Agriculture Program (ABC) as the main strategy for sustainable agriculture development, including by restoring an additional 15 million hectares of degraded pasturelands by 2030 and enhancing 5 million hectares of integrated cropland-livestock-forestry systems (ICLFS) by 2030;

Some generic unquantified commitments are presented for some sectors:

- in land use change and forests: strengthening and enforcing the implementation of the Forest Code, at federal, state and municipal levels; enhancing sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management, with a view to curbing illegal and unsustainable practices;
- in the industry sector, promote new standards of clean technology and further enhance energy efficiency measures and low carbon infrastructure;
- in the transportation sector, further promote efficiency measures, and improve infrastructure for transport and public transportation in urban areas.

Brazil also works with previous voluntary commitments linked to its NAMAs, enshrined in the 2009 Climate Change Law (12187/09) and related executive decrees. These define targets for 2020 like deforestation reduction goals among others.

The issue of transparency in the assessment of results of these previous UNFCCC commitments and of the implementation of future NDC related actions is key especially because an emissions pathway was not defined: only a target for 2025, with another possible target for 2030, were established. Article 13 of the Paris Agreement establishes the guidelines for Monitoring, Reporting, and Verification (MRV) issues. One relevant aspect is civil society participation. Since March 2017, the instance for the discussion of a roadmap for the implementation of the Brazilian NDC is the Brazilian Climate Change Forum (FBMC).

The President of Brazil chairs the Forum, constituted by the government and civil society representatives. Its members belong to the government, the private sector, NGOs and academia. It has nine Thematic Chambers (TCs): 1 – Forests & Agriculture; 2 – Energy; 3 - Transport; 4 – Cities and Waste; 5 – Industry; 6 – Finance; 7 – Technology & Innovation, 8 – Long-Term Strategy 9 – Adaptation. The logistics for the various FBMC activities and products are provided by NGOs, members of the business sector and academia with the oversee and eventual technical support of some of its governmental participants.

The Forum has promoted, since March 2017, a process for discussion of a roadmap for the implementation of the Brazilian NDC to be submitted to the President. As a result, the Forum has selected sets of mitigation actions constituting a document concluded in June this year. The process involved the public in general, bilateral discussions with relevant public and private actors, technical and scientific consultations and a discussion of new economy-wide low carbon financial instruments like carbon taxation, domestic cap and trade carbon markets and other carbon pricing tools. The Forum proposed two scenarios for the implementation of the Brazilian NDC with different ways to achieve the economy-wide aggregate goals: a "AFOLU Scenario" very much dependent on mitigation actions related to land use and a "Balanced Scenario" in which Brazil will be counting less on AFOLU and putting more efforts in the energy sector, especially from fossil fuel consumption in the transport sector.

From a legal perspective, unlike the voluntary goals linked to the NAMAs, the 2025 and 2030 commitments assumed in the Paris Agreement still need a domestic legal framework supporting the NDCs implementation and setting an MRV system.

1.2. Project Presentation, Objectives and Methodology

This project is an initial step towards the establishment of a robust and transparent MRV process capable of assessing the various actions that will lead to the desired accomplishment of the Brazilian NDC mitigation targets in a transparent and participatory process. It will also help the design of the eventual carbon market and pricing mechanisms that depend upon a trustworthy MRV of the performance of the various kinds of mitigation actions.

The project objective is the development of a methodology to calculate the effect of different sets of mitigation actions (grouped in mitigation scenarios) in terms of avoided GHG emissions to help measuring/monitoring, reporting and verification – MRV of the progress achieved in the implementation of quantified commitments of the Brazilian NDC. This will allow proposing a draft decree expanding the regulation of the climate change national policy to embrace the follow-up of NDCs.

The project methodology starts by the estimate of a baseline scenario (Scenario A) to represent the current emission trends in the country up to 2030, considering the pre-NDC commitments and policies as well as the current mitigation actions supporting the NDC commitment. This includes the mitigation actions established by the Brazilian NAMA and resulting legal and normative framework. This assessment allows a more realistic assumption of a baseline for 2025 and 2030 and the true effort still needed to fulfill the NDC targets.

The quantified mitigation actions required to meet the NDC targets are grouped in two other different scenarios (Scenarios B and C) with emissions estimated up to 2030. They will respect the economy-wide targets for 2025 and 2030, representing different combinations of sectorial mitigation actions allowing for achieving the NDC goals.

The three scenarios are described below:

Scenario A (Real Path Scenario) is based upon current GHG emission trends including all the policies and measures put in place to cope with the Brazilian NAMAs (here considered with the values presented in the Decree 7390[1]) and NDC commitments. This scenario represents the most likely emissions level the country would achieve if the implementation of the mitigation measures follows the current path.

Scenario B (AFOLU Scenario) will reach the mitigation targets for 2025 and 2030 as in the NDC commitment and includes several mitigation actions proposed by the Forum with more emphasis on the AFOLU sector.

Scenario C (Balanced Scenario) will also reach the mitigation targets for 2025 and 2030 as in the NDC commitment and includes another set of mitigation actions proposed by the Forum but is more balanced, with a substantial reduction of emissions from other sectors than AFOLU.

Each scenario associates the activity levels of the general GHG emission drivers (population and economic growth) and of the different sectorial drivers (deforestation, agricultural production, cattle raising output, energy demand, energy supply mix, among others) with the GHG emission levels through a set of specific emission factors (compatible with those used in national GHG emission inventories).

The effect of mitigation actions translates into the level of GHG emissions in each sector. The monitoring of these indicators will allow for an assessment of the progress made in each sector for achieving the NDC targets.

This first report presents the assumptions selected in the three scenarios and the results obtained for Scenario A, under current mitigation policies. It will be followed by a report comparing the results of the three scenarios and by a final report including an MRV framework proposal for the Brazilian NDC.

[1] The values in the NAMAs and in the Decree 7390 differ in respect to Land Use Change and Forestry. See a complete discussion in Report 3.

2. ECONOMIC SCENARIO

The economic scenario of the MRV project is based on qualitative narratives of plausible and pertinent futures stories derived from hypotheses about the evolution of the Brazilian economy, described in the National Energy Plan – PNE 2050 (EPE, 2015), and in the Ten Year Energy Plan 2026 (PDE 2026), with revised growth rates. According to the scenario methodology approach, projections are not forecasts, that is, their purpose is not to present the future that is deemed most likely. In addition, the economic scenario produced for the MRV project was an exploratory, not a normative, scenario, to verify the consequences resulting from the assumptions selected in this scenario, not the ways to reach a more desired scenario.

As indicated above, basic macroeconomic scenario adopted assumptions very similar to those of the National Energy Plan (PNE 2050) regarding the economic structure, however, considered growth rates somewhat smaller, which will be detailed later. This governmental sectoral plan is the longer term, covering the entire period of analysis, until the horizon of 2050. Even with the revision of growth rates down, this scenario is based on high rates of world economic growth and the Brazilian economy, presupposing the success of the public policies applied to overcome the economic crisis. It is, therefore, an appropriate benchmark for a comparative analysis of mitigation scenarios to identify the economic and social implications of the adoption of emission mitigation measures.

Unlike some studies previously mentioned, this scenario is not a baseline without any mitigation of GHG emissions ("business as usual"). It is a scenario that incorporates the policies and measures already decided and in place in the country. However, additional mitigation measures are not included in those already established in government policies, with only a continuation of their implementation planned until 2030.

2.1. Description of Premises of the Economic Scenario

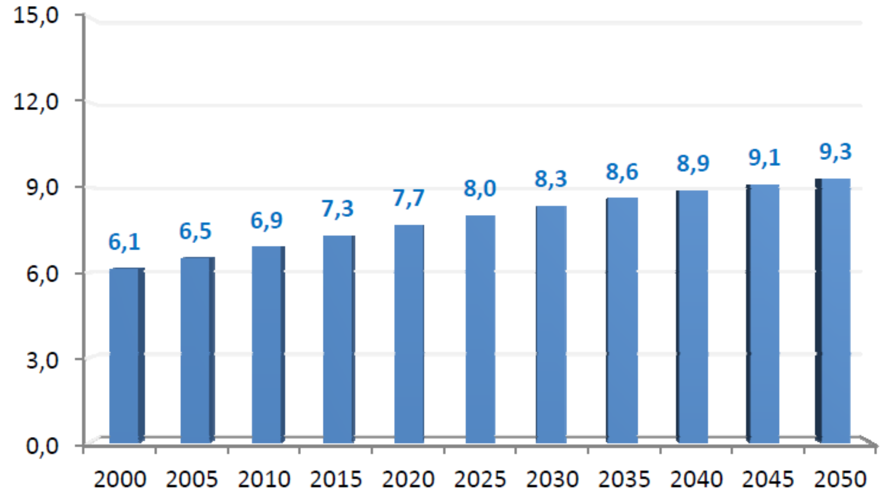
This section presents the set of assumptions used in the calibration of sectorial models and the IMACLIM-BR model. The IMACLIM-BR macroeconomic model was calibrated in order to reach the closest possible values of the numbers provided in this section. With the new equilibrium of the economy in 2030, found by the IMACLIM-BR model from the hypotheses described in this section, it can be said that this economic scenario is feasible and consistent from the macroeconomic point of view. This macroeconomic scenario was also used in La Rovere et al (2017).

Today, Brazil is facing one of the most serious recessions in history. GDP has fallen by approximately 7% in the last three years. In 2017, the Brazilian GDP increased by only 1%, even after this severe crisis, and by the end of March 2018, the unemployment rate had reached 13.1%, which represents about 13.7 million workers without occupation, according to IBGE data. It requires a major rearrangement of the economy to resume sustained economic growth, which is only projected in our scenario from 2020. With this new trend in mind, we have reduced the pre-crisis projections of high economic growth made by the government and used as a base in the development of the Brazilian NDC. In the Economic Scenario for the MRV Project, the new average annual growth rate assumed for the period 2018-2020 is now 2.5% per year, and for the period 2021-2030, of 3.2%. Considering the whole projection period (2018-2030), the average annual GDP growth was 3.0% per annum, lower than the 3.2% per year average observed between 1994, year of creation of the real plan, and 2014, last year with positive growth before this economic crisis. As a basis for comparing these growth assumptions, in 2030, Brazilian per capita GDP would reach the current level of higher middle-income countries in Latin America and Eastern Europe, such as Argentina, Hungary, and Poland, and by 2050 would reach current levels Portugal and the Czech Republic.

The macroeconomic scenario used in the IES-Brazil project modeling was based on official prospective studies undertaken by the Energy Research Company, in particular, the reports of the National Energy Plan 2050 (PNE 2050) and the Ten-Year Energy Plan 2026 (PDE 2026). The report "Economic Scenario 2050" (Technical Note DEA XX / 15) (EPE, 2015), released in September 2015, provides most of the variables incorporated in the model, complemented by the report "Demand for Energy 2050" (Technical Note DEA 13 / 15) (EPE, 2016).

2.2. World Population

The hypothesis is that the world population grows at an average rate of 0.8% per year, reaching 8.3 billion people in 2030 and 9.3 billion people in 2050. The most significant growth is in developing countries, especially in Africa and Asia.

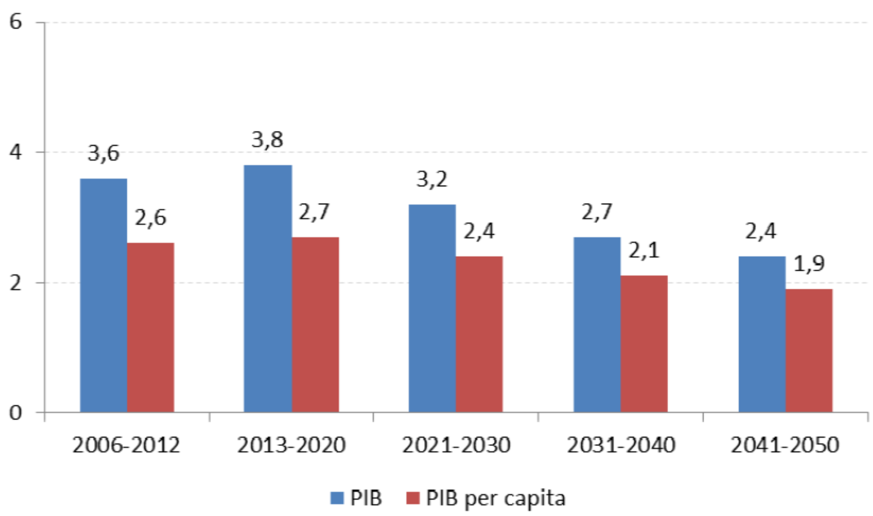


Source: EPE (2015)

Figure 1. World Population Projection (billion)

2.3. World Economic Activity

The level of world economic activity is accelerating in the period between 2013 and 2020, with an average of 3.8% per year, driven by the growth of emerging economies, while developed countries recover from the economic crisis that began in 2008/2009. After 2020, economic growth slows as growth rates in China and other emerging countries cool down. During the period 2021-2030, world GDP is estimated to grow to 3.2% per year.



Source: EPE (2015)

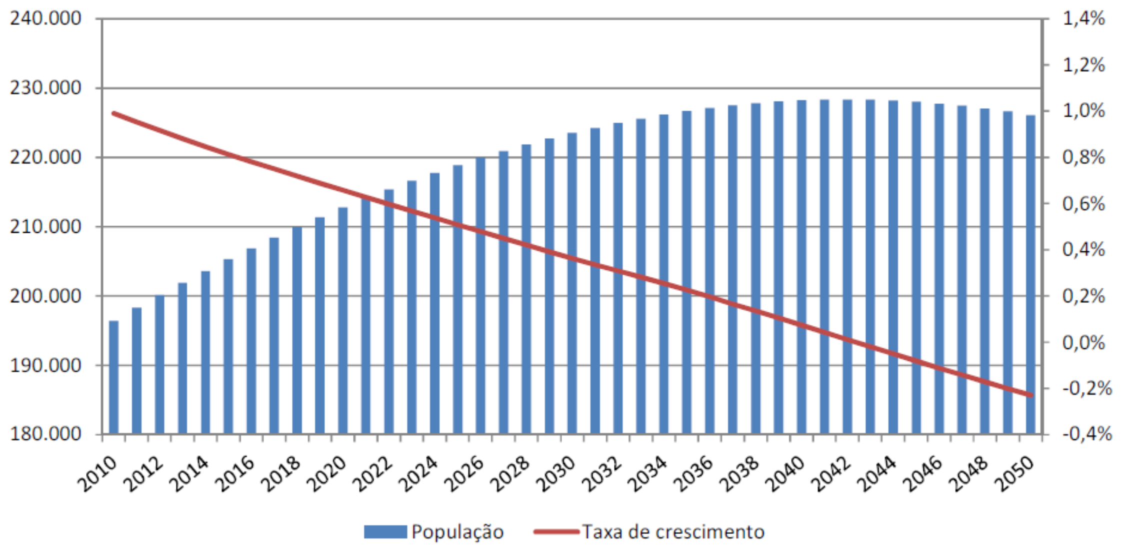
Figure 2. Average world economic growth per year (%)

2.4. International Price of Oil

The international oil price hypothesis is backed by the International Energy Agency's World Energy Outlook low price scenario, which estimates the price of a barrel of oil below US$ 80 per barrel by 2030 and is in line with recent projections of EPE. Throughout the period 2016-2030, the price of a barrel of oil (Brent) is around 80 US$ / barrel. Among the determinants for the indicated level are: i) recovery of world economic growth; ii) maturation of oil and gas E&P projects (particularly with non-conventional resources); iii) peak production of US shale / tight oil, estimated around 2020; (iv) increasing the competitiveness of other substitute sources (including renewable sources and non-conventional natural gas, especially shale / tight gas); (v) reducing the share of the role of oil as a speculative financial asset; and (vi) gradually increasing energy efficiency and replacing it with other sources.

2.5. Brazilian Population

It is estimated an intensification of the trend of deceleration of the Brazilian population growth rate, a function of lower fertility rates, which has already been observed in the last decades. In 2030, the population reaches a level of 223 million people (IBGE, 2014).



Source: EPE (2015), from IBGE (2014)

Figure 3. Brazilian population (million)

2.6. Evolution of Labor Productivity

The Reference Scenario has as one of its premises that Brazil will continue to reduce the inequality between the different income classes by increasing investments in education in order to increase worker productivity and, consequently, Brazilian competitiveness – increased income and increased investment in education contribute to a more skilled and therefore more productive workforce. The hypothesis used in IMACLIM-R BR for the evolution of the average productivity of the worker by sector is consistent with the growth of the sectoral production presented in PNE 2050, corrected, however, for lower growth rates, as already explained.

2.7. Brazilian GDP Growth Rates

The domestic macroeconomic scenario is characterized by the reduction of the "Brazil Cost" from the improvement of the infrastructure, contributing to the reduction of transport costs and increase the competitiveness of the productive sectors. There are also expected improvements in education, with greater investments in this area, part of which comes from oil exploration revenues in the Pre-Salt layer, as well as a pension reform, in order to stabilize spending in relation to GDP in the standards. These policies contribute to the greater overall productivity of the Brazilian economy.

In terms of economic policy, the country is expected to maintain the so-called macroeconomic tripod, based on floating exchange rates, inflation targets and primary surplus.

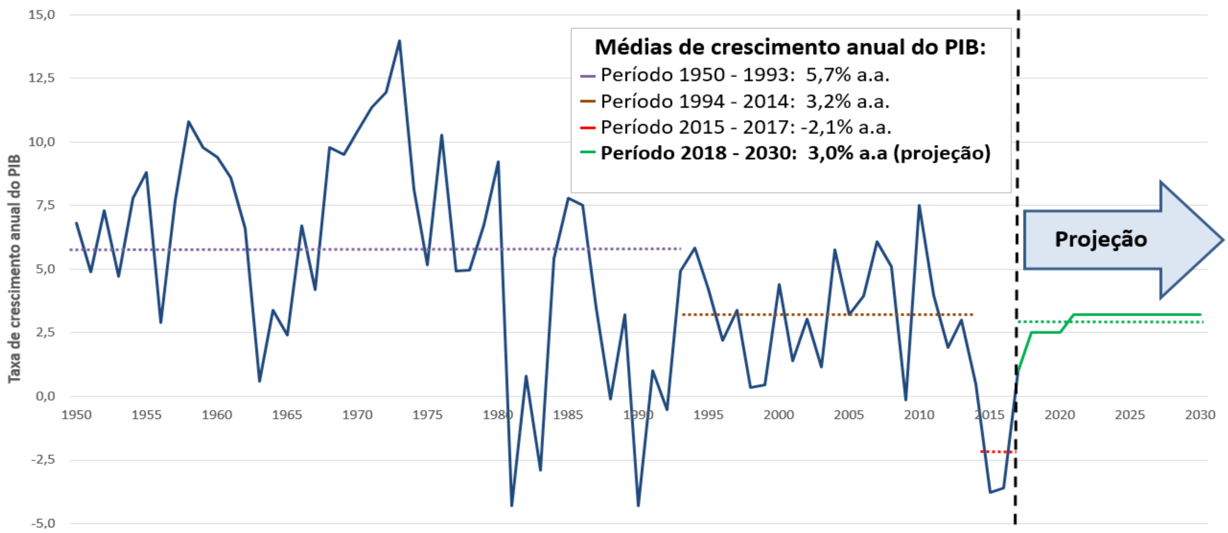
In this way, it is estimated that Brazil will grow at rates lower than the world average until 2020 when it would leave the current crisis. Between 2021 and 2030, reaping the fruits of the reforms initiated at the end of the previous decade, Brazil would grow in the average of the rest of the world: 3.2% per year. The table below shows the growth rates for each period.

Table 1. Real GDP Growth (% per year) – Historic data and projection

Period	GDP growth per year
1950 – 1993	5,7%
1994 – 2014	3,2%
2015	-3,8%
2016	-3,6%
2017	1,0%
2018-2020*	2,5%
2021-2030*	3,2%

Source: based on IPEADATA (2018) e BACEN (2018).
* Projection

Figure 4 shows the real GDP growth rate between 1950 and 2017 and the growth projection between 2018 and 2030.



Source: based on IPEADATA (2018) e BACEN (2018).

Figure 4. Real GDP Growth (% per year) – Historic data and projection

Figure 5, below, shows the evolution of indicators such as GDP, GDP per capita and the Brazilian population between 2005 and 2030, using the base 2005 = 1.

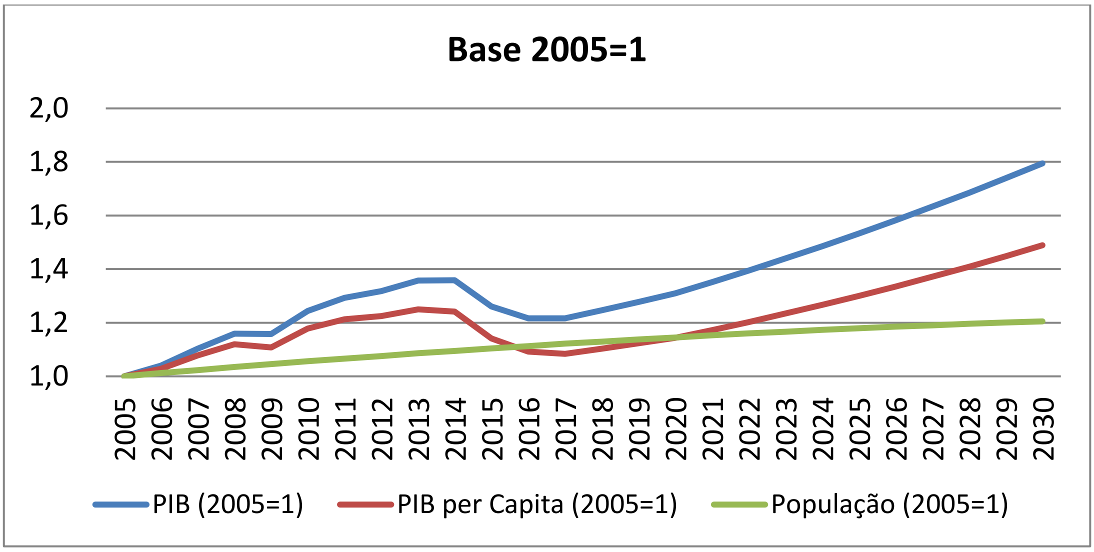


Figure 5. Evolution of selected indicators (Base 2005 = 1)

Due to the great recession of the last few years, Brazilian GDP would only return to 2014 (peak) levels in 2022. GDP per capita would be even more affected by the increase in population and would only return to the level of 2013 (peak) in 2024.

The level of income inequality, which fell between 2000 and 2010, rose again between 2015 and 2020, because of the very deep economic crisis, although it did not reach the levels observed at the beginning of the 2000s. As of 2021, with a stronger economic growth and the progressive improvement of the educational level of the population, and the tendency to formalize the work, inequality in the country would slowly reducing until the end of the studied horizon, arriving in 2050 at a Gini coefficient of 0.45, the level observed in 2005 in some less wealthy European countries such as Portugal.

PNE 2050 does not provide projections about the level of the economy's exchange rate. A nominal parity of 3.15 R$ / US$ constant during the analyzed period (both currencies in 2015 values) was considered in this study.

2.8. Sectorial Premisses

The composition of the economy with a more intense resumption of the industry compared to what was projected in PNE 2050: more in line with PDE 2026 (in fact loses participation in a slower way).

The solution of bottlenecks, the reduction of social inequalities and the increase in total factor productivity (labor, capital, land), as well as higher per capita income, contribute to change the profile of the sectors' participation in the economy.

There is continuity of the loss of participation of the basic industry in the economy, but in a slower way than the one described in the PDE 2050, being this premise more in line with what is presented by PDE 2026. Considering the high comparative advantage of the Brazilian agricultural industry against the rest of the world and the maintenance of the increase in the price of agricultural commodities, this sector increases its share in the Brazilian economy in the analyzed period. In addition to the agricultural sector, the Oil, Natural Gas, Electricity, Biomass for Energy, Pulp and Paper and Mining sectors also grow more than the rest of the economy because they have natural comparative advantages over the rest of the world.

Agriculture

A growth rate of the agricultural sector is projected above the GDP growth rate. The determinants on the demand side are population growth, both Brazilian and worldwide, and income. In addition, it is expected to expand the use of biofuels, which use agricultural goods such as sugarcane, soybeans, and palm as the raw material in the Brazilian case. It is considered that the sector has the capacity to meet the growing demand, given the favorable conditions regarding climate, availability of land and technology. It is noteworthy that significant productivity increases are projected for the main agricultural and animal husbandry activities.

Industry

Some assumptions referring to the industrial sector should be highlighted, especially in the energy and emission-intensive industries.

Cement

The cement industry is characterized by low international competition, since this product presents a relation between value-added and low specific gravity, making its transportation uninteresting. In general, cement production accompanies the expansion of the civil construction and infrastructure sectors.

Iron and Steel

Like the cement industry, the steel industry generally follows the expansion of the construction and infrastructure sectors, although it is also driven by the development of the automotive and capital goods industries. However, the steel industry is more exposed to international competition than cement, although it is reasonably competitive on the world stage. Average growth is projected below that expected for the rest of the economy.

Non-Ferrous Metals

Among the non-ferrous metals, aluminum stands out, a highly energy-intensive industry. Its development accompanies the expansion of sectors such as construction, transport, and packaging. For the specific case of primary aluminum, average growth is projected below the rest of the economy in the analyzed period, considering that this element has some substitutes such as copper, magnesium, and titanium.

Pulp and Paper

The pulp and paper sector in Brazil has a good comparative advantage compared to the rest of the world. However, its performance depends on the global economy, since more than half of the Brazilian production is exported. A higher pulp production growth is projected than paper production, although the per capita consumption of paper will increase considerably over the period. In this way, there are higher levels of pulp exports in the analyzed horizon.

Overall, the average growth of the paper and pulp sector is estimated above the rest of the economy over the time horizon of the study.

Chemical industry

The Brazilian chemical industry is characterized by its heterogeneity and high external dependence. In PNE 2050, three specific branches are analyzed: petrochemicals, fertilizers, and soda-chlorine. The fertilizer sector is responsible for an expressive increase in chemical production in the country, related to the expansion of the agricultural sector, although a significant expansion of the other sectors is expected. For the petrochemical sector, the prospect is of growth driven by its possibilities of application in the civil construction, automotive, textile and packaging sectors. On the other hand, the soda-chlorine branch is relevant due to the high cost that electric energy represents in its production process. These products are fundamental to produce chemists and pharmacists of high commercial relevance, as well as in civil construction and in the paper and cellulose sector.

The average growth projected for the chemical sector is below the rest of the economy in the period studied.

Automotive industry

Real per capita income growth and higher urbanization rates contribute to increasing demand for freight and passenger transportation services, with emphasis on individual light vehicles, leveraging the country's automotive industry. It is also important to mention the importance of this sector in the economy, since it employs a considerable portion of the available labor force, directly or indirectly.

With the growth of the fleet of light vehicles, there is an increase in the rate of motorization, which is close to the standards observed in some OECD countries.

Services

In general, the Services sector tends to increase its participation in the economy. In the case of Brazil, the sector already represents a significant portion of GDP, but it has low labor qualification and low productivity.

Advances in the transport sectors and the maturation of investments in infrastructure and logistics, as well as the expansion of the tourism sector, contribute to the dynamism of the services sector as a whole, however, in this scenario, this sector grows less than some sectors with clear comparative advantages with the rest of the world, as explained above.

Figure 6, below, shows the evolution of the participation of large sectors in the Brazilian economy.

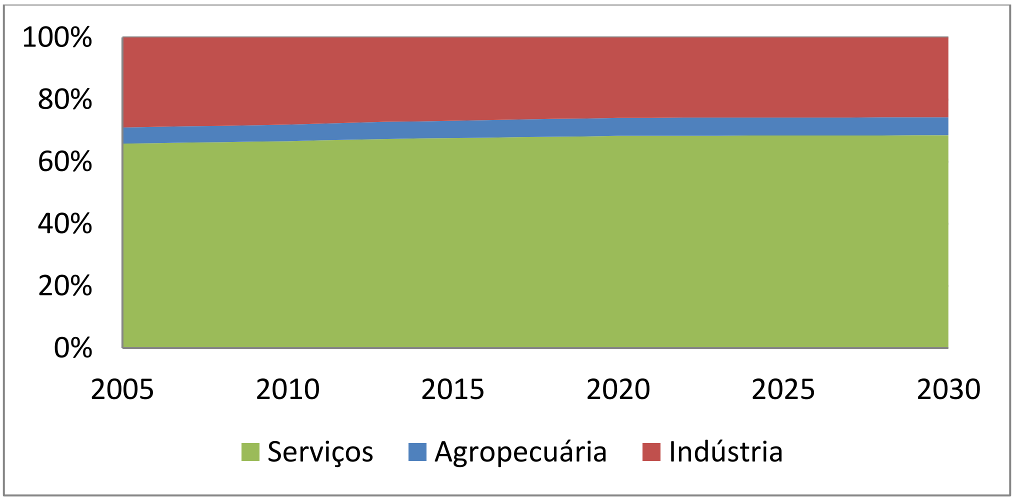


Figure 6. Participation of sectors in the Brazilian economy (%)

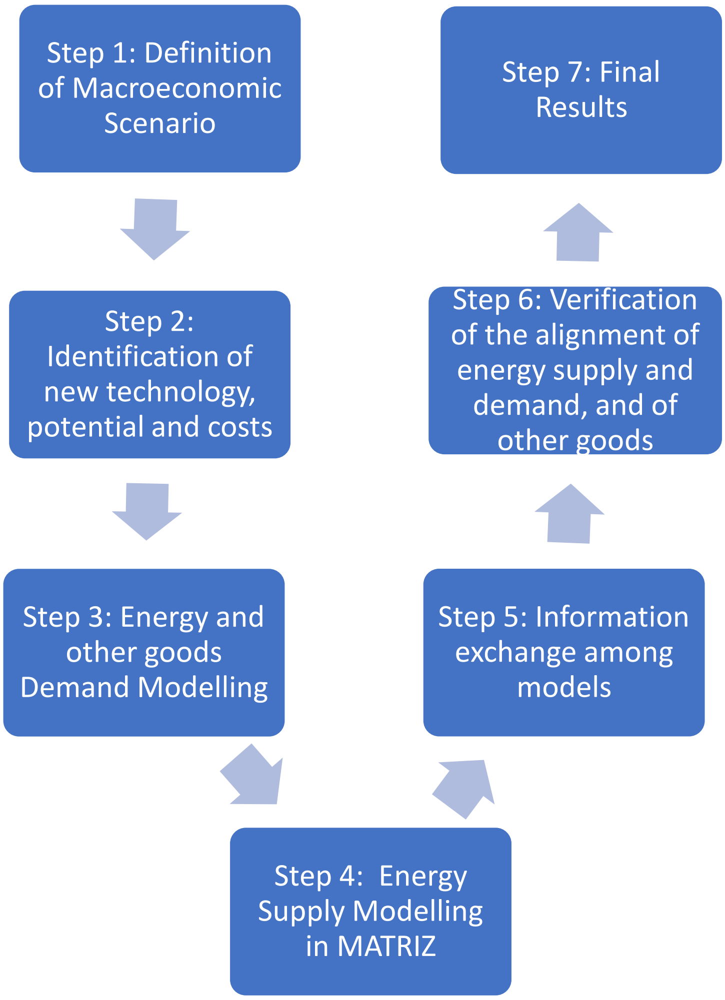
Further details on the assumptions and calibration of this economic scenario can be found in Wills & Lefevre (2016).

2.9. Sum-up of the Economic Premises

- Demography:
- Projection of the Brazilian population aligned with IBGE
- Peak in the early 2040s and then falls slowly
- Total working age population peaks in the mid-2030s
- Participation of the working age population begins to fall already in the 2020s
- Oil Prices:
- Aligned with the International Energy Agency's low-price scenario
- Price of a barrel of oil: constant at 80US$ / barrel from 2018
- It makes the pre-salt production possible, but conservatively accounts for its revenues
- Macroeconomics:
- Revenues originated from pre-salt exports used to import capital goods
- Increased productivity of the Brazilian economy
- Balanced trade balance (balance close to zero)
- Constant exchange rate at 3.15 R $ / US $ (2015)
- GDP growth rate:
    - ✓ 2018-2020: 2.5% per year
    - ✓ 2020-2030: 3.2% per year

3. INTEGRATED MODELLING METHODOLOGY

The following figure presents the flowchart of information between the models and the iterations that were necessary to achieve an adequate alignment of the models.



- Step 1 – The first step was to define the macroeconomic scenario, which was based on PNE 2050 and PDE 2026 but had its growth rates reduced.
- Step 2 – The second step consisted of the work of the technical team in order to progress in the detailing and identification of new technologies that should enter by 2030 in each scenario.
- Step 3 – In the third step, the new technologies were inserted in the sectoral models so that the energy demands by sector could be calculated, which were consolidated in the LEAP model.
- Step 4 – The fourth step was to simulate the MATRIZ energy supply model, in order to meet the energy demand each year provided by the LEAP model.
- Step 5 – In the fifth step, the results of the Energy Supply model (MATRIZ) were informed of the sectorial models, which were then adjusted for that energy supply scenario.
- Step 6 – In the sixth step, the activity levels of the sectors were verified, especially with respect to the intersection between the AFOLU and Energy (Biomass, ethanol, firewood, etc.) and Waste (Biogas) sectors, ensuring alignment in physical volumes between the various sectoral demand models and the MATRIZ model, for energy and other goods.
- Step 7 – The seventh step was to consolidate production levels, fuel consumption, and greenhouse gas emissions to reach the final results of the project.

Figure 7. Information flowchart in the integration between the sectorial models and the energy supply optimization model (Matrix)

Figure 8 below schematically describes the integrated modeling used in this study, which had important information exchange and great interaction between the sectoral demand models and the energy supply optimization model (MATRIZ).

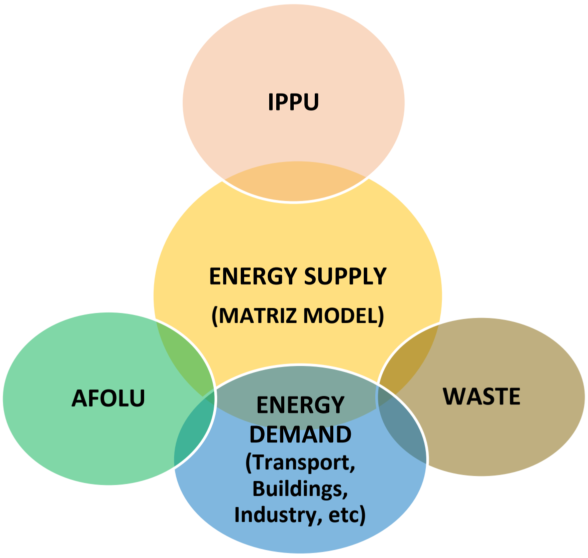


Figure 8. Methodological Approach: Integrated Modeling Diagram

Figure 8 presents the integration of the models, with special emphasis on the models that calculate the demand and supply of energy (MATRIZ), which is the model that effectively integrates all the other models in this project.

All sources of GHG emissions are counted, such as Land Use, Land Use Change, and Forests (LULUCF); Agriculture and Livestock; Energy Production and Use (disaggregated by sectors: industry, transport, energy sector, residential, services, agriculture); Industrial Processes and Waste.

The integrated modeling tool proposed in this study was adequate to answer the questions raised by the FBMC and to represent the behavior of each productive sector in the 2030 horizon. The integrated architecture presented here was a simplification of that proposal in Wills (2013), without the use of a general equilibrium model to verify the implications of each investment scenario on the economy (feedback on the economy). This simplified approach was chosen due to the limited resources of the project and due to the scarce time for the simulations. The details of each sectoral model will be made in the respective sector reports.

4. SECTORIAL ESTIMATES

4.1. Agriculture, Forestry and Land Use (AFOLU)

4.1.1. Emission Sources and Removal Sinks

4.1.1.1 Land-use Change and Forestry

Carbon stock changes in the Land Use Change and Forestry sector are associated with biomass gains and losses due to deforestation and other land use changes (CO_2 emissions and removals). GHG is also emitted with forest residue burning (N_2O e CH_4 emissions) and use of liming in agriculture (CO_2 emissions). Carbon is removed by planted forests (Eucalyptus and Pinus species), restoration of native forests, restoration of degraded pastureland, forest-livestock integration systems; protected areas (conservation units and indigenous lands), and conservation of secondary forest.

A description of the emission sources and removal sinks and the analysis of their historical evolution and recent trends are below:

Emission Sources

a) Deforestation and other land use

Land use change is the main source of GHG emissions in Brazil. Emissions of CO_2 occur when the land cover is changed to a type of land use with lower carbon stock per hectare (IPCC, 2003). For example, conversion of forest to pasture or agriculture emits GHG due to loss of carbon stocks from the forest withdrawal and its burning. On the other hand, vegetation growth removes carbon from the atmosphere.

Conversion of forests to pasture and agricultural land in the Brazilian Amazon has reached extremely high levels during the past two decades (an average of 18,165 km^2 from 1990 to 2000 and 19,289 km2 from 2001 to 2010), releasing an average of 1.3 Gt CO_2 per year, according to the Greenhouse Gas Emission Estimate System (SEEG, 2015).

Between 2005 and 2012, the country's GHG emissions were reduced by 54% (MCTI, 2016), mostly by cutting deforestation by 78%. However, the country's recent record on land-use policies and practices has not been bright (Rochedo et al, 2018).

Analysis of the historical data shows that the pre- 2005 period was subject to a very poor level of environmental governance that lead to high rates of deforestation. From 2005 to 2012 there were improvements in the governance mechanisms and effective results in reducing deforestation, mainly in the Amazon biome. In the 2013–2017 period, there was a reversal in the downward trend in the Amazon deforestation levels with high deforestation rates taking place also in the Cerrado biome (Rochedo et al, 2018).

The major driver for that was the revision of the Forest Code that took place in 2012, that granted amnesty to past illegal loggers. Other drivers were the lower environmental licensing requirements, the suspension of the ratification of indigenous lands and the reduction the size of protected areas in the Amazon are factors that contributed to weakening the environmental governance and increase emissions.

This study is based on the data provided by PRODES (INPE/PRODES, 2018) regarding the annual deforestation area in the Amazon biome between 2005-2017. For the other biomes, we used the annual data from the project Deforestation Monitor of the Brazilian Biomes by Satellite (IBAMA, 2013). The GHG emissions data from deforestation published by SEEG (2018) was also analyzed.

b) Burning of forest residues

Besides CO_2 emissions, forest biomass burning for firewood production and timber extraction also emit N_2O and CH_4. We used the SEEG data for the period 2005-2017 in our estimates.

c) Emissions from soil liming

CO_2 emissions are also associated with the amount of limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) consumed to correct soil acidity and improve soil fertility. The data supporting our estimates are those published by the III National Inventory (BRASIL, 2016) and the Annual Estimates of Greenhouse Gas Emissions in Brazil (MCTI, 2018) for the period 2005-2015.

Removal Sinks

a) Protected areas (Conservation Units and Indigenous Lands)

The annual increment of carbon stocks in protected areas such as Conservation Units and Indigenous Lands is accounted for in the total carbon removals since they are a category of managed forest areas in the IPCC (2006). The private natural heritage reserves are not included.

Data and information on the Conservation Units and Indigenous Land for the period 2010 -2017 were compiled from the National Indian Foundation (www.funai.com.br) and the Ministry of the Environment (www.mma.gov.br/cadastro_uc).

b) Commercial planted forest (Eucalyptus and Pinus species)

The increase of commercial planted forest areas with Pinus and Eucalyptus species is a sink as forest plantation captures and stocks high amounts of carbon. Commercial planted forest areas published by ABRAF for the period 2005-2013 and IBA for 2014-2017 were used as our baselines to estimate further forest plantation areas and related carbon removals, as well as the Matriz model outputs and other sectorial demands for wood.

c) Restoration of native forests

The potential for native forest restoration in different biomes was also estimated as carbon sinks. Native species planted on degraded areas increase biomass stocks and therefore carbon stocks.

d) Restoration of degraded pasture

The restoration of degraded pasture removes and traps CO_2 to the soil while improving the quality of the grassland. Data published by the ABC Plan Observatory (2016) show an increase of 3.9 million hectares of restored pasture in the period 2010-2015 and was used as our baseline to estimate further increases in the restored area.

e) Forest-livestock integration systems

The forest biomass and soil of the areas under forest-livestock integration systems are carbon sinks. Data published by Embrapa (www.embrapa.br/web/rede-ilpf) show an increase of 9.0 Mha in the area under integration systems in the period 2005-2015. The total area under integration systems in 2015 reached 11,5 Mha, with 17% hosting the tree component of the system. It is worth mentioning that there are distinct types of integration systems: Crop-Livestock-Forest System; Crop-Forest System and Livestock-Forest Systems.

f) Conservation of secondary forest.

The annual increment of carbon in secondary forest areas is also a sink. Data published by SEEG (2018) show an increase in these areas in the 2005-2010 period and stabilized between 2010-2016.

4.1.1.2 Agriculture

a) Agricultural Soils

Land management (cropland, grassland and forest) modifies soil carbon (C) stocks to varying degrees depending on how specific practices influence C input and output from the soil system (IPCC, 2006). Emissions from agricultural soils (N_2O) are a result of the application of synthetic and organic fertilizers in agricultural and pasture areas; of nitrogen from crop residues; and deposition of animal waste on pasture areas.

Data published by MCTIC (2018) shows increasing emissions from agricultural soils in the period 2005-2015, mainly due to an expansion of the agricultural area and livestock.

b) Rice Cultivation

Anaerobic decomposition of organic material in flooded rice fields produces methane (CH_4), which escapes to the atmosphere primarily by transport through the rice plants. The annual amount of CH_4 emitted from a given area of rice is a function of the number and duration of crops grown, water regimes before and during cultivation period, soil type, temperature, and rice cultivar (IPCC,2006).

In our estimates, the amount of CH_4 emission from rice cultivation depends on the planted area. Data published by MCTI (2018) shows small changes in emissions from rice cultivation from 2005 to 2016.

c) Burning of Agriculture Residues

The burning of agricultural residues, particularly from sugarcane, emits CH_4 and N_2O. The amount of biomass burned depends on the area harvested and the environmental legislation that prohibits this practice in some Brazilian states. Data published by MCTIC (2018) shows increasing emissions until 2010 and a reduction in the subsequent period (2011-2016).

d) Enteric Fermentation and Manure Management

Livestock production can result in CH_4 emissions from enteric fermentation and both CH_4 and N_2O emissions from livestock manure management systems.

Cattle are an important source of CH_4 because of their large population and due to their ruminant digestive system. Methane emissions from manure management tend to be smaller than enteric emissions, with the most substantial emissions associated with confined animal management operations where manure is handled in liquid-based systems. Nitrous oxide emissions from manure management vary significantly between the types of the management system used and can also result in indirect emissions due to other forms of nitrogen loss from the system (IPCC, 2006).

The amount of CH_4 and N_2O emission from Enteric Fermentation and Manure Management depends on the annual populations (number of cattle, swine and other categories), subcategories, and, for higher Tier methods, feed intake and characterization.

Data from ABIEC (2016) and IBGE (2016) about livestock categories and annual population were compiled for the period 2005-2015. Data from MCTI (2017) shows an increasing trend in emissions provided by enteric fermentation and manure management with small annual oscillations, between 2005-2015.

4.1.2. Scenario A – Assumptions

4.1.2.1 Land Use Change and Forestry

Land Use Change and Forestry in Scenario A is based upon current GHG emissions trends observed during the 2005-2016 period. The estimates take into account the sectorial mitigation measures defined in the governmental commitments (NAMA and NDC) and governmental policies for the agriculture sector – Low-Carbon Agriculture – ABC Plan (Brazil, 2010). The assumptions for each mitigation measure are presented below and the respective penetration rate is in Table 2.

Mitigation measures

a) Reduction of deforestation

The Brazilian Government has a strong commitment to the UNFCC to reduce GHG emissions, specifically from deforestation.

Brazil's Nationally Appropriate Mitigation Actions – NAMAs (COP 15 – Copenhagen) relied mostly on the land use change sector, the largest emission source in the country establishing deforestation reduction targets of 80% in the Amazon biome by 2020 (in relation to the average rate in the period 1996–2005), and by 40% in the Cerrado (in comparison with the average deforestation rate in the period 1999–2008) (Brazil, 2010). Brazil's Nationally Determined Contribution (NDC) offered at COP21 (Paris), is also noteworthy in focusing on emissions from deforestation control and other land use change. Brazil has committed to eliminate illegal deforestation in the Amazon by 2030 (Brazil, 2015).

The annual emissions from deforestation during the period 2017-2030 in *Scenario A* was assumed to be the same as the average annual emissions from deforestation on the period 2012–2016[2], for all biomes, with values obtained from the data published by SEEG (2018). This baseline period was chosen due to the fact that in 2012 there was a reversal in the declining deforestation trend in the Brazilian Amazon, and deforestation has leveled out at high rates in the Cerrado biome. Therefore, the average annual GHG emissions from deforestation and other land use change from 2017 to 2030 would be 895,5 Mt CO_2-eq if the current deforestation trajectory is maintained until 2030.

b) Increase of protected areas (increased accounting of carbon sinks)

Conservation units and indigenous lands that were already protected in 2010 and 2017 as published by National Indian Foundation (www.funai.com.br) and the Ministry of the Environment (www.mma.gov.br/cadastro_uc), respectively, were assumed to be constant over time since in Scenario A there would be no extra efforts in the current policies. Therefore, 2017 value of 269 Mha under the category of protected areas would remain the same until 2030.

c) Increased Restoration of native forests

The area of native forest to be restored until 2030 covering all biomes (Amazon, Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampa) would be 1.4 Mha. This target would contribute to the recovery of forest liabilities according to the new Forest Code, estimated by Soares Filho (2013).

d) Carbon sinks in the natural regrowth of deforested areas

Data published by SEEG (2018) about removals from secondary forest show an increase in removals between 2005-2010 and stabilization between 2010-2016. In Scenario A, the removals provided by secondary forest were assumed to be proportional to the emissions from deforestation and other land use changes.

2 Deforestation in the Amazon reached 27 thousand km² in 2004 and fell to 4,5 thousand km² in 2012. It then rose again to almost 8 thousand km² in 2016, with a possible new inflection point in 2017, when it dropped to 6.7 thousand km²

e) Increase in commercial planted forest

Forest planted areas (Eucalyptus and Pinus) supply raw material for the energy and the pulp and paper industries, as well as for wood industrialization (sawn wood, plywood, panels) and are carbon sinks. The estimates of these areas consider the historical data (area in the period 2005-2016), future demands and the branches growth rates.

Therefore, the requirement for planted areas would be 7,3 Mha, (0,8 Mha additional to 2010) in 2030. It should be noted that the energy segment absorbs a percentage of wood from native forests if planted forests are not available. We assume that there would be a gradual increase in wood supply from planted forests and that no wood would come from native forests by 2030.

f) Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+lCLF)

The area under integration systems (Livestock-Forest, Crop-Forest and Crop-Livestock-Forest) is estimated considering the historical data (from 2005 to 2015), published by Embrapa (www.embrapa.br/web/rede-ilpf). The total area under all types of agroforestry systems corresponds to 11.5 Mha in 2015, but only 17% has trees as one of the components. The estimated area under forest system would be 3.8 Mha by 2030 and was computed considering the annual increment of the area in the period 2005-2010 (0.73 Mha/year) which shows lower performance than the period 2010-2015 (1.19 Mha/year).

g) Increased Restoration of pastureland

The restoration of degraded pastureland is estimated considering the data of pastureland restored in Brazil from 2010 to 2015 (Observatório ABC, 2017). According to this study, 3.9 Mha were restored between 2010 and 2015, which represents an annual increment of 0.78 ha/year. However, in *Scenario A* the future annual increment would be of only 0.6 Mha/year, amounting to 12.9 Mha of restored pasture in 2030.

4.1.2.2 Agriculture

a) Increase of zero-tillage practices (crops)

The agricultural area under zero-tillage system is estimated in Scenario A considering the production area with grains in the period 2005-2015 (IBGE, 2016), the GDP annual growth rate adopted in this study, historical data about areas under zero-tillage from 2005 to 2012, published by FEBRAPDP (2012), and the target established in the ABC Plan (Brazil, 2010) for 2020 (an increase of 8 million ha in relation to 2010).

The assumption is that 39 Mha would be under zero-tillage techniques in 2020. Between 2020-2030 the assumption is zero-tillage in 100% of the expanded soybean area, totaling 45 Mha by 2030.

b) Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)

The agricultural area under Biological Nitrogen Fixation is estimated in *Scenario A* considering the production area of grains in the period 2005-2015 (IBGE, 2016), the GDP annual growth rate estimates adopted in this study, the historical data of soybean areas under BNF (2005-2015), and the target established in the ABC Plan (Brazil, 2010) by 2020 (an increase of 5.5 Mha in relation to 2010).

The assumption is that 33 Mha would be under BNF in 2020 (an increase of 9.3 Mha in relation to 2010). Between 2020 and 2030, the assumption is that 100% of the expanded soybean area would be under BNF, amounting to 38.5 Mha by 2030.

c) Increase of manure management (from cattle, swine and other animals)

The amount of animal waste treated until 2030 is estimated considering historical data of the annual populations (number of cattle, swine and other animal categories) and the GDP annual growth rate adopted in this study. The percentage of waste treated in *Scenario A* would be the same as in 2015 by 2030.

Table 2 summarizes the evolution of the penetration of the mitigation measures in *Scenario A* in terms of area (observed values for 2005-2015 and estimated values for 2016-2030).

Table 2. Mitigation measures and penetration estimates in Scenario A (million ha, m^3).

Mitigation measure	Area (Million ha)							
	2005	2010	2015	2016	2017	2020	2025	2030
Increase of protected areas (increased accounting of carbon sinks)		191.6	247.0	258.1	269.2	269.2	269.2	269.2
Increased Restoration of native forests				0.2	0.5	0.5	0.9	1.4

Mitigation measure	Area (Million ha)							
	2005	2010	2015	2016	2017	2020	2025	2030
Increase in commercial planted forests	5.3	6.5	6.8	7.2	6.4	6.3	6.7	7.4
Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)	0.3	0.9	2.0	2.1	2.2	2.6	3.2	3.8
Increase of zero-tillage practices (crops)	25.5	30.8	34.1	34.1	36.1	39.3	42.9	45.1
Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)		23.3	32.2	32.3	32.4	32.7	36.3	38.4
Increased Restoration of pastureland			3.9	4.9	6.0	6.9	9.9	12.0
Increase of manure management (from cattle swine and other animals) (m^3)		7.4	9.4	9.8	10.3	9.4	9.4	9.4

4.1.3. Scenario A – Results

AFOLU estimates in *Scenario A* are presented for:

- Crop, forestry and livestock production;
- Crop, forestry and grassland area;
- CO_2-eq emissions and removals from the mitigation measures analyzed.

The agricultural production with crops, commercial planted forests and pasture, livestock production and the agricultural land area between 2005 and 2030 are presented in Table 3, Table 4 and Table 5 respectively. The simulation shows that crop production is growing in the period 2015-2030, except for maize that presents a negative growth rate in the period 2015-2020. Soybean is the crop with the highest output growth rate (Table 3). It is possible to see that even with the increase in crop production, planted areas with these crops do not increase in the same proportion (Table 5).

Table 3. Agricultural production in Scenario A (Mt , m^3)

Production	2005	2010	2015	2016	2017	2020	2025	2030
Crops (Mt)								
Sugarcane	385	620	571	594	594	605	638	730
Maize	35	55	85	78	80	83	93	110
Soybean	51	69	97	96	97	108	123	137

Production	2005	2010	2015	2016	2017	2020	2025	2030
Other grains	28	26	29	29	29	30	31	34
Planted Forest (Million m^3)								
Wood production (homogeneous forest)	197	229	235	265	256	222	235	256
Wood production (integrated systems)	5	13	28	31	33	37	46	55
Total wood production	202	242	263	295	289	259	281	311

*Values beyond 2015 estimated.

Table 4. Livestock production in Scenario A (millions of heads)

Livestock (million of heads)	2005	2010	2015	2016	2017	2020	2025	2030
Cattle	228	210	215	208	209	210	213	218
Swine	34	39	40	42	42	43	46	50

*Values beyond 2015 estimated.

Concerning livestock, the variation in the number of cattle heads is small in the period 2015-2030. The pasture area is smaller by 2030 due to an increase in the stocking rate provided by the recovery of degraded pasture area (1.3 cattle head/hectare in unrestored pastures and 1.85 cattle head/hectare in restored pasture). There is a reduction in the total area devoted to agriculture activities due to productivity gains until 2030.

Table 5. Agricultural land area in Scenario A (million hectares)

Agricultural Area (million ha)	2005	2010	2015	2016	2017	2020	2025	2030
Crops								
Crops (sugarcane, maize, soybean, other grains)	51.10	51.20	58.10	52.30	52.60	54.89	58.23	60.09
Forest Plantation								
Homogeneous Forest	5.29	6.51	6.85	6.65	6.37	6.33	6.74	7.35
Integrated Forest	0.32	0.56	1.17	1.24	1.31	1.54	1.91	2.28
Total Area	5.61	7.07	8.02	7.89	7.68	7.88	8.65	9.63
Grassland								
Pasture	182.79	182.21	171.96	165.93	165.69	164.77	163.78	163.73
Total Area	239.46	240.45	238.05	226.12	225.84	227.53	230.66	233.45

According to the data from the Third National Inventory of GHG Emissions (BRAZIL, 2016), in 2005 the AFOLU sector emitted 2381 Mt CO_2-eq. Emissions from agriculture amounted to 460 Mt CO_2-eq and Land Use Change and Forestry to 1922 Mt CO_2-eq. Emissions and removals of CO_2-eq from the AFOLU sector in the period 2005-2030 are presented in Table 6.

Table 6. Gross emissions, removals and net emissions from AFOLU in Scenario A (Mt CO_2-eq)

AFOLU	2005	2010	2015	2020	2025	2030
Land Use Change and Forestry						
Gross Emission	**2171**	**668**	**913**	**925**	**927**	**928**
Deforestation and other land use change	0	0	883	896	896	896
Liming and forest residues	0	0	30	30	31	32
Removals	**-249**	**-313**	**-500**	**-518**	**-538**	**-553**
Commercial planted forest	0	0	-12	0	-14	-22
Restoration of native forest	0	0	0	-6	-15	-23
Restoration of pastureland	0	0	-14	-25	-22	-22
Integrated systems (ILF+ICF+ICLF)	0	0	-25	-15	-15	-15
Protected areas (UC and IL)	0	0	-354	-382	-382	-382
Secondary forest	0	0	-95	-90	-90	-90
Total Net Emission	**1922**	**355**	**413**	**408**	**388**	**375**
Agriculture						
Enteric Fermentation	0	312	358	349	355	364
Manure Management	0	21	22	18	19	21
Agricultural soils	0	120	129	125	129	135
Rice Cultivation	0	13	14	10	8	7
Burning of agriculture residues	0	6	7	3	3	3
Zero tillage (Removal)	0	0	-6	-16	-16	-11
Total Emission	**460**	**473**	**522**	**491**	**498**	**519**
AFOLU – Net Emission	**2381**	**828**	**935**	**899**	**887**	**894**

AFOLU net GHG emissions in 2015 totaled 946 Mt CO_2-eq, of which 424 Mt CO_2-eq came from Land Use Change and Forestry and 522 Mt CO_2-eq from the agricultural sector. In the period 2005-2015, there was a 40% reduction in the total net emissions, attributed mainly to the decrease in deforestation rates.

In the 2015-2030 period, there would be a small reduction in the AFOLU net emissions (5%), amounting to 904 Mt CO_2-eq in 2030 (Table 6). Although there is an increase in carbon removal in the Land Use Change and Forestry sector in this period (from 313 to 546 Mt CO_2-eq), the maintenance of current deforestation rates in the period 2017-2030 and the increase in agriculture emissions lead to a low net emission reduction by 2030. Conversely, the main removal sinks are the protected areas (Conservation Units and Indigenous Lands), conservation of secondary forest and restoration of native forest.

GHG emissions increase by 13% in the agricultural sector in the period 2005-2015. Between 2015 and 2025 there would be a small emission reduction that would grow again until 2030. Enteric fermentation followed by agricultural soil are the main sources (Table 6).

The Brazilian Nationally Appropriate Mitigation Actions (NAMAs) (as in Decree 7.390 that regulates the PNMC – Brazil, 2010) established mitigation measures and targets to the AFOLU sector by 2020 as described below:

i) a reduction in the deforestation area in the Amazon biome by 2020 (80% in relation to the average rate over 1996–2005) and in the Cerrado biome (40% in comparison with the average deforestation rate over 1999–2008) (Brazil, 2010);

ii) the recovery of 15 million ha by 2010 of degraded lands);

iii) the implementation of 4 Mha of crop-livestock systems (Mha – with a range of 18-22 Mt CO_2-eq estimated reduction, in 2020);

iv) the establishment and the improvement of 8 Mha of no-till planting techniques (8 with an estimated mitigation range of 16-20 Mt CO_2-eq, in 2020);

v) the establishment and the improvement of 5.5 Mha of Biological Nitrogen Fixation cropping technique (with an estimated mitigation range of 16-20 Mt CO_2-eq, in 2020).

In the same context, Brazil's NDC (Brazil, 2015) includes mitigation measures and targets by 2025 and 2030, relative to the base year 2005. These measures are presented below:

i) In land use change and forestry:

- strengthening and enforcing the implementation of the Forest Code, at federal, state and municipal levels;
- strengthening policies and measures with a view to achieving, in the Brazilian Amazon, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030;
- restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes;
- increasing sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management, with a view to curbing illegal and unsustainable practices.

ii) In the agriculture sector, strengthen the Low Carbon Emission Agriculture Program (ABC) as the main strategy for sustainable agriculture development, including by restoring an additional 15 million hectares of degraded pasturelands by 2030 and enhancing 5 million hectares of integrated cropland-livestock-forestry systems by 2030.

In Scenario A, the 80% reduction in the deforestation rate in the Amazon biome would not be achieved, in 2020. According to the assumption adopted (average 2012-2016 during the period 2017-2030 – applying data from SEEG-2018), the deforestation area in the Amazon biome would be 591.5 thousand ha in 2020, 50% higher than the target established (392.5 thousand ha). The emission reduction in relation to the average rate in the period 1996–2005 amounts 1Mt CO_2-eq[3], in 2020. The goal of zero illegal deforestation by 2030, as proposed in the NDC, would not be accomplished in this Scenario too.

In the case of the Cerrado biome, the target would be achieved, in 2020. The deforestation area would be 838 thousand ha (average of the period 2012-2016) while the NAMA value is 942 thousand ha.

The restoration of degraded pastureland and implementation of forest–livestock integration systems wouldn`t meet the Plano ABC (NAMA) and NDC targets for 2020 and 2030 due to the current low levels of their implementation. On the other hand, zero-tillage and Biological Nitrogen Fixation targets would be met.

4.1.4. Scenario B – Assumptions

4.1.4.1 Land Use Change and Forestry

a) **Reduction of deforestation** In *Scenario B* the annual rate of deforestation until 2030 will be estimated based on the targets of the governmental policies for the Amazon and Cerrado biomes, established in both NAMA and NDC. As proposed by the Brazilian Climate Change Forum (FBMC), the illegal deforestation area in the Amazon would be curbed down to 95% by 2030.

b) **Increase of protected areas (increased accounting of carbon sinks)**

Protected areas (Conservation Units and Indigenous Lands) in 2020 would be similar to the area under this category that reached 269 Mha, in 2017. In the period 2020-2030, we

[3] This value was calculated considering the estimatives of CO_2 emissions from SEEG (average 2012-2016 for Amazon biome) and carbon stocks data from Third National Inventory of GHG Emissions (BRAZIL, 2016).

assumed an increase of 36 Mha, as suggested by the Brazilian Climate Change Forum (FBMC). This area is equivalent to 50% of the forest areas with no assignment of property rights according to the Brazilian Forest Service (http://www.florestal.gov.br). The protected area by 2030 would then be 305.1 Mha in Scenario B.

c) Increased Restoration of native forests

Native forest to be restored covering all biomes (Amazon, Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampa) would be 9.0 Mha until 2030. This value is an estimate of the compliance requirements of the liabilities resulting from the new Forest Code according to Soares Filho (2013) and was decided considering that the Brasil's NDC target (restoring and reforesting 12.0 million hectares of forests by 2030, for multiple purposes) would be partially achieved. It is also in accordance with the value suggested by the Brazilian Climate Change Forum (9.3 Mha).

d) Carbon sinks in the natural regrowth of deforested areas

In *Scenario B,* removals provided by secondary forests were assumed to be proportional to the emissions from deforestation and other land use changes.

e) Increase in commercial planted forest

In Scenario B, planted forest area would be in accordance with the ABC Program and the Brazilian NDC goals, as recommended by the Brazilian Climate Change Forum. Therefore, there would be an increase of 3.0 million hectares of commercial planted forest by 2030 relatively to 2010.

f) Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+lCLF)

The total area under integrated systems in 2015 corresponded to 11.5 Mha, where 17% with trees as a component in the system. The area under forest-livestock integration in Scenario B is 5.0 Mha by 2030. This value was computed considering the annual increment of the area in the period 2010-2015 (1.19 Mha/year).

g) Increased Restoration of pastureland

In Scenario B, carbon storage from the annual increment of 1.07 Mha/year will be simulated for the period 2016-2030, amounting 20.0 Mha of restored pasture in 2030.

4.1.4.2 Agriculture

a) Increase of zero-tillage practices (crops)

The assumption for the agricultural area under zero-tillage in 2020 will be 39.0 Mha, the same as in Scenario A. However, between 2020 and 2030 the assumption will be zero-tillage in 100% of the expanded soybean area and other grains area, amounting 47.9 Mha by 2030.

b) Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)

The assumption for the adoption of BNF until 2020 will be 33.0 Mha, (increase 9.3 Mha in relation to 2010) as in *Scenario A*. Between 2020 and 2030 the assumption is that BNF will be adopted in 100% of the expanded soybean area and in 10% of the expanded other grains area, amounting 42.5 Mha by 2030.

c) Increase of manure management (from cattle, swine and other animals)

The amount of waste treated in Scenario B by 2020 is according to the target established in the ABC Plan (Brazil, 2010), reaching 4.4 million cubic meters of treated manure. For the subsequent period, values reach 13.7 million m3 by 2030, as a result of the policies for waste biogas recovery and power generation.

d) Intensification in livestock productivity

The Intensification of livestock productivity will be simulated considering an exponential increase of 20% in herd productivity from 2020 on, the restoration of 20.0 Mha of pastureland, management of pasture areas, genetic improvement and reduction of the slaughter age from 37 to 27 months, according to information published by Strassburg (2014).

Table 7 summarizes the evolution of the penetration of the mitigation measures in *Scenario B* in terms of area (observed values for 2005-2015 and estimated values for 2016-2030).

Table 7. Mitigation measures and penetration estimates in Scenario B (million ha and m^3).

Mitigation measure	Area (Million ha)							
	2005	2010	2015	2016	2017	2020	2025	2030
Increase of protected areas (increased accounting of carbon sinks)		191.6	247.0	258.1	269.2	269.2	287.2	305.2
Increased Restoration of native forests				0.2	0.5	1.3	3.4	9.0
Increase in commercial planted forests	5.3	6.5	6.8	7.2	7.2	7.7	8.6	9.5
Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)	0.3	0.9	2.0	2.1	2.3	2.9	3.9	4.9
Increase of zero-tillage practices (crops)	25.5	30.8	34.1	34.1	36.1	39.2	45.2	47.9
Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)		23.3	32.2	32.3	32.4	32.7	39.2	42.4
Increased Restoration of pastureland			3.9	4.9	6.0	9.3	14.6	20.0
Increase of manure management (from cattle swine and other animals) (m^3)		7.4	9.4	9.8	10.3	11.8	12.8	13.5

4.1.5. Scenario B – Results

Agricultural production including crops, planted forest, pasture, cattle and swine herding, are shown in Table 8 and Table 9, and the corresponding areas are in Table 10. In 2030, there was a 10% increase in sugarcane production in Scenario B in relation to Scenario A. In this scenario, this is due to the higher demand for ethanol – mainly from the transportation sector (17% above Scenario A). Soybean production in Scenario B is 5% higher than in Scenario A, in large part, due to the increased demand for biodiesel (48% higher than in scenario A).

The production of wood from planted forests in 2030 is also higher than that for Scenario A, since Scenario B adopted the premises of adding 3 million ha of forests planted for economic purposes (in comparison to the year 2010) and of implementing 5 million hectares of integrated systems including forest, in line with the NAMA and NDC goals.

The cattle herd declined by about 15% in the period 2015-2030 and registers a 17% reduction in relation to Scenario A (218 million heads) in 2030. The reduction in the number of cattle in Scenario B is attributed to the productivity gain of the herd in 2020, when improvements in farming practices are taken into consideration, such as, for example, vaccination control, rotational grazing and reduction of the age of slaughter.

Table 8. Agricultural production in Scenario B (Mt , m^3)

Production	2005	2010	2015	2016	2017	2020	2025	2030
Crops (Mt)								
Sugarcane	385	620	571	594	594	605	657	799
Maize	35	55	85	78	80	83	93	110
Soybean	51	69	97	96	97	108	132	147
Other grains	28	26	29	29	29	30	31	34
Planted Forest (Million m3)								
Wood production (homogeneous forest)	197	229	235	265	256	259	282	334
Wood production (integrated systems)	5	13	28	31	33	43	57	72
Total wood production	202	242	263	295	289	302	340	406

*Values beyond 2015 estimated.

Table 9. Livestock production in Scenario B (millions of heads)

Livestock (Million of head)	2005	2010	2015	2016	2017	2020	2025	2030
Cattle	228	210	215	208	209	210	204	182
Swine	34	39	40	42	42	43	46	50

*Values beyond 2015 estimated.

As shown in Table 10, Scenario B entails a 12% reduction in the total area used for agriculture in the period 2015-2030. Although the agricultural and planted forests areas grow, there is a 23% drop in the pasture area, resulting from the recovery of 20 Mha of degraded pastures over the same period. The restoration of those areas provides better quality fodder and, consequently, the increase of the stocking rate (cattle heads/ha). There is a reduction of 11% of the total agricultural area in 2030, as compared to Scenario A, which is of 233 Mha (Table 5).

Table 10. Agricultural land area in Scenario B (million ha)

Agricultural Area (Million ha)	2005	2010	2015	2016	2017	2020	2025	2030
Crops								
Crops (Sugarcane, Maize, Soybean, other grains)	51.1	51.2	58.1	52.3	52.6	55.0	61.2	63.5
Forest Plantation								
Homogeneous Forest	5.3	6.5	6.9	6.7	6.4	7.8	8.6	9.5
Integrated Forest	0.3	0.6	1.2	1.2	1.3	1.8	2.4	3.0
Total Area	5.6	7.1	8.0	7.9	7.7	9.6	11.0	12.5

Agricultural Area (Million ha)	2005	2010	2015	2016	2017	2020	2025	2030
Grassland								
Pasture	182.8	182.2	172.0	165.9	165.7	164.6	155.0	132.4
Total Area	239.5	240.5	238.1	226.1	225.8	229.2	227.2	208.5

In terms of emissions reduction, Scenario B entails greater effort in the AFOLU sector. The mitigation measures considered in this scenario are the same as in Scenario A. However, the targets to be achieved are higher than those of scenario A, are in line both with the NAMA (Brazil, 2010) and NDC (Brazil, 2015) goals and include mitigation actions and targets proposed by the Brazilian Climate Change Forum.

The net emissions of the AFOLU sector in 2030 totaled 344 Mt CO_2-eq in Scenario B (Table 11). In the period 2015-2030, there is a 64% reduction in net emissions. This reduction is associated with Land Use Change and Forests and can be attributed to the reduction of annual deforestation rates.

Table 11. Gross emissions, removals and net emissions from AFOLU in Scenario B (Mt CO_2-eq)

AFOLU	2005	2010	2015	2020	2025	2030
Land Use Change and Forestry						
Gross Emissions	**2,171**	**668**	**913**	**760**	**655**	**626**
Deforestation and other land use change	-	-	883	729	622	592
Liming and forest residues	-	-	30	31	33	35
Removals	**-249**	**-313**	**-500**	**-567**	**-622**	**-735**
Commercial planted forest	-	-	-12	-33	-31	-31
Restoration of native forest	-	-	-	-21	-55	-145
Restoration of pastureland	-	-	-14	-34	-39	-39
Integrated systems (ILF+ICF+ICLF)	-	-	-25	-25	-25	-24
Protected areas (UC and TI)	-	-	-354	-382	-410	-437
Secondary forest	-	-	-95	-73	-62	-59
Total Net Emissions	**1922**	**355**	**413**	**193**	**33**	**-109**
Agriculture						
Enteric Fermentation	-	312	358	349	340	304
Manure Management	-	21	22	13	12	11
Agricultural soils	-	120	129	125	125	119
Rice Cultivation	-	13	14	10	8.2	6.9
Burning of agriculture residues	-	6.5	6.6	3.4	3.1	3.1
Zero tillage	-	-	-6.1	-16	-20	-16
Total Emissions	**460**	**473**	**522**	**486**	**468**	**429**
AFOLU – Net Emissions	**2,381**	**828**	**935**	**679**	**500**	**320**

According to the premise adopted in Scenario B, the goals of 80% reduction in the annual deforestation rate in the Amazon biome and 40% in the Cerrado biome are reached in 2020 (NAMA target). And in 2030 there is a 95% reduction in the rate of illegal deforestation in the Amazon (according to suggestions from the Forum and the NDC target). For the other biomes, the average annual emissions from deforestation on the period 2012–2016, according to data published by SEEG (2018), is maintained until 2030. Thus, the annual rate of illegal deforestation in the Amazon in 2020 and 2030 are 392.5 and 93.2 thousand hectares, respectively, while In the Cerrado this rate remains at 838.2 thousand hectares in both years. Recent data on deforestation of the Cerrado indicate that in 2016 and 2017 it lost 677 and 740.8 thousand hectares, respectively (http://www.dpi.inpe.br/fipcerrado/dashboard/ cerrado-rates.html). Despite the high annual rates, the NAMA goal is being met. Therefore, in Scenario B, both the NAMA and NDC targets in terms of deforested area reduction are met.

In terms of CO_2-eq emissions, meeting the targets for reducing deforestation in the Amazon and Cerrado results in emissions of 468 and 335 Mt CO_2-eq in 2020 and 2030, respectively. Considering the removal factors of each biome adopted in this study, the emissions of these two biomes in 2005 would total 1.8 Mt CO_2-eq. Therefore, compliance with these targets would represent an emissions reduction of 1.4 Mt CO_2-eq in 2030, as compared to 2005.

In regards to total removals, there is a 49% rise over the period 2015-2030 due mainly to the increased removals in Protected Areas (Conservation Units and Indigenous Lands) and to the Restoration of Native Forests (Table 11). The allocation of 50% of untitled forests areas (averaging 36 Mha) to protected areas in the period 2020-2030 would result in the removal of 437 Mt CO_2-eq by 2030. In addition, the restoration of 9.0 Mha of native forest in the different biomes would bring about a cumulative removal of 145 Mt CO_2-eq by 2030. These two measures are the main sources of removals in the AFOLU sector and aim to contribute to meeting the NDC (Brazil 2015) goals: " compliance with the Forest Code at the federal, state and municipal levels "and to restore and reforest 12 million hectares of forest by 2030 for multiple uses."

Measures related to the expansion of planted forests, the restoration of degraded pastures and the implementation of integrated systems are meant to meet the targets of the ABC Plan (NAMA) and NDC for 2020 and 2030. The removals resulting from these measures total 83 Mt CO_2-eq in 2030.

Emissions related to agriculture are expected to decrease by 15% in the period 2015-2030 (Table 11). This decrease is due to the reduction of the emissions from enteric fermentation and the rise of removals promoted by the expansion of the zero-tillage areas. In the first case, the measures related to the improvement of farming practices (vaccine control, rationing of grazing and reduction of the slaughter age) increase the productivity of cattle raising and, consequently, are conducive to reducing livestock numbers and GHG emissions from enteric fermentation. The expansion of 8.0 Mha of the zero-till area by 2020, as mentioned in the ABC Plan, results in a removal of 16 Mt CO_2eq in that year. Therefore, this meets NAMA's goal both in terms of area and emissions.

4.1.6. Scenario C – Assumptions

4.1.5.1 Land Use Change and Forest

a) Reduction of deforestation

Scenario C for 2020 is the same as Scenario B. For the period 2020-2030 the ambition is to reach 60% of the emission reduction potential proposed in Scenario B (reduction of 57% in illegal deforestation in Amazon biome, instead of 95%) according to the recommendation of the Brazilian Climate Change Forum (FBMC).

b) Increase of protected areas (increased accounting of carbon sinks)

Protected areas (Conservation Units and Indigenous Lands) in 2020 would be similar to the area under this category that reached 269.0 Mha, in 2017. In the period 2020-2030, we assumed an increase of 18.0 Mha, as suggested by the Brazilian Climate Change Forum (FBMC). This area is equivalent to 25% of the forest areas with no assignment of property rights according to the total area published by Brazilian Forest Service (http://www.florestal.gov.br). The protected area by 2030 would then be 287.1 Mha in Scenario C.

c) Increased Restoration of native forests

Native forest to be restored covering all biomes (Amazon, Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampa) would be 3.0 Mha until 2030. This target would contribute to the recovery of forest liabilities according to the new Forest Code, estimated by Soares Filho (2013).

d) Carbon sinks in the natural regrowth of deforested areas

In Scenario C, removals provided by secondary forests were assumed to be proportional to the emissions from deforestation and other land use changes.

e) Increase in commercial planted forest

The commercial planted forest area (Eucalyptus and Pinus) will be estimated according to the wood demand until 2030 to be simulated in the other sectors.

f) Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)

The area under the forest-livestock integration system by 2030 will be 4.4 Mha. This value was computed considering the same annual increment of the area in the period 2010-2015 (0.96 Mha/year).

g) Increased Restoration of pastureland

In Scenario C, carbon storage from the annual increment of 0.78 Mha/year will be simulated for the period 2016-2030, amounting 15.6 Mha of restored pasture in 2030.

4.1.5.2 Agriculture

a) Increase of zero-tillage practices (crops)

The same as in Scenario A.

b) Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)

The same as in Scenario A.

c) Increase of manure management (from cattle, swine and other animals)

The same as in Scenario A.

d) Increase in livestock productivity

The increase in livestock productivity was simulated considering an exponential increase of 20% in herd productivity from 2020 on, the restoration of 15.6 Mha pastureland, management of pasture areas, genetic improvement and reduction of the slaughter age from 37 to 27 months, according to information published by Strassburg (2014).

Table 12 summarizes the evolution of the penetration of the mitigation measures in Scenario C in terms of area (observed values for 2005-2015 and estimated values for 2016-2030).

Table 12. Mitigation measures in agriculture and penetration estimates in Scenario C (million ha, m^3).

Mitigation measure	Area (Million ha)							
	2005	2010	2015	2016	2017	2020	2025	2030
Increase of protected areas (increased accounting of carbon sinks)		191.6	247	258.1	269.2	269.2	278.2	287.2
Increased Restoration of native forests				0.2	0.5	0.4	1.1	3
Increase in commercial planted forests	5.3	6.5	6.8	7.2	7.2	6.2	6.5	6.9
Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)	0.3	0.9	1.95	2.1	2.3	2.8	3.6	4.4
Increase of zero-tillage practices (crops)	25.5	30.8	34.1	34.1	36.1	39.3	45.1	47.8
Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)		23.3	32.2	32.3	32.4	32.7	38.6	41.3
Increased Restoration of pastureland			3.9	4.9	6	7.8	11.7	15.6
Increase of manure management (from cattle swine and other animals) (m^3)		7.4	9.4	9.8	10.3	9.4	9.4	9.4

4.1.7. Scenario C – Results

The crop production values in Scenario C are like Scenario B, with the exception of sugarcane, which simulated production is referent to sugar and ethanol demand, which is 12% higher than in Scenario B and 32% higher than in Scenario A in 2030. The production of sugarcane in this Scenario is calculated to be 899 Mt in 2030 (Table 12).

On the other hand, wood production from planted forests is closer to the Scenario A estimate, since, in this scenario, forestry production was projected in reference to wood demand for industrial, energy and other uses and not in conformity with the area expansion target of the NAMA and the ABC Plan as adopted in Scenario B.

Table 13. Agricultural and livestock production in Scenario C (Mt , m^3).

Production	2005	2010	2015	2016	2017	2020	2025	2030
Crops (Mt)								
Sugarcane	385	620	571	594	594	645	720	899
Maize	35	55	85	78	80	83	93	110
Soybean	51	69	97	96	97	108	131	148
Other grains	28	26	29	29	29	30	31	34
Planted Forest (Million m^3)								
Wood production (homogeneous forest)	197	229	235	265	256	218	229	239
Wood production (integrated systems)	5	13	28	31	33	40	52	64
Total wood production	202	242	263	295	289	258	281	303

*Values beyond 2015 estimated.

Table 14. Livestock production in Scenario C (millions of heads)

Livestock (million of heads)	2005	2010	2015	2016	2017	2020	2025	2030
Cattle	228	210	215	208	209	210	204	182
Swine	34	39	40	42	42	43	46	50

The number of heads of cattle does not change when compared to Scenario B because the improvement of the farming practice in this Scenario is similarly simulated. The emissions reduction in relation to Scenario A is 17%. On the other hand, the pasture area is smaller as compared to Scenario A (164 Mha) and higher than in Scenario B (132 Mha). This is due to the restored pasture area adopted in this scenario which is 15.6 Mha by 2030 (Table 12).

The planted forest area is similar to Scenario A and 23% lower than scenario B, due to the assumptions adopted for these Scenarios. The total agricultural area in Scenario C is similar to Scenario B, and both are less than that in Scenario A.

Table 15. Agricultural land area in Scenario C (million ha)

Agricultural Area (Million ha)	2005	2010	2015	2016	2017	2020	2025	2030
Crops								
Crops Crops (Sugarcane, Maize, Soybean, other grains)	51.1	51.2	58.1	52.3	52.6	55.5	61.7	64.8
Forest Plantation								
Homogeneous Forest	5.3	6.5	6.9	6.7	6.4	6.2	6.6	6.9
Integrated Forest	0.3	0.6	1.2	1.2	1.3	1.7	2.2	2.7
Total Area	5.6	7.1	8.0	7.9	7.7	7.9	8.7	9.6
Grassland								
Pasture	182.8	182.2	172.0	165.9	165.7	164.4	155.9	134.3
Total Area	**239.5**	**240.5**	**238.1**	**226.1**	**225.8**	**227.9**	**226.4**	**208.7**

Scenario C is characterized by an intermediate effort in terms of emissions reduction in the AFOLU sector. The mitigation measures considered in this scenario are the same as in Scenarios A and B. However, the targets related to these measures differ, as well as the potential for penetration of these measures over the years.

The AFOLU sector net emissions in 2030 totaled 546 Mt CO_2-eq in Scenario C (Table 16). In the period 2015-2030, there was a 42% reduction in net emissions which can be attributed to the reduction in the annual deforestation rates of the Amazon and Cerrado biomes.

Table 16. Gross emissions, removals and net emissions from AFOLU in Scenario C (Mt CO_2-eq)

AFOLU	2005	2010	2015	2020	2025	2030
Land Use Change and Forestry						
Gross Emissions	**2,171**	**668**	**913**	**759**	**677**	**673**
Deforestation and other land use change	-	-	883	729	645	640
Liming and forest residues	-	-	30	30	32	33
Removals	**-249**	**-313**	**-500**	**-510**	**-540**	**-582**
Commercial planted forest	-	-	-12	-	-13	-12
Restoration of native forest	-	-	-	-7	-18	-48
Restoration of pastureland	-	-	-14	-29	-29	-29
Integrated systems (ILF+ICF+ICLF)	-	-	-25	-20	-20	-20
Protected areas (UC and TI)	-	-	-354	-382	-396	-410
Secondary forest	-	-	-95	-73	-64	-64
Total Net Emissions	**1922**	**355**	**413**	**249**	**137**	**91**
Agriculture						
Enteric Fermentation	-	312	358	349	340	304
Manure Management	-	21	22	18	19	20
Agricultural soils	-	120	129	126	127	123
Rice Cultivation	-	13	14	10	8.2	6.9
Burning of agriculture residues	-	6.5	6.6	3.7	3.5	3.5
Zero tillage	-	-	-6.1	-16	-20	-16
Total Emissions	**460**	**473**	**522**	**492**	**478**	**442**
AFOLU – Net Emissions	**2,381**	**828**	**935**	**741**	**614**	**533**

According to the premise adopted in Scenario C, the goal of 80% reduction in the annual deforestation rate of the Amazon region and of 40% in the Cerrado is reached in 2020 (NAMA target). In 2030, it is expected to reach 60% of the emission reduction potential of Scenario B in the Amazon biome, that is, 57% reduction of deforestation instead of 95%. For the other biomes, the annual deforestation rate between 2012-2016[4] is maintained until 2030. Thus, the annual rate of illegal deforestation in the Amazon in 2020 and 2030 is 392.5 and 157 thousand hectares, respectively. While for the Cerrado, this rate is equivalent to 838.2 thousand hectares in 2020

[4] Data from SEEG (2017).

and remains unchanged until 2030. Despite the high deforestation rates of the last few years in the Cerrado biome, the NAMA target is met. Therefore, in Scenario C, the explicit NAMA goal is met in contrast to the NDC goal of zero illegal deforestation in the Amazon in 2030.

The reduction of deforestation in the Amazon and Cerrado regions results in an emission of 335 Mt CO_2-eq in 2030 which, according to the removal factors used in this study, represents a reduction of 1.4 Mt CO_2 -eq in relation to 2005.

Total removals show an increase of 18% during the period 2015-2030. This reduction is attributed to the increased removals in Protected Areas (Conservation Units and Indigenous Lands) (Table 12). The allocation of 18 Mha of untitled lands forest to protected areas in the period 2020-2030 resulted in the removal of 410 Mt CO_2 -eq by 2030 (Table 16). The restoration of 3 Mha of native forest in the different biomes leads to the cumulative removal of 48 Mt CO_2-eq by 2030, while the removal of CO_2 by secondary forests adds up to 64 Mt CO_2-eq. These three measures are the main removal sinks of the AFOLU sector and contribute to meeting the Brazilian NDC (2015) goals.

Except for the implementation of integrated systems, measures related to the expansion of planted forests and the restoration of degraded pastures do not meet the goals of the ABC Plan (NAMA) and the NDC for 2020 and 2030, in terms of area. The removals provided by these measures amounted to 52 Mt CO_2-eq in 2030.

Agricultural-related emissions fell by 14% in the period 2015-2030 (Table 16). As in Scenario B, this decrease is attributed to the reduction of emissions from enteric fermentation and to the increased removals due to the expansion of zero-tillage areas. The expansion of 8.0 Mha of the zero-till area by 2020, as mentioned in the ABC Plan, results in a removal of 16 tCO_2-eq that year.

Figure 9 shows the total net emissions of the AFOLU sector in the period 2005-2030 for Scenarios A, B and C. It should be noted that the two different values for 2005 are taken from the 2nd and 3rd Brazil National Communications (Brazil, 2010 and 2015).

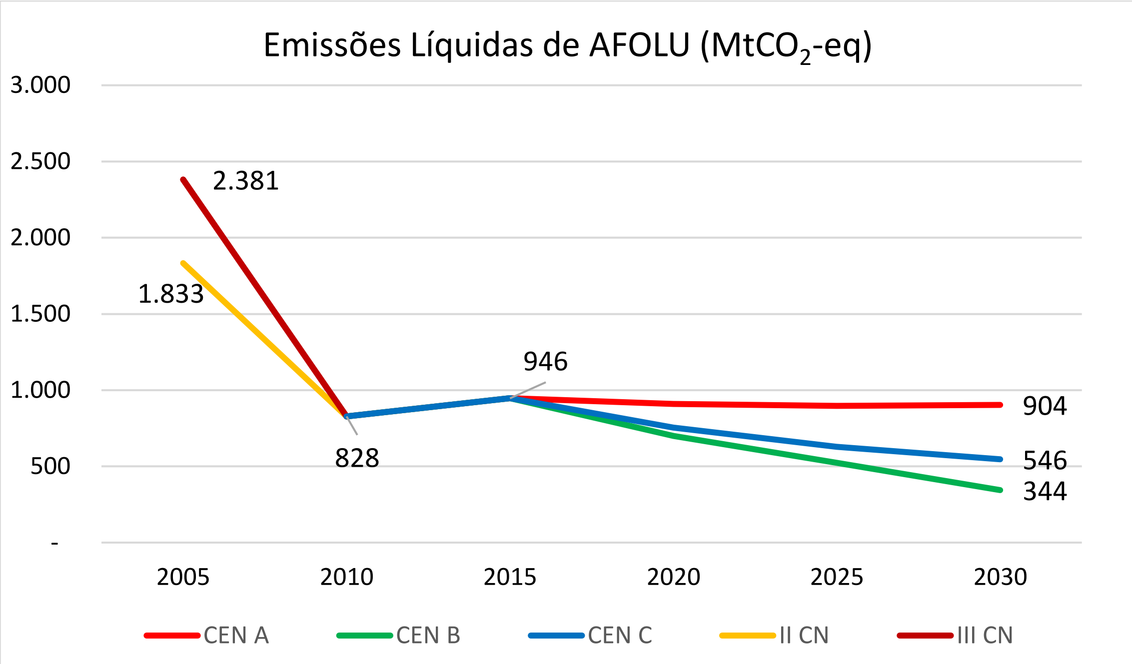


Figure 9. AFOLU net emissions (Mt CO_2-eq)

4.1.8. Comparative Analysis of Scenarios A, B and C – Avoided Emissions by Mitigation Actions

Table 17 shows the comparison of avoided emissions and carbon sequestration (removals), expressed in CO_2-eq, for each mitigation measure between Scenarios A and B, Scenarios A and C, and Scenarios B and C.

4.1.7.1 Mitigation Measures to Reduce Emissions – Avoided Emissions

a) Reduction of deforestation

Meeting the targets for the reduction of deforestation in the Amazon and the Cerrado (as foreseen by NAMA, NDC and FBMC suggestions) resulted in avoided emissions of 160 Mt CO_2-eq in 2020, 265Mt CO_2-eq in 2025 and 293 Mt CO_2-eq in 2030 in Scenario B in relation to Scenario A (Table 17). It should be noted that in Scenario A the average emissions of the deforested area in the period 2012-2016 up to 2030 did not change, without including any further reduction target.

Table 17. Avoided emissions and sequestration increased by each mitigation measure between scenarios A, B and C (Mt CO_2-eq)

Avoided Emissions and Removals (Mt CO_2-eq)									
Emission from Mitigation Measure	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**
Emissions	**Avoided emissions in Scen B in relation to Scen A**			**Avoided emissions in Scen C in relation to Scen A**			**Avoided emissions in Scen B in relation to Scen C**		
Land Use Change and Forestry									
Reduction of Deforestation	160	265	293	160	242	247	-	22	47
Agriculture									
Increase in livestock productivity	-	15	60	-	15	60	-	-	-
Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)	-	1.5	2.1	-0.42	-0.88	-1.3	0.42	2.4	3.4
Reduction in fertilizer application and in animal manure deposit on soil (due to a decrease in the average cattle slaughtering age)	-	3.6	14	-	3.6	14.2	-	-	-
Increase of manure management (from cattle swine and other animals)	4.9	7.3	9.7	-0.10	0.21	1.2	5.0	7.1	8.5
Removals	**Increased removals in Scen B in relation to Scen A**			**Increased removals in Scen C in relation to Scen A**			**Increased removals in Scen B in relation to Scen C**		
Land Use Change and Forestry									
Increased Restoration of native forests	-15	-40	-122	-1.2	-3.0	-26	-14	-37	-96
Increase of protected areas (increased accounting of carbon sinks)	-	-28	-55	-	-14	-28	-	-14	-27
Increase in commercial planted forests	-33	-16	-9.0	-	1.7	10	-33	-18	-19

Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)	-9.6	-9.6	-9.5	-4.8	-4.8	-4.8	-4.8	-4.8	-4.8
Increased Restoration of pastureland	-8.7	-17	-17	-3.3	-6.6	-6.6	-5.4	-11	-11
Carbon sinks in the natural regrowth of deforested areas	17	27	30	17	25	26	-	2.29	4.81
Agriculture	-	-	-	-	-	-	-	-	-
Increase of zero-tillage practices (crops)	-	-4.3	-5.2	-	-4.1	-5.2	-	-0.12	-0.08
Emissions from other changes	**Avoided emissions in Scen B in relation to Scen A**			**Avoided emissions in Scen C in relation to Scen A**			**Avoided emissions in Scen B in relation to Scen C**		
Other land use change (net effect of crop switches)	6.1	9.2	10	6.1	8.6	8.7	-	0.67	1.4
Liming for pH correction of agricultural soil	-0.74	-1.8	-2.4	-0.46	-0.85	-1.1	-0.28	-1.0	-1.3
Burning of agriculture residues (in sugar cane pre-harvesting)	-	-0.11	-0.31	-0.27	-0.47	-0.77	0.27	0.36	0.45
Returning of agriculture residues to agricultural soil	-	-0.69	-0.94	-0.19	-0.88	-1.4	0.16	0.19	0.47

Source: Study Data

Comparing Scenarios A and C, both do not fully meet the targets of the analyzed policies. There is an avoided emission equivalent to 242 Mt CO_2-eq in 2025 and 247Mt CO_2-eq in 2030, from Scenario C in comparison to A, that is, they are lower than the avoided emissions of Scenarios B and A, during those same years. However, the emissions avoided up to 2020 are similar, since in Scenarios B and C the reduction targets are identical until 2020. After 2020, Scenario B shows a greater commitment to the NDC goal with respect to the reduction of deforestation in the Amazon when compared to Scenario C.

The avoided emission of Scenario B in relation to Scenario C in the years 2025 and 2030 are, respectively, 22 Mt CO_2-eq and 47 Mt CO_2-eq. Although both scenarios are based on NAMAS, NDC and those suggested by the FBMC. In Scenario C the efforts expended to meet the targets are lower, especially about reducing illegal deforestation in the Amazon.

Scenario B is the one with the greatest potential for reducing emissions from deforestation in the period 2015-2030.

b) Increase in livestock practices

The emissions resulting from this mitigation measure are from enteric fermentation. Since the premises related to the improvement of farming practices in Scenarios B and C are the same and result in the same amount of livestock in 2025 and 2030. The avoided emissions of Scenario B in relation to Scenario A as of Scenario C in comparison to Scenario A are 15 Mt CO_2-eq and 60 Mt CO_2-eq in 2025 and 2030, respectively. The emissions of Scenarios B and C do not differ.

c) Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)

According to the assumptions adopted, Scenario B has the highest adoption of Nitrogen Biological Fixation (100% of the expanded soybean area and 10% of the expanded area for other grains) and the area planted with soybean is similar to that in Scenario C, and both are higher than in Scenario A. Therefore, in Scenario B there is a greater reduction in the use of Nitrogen Fertilizer and leading, consequently, to lower GHG emissions from this source.

Scenario B provide 0.05 Mt CO_2-eq, 1.2 Mt CO_2-eq and 1.5 Mt CO_2-eq in avoided emissions in 2020, 2025 and 2030, respectively, when compared to Scenario A. Scenarios B and C, in view of the larger projected soybean area and considering that Scenario B involves the application of FBN in soybeans and in a percentage of the area for other grains, while in Scenario C, the FBN use is only in the soybean area.

d) Increase of manure management (from cattle, swine and other animals)

The avoided emissions of Scenario B in relation to Scenarios A and of Scenario B in comparison to C are the same and equal to 0.0022 Mt CO_2-eq, 0.0044 Mt CO_2-eq and 0.0065 Mt CO_2-eq in 2020, 2025 and 2030, respectively. This is due to the difference in the volume of manure treated in Scenario B compared to that treated in Scenarios A and C (which are equal). Therefore, the avoided emissions of Scenario A as compared to C are zero.

4.1.7.2 Mitigation Measures to Promote Carbon Sequestration – Increased Removals

a) Increase of protected areas (increased accounting of carbon sinks)

As shown in Table 17, Scenario B presents higher removal from Protected Areas (UC and TI), equivalent to 28 Mt CO_2-eq in 2025 and 55 Mt CO_2-eq in 2030. This increase in removals results from the increase of 36 million hectares in areas of Conservation Units and of Indigenous Lands in the period 2020-2030 according to the premise suggested by the FBMC. Likewise, as a result of the added protected area in Scenario C in relation to Scenário A, Scenario C provides additional removal of 14 Mt CO_2-eq in 2025 and 28 Mt CO_2-eq in 2030 in comparison to Scenario A. Increased Scenario B removal relative to C was 14 Mt CO_2-eq in 2025 and 27 Mt CO_2-eq in 2030.

b) Increased Restoration of native forests

The restored native forest area occurs in greater proportion in Scenario B, totaling 9 Mha in 2030. The additional Scenario B removal when compared to Scenario A (restoration of 1.4 Mha) is 15 Mt CO_2-eq in 2020, 40 Mt CO_2-eq in 2025 and 122 Mt CO_2-eq in 2030. Likewise, Scenario B provides an increase over Scenario C removal of 14 Mt CO_2-eq, 37 Mt CO_2-eq and 96 Mt CO_2-eq in 2020, 2025 and 2030, respectively. On the other hand, considering the premises for the area to be restored in Scenarios A and C (lower than for Scenario B), the higher removal in Scenario C over A was only 1 Mt CO_2-eq, 3 Mt CO_2-eq and 26 Mt CO_2-eq in 2020, 2025 and 2030 respectively.

c) Increase in commercial planted forest

In Scenario B, this measure provided a removal increase over Scenario A of 33 Mt CO_2-eq, 16 Mt CO_2-eq and 9 Mt CO_2-eq in 2020, 2025 and 2030, respectively. In this same proportion, an additional Scenario B removal over C is observed (Table 17). The increase of removal in Scenario B in relation to Scenarios A and C results from the higher rates of simulated area expansion of 3 million hectares in Scenario B by 2030. In Scenarios A and C the evolution of the area of planted forests responded to the demand for wood from the sectors. In Scenario A increased removal to 1.7 Mt CO_2-eq and 10 Mt CO_2-eq in 2025 and 2030, respectively in comparison to Scenario C.

d) Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+lCLF)

Scenario B shows an increase in removal over Scenario A of 5.2 Mt CO_2-eq in 2020, 2025 and 2030. Likewise, this removal is higher in Scenario C in relation to A (2.6 Mt CO_2-eq) and in Scenario B and relation to C (2.6 Mt CO_2-eq). The additional removals for 2020, 2025 and 2030 are the same because the increase of the annual area is constant in each scenario during the period 2016-2030 (Table 17).

e) Increased Restoration of pastureland

This measure gives Scenario B an additional removal of 9 Mt CO_2-eq in 2020, 17 Mt CO_2-eq in 2030, respectively, in relation to Scenario A. Likewise, Scenario B provides an increase in removal in relation to C, as shown in Table 17. According to the assumptions adopted, Scenario B is the one with the highest recovered pasture area in 2030. There is also an increase in Scenario C removal in relation to A, but on a smaller scale than those observed in the comparisons between Scenarios A and B and Scenarios B and C (Table 17).

f) **Carbon sinks in the natural regrowth of deforested areas**

The premise that the removal of CO_2-eq in secondary forests is proportional to deforestation emissions was adopted. Given that the emissions from deforestation are greater in Scenario A than in B, the additional removal of Scenario A over B is 17 Mt CO_2-eq and 27 Mt CO_2-eq and 30 Mt CO_2-eq in 2020, 2025 and 2030, respectively. Likewise, Scenario C increased removals relative to Scenario A similarly (Table 17). The additional removals from Scenario C over B were lower and correspond to 2.3 Mt CO_2eq and 4.8 Mt CO_2-eq in 2025 and 2030, respectively.

g) Increase of zero-tillage practices (crops)

The increase in removal in both Scenario B and Scenario C over A is, on average, 4 Mt CO_2-eq and 5 Mt CO_2-eq in 2025 and 2030, respectively. Scenario B in relation to C provides minor additional removals (close to zero). These results reflect the assumptions for the adoption of the zero-tillage practices in Scenarios A, B and C as well as the increase of the soybean area in scenarios B and C.

4.2. TRANSPORT

4.2.1. Emission Sources

GHG Emissions from transport are divided into two categories: passenger and freight. Passenger transportation considers four modes of transportation (air, water, rail and road), while freight transportation comprises five modes (air, water, rail, road and duct). Therefore, emissions are derived from the energy consumed in each mode and emission factors for fuels. In the case of road transportation, energy consumption is estimated considering also the type of vehicle, year and energy source. To explain the amount of GHG emissions estimated in the baseline (2017), we estimated the historical trend from 1980 to 2016. Although the analysis starts from 2005, estimating data from 1980 is important to comprehend historical events that justify current emissions.

Regarding energy consumption, the historical participation of fossil fuels and renewable is illustrated in Figure 10.

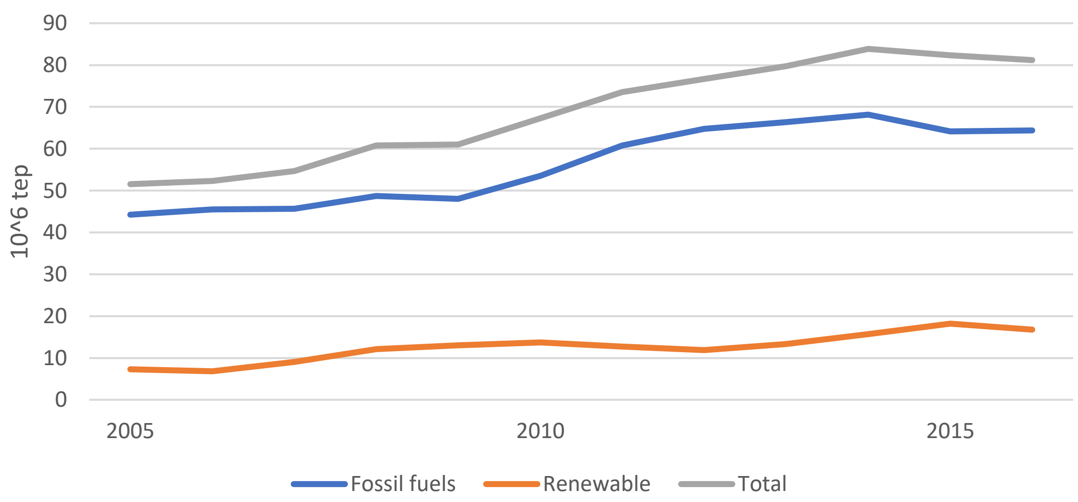


Figure 10. Energy consumption from the transport sector (Million toe).

As shown, in 2005 the participation of renewable sources of energy was only 14% of the total energy consumption, whilst in 2016 the participation is 21% mostly represented by the consumption of ethanol (97% of all renewable energy in 2005 and 85% in 2016). Generally, energy consumption grew by 57% in the period. Since energy consumption and GHG emissions are directly related, CO_2-eq emissions increased by 43% in the meantime as shown in Figure 11.

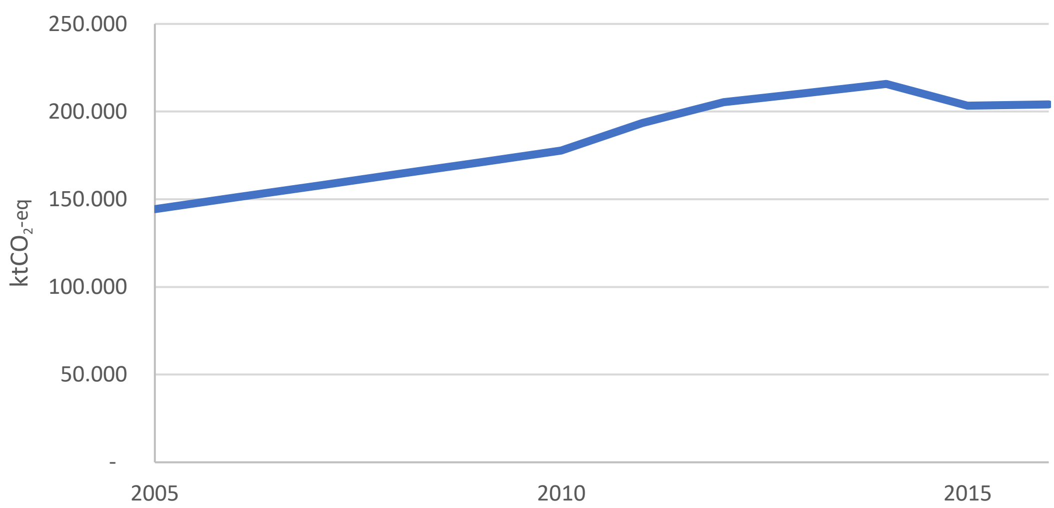


Figure 11. GHG emissions from the transport sector (kton CO_2-eq).

As evidenced, all figures show a decline between 2014 and 2016 due to the country's economic performance in those years, and thus this information is used to estimate the baseline and to project future energy and GHG emissions by 2030. Next section describes the assumptions and results of Scenario A.

4.2.2. Scenario A

To simulate the energy consumption and GHG emissions for the time horizon (2017-2030), there is a need to consider trends of the transportation sector in a longer perspective, as well as the ongoing infrastructure investments. Next sections describe the assumptions and results of Scenario A.

4.2.2.1 Assumptions

The evolution of the car fleet forecasting considers a growth rate of 2% per year, in line with the Decennial Energy Expansion Plan 2026 (EPE, 2017) and the RenovaBio program. For the light commercial vehicles, we consider the growth of the participation of engines operating on the conventional diesel cycle, due to the increasing preference for this type of motor by the Brazilian market consumer (starting from 5% of the commercial vehicles sales in 2012 to 9% in 2018) (ANFAVEA, 2018).

Moreover, the evolution of the road freight fleet forecasting (light, medium, heavy trucks and variations) is in line with the transportation activity forecasting, estimated based on the variation of the national GDP. In the same way, we consider the moment of transport to estimate the evolution of the national fleet of heavy passenger vehicles (urban bus, microbus and interstate bus). In this case, the transport activity is projected considering the national GDP per capita, since it is the variable that best explains the phenomenon in regression models. In addition, for the interstate passenger transport performed by bus, we also consider the demand tends to be captured by the air transportation during the time horizon of the analysis.

The modal split for freight transport (all modes) is based on the pessimistic economic scenario of the National Logistics Plan – PNL (EPL, 2018). Considering passenger transportation, the modal split is developed by the evolution of the remaining works of the Growth Acceleration Program (PAC) and the Avançar Program (EPL, 2018) (Table 18). In Scenario A, we consider the expected completion date of the infrastructure works with a five-year additional period. This decision is justified by the average construction backlog of similar works and by the experience of the working group.

Table 18. Remaining works of transport infrastructure programs (km)

Mode	Extension (km)
Road	7,756
Rail	3,783
Aquatic	560

Source: EPL (2018).

Regarding energy efficiency in the top-down approach, potential gains are based on the lower limit identified during the literature review. For the bottom-up approach, we consider the historical growth of energy efficiency for automobiles and heavy vehicles (freight and passengers). The electromobility share in the fleet is restricted, and therefore, considered in: (1) experiments with municipal buses (microbuses and urban buses), conducted in selected cities; (2) heavy trucks of urban waste collection (e. g. performed by individuals companies); and (3) small part of the current fleet of light commercial vehicles, considering the absence of new subsidies from the national government and the high prices for most consumers during the analysis period.

Rota 2030 program is not included in this scenario, given the uncertainties regarding the approval of the program or its effective starting date. The uncertainties are related to the successive negotiation rounds between the Ministry of Finance and the Ministry of Development, Industry and Foreign Trade (MDIC), discussing the tax credit available under the program.

Scenario A acknowledges the alignment between the supply of ethanol and the market estimates, obtained from the National Association of Fuel Distributors, Lubricants, Logistics and Convenience – Plural (representing approximately 35 billion liters). In this case, the amount of ethanol approximates the volume exposed in the low growth scenario of the study "Ethanol Supply Scenarios and Otto Cycle Demand 2018-2030" (EPE, 2018), which represents 38.7 billion liters. In Scenario A, the consumption of biokerosene in air transportation is not considered.

Moreover, the biodiesel blend in mineral diesel oil will be maintained at 10% (B10) by the end of the period (2030). We opted to maintain a conservative percentage since there is no technical report from the Government so far that shows viability for blends higher than 10% in the next years. Currently, the decision about increasing the blend at 15% (B15) is planned for 2019.

The assumptions and targets (NDC/NAMA) are listed in Table 19.

Table 19. Targets and assumptions considered in transportation, in Scenario A.

FBMC (NDC/NAMA)	Assumptions
Optimizing and diversifying freight transport	Expansion of railways and waterways with the completion of ongoing works of the Growth Acceleration Program (PAC) and the Avançar Program.
Expansion of public transportation, active mobility and optimization of private motorized transport	Passengers captured by public transportation with the completion of ongoing works of the Growth Acceleration Program (PAC) and the Avançar Program, considering a five-year additional period.
	Incentive for active transportation behavior.
Energy efficiency gains for the fossil fuel fleet, considering passengers and freight transport	Lower carbon intensity (tC/TJ) and energy intensity (TJ/t.km or TJ/pass.km) in the transportation matrix.
	Regular efficiency gains for other segments.
Expansion of alternative vehicles fleet and the supply of biofuels	RenovaBio, increasing the supply of ethanol to 35 billion liters; Market share of flexible-fuel vehicles at 30%.
	Participation of electric vehicles in the fleet of 1.3% for light vehicles; 0.5% motorcycles and 0.5% urban buses.
	Biodiesel Blend at 10% (B10)

4.2.2.2 Results

As illustrated in Figure 12, the fleet grows 36% until 2030, in other words, from 58 million vehicles in 2017 to 76 million in 2030. In this context, cars represent 58% of the fleet at the end of the period. In this situation, gasoline-powered cars are residual by 2030 from 24.4 % to only 4.9% of the total car fleet. Meanwhile, flexible fuel cars will dominate the market in 2030 (93.6%).

BEV and hybrid cars present a slight increase in the market share up to 2030. BEV grows from almost 0% to 0.1%, while hybrids increase its share from 0.02% to 1.1% at the end of the period. Regarding motorcycles, the flexible fuel share increases from 28% in 2017 to 53% in 2030. Obviously, it is aligned with the necessity to increase the ethanol supply in the market (which is an assumption of this scenario). In relation to public transportation, BEV buses share tends to increase from 0% to 0.6% of the bus fleet. Considering other types of vehicles, growth is based on the historical trend.

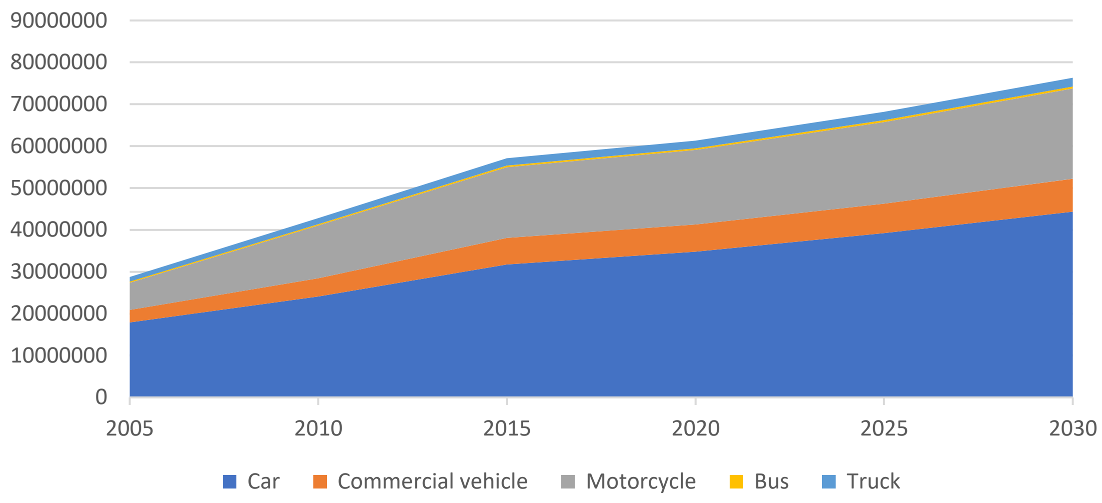


Figure 12. Fleet´s projection of road transportation in Scenario A (number of vehicles)

With regards to the activity of freight transportation (all modes), Figure 13 presents the trajectory according to the assumptions of Scenario A.

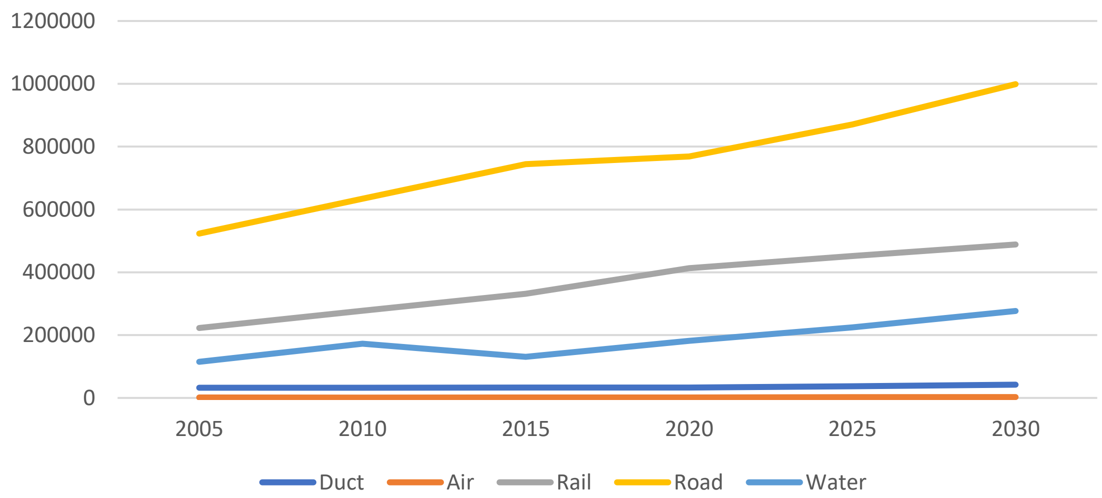


Figure 13. Transport activity of freight transportation in Scenario A (t-km)

From 2017, where the activity considering all modes is around 1,21 billion tons per kilometer, the transport activity grows 36% until 2030, reaching the amount of 1,80 billion tons per kilometer. Figure 14 shows the activity of passenger transportation.

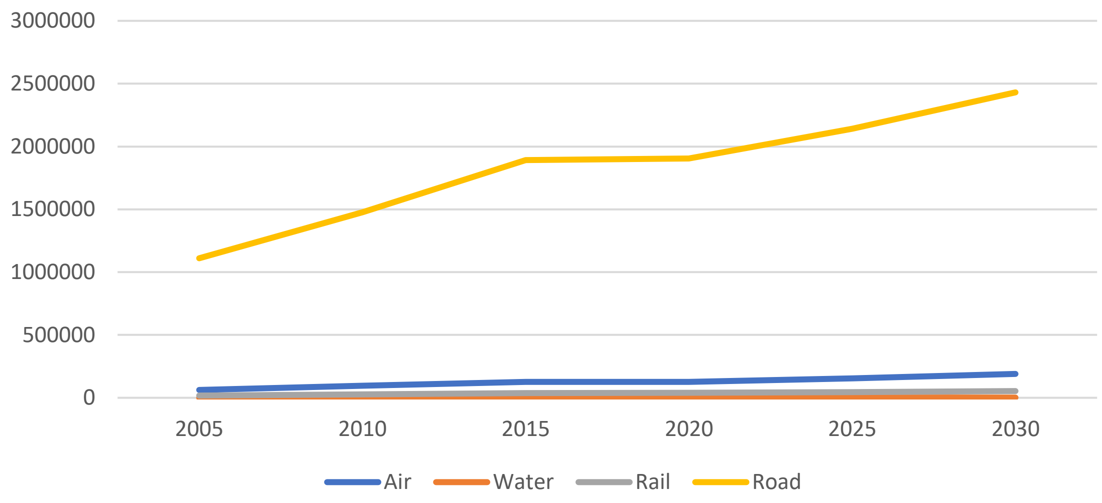


Figure 14. Transport activity of passenger transportation in Scenario A (pass-km)

In this case, the transport activity increases 30% during the period, from 2,06 billion passenger per kilometer to 2,67 billion. Here, road mode represents 90.8% of the transport activity (1.39% lower than in 2017). Figure 15 illustrates the modal share of freight and passenger transportation according to the sector activity.

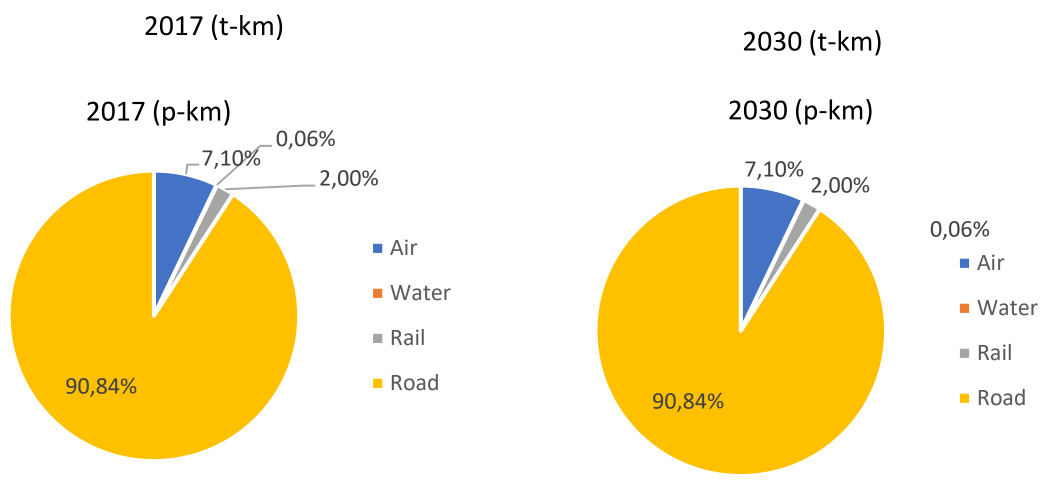


Figure 15. Modal split of freight and passenger transportation in Scenario A (%).

From the energy use perspective, Figure 16 shows the projection. In 2017, the share of renewables is 20.7% of the total energy consumption. At the end of the projection, the share grows to 22.6% (1.8% higher than in 2017).

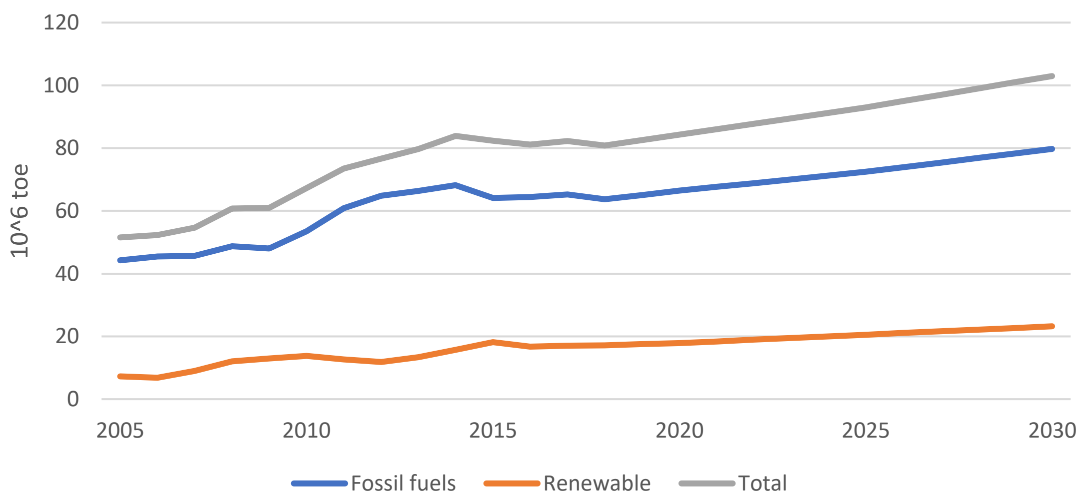


Figure 16. Energy consumption from the transport sector in Scenario A (million toe).

To expose the disaggregated energy use, Figure 17 reveals the energy consumption by source. In 2030, there is less dependence on gasoline and diesel, due to incentives for producing ethanol and biodiesel by the advent of RenovaBio program. Despite this, fuel oil also increases its share by 2030 since the completion of ongoing works of the Growth Acceleration Program (PAC) and the Avançar Program. In this scenario, electricity grows by 54% by 2030 compared to the baseline. Nevertheless, it has minor effects on energy consumption.

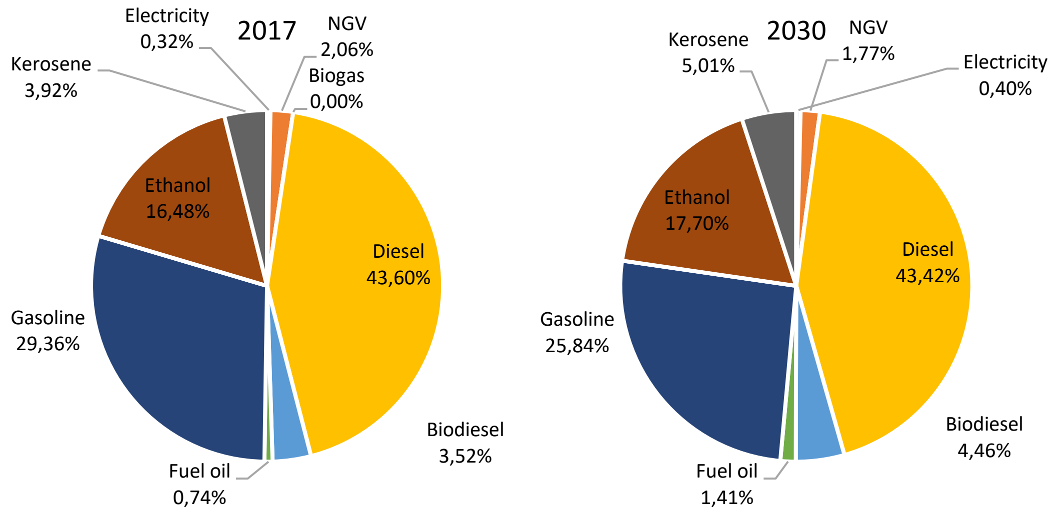


Figure 17. Energy consumption by source (toe).

Respecting the emissions expressed in CO_2-eq, Figure 18 presents the results up to 2030. As in the case of energy consumption, GHG emissions increases at similar levels. Therefore, it is expected that GHG emissions grow 19.1% up to 2030 (compared to the baseline), in other words, from 206.9 Mt CO_2-eq to 246.5 Mt CO_2-eq. At the end of the period, the road mode is responsible for 89.6% of the emissions, slightly lower than in 2005 when it accounted for 91.1%. Meanwhile, rail mode increases its participation from 1.5% in 2005 to 2.0% in 2030.

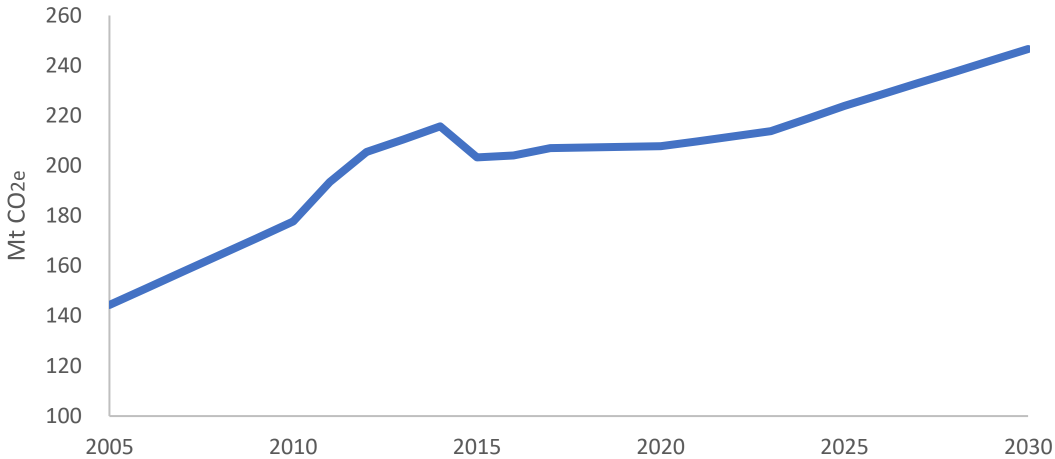


Figure 18. GHG emissions from the transport sector in Scenario A (Mt CO_2-eq).

In short, the synthesis of the results is evidenced in Tables 20 and 21.

Table 20. Energy use from the transportation sector in Scenario A (10^3 toe).

Year	Scenario A 10^3 toe		
	Fossil fuels	Renewable	Total
2005	44.2	7.2	51.5
2010	53.5	13.7	67.2
2015	64.1	18.1	82.3
2016	64.4	16.7	81.1
2017	65.2	17.0	82.2
2020	66.4	17.8	84.3
2025	72.4	20.5	92.9
2030	79.7	23.2	102.9

Table 21. Emissions from the transportation sector in Scenario A (Mt CO_2-eq).

Year	Scenario A
	Mt CO_2-eq
2005	144
2010	178
2015	203
2016	204
2017	207
2020	208
2025	224
2030	247

Next section discusses the assumptions and results of Scenario B.

4.2.3. Scenario B

Scenario B considers more incentives to public policies and private initiatives, simulating a more efficient use of transport modes and renewable fuels. Next sections describe the assumptions and results of Scenario B.

4.2.3.1 Assumptions

Here, we adopt the same growth rate as Scenario A (2% per year for cars), indicated in the Decennial Energy Expansion Plan 2026 (EPE, 2017) and RenovaBio program. For the light commercial vehicles, the growth of the participation of engines operating on the conventional diesel cycle is stabilized in 2020, aligned to the growth levels of vehicles equipped with Otto cycle engines.

There is a greater capture of passengers for urban public transportation by the increase of the occupancy rate. In addition, the fleet of heavy passenger vehicles (urban bus, microbus and interstate bus) also evolves according to the transport activity (considering the GDP per capita). For interstate road passenger transportation (bus), we also consider the passengers captured by air transportation. The projection of freight vehicles (light, medium, heavy trucks and variations) follows the transport activity, estimated in analogy to the national GDP.

The modal split is also aligned based on the remaining works of the Growth Acceleration Program (PAC) and the ongoing works of the Avançar Program. However, we consider an average delay of three years in relation to the expected completion date of the infrastructure works (two less than in Scenario A). Additionally, it is considered the increase of the exclusive bus lanes (microbuses and urban buses), reducing the effects of congestion and stimulating the use of public transportation.

In this scenario, there is a prominent development of cabotage transport due to public policies that encourage the competitiveness of this transport mode, e.g. reducing the Tax on Circulation of Goods and Services (ICMS) levied on fuel oil. It is not considered significant expansions in the infrastructure of ports and waterways.

Besides considering the trend of growth in energy efficiency for automobiles and heavy vehicles (freight and passengers), as pointed out in Scenario A, there is an extra gain of approximately 2.5% for the freight transportation resulting from the adoption of a set of good practices by member companies of sustainable programs, such as the Green Logistics Program Brazil (PLVB) with the adoption of sustainability standards and certifications. Therefore, it simulates a scenario of the adoption of a set of good practices by the member companies, with a larger increase between the years 2020 and 2025. In addition, Scenario B considers the beginning of the Rota 2030 program with gains of energy efficiency of around 12% up to 2030. The "Energy Efficiency of Urban Mobility – EEMU" technical booklet for passenger transportation is implemented by Brazilian municipalities in 2025. Thus, there are gains in energy efficiency for public transportation (micro-buses and buses) and supports measures to increase all aspects of active transport. The effect also captures demand from private transport.

As stated in Scenario A, we also consider the RenovaBio program although the amount of ethanol approximates the volume exposed between the Medium Growth Scenario and Low Growth Scenario of the study "Ethanol Supply Scenarios and Otto Cycle Demand 2018-2030" (EPE, 2018), representing 42 billion liters. Biodiesel blend in mineral diesel oil will be increased at 15% (B15) by the end of the period (2030), starting from 1% per year in 2020 until 2025, when the blend will reach 15%. As in Scenario A, the consumption of biokerosene in air transportation is not included. Table 22 indicates the targets and assumptions considered in Scenario B.

Table 22. Targets and assumptions considered in Transportation, in Scenario B.

<table>
<tr><th>FBMC (NDC/NAMA)</th><th>Assumptions</th></tr>
<tr><td rowspan="3">Optimizing and diversifying freight transport</td><td>Adjust concessions or renewal contracts for railways in the scope of the Investment Partnership Program (PPI), to ensure greater integration between the lines.</td></tr>
<tr><td>Expansion of rail and water networks with the completion of ongoing programs (PAC and Avançar).</td></tr>
<tr><td>Tax differentiation for inland navigation and cabotage.</td></tr>
<tr><td rowspan="4">Expansion of public transportation, active mobility and optimization of private motorized transport</td><td>Demand captured from private transport to BRT, VLT, subway and urban trains by the conclusion of all ongoing works (PAC and Avançar) with an average delay of three years.</td></tr>
<tr><td>Qualification of buses and expansion of exclusive bus lanes.</td></tr>
<tr><td>Measures to increase all aspects of active transport (40.10^9 pass-km)</td></tr>
<tr><td>Integrating policies in urban passenger transport</td></tr>
<tr><td rowspan="3">Energy efficiency gains for the fossil fuel fleet, considering passengers and freight transport</td><td>Rota 2030 Program (12% of gains in energy efficiency)</td></tr>
<tr><td>Lower carbon intensity (tC/TJ) and energy intensity (TJ/t-km or TJ/pass-km) in the transportation matrix.</td></tr>
<tr><td>Regular efficiency gains for other segments (emphasis on PLVB for freight, and EEMU for passengers).</td></tr>
<tr><td rowspan="3">Expansion of alternative vehicles fleet and the supply of biofuels</td><td>RenovaBio, increasing the supply of ethanol to 42 billion liters; Market share of flexible-fuel vehicles at 40%.</td></tr>
<tr><td>Participation of electric vehicles in the fleet of 2% for light vehicles; 4.5% motorcycles and 6% urban buses.</td></tr>
<tr><td>Biodiesel Blend at 15% (B15)</td></tr>
</table>

4.2.3.2 Results

In Scenario B, there are no significant changes concerning the fleet compared to Scenario A. As illustrated in Figure 19, it starts from 58 million vehicles in 2017 to 76 million in 2030. In this context, cars also represent 58% of the fleet at the end of the period.

Gasoline-powered cars have the same share of Scenario B (4.9% of the car fleet). Nonetheless flexible fuel vehicles present a smaller share of 92.7% (against 93.6% in Scenario B). Although the number of flexible fuel vehicles indeed decreases when comparing the last year of both scenarios (from 41,490,852 in Scenario A to 41,127,937 in Scenario B), the smaller share of this type of vehicle is due to the more representative share of BEV and hybrid cars, with 0.3% and 1.8% of the car fleet in 2030 respectively.

With regards to public transportation, BEV buses tend to increase participation from 0% to 0.6% of the bus fleet. Considering other types of vehicles, growth is based on the historical trend, in other words, in accordance with GDP and GDP per capita. Figure 19 illustrates the projected fleet from 2005 to 2030.

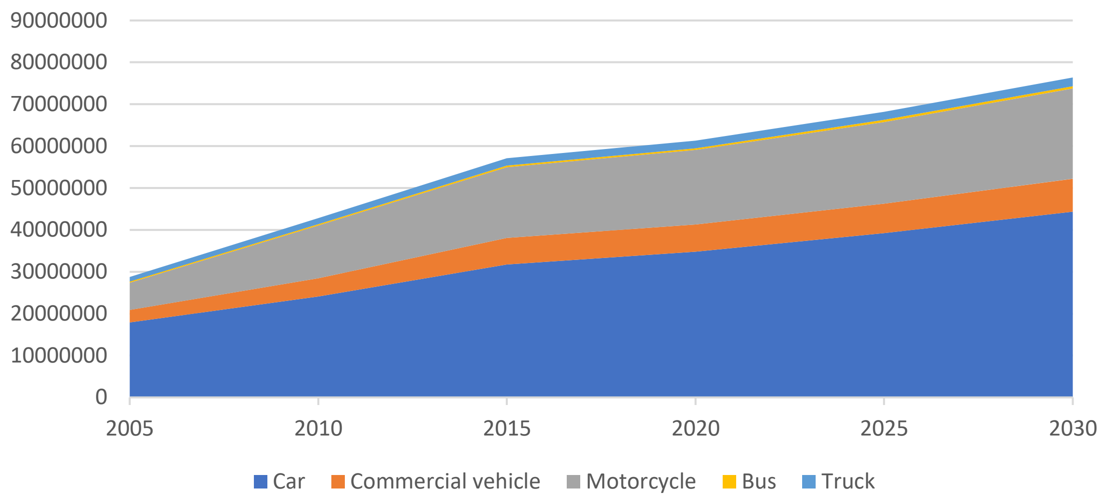


Figure 19. Fleet´s projection of road transportation in Scenario B (number of vehicles).

With regards to the activity of freight transportation (all modes), Figure 20 presents the trajectory according to the assumptions of Scenario B.

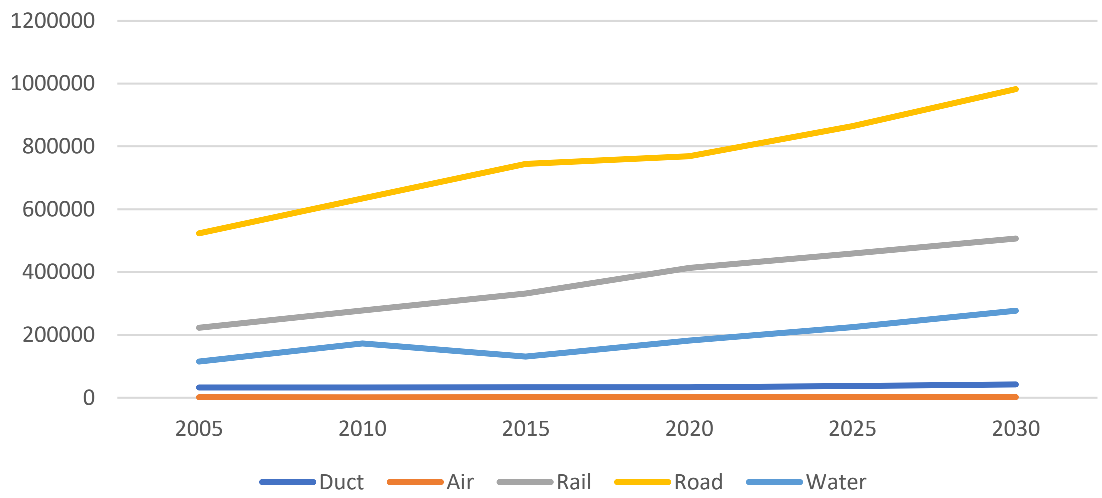


Figure 20. Transport activity of freight transportation (t-km).

Again, results are to those reported in Scenario A. From 2017, transport activity grows 36% up to 2030. Although the total activity remains practically the same, there are significant changes in the modal split. For example, in Scenario B, rail transportation is responsible for 27.9% of the modal split, (against 26.9% in Scenario A). This is in line with the expansion of rail and water networks.

Figure 21 shows the transport activity for passengers. In this case, the transport activity increases 30% during the period, from 2,065 billion passenger per kilometer to 2,675 billion.

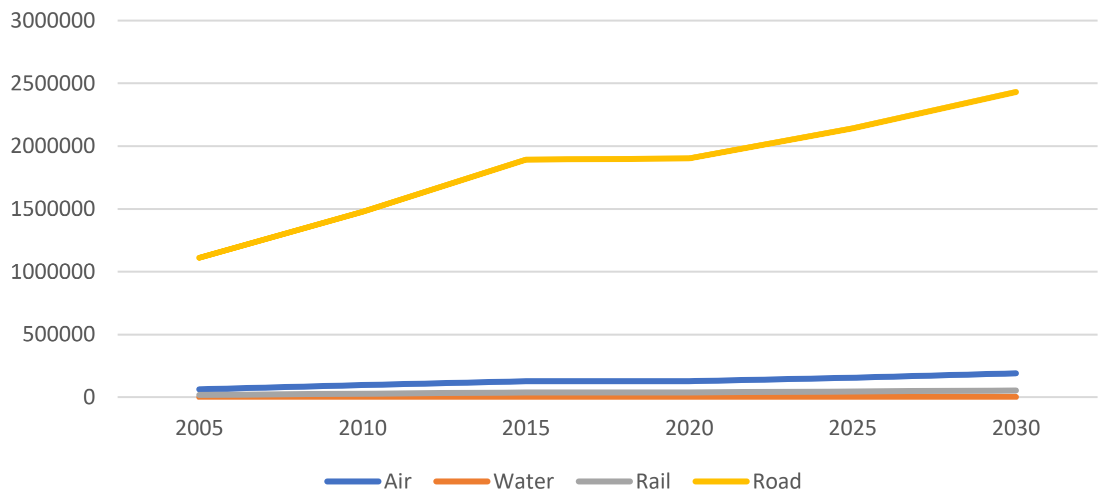


Figure 21. Transport activity of passenger transportation (pass-km).

Here, road transportation represents 90.8% of the transport activity, which is practically the same result as Scenario A.

Concerning energy consumption, Figure 22 illustrates the projection throughout 2030.

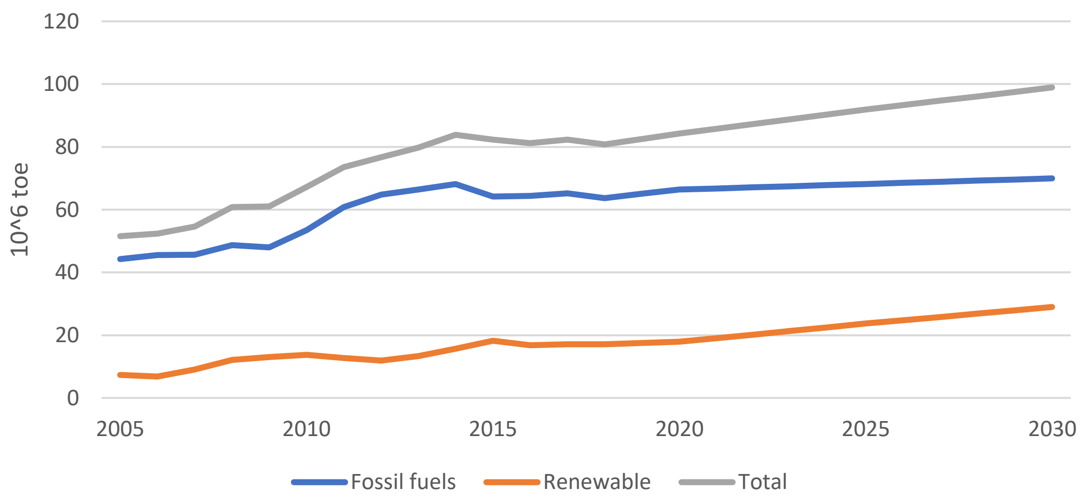


Figure 22. Energy consumption from the transport sector (million toe).

In 2017, the share of renewable sources of energy is 20.7% of the total energy consumption. At the end of the projection, this share is 29.3%, which is 6.7% higher than in Scenario A. This result indicates a trend towards more sustainable use of energy in Scenario B. The emissions are presented in Figure 23.

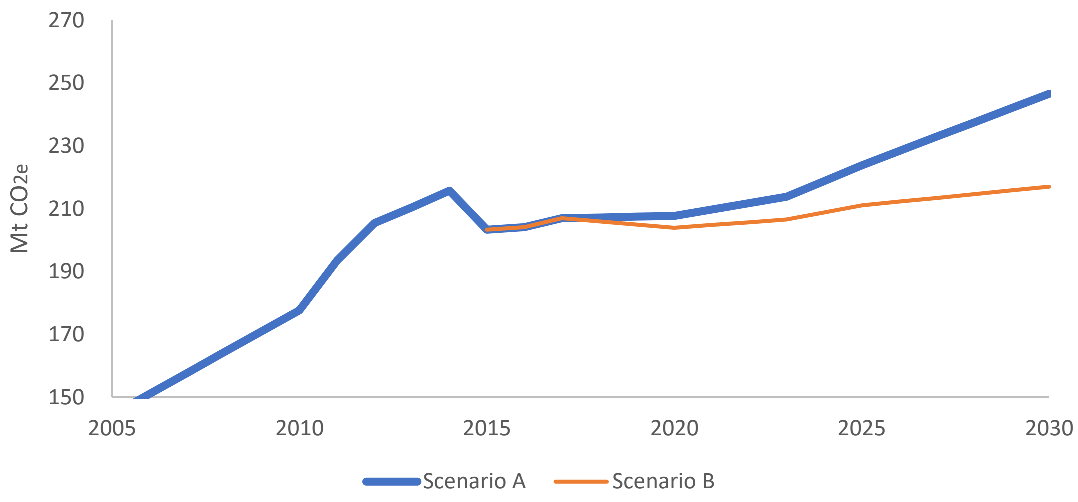


Figure 23. GHG emissions from the transport sector in Scenario B (Mt CO_2-eq).

When comparing to the baseline, it is projected an expansion of 4.9% of GHG emissions up to 2030, representing an amount of 217.0 Mt CO_2-eq. This tendency is 14.3% lower than the emissions observed in Scenario A (246.5 Mt CO_2-eq), which adopt more conservative assumptions.

Thus, the synthesis of the results is showed in Tables 23 and 24. Next section details the assumptions and results of Scenario C.

Table 23. Energy use from the transportation sector in scenarios A and B (10^3 toe).

Year	Scenario A			Scenario B		
	Fossil fuels	Renewable	Total	Fossil fuels	Renewable	Total
2005	44.2	7.2	51.5	44.2	7.2	51.5
2010	53.5	13.7	67.2	53.5	13.7	67.2
2015	64.1	18.1	82.3	64.1	18.1	82.3
2016	64.4	16.7	81.1	64.4	16.7	81.1
2017	65.2	17.0	82.2	65.2	17.0	82.2
2020	66.4	17.8	84.3	66.4	17.8	84.2
2025	72.4	20.5	92.9	68.1	23.6	91.8
2030	79.7	23.2	102.9	69.9	28.9	98.9

Table 24. Emissions from the transportation sector in scenarios A and B (Mt CO_2-eq)

Year	Scenario A	Scenario B
	Mt CO_2-eq	
2005	144	144
2010	178	178
2015	203	203
2016	204	204
2017	207	207
2020	208	204
2025	224	211
2030	247	217

4.2.4. Scenario C

Scenario C adds the prognoses of Scenario B, with more emphasis on policies that encourage active transportation, as well as alternatives for more efficient and low-carbon energy consumption.

4.2.4.1 Assumptions

Increment of the vehicles´ occupancy rate in passenger transport. For private transportation (automobiles and light commercial vehicles), there is greater participation of alternative vehicles (hybrids and electric) from 2025, being no longer a niche in the marketplace. In addition, we consider the effective participation of the travel-sharing segment as ride-hailing; ride sharing; and car sharing (mostly electric-powered).

Modal split considers the completion on time of all works of the PAC and Avançar programs. There are more integrating policies in urban passenger transport (buses integration, using exclusive lanes and subways) and greater implementation of exclusive lanes for public transport as well as active transport measures. Moreover, there is a greater qualification of the bus fleet (adoption of advanced international standards). For automobiles and light commercial vehicles, we consider a reduction in the average age of vehicles and a more intense scrapping rate due to partnerships with automakers and dealers for the immediate scrapping of old vehicles with lines of credit for the acquisition of new ones.

There is a gradual adoption of global trends toward electrification (IEA, 2018), with incentives for resale and production, except for batteries, of light and heavy vehicles (buses). In addition, there is greater participation of sustainable programs for freight transport (e.g. PLVB) and passengers (e.g. EEMU). Nonetheless, there are more incentives to adopt modes with lower carbon intensity (tC/TJ) and energy intensity (TJ/t-km or TJ/pass-km) in the transportation matrix. Along these lines, the share of water transport (especially cabotage) is increased in the transport matrix due to the higher demand from tax incentives and the reduction of the segment's bureaucracy. Here, rail capacity is also enhanced.

For cars and light commercial vehicles, there are gradual gains in energy efficiency of 12% (up to 2025) and 18% (up to 2030), from the Rota 2030 program. Regarding the RenovaBio program, we consider the use of biokerosene in air transportation from 2025 and biomethane in road transportation until 2030. Furthermore, the supply of ethanol is close to the scenario of average growth scenario of the study "Ethanol Supply Scenarios and Otto Cycle Demand 2018-2030" (EPE, 2018), representing 47 billion liters.

Table 25 shows the targets and assumptions considered in Scenario C.

Table 25. Targets and assumptions considered in Scenario C.

FBMC (NDC/NAMA)	Assumptions
Optimizing and diversifying freight transport	Adaptation of the railway network, increasing the capacity and reusing underused lines.
	Adjust concessions or renewal contracts for railways in the scope of the Investment Partnership Program (PPI), to ensure greater integration between the lines.
	Expansion of rail and water networks with the completion of ongoing programs (PAC and Avançar).
	Tax differentiation for inland navigation and cabotage.
Expansion of public transportation, active mobility and optimization of private motorized transport	Demand captured from private transport to BRT, VLT, subway and urban trains by the conclusion on time of all ongoing works (PAC and Avançar).
	Qualification of the bus fleet (stimulating the electrification) and expansion of exclusive bus lanes.
	Measures to increase all aspects of active transport (76.10^9 pass-km)
	Integrating policies in urban passenger transport
	Effective participation of the vehicle and ride sharing segment (carsharing, carpooling and ridesharing)
Energy efficiency gains for the fossil fuel fleet, considering passengers and freight transport	Rota 2030 Program (18% of gains in energy efficiency)
	Lower carbon intensity (tC/TJ) and energy intensity (TJ/t-km or TJ/pass-km) in the transportation matrix.
	Regular efficiency gains for other segments (emphasis on PLVB for freight, and EEMU for passengers).
Fostering aviation biokerosene and greater efficiency in air transport	biokerosene in the air transport mode from 2025, with the implementation of the RenovaBio, reaching the blend of 5% (B5) in 2030.
Expansion of alternative vehicles fleet and the supply of biofuels	RenovaBio, increasing the supply of ethanol to 47 billion liters; Market share of flexible-fuel vehicles at 60%.
	Participation of electric vehicles in the fleet of 5% for light vehicles; 10% motorcycles; 12.5% urban buses and 2% trucks.
	Biodiesel Blend at 17% (B17)
	Replacement of 10% of the demand for NGV (1.215 10^3 toe in 2030) by biogas (to be consumed in the states of Rio de Janeiro and São Paulo).

4.2.4.2 Results

Scenario C presents a slight difference in the fleet compared to scenarios A and B. Part of this is due to the growth of buses, reaching a share of 0.8% of the total fleet in 2030 (against 0.6% and 0.7% in scenario A and B respectively). Commercial vehicles decrease participation by 0.4%, from 10.3% in scenarios A and B to 9.9% in Scenario C.

Cars will remain the first in vehicle stocks, reaching 58.2% of the fleet, but there are significant changes in the type of fuel consumed or the traction system. For example, BEV and hybrid cars will reach 3% and 2.6% of the car fleet, which is an optimistic figure compared to a baseline where this share is almost none. Moreover, flexible fuel vehicles will decrease their participation by 2030 to 89.1% of the total car fleet. Although this share is smaller compared to scenarios B and C, we estimate that users will opt to hydrous ethanol while fueling about 60% of the time (in line with the assumption “Expansion of alternative vehicles fleet and the supply of biofuels”).

Moreover, total fleet grows from 58,090,586 in 2017 to 73,811,963 in 2030. This result is smaller than the estimated for Scenario B (76,386,852) and A (76,324,887). Figure 24 illustrates the projected fleet from 2005 to 2030.

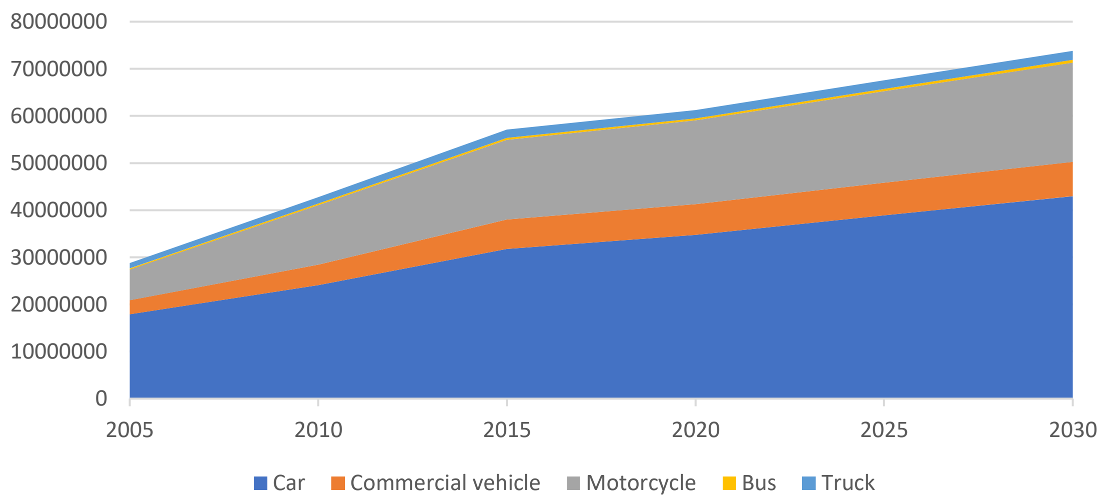


Figure 24. Fleet´s projection of road transportation in Scenario C (number of vehicles)

Figure 25 presents the trajectory of the transportation activity for all modes, according to the assumptions of Scenario C.

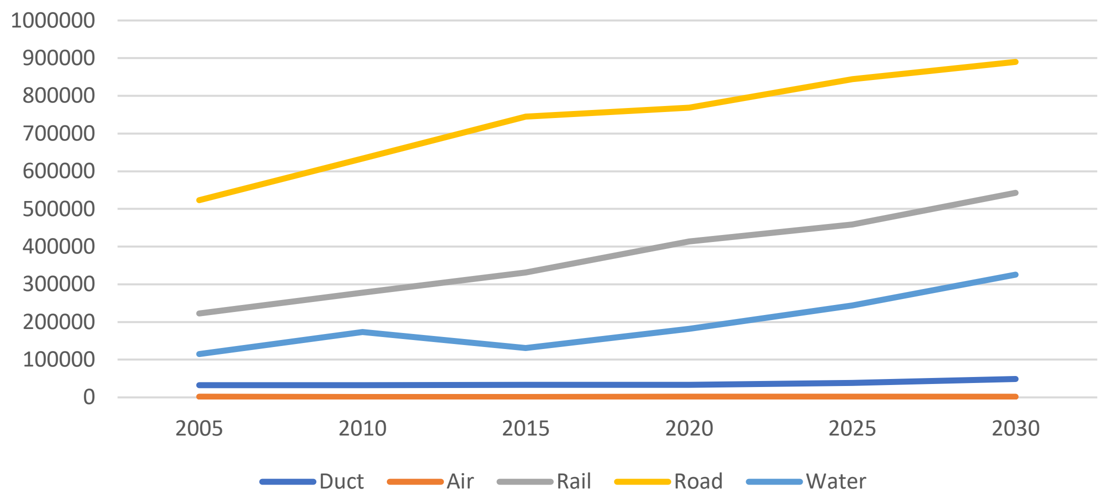


Figure 25. Transport activity of freight transportation (t-km).

Considering the total activity of the freight transportation, there are no significant changes compared to the scenarios A and B. When comparing the modal split, the share of road transportation abruptly decreases (from 58.9% in 2017 to 49.2% in 2030). This result is smaller than the estimated for Scenario A (55.1%) and B (54.2%). which means that companies will choose transportations modes with higher capacity and lower energy consumption. This is observed in the share of rail (30%) and water (18%) transportation by 2030, evidencing a more balanced transportation matrix.

Figure 26 shows the transport activity for passengers. In this case, there are no significant changes since the share of road transportation remains at 90.0% of total activity (90.8% in Scenario B).

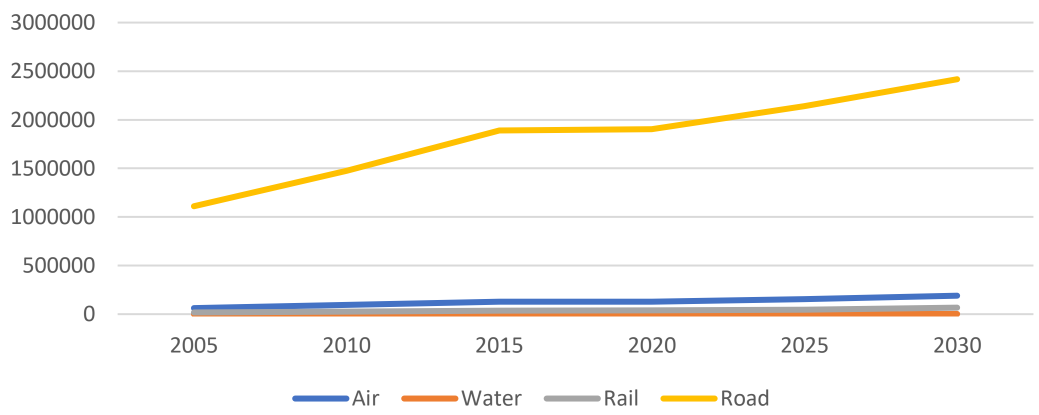


Figure 26. Transport activity of passenger transportation (pass-km).

With regards to energy consumption, Figure 27 shows the projection throughout 2030. Unlike the other scenarios, there is intensive use of renewable sources of energy 39.7% of the total (or 89,391 toe). There is a notable advance towards sustainable transportation compared to Scenario A (22.6%) and B (29.3%).

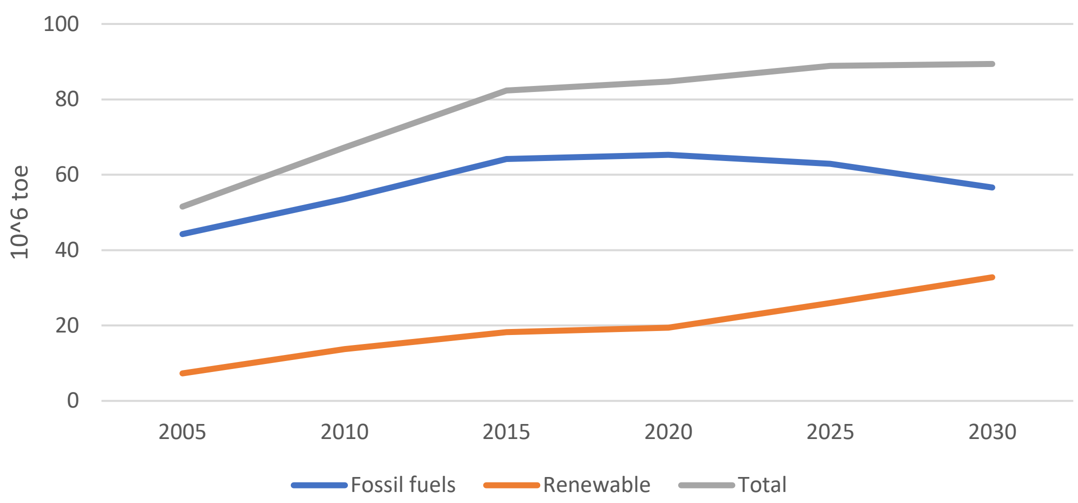


Figure 27. Energy consumption from the transport sector (million toe).

This result representing a more intensive transportation activity in biofuels and electricity, going beyond the conservative scope observed in the scenarios A and B.

Next figure shows the emissions up to 2030.

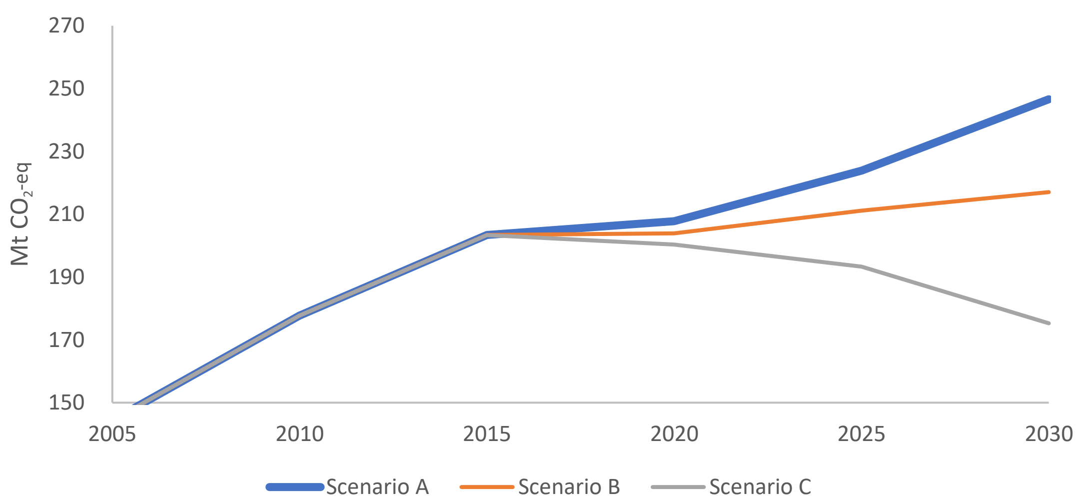


Figure 28. GHG emissions from the transport sector in Scenario C (Mt CO_2-eq)

Different from the previous scenarios, it is projected a decrease of 15.3% of GHG emissions up to 2030, compared to 2017, representing an amount of 175.2 Mt CO_2-eq. This result is 19.3% lower than the emissions observed in Scenario B (217.0 Mt CO_2-eq) and A (246.5 Mt CO_2-eq).

4.2.5. Comparative Analysis of Scenarios A, B and C – Avoided Emissions by Mitigation Actions

The synthesis of scenarios A, B, and C results are shown in Tables 26 and 27.

Table 26. Energy use from the transportation sector in scenarios A, B and C (10^3 toe)

Year	Scenario A			Scenario B			Scenario C		
	10^3 toe								
	Fossil fuels	Renewables	Total	Fossil fuels	Renewables	Total	Fossil fuels	Renewables	Total
2005	44.2	7.2	51.5	44.2	7.2	51.5	44.2	7.2	51.5
2010	53.5	13.7	67.2	53.5	13.7	67.2	53.5	13.7	67.2
2015	64.1	18.1	82.3	64.1	18.1	82.3	64.1	18.1	82.3
2016	64.4	16.7	81.1	64.4	16.7	81.1	64.4	16.7	81.1
2017	65.2	17.0	82.2	65.2	17.0	82.2	65.2	17.0	82.2
2020	66.4	17.8	84.3	66.4	17.8	84.2	65.2	19.4	84.7
2025	72.4	20.5	92.9	68.1	23.6	91.8	62.8	25.9	88.8
2030	79.7	23.2	102.9	69.9	28.9	98.9	56.5	32.7	89.3

Table 27. Emissions from the transportation sector in scenarios A, B and C (Mt CO_2-eq)

Year	Scenario A	Scenario B	Scenario C
	Mt CO2-eq		
2005	144	144	144
2010	178	178	178
2015	203	203	203
2016	204	204	204
2017	207	207	207
2020	208	204	200
2025	223	211	193
2030	247	218	175

Mitigating Impacts on Emissions

This section presents the impacts on emissions of the mitigating efforts, according to the assumptions of the Scenarios B and C. Table 28 shows the assumptions considered for estimating the mitigation impacts and the elements affected by each measure in Scenario B.

Table 28. Assumptions of Scenario B considered for estimating the mitigation impacts.

Mitigating actions		Elements
1	Shifting freight transport patterns and its infrastructure	Increasing the share of rail and water transportation, considering only investments in progress
2	Growth of biofuels supply	Biodiesel and ethanol
3	Expansion of electric vehicles fleet (BEV and hybrids)	Automobile, light commercial, motorcycle, urban buses
4	Adoption of sustainable programs for freight transportation	PLVB, Despoluir, CONPET programs
5	Adoption of sustainable programs for passenger transportation and incentives to active transportation	EEMU and Active Transport
6	Energy efficiency gains in transportation	From newly registered vehicles of air, water, rail and road transportation. Focus on engine technology and traction system.
7	Incentive for collective transportation systems	Demand captured from private transport to public transportation, bus fleet qualification, bus renewal schemes, integrating policies (fares), expansion of exclusive bus lanes, and optimization of public transportation

To estimate the impact of each mitigating action on the respective transportation elements, we employed a decomposition analysis approach, resulting in the carbon saving potential presented in Table 29. Here, the order of mitigating measures indicates which actions were analyzed first. It is important to state that all mitigating actions of the transportation sector are closely related, being is complex to isolate all variables in question, for instance, energy efficiency gains are observed also when expanding the electric fleet or optimizing freight transport. In this case, we opted to restrict the energy efficiency gains to those observed in the new internal combustion engines.

Table 29. Mitigating impacts from the assumptions in Scenario B (Mt CO_2-eq)

Mitigating actions	Difference in Mitigation (Scenarios A-B) Mt CO_2-eq			
	2020	2025	2030	2020 to 2030
Changes in freight transport patterns and infrastructure	0	1.8	4.0	23
Increased use of biofuels	1.5	6.7	13	82
Expansion of the electric vehicles fleet (battery electric vehicles - BEV and hybrids)	0	0.37	3.4	13
Improved logistics of freight transportation	-	0.80	2.0	11
Improved logistics of passenger transportation and increased active transportation	-	0.58	1.3	7.3
Gains in energy efficiency in the transportation sector	1.5	1.6	3.8	25
Increased use of mass transportation systems	0.82	1.0	2.4	16
Total	**3.8**	**13**	**30**	**178**

The mitigating action that presents the greatest impact on carbon saving potential is "Growth in biofuels supply" with 46.3% of the total potential (82.2 Mt CO_2-eq). Moreover, 53% of its results is related to the biodiesel supply, while 47% results from ethanol supply. As stated, Scenario B does not consider the use of biomethane and biokerosene.

Energy efficiency gains are also an important measure to mitigate emissions (25.4 Mt CO_2-eq or 14.3% of the total mitigation), as well as shifting freight transport patterns, with 12.7% of the total mitigation. Finally, the expansion of the electric fleet and sustainable programs of freight and passenger transportation accounts for 7.4%, 6.1% and 4.1% respectively.

In respect to the impacts on emissions of the mitigating efforts in Scenario C, Table 30 shows the assumptions considered for estimating the mitigation impacts and the elements affected by each measure. The order is the same as Scenario B.

Table 30. Assumptions of Scenario C considered for estimating the mitigation impacts.

Mitigating actions		Elements
1	Shifting freight transport patterns and its infrastructure	The same elements of Scenario B, but setting more ambitious targets
2	Growth of biofuels supply	The same as Scenario B, adding biomethane and biokerosene
3	Expansion of electric vehicles fleet (BEV and hybrids)	The same as Scenario B, adding light and medium trucks
4	Adoption of sustainable programs for freight transportation	The same elements of Scenario B, but setting more ambitious targets

Mitigating actions		Elements
5	Adoption of sustainable programs for passenger transportation and incentives to active transportation	The same elements of Scenario B, but setting more ambitious targets
6	Energy efficiency gains in transport the transportation sector	The same elements of Scenario B, but setting more ambitious targets
7	Incentive for collective transportation systems	The same elements of Scenario B, but setting more ambitious targets

As observed, this scenario introduces the use of biokerosene and biomethane (from 2025 in air and road transportation, respectively). Carbon saving potential of each measure is presented in Table 31.

Table 31. Mitigating impacts from the assumptions in Scenario C (Mt CO_2-eq)

	Difference on Mitigation (Scenarios A - C) Mt CO_2-eq			
Mitigating actions	**2020**	**2025**	**2030**	**2020 to 2030**
Changes in freight transport patterns and infrastructure	0.0	4.0	12	55
Increased use of biofuels	1.5	15	27	162
Expansion of the electric vehicles fleet (battery electric vehicles - BEV and hybrids)	0.10	1.5	12	44
Improved logistics of freight transportation	1.3	2.3	4.4	29
Improved logistics of passenger transportation and increased active transportation	1.2	2.2	3.5	25
Gains in energy efficiency in the transportation sector	2.0	3.6	7.7	47
Increased use of mass transportation systems	1.3	1.7	5.3	29
Total	**7.4**	**31**	**71**	**390**

The growth in biofuels supply is still the action that presents the greatest mitigation of carbon emissions (41.5% of the total), however, this proportion is lower when compared with scenario B (46.3%). The novelty is that shifting freight transport patterns is the second action that most mitigate emissions (13.9%), followed by energy efficiency gains, with 12.1% (or 47.4 Mt CO_2-eq). The expansion of electric vehicles fleet is responsible for 11.1%, a great expansion compared to Scenario B. Collective transportation contributes with 7.3% of the mitigating potential up to 2030, the same result as adopting sustainable programs for freight transportation, e.g. PLVB (7.3%). Furthermore, the adoption of sustainable programs for passenger transportation accounts for 6.4%.

Table 32 shows the comparison between the carbon saving potential from Scenario C and B up to 2030.

Table 32. Comparing impacts between Scenario C and B (Mt CO_2-eq)

Mitigating actions	Difference in mitigation (Scenarios B–C) Mt CO_2-eq			
	2020	**2025**	**2030**	**2020 to 2030**
Changes in freight transport patterns and infrastructure	-	2.3	7.5	32
Increased use of biofuels	-	8.6	15	80
Expansion of the electric vehicles fleet (battery electric vehicles - BEV and hybrids)	0.10	1.1	8.5	30
Improved logistics of freight transportation	1.3	1.5	2.4	18
Improved logistics of passenger transportation and increased active transportation	1.2	1.6	2.2	18
Gains in energy efficiency in the transportation sector	0.50	2.0	3.9	22
Increased use of mass transportation systems	0.50	0.70	2.9	13
Total	**3.5**	**18**	**42**	**212**

In 2020, there are no significant mitigations comparing both scenarios due to most of the investments on infrastructure, incentives on electromobility and sustainable programs are not fully implemented at this time. From 2025, freight transportation patterns and biofuels supply present a more carbon-intensive abatement, maintaining the trajectory by 2030.

The greater expansion is observed in the electric vehicles fleet (BEV and hybrids), reaching the New Policies Scenario (NPS) of the “Rest of the world” category for 2030 (IEA, 2018). This is due to cost reductions in batteries and a larger number of electric vehicles stocks from 2025.

More information about the method for estimating energy consumption, transport activity and GHG emissions of the baseline and projections are detailed in the Appendix section.

4.3. INDUSTRY

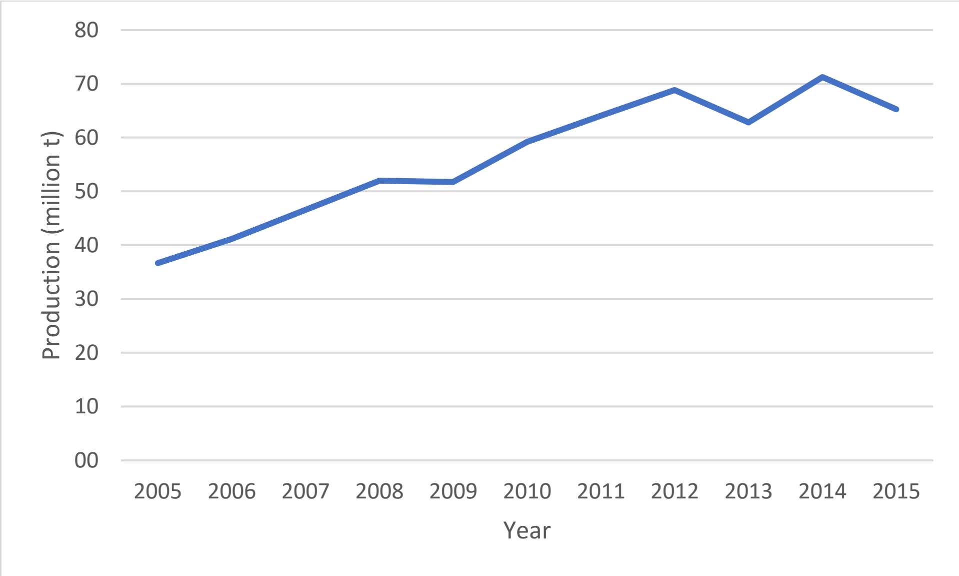
4.3.1. Emissions Sources

In the industrial sector, GHG emissions arise from (i) energy consumption and (ii) industrial processes and product use (IPPU). Energy is used in the industrial sector for a wide range of purposes, such as process and assembly, steam and cogeneration, process heating and cooling, and lighting, heating, and air conditioning for buildings (EPA, 2017). Emission sources are also released from industrial processes that chemically or physically transform materials (for example, the blast furnace in the iron and steel industry, ammonia and other chemical products manufactured from fossil fuels used as chemical feedstock and the cement industry are notable examples of industrial processes that release a significant amount of emissions. During these processes, many different greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), can be produced. In addition, greenhouse gases often are used in products such as refrigerators, foams or aerosol cans. For example, HFCs are used as alternatives to ozone-depleting substances (ODS) in various types of product applications. Similarly, sulfur hexafluoride (SF_6) and N_2O are used in several industrial products (e.g., SF_6 used in electrical equipment, N_2O used as a propellant in aerosol products, etc.) (IPCC, 2006).

In this section, the emissions accounted r are those from fuel combustion for energy purposes (energy sources), and emissions from fuels consumed as feedstock, from industrial processes and product use (IPPU). Emissions arising from the generation of electricity consumed in the industrial sector are accounted for in the energy supply section.

4.3.1.1 Cement Industry

The Brazilian cement industry is the sixth largest in the world with 100 factories and an annual cement production capacity of 100 Mt. Figure 29 shows the Brazilian annual cement production, in Mt, between 2005 and 2015. In 2005, the cement production was 37 Mt, growing to 59 Mt in 2010 and 65 Mt in 2015, an increase of 75% in 10 years (SNIC, 2017).



Source: self-elaboration based on SNIC (2017)

Figure 29. Annual cement production in Brazil between 2005 and 2015 (Mt)

Table 33 shows the energy consumption by source for cement production between 2005 and 2016 in million toe. Petroleum coke is the main energy source used in this branch, accounting for 71% of the total energy consumed in 2016 (EPE, 2017).

Table 33. Energy consumption in the Cement Industry in Brazil between 2005 and 2016 (1,000 toe)

SOURCES	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	1,000 toe											
Natural Gas	17	18	24	25	26	23	29	55	31	25	12	5
Mineral Coal	45	59	51	53	51	52	98	108	133	123	70	60
Firewood	0	0	0	0	0	0	37	81	83	79	70	64
Diesel Oil	35	33	41	43	42	45	65	70	68	72	60	55
Fuel Oil	23	23	26	29	29	8	20	17	17	14	9	5
Electricity	377	403	450	497	500	553	598	645	673	681	611	568
Charcoal	249	261	222	249	55	63	178	142	128	122	109	99
Petroleum Coke	1,881	2,031	2,300	2,561	2,727	3,161	3,582	3,578	3,696	3,763	3,386	3,048
Other Not Specified	275	300	330	362	349	350	427	440	458	460	417	366
Total	**2,902**	**3,129**	**3,444**	**3,820**	**3,778**	**4,255**	**5,033**	**5,135**	**5,287**	**5,338**	**4,744**	**4,271**

Source: Author based on EPE (2017)

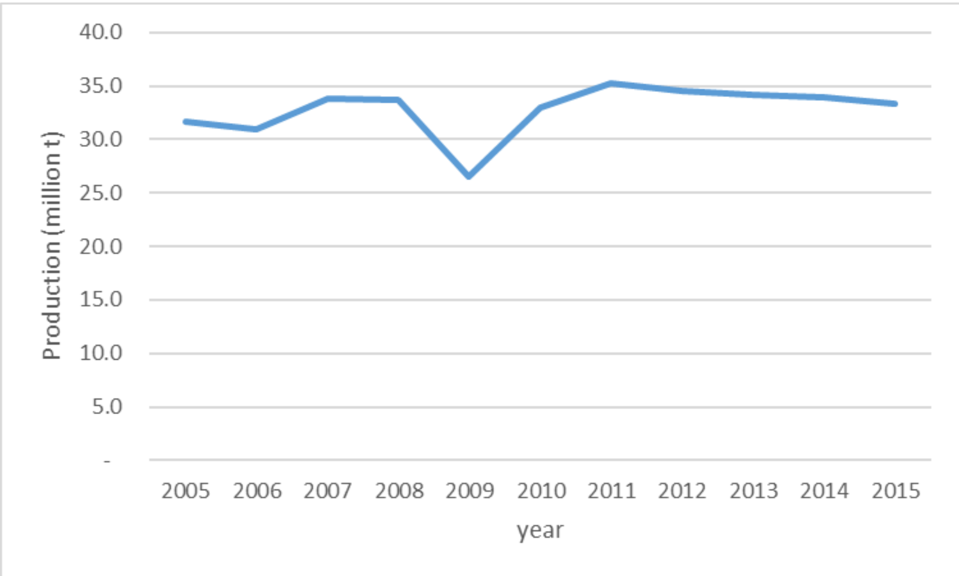
The cement production process consists of three stages. The first is the preparation of the raw material, usually limestone and clay, through grinding and sifting. The second, calcination, consists in taking the product of the preparation to the calcination kiln, where temperatures can reach 1,500ºC, obtaining clinker as an intermediate product. Finally, the clinker is cooled, milled and then mixed with gypsum and other additives forming the cement, more specifically Portland cement (Henriques, 2010).

Emissions in this industrial branch arise from fuels used to generate energy for direct heating, process heating and driving force. Other emissions arise from the production of clinker, with limestone ($CaCO_3$) decarbonization producing lime (CaO) and CO_2 (Henriques, 2010; MCTIC, 2010).

4.3.1.2 Iron and Steel Industry

With 29 industrial plants, the Brazilian steel industry is the largest in Latin America and the ninth in the world, with a production capacity of 48 Mt of steel per year, representing 2% of the world and 52% of the Latin American (MME, 2017).

Figure 30 shows the Brazilian iron and steel production between 2005 and 2015, that grew 5.7% (from 31.6 to 33.3 Mt) in the period with no significant variation in the shares of iron and steel (EPE, 2017).



Source: Author based in SNIC (2017)

Figure 30. Annual iron and steel production in Brazil between 2005 and 2015 (Mt)

Table 34 shows the energy sources used between 2005 and 2015. The main source was coal coke (45% of the total) followed by charcoal (18%) in 2015. The share of charcoal has decreased over the years, from 25% in 2005 to 18% in 2015.

Table 34. Energy consumption in the Iron and Steel Industry in Brazil between 2005 and 2015 (1,000 toe)

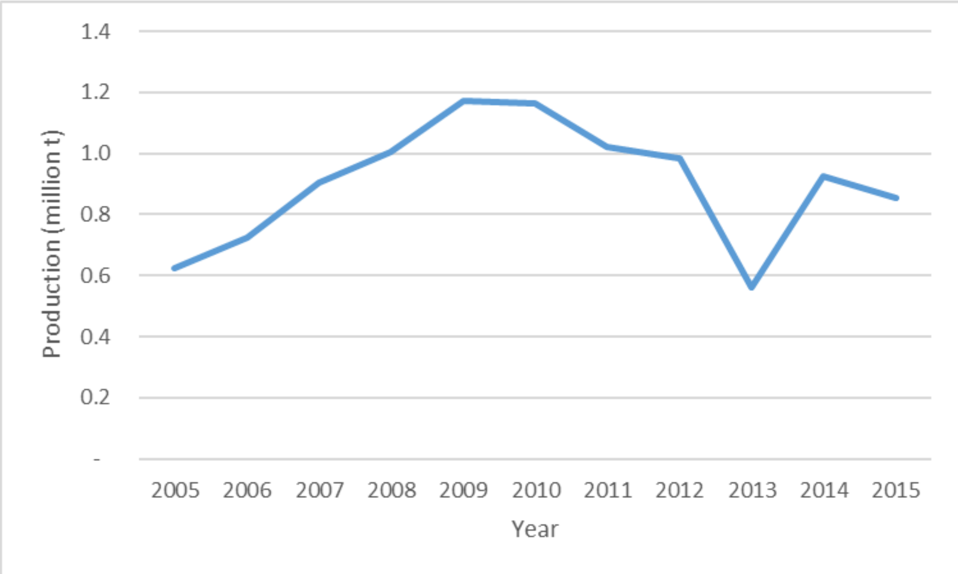
Sources	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	1,000 toe										
Natural Gas	1,113	1,105	1,214	1,158	695	897	997	1,067	1,020	1,036	1,223
Mineral Coal	1,829	1,813	1,939	2,052	1,578	1,772	1,924	1,854	1,808	2,053	2,124
Diesel Oil	44	40	14	14	14	15	35	38	37	35	29
Fuel Oil	82	107	145	142	114	168	29	29	40	35	2
Liquefied Petroleum Gas	100	85	88	97	90	71	26	20	19	26	25
Kerosene	1	1	0	0	1	0	0	0	0	0	0
Coke Oven Gas	1,016	980	1,039	1,065	1,011	1,250	1,288	1,237	1,200	1,200	1,148
Coal Coke	6,067	5,763	6,320	6,289	4,969	7,153	7,750	7,495	7,309	7,237	7,441
Electricity	1,397	1,452	1,579	1,602	1,281	1,613	1,714	1,696	1,691	1,671	1,609
Charcoal	4,804	4,636	4,775	4,679	2,724	3,372	3,492	3,338	3,021	2,962	2,988
Other Sec. Petroleum	462	464	551	528	531	134	145	139	129	133	135
Total	**16,914**	**16,446**	**17,664**	**17,627**	**13,008**	**16,445**	**17,401**	**16,914**	**16,274**	**16,387**	**16,725**

Source: self-elaboration based in EPE (2017)

There are two main processes to make crude steel: in a blast furnace that uses iron ore or scrap and coke, mineral coal or charcoal, and in an electric arc furnace that reduces iron or scrap directly (Henriques, 2010; Pinto, 2017).

4.3.1.3 Iron Alloy Industry

The production of iron alloys in Brazil has been decreasing over the recent years, as shown in Figure 31, from 0.6 Mt in 2005 to 1.2 Mt in 2010 and 0.9 in 2015 (MME, 2009. 2010, 2017). According to ABRAFE (2015), the main reason for this fall is the electricity prices that have been increasing in recent times.



Source: Author based in MME (2009, 2010, 2017)

Figure 31. Annual iron alloy production in Brazil between 2005 and 2015 (Mt)

The energy consumption between 2005 and 2015 is shown in Table 35. In 2005 the total energy consumption reached 1,613 thousand toe and in 2015 the consumption decreased to 1,206, *i.e.* a reduction of 26%. The two main energy sources in this branch are (i) electricity representing 43% of the total amount and (ii) charcoal and firewood with 38%.

Table 35. Energy consumption in the Iron Alloy Industry in Brazil between 2005 and 2015 (1,000 toe)

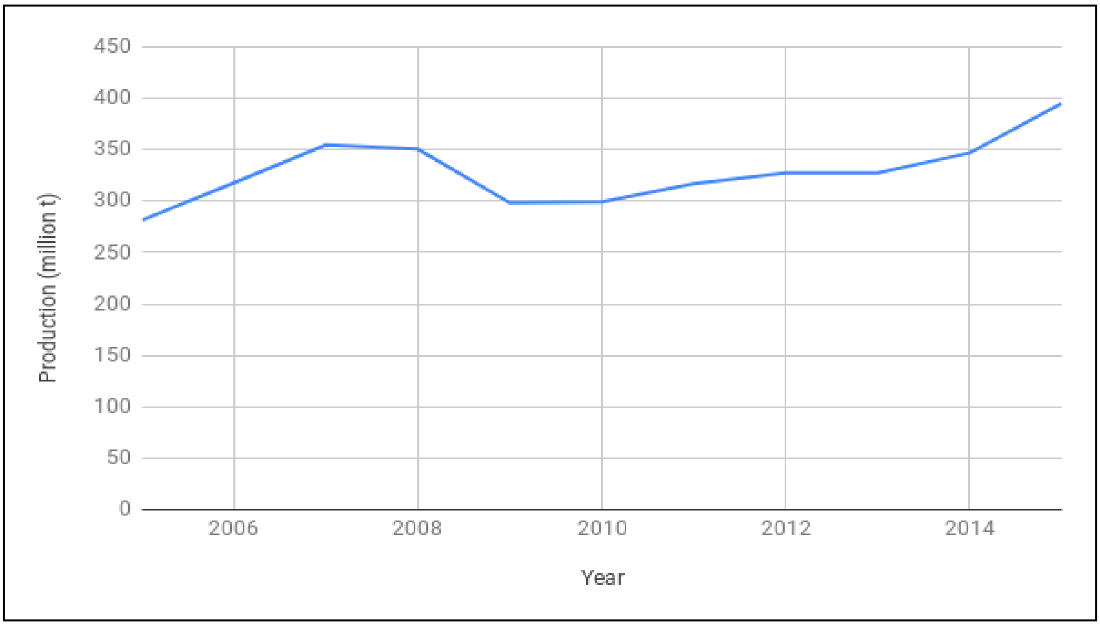
Sources (1,000 toe)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	2	2	29	2	2	2	3	3	22	20	6
Coal of Mineral Coal	92	93	104	119	92	107	96	93	84	78	70
Electricity	665	662	746	751	580	728	678	666	626	582	524
Coal and Wood Coal	662	668	715	730	564	660	592	580	544	506	455
Other Not Specified	192	187	209	210	210	198	187	223	229	245	151
Total	**1,613**	**1,613**	**1,803**	**1,811**	**1,447**	**1,695**	**1,555**	**1,565**	**1,505**	**1,431**	**1,206**

Source: Author based in EPE (2017)

4.3.1.4 Mining and Pelleting Industry

Mining and pelleting comprehends an industrial activity related to the extraction of metallic minerals, *e.g.* iron ore (70% of all products), bauxite, copper, manganese, nickel, lead, or non-metallic minerals limestone, gypsum, sea salt, and others (Henriques, 2010; Branco, 2017).

Figure 32 presents the total amount of iron ore produced in Brazil between 2005 and 2015. The production was about 280 Mt of iron ore in 2005, 299 Mt in 2010 and 395 Mt in 2015, a growth of 40% in the period (DNPM, 2006, 2016).



Source: Author based in DNPM (2006; 2016)

Figure 32. Annual mining and pelleting production in Brazil between 2005 and 2015 (Mt)

Table 36 presents the amount of energy consumed in the mining and pelleting branch between 2005 and 2015. The energy consumption has grown in this period 21%, from 2,764 thousand toe in 2005 to 3,346 thousand toe in 2015. The electricity consumption was the main energy source, representing about 33% of the total.

Table 36. Energy consumption in the Mining and Pelleting Industry in Brazil between 2005 and 2015 (1,000 toe).

SOURCES (1,000 toe)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	270	260	233	426	170	628	695	673	634	707	657
Coal	550	543	579	592	342	424	500	450	452	431	478
Diesel	211	221	242	249	224	260	366	384	396	424	395
Fuel Oil	572	650	763	502	351	371	200	191	203	166	166
Liquefied Petroleum Gas	32	20	21	22	22	19	22	31	38	28	22
Kerosene	1	1	1	1	2	1	1	1	1	1	1
Electricity	829	863	928	970	708	972	1,027	1,011	1,018	1,057	1,095
Petroleum Coke	300	318	429	437	436	508	525	498	506	544	533
Total	**2,764**	**2,875**	**3,195**	**3,198**	**2,255**	**3,182**	**3,335**	**3,240**	**3,247**	**3,358**	**3,346**

Source: Author based in EPE (2017)

4.3.1.5 Non-Ferrous and Other Metals Industry

Non-ferrous and other metals branch comprehends the production of aluminum, copper, zinc, silicon metal and other metals presented in Table 37. The total amount of non-ferrous and other metals produced per year had a reduction of 30%, from 2,449 Mt in 2005 to 1,694 Mt in 2015. The aluminum production had its share reduced from 62% in 2005 of all non-ferrous and other metals produced to 46% in 2015 (MME, 2010, 2017).

Table 37. Annual production in Non-Ferrous and Other Metals Industry in Brazil between 2005 and 2015 (Mt).

Non-ferrous and other metals	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	Mt										
Aluminum	1,497	1,603	1,654	1,661	1,536	1,536	1,440	1,436	1,304	962	772
Lead	105	143	143	143	104	114	116	165	152	160	176
Copper	306	353	359	384	201	218	218	179	261	241	241
Tin	9	9	10	11	10	7	7	10	15	22	18
Nickel	37	36	37	36	33	42	43	-	58	78	77
Silicon metal	229	226	225	220	154	184	210	225	230	230	140
Zinc	266	272	265	249	242	288	284	246	242	246	270
Total	**2,449**	**2,642**	**2,693**	**2,702**	**2,280**	**2,389**	**2,318**	**2,262**	**2,261**	**1,939**	**1,694**

Source: Authors based in MME (2010, 2017)

Table 38 shows the energy consumption by source between 2005 and 2015. From 5,403 thousand toe consumed in 2005, the energy consumption in the non-ferrous and other metal branch grew to 6,492 thousand toe in 2010, an increase of 20%. However, the consumption fell by 13%, to 5,646 thousand toe, from 2010 to 2015.

Table 38. Energy consumption in Non-Ferrous Metals and Other Metals Industry in Brazil between 2005 and 2015 (1,000 toe).

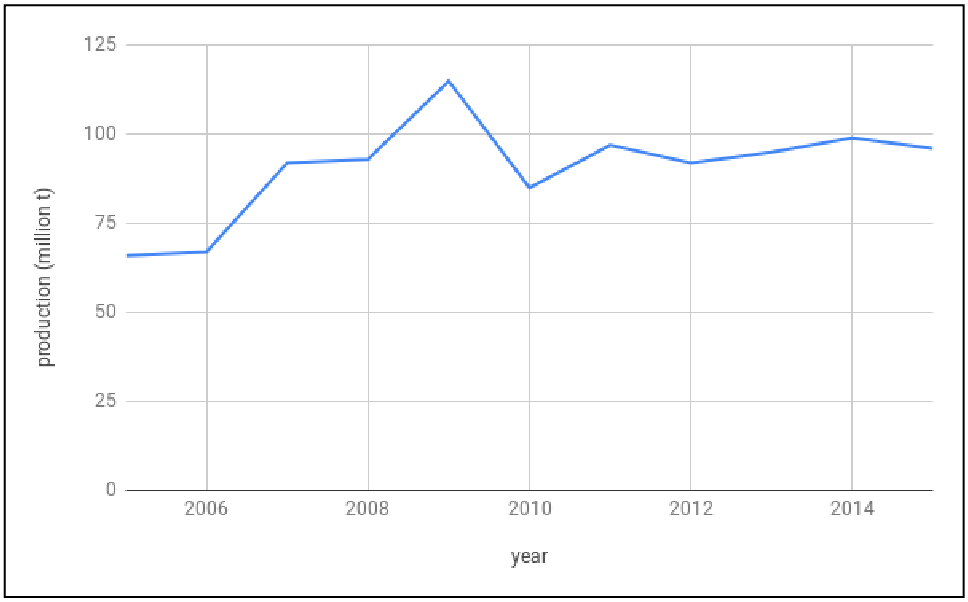
Source (1,000 toe)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	490	528	632	675	405	727	776	857	942	896	593
Fuel Oil	1,147	1,091	1,124	1,062	987	1,098	1,177	1,163	1,148	1,200	1,238
LNG	18	85	91	85	86	79	47	44	53	51	45
Coal and Coke	228	233	243	178	165	768	1,022	1,030	1,023	1,062	935
Electricity	2,999	3,174	3,273	3,366	3,114	3,198	3,308	3,255	3,104	2,798	2,315
Charcoal	8	8	9	9	8	9	9	10	11	14	11
Other Sec. Petroleum	513	548	583	590	588	612	734	699	654	595	510
Total	**5,403**	**5,668**	**5,954**	**5,966**	**5,353**	**6,492**	**7,074**	**7,057**	**6,935**	**6,616**	**5,646**

Source: Author based in EPE (2017)

4.3.1.6 Chemical Industry

The chemical branch is characterized by a wide diversity of products, *e.g.* basic petrochemicals, intermediates for fertilizers, plastics, plasticizers, synthetic and fibers, industrial solvents, thermoplastic resins, and others. The Brazilian chemical industry had one thousand plants and revenue of US $ 157 billion in 2011, ranking the sixth position worldwide (Dantas, 2013 *apud* de Oliveira, 2017).

Figure 33 shows the total amount of chemical products made in Brazil between 2005 and 2015. The production went from 66 Mt , reaching 115 Mt in 2009 and decreasing to 96 Mt in 2015. In the period the total increase was about 45%.



Source: Authors based in IBGE, (2005 – 2015)

Figure 33. Annual chemicals production in Brazil between 2005 and 2015 (Mt)

Table 39 shows the energy consumption by source in the chemical industry between 2005 and 2015. In 2005, the energy consumption was 7,132 thousand toe, reaching 7,214 thousand toe in 2010, a 1.2% growth, and falling to 6,874 in 2015. In the period, total energy consumption decreased by 4%.

Table 39. Energy consumption in Chemical Industry in Brazil between 2005 and 2015 (1,000 toe)

SOURES (10,000 toe)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	2,159	2,236	2,259	2,323	2,276	2,289	2,437	2,218	2,037	2,022	2,222
Steam Coal	80	63	85	92	71	125	105	164	152	169	172
Firewood	50	52	51	51	45	49	48	47	50	49	48
Sugarcane Bagasse	96	98	105	95	95	93	92	90	91	89	85
Diesel	133	137	152	154	136	27	12	13	23	20	18
Fuel Oil	622	643	481	476	476	233	377	328	424	323	207
LPG	21	61	62	66	67	64	176	190	192	217	215
Electricity	1,814	1,880	1,985	1,901	1,996	2,055	2,014	2,023	1,962	1,922	1,940
Charcoal	17	17	17	17	18	20	20	19	19	18	18
Other Sec. Petroleum	2,139	2,178	2,517	2,033	2,169	2,259	2,158	2,145	2,035	1,880	1,950
Total	**7,132**	**7,364**	**7,715**	**7,209**	**7,350**	**7,214**	**7,440**	**7,237**	**6,985**	**6,708**	**6,874**

Source: self-elaboration based in EPE (2017)

4.3.1.7 Food and Beverage Industry

Food and beverage is a major industry branch in the Brazilian economy with a R$ 614 billion revenue in 2016, about 10% of the Brazilian GDP and 25.4% of the transformation industry revenue (ABIA, 2017).

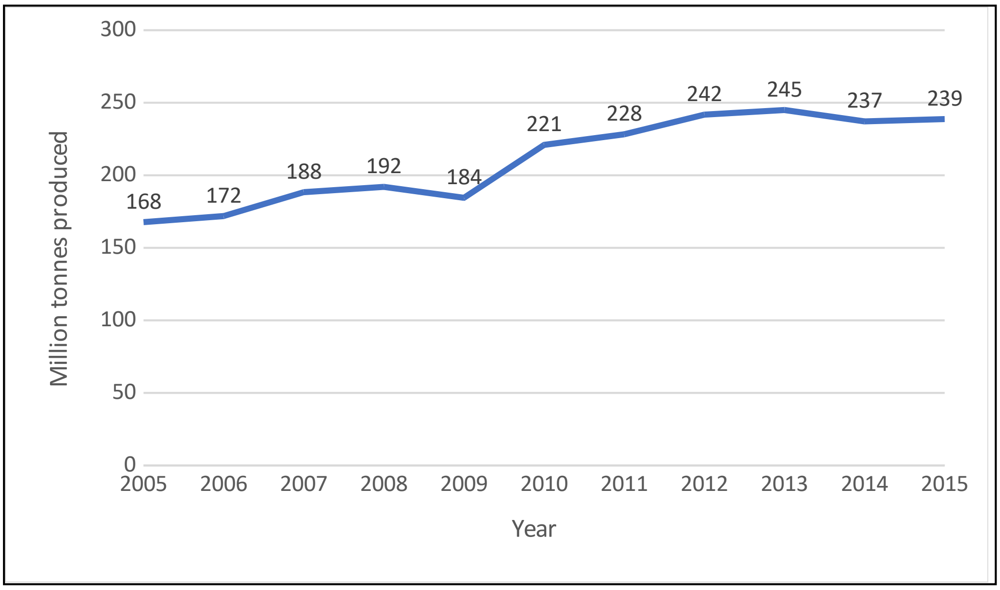
This branch is highly diversified, with 850 different food and beverage products (CNI 2010). Main products in 2010 are shown in Table 40.

Table 40. Food and Beverage production per product in 2010 (ton)

Product	Amount produced (ton)
Meat products	18,927,430
Tea, coffee and cakes	7,188,382
Oil and fat	6,111,537
Dairy products	11,766,629
Wheat derivatives	4,117,392
Fruit and vegetable derivatives	558,308
Miscellaneous	26,824,122
Chocolate cocoa and candies	910,786
Canned food and fish	263,066
Drinks	30,845,588

Source: Author from publication in IBGE (2014)

The total amount of food and beverage produced from 2005 to 2015 is presented in Figure 34. In the first year, 2005, the total amount was 168 Mt , growing 9.5% by 2010, and reaching 239 Mt in 2015, an increase of 42% in the total period.



Source: Author based on IBGE (2005-2015)

Figure 34. Annual food and beverage production in Brazil between 2005 and 2015 (Mt)

Table 41 presents the energy consumption in this branch between 2005 and 2016. It is worth noting the high consumption of sugarcane bagasse, the main energy source, with 17,524 thousand toe in 2016, representing 74% of the total amount.

Table 41. Energy consumption in the Food and Beverage Industry in Brazil between 2005 and 2016 (1,000 toe)

SOURCES (10,000 toe)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Natural Gas	511	559	587	581	552	662	652	720	688	736	834	833
Steam Coal	62	39	46	37	48	71	90	68	69	66	65	51
Firewood	1,813	1,831	1,885	1,999	2,039	2,267	2,312	2,319	2,273	2,250	2,171	2,150
Sugarcane Bagasse	13,050	15,224	16,116	15,353	16,148	17,248	16,861	17,844	17,213	16,120	15,485	17,524
Diesel Oil	61	65	77	82	82	148	191	212	260	249	239	242
Fuel Oil	529	412	451	467	467	325	318	271	198	177	119	87
Liquefied Petroleum Gas	125	144	174	190	187	202	225	266	282	315	320	331
Electricity	1,777	1,848	1,926	1,985	2,025	2,319	2,342	2,423	2,355	2,324	2,242	2,314
Total	**17,926**	**20,122**	**21,262**	**20,694**	**21,547**	**23,244**	**22,992**	**24,123**	**23,338**	**22,238**	**21,475**	**23,531**

Source: Author based in EPE (2017)

Table 42 shows the main final energy use in the food and beverage industry.

Table 42. Examples of final energy use in the Food and Beverage Industry

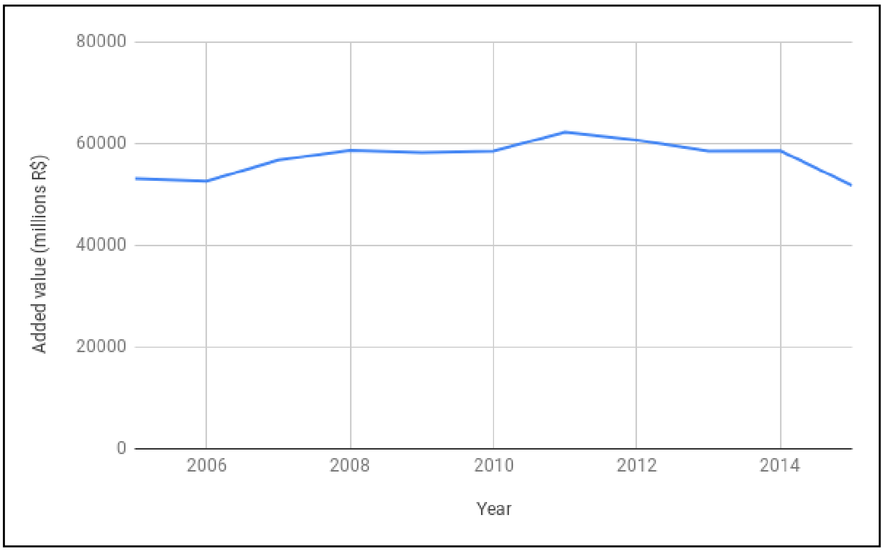
Final energy use	Examples
Direct Heating	Roasting operations; toasting operation; drying operation; sterilizing operations
Process heat	Cooking; frying; fermentation
Refrigeration	Refrigeration; freezing; storage and air conditioning
Driving Force	Extrusion operations; milling; crushing.
Illumination	Illumination of buildings and plants

Source: Author based on HENRIQUES (2010) *apud* COUTO (2017)

4.3.1.8 Textile Industry

The Brazilian textile branch ranks the fourth worldwide position, producing about 5 Mt of fibers and filaments, made-up articles and textile articles per year (IEMI 2014 apud Pacheco 2017).

Figure 35 shows the value added of the textile industry between 2005 and 2015 in Brazil. In 2005 the value added by the textile industrial branch was 53 thousand million reais, reaching 58 thousand million reais in 2010, a relative growth of 10% but falling to 51 million reais in 2015, 4% lower than 2005.



Source: Author.

Figure 35. Annual value added in the textile production in Brazil between 2005 and 2015 (million R$).

Table 43 shows the energy consumption by source in the textile industry between 2005 and 2015. In the first year presented, the energy consumption was 1,202 thousand toe, peaking 1,212 thousand toe, in 2010, and subsequently falling 26% to 895 thousand toe in 2015.

Table 43. Energy consumption in Textile Industry in Brazil between 2005 and 2015 (1,000 toe)

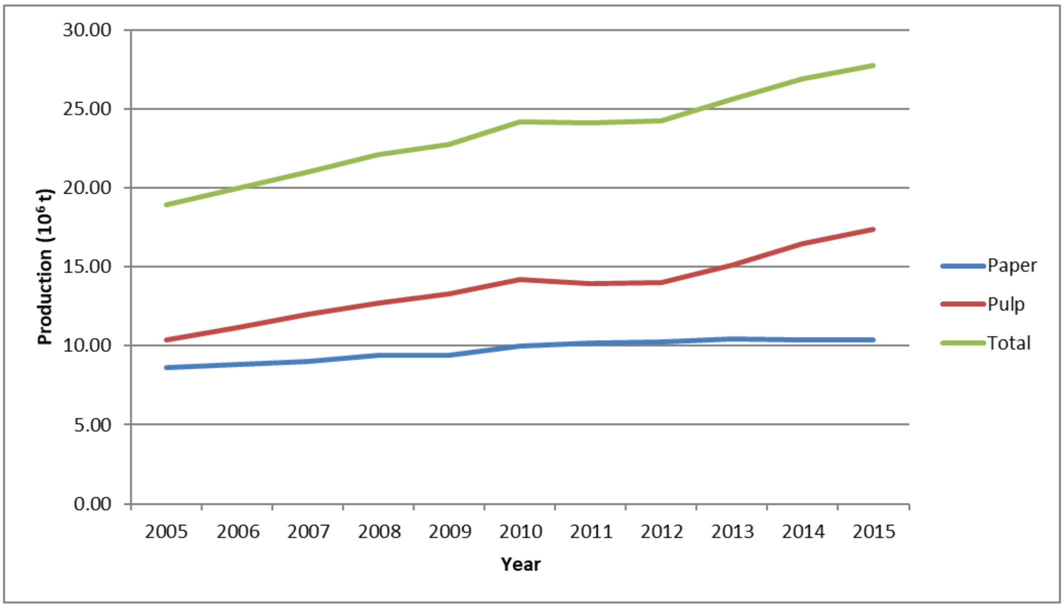
SOURCE	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	327	334	372	322	300	329	327	317	312	248	215
Firewood	93	94	96	95	88	92	76	73	71	69	62
Diesel	2	2	3	3	3	3	6	8	6	5	2
Fuel Oil	112	105	108	106	106	64	55	45	46	34	19
LPG	9	9	11	10	10	10	29	28	31	40	37
Electricity	660	669	685	672	665	715	707	645	635	622	560
TOTAL	**1,202**	**1,213**	**1,275**	**1,208**	**1,172**	**1,212**	**1,201**	**1,116**	**1,101**	**1,017**	**895**

Source: Author based in EPE (2017)

4.3.1.9 Pulp and Paper Industry

The Brazilian pulp and paper branch is one of the largest worldwide occupying the fourth position in pulp production and the tenth in paper production.

Figure 36 shows the production of pulp and paper between 2005 and 2015. This industrial branch grew 46% between 2005 and 2015, from 19 Mt of pulp and paper to 28 Mt .



Source: Author based in IBA (2017)

Figure 36. Annual pulp and paper production in 10^6 t between 2005 and 2015 in Brazil (Mt).

Table 44 shows the energy consumption by source between 2005 and 2015 in the pulp and paper industry. In this period, the energy consumption grew 52%, from 7,713 thousand toe in 2005 to 11,729 in 2015. It is worth noting the increase in the black liquor consumption, a source that reached a share of 50% of total energy demand in 2015.

Table 44. Energy consumption in Pulp and Paper Industry between 2005 and 2015 in Brazil (1,000 toe)

SOURCES	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	519	560	597	509	483	676	730	769	809	848	805
Steam Coal	85	82	80	81	84	112	126	124	124	117	86
Firewood	1,172	1,252	1,296	1,374	1,449	1,513	1,516	1,532	1,616	1,713	1,833
Sugarcane Bagasse	33	34	36	37	39	41	41	24	25	25	27
Black Liquor	3,342	3,598	3,842	4,078	4,335	4,711	4,721	4,640	4,983	5,432	5,837
Other Renewable Sources	540	660	713	756	786	870	871	777	831	656	691
Diesel Oil	60	44	65	68	68	76	115	124	137	164	173
Fuel Oil	633	432	471	499	499	466	390	328	304	365	341
LPG	56	25	29	29	30	31	45	50	60	73	72
Electricity	1,270	1,330	1,426	1,528	1,574	1,636	1,641	1,636	1,684	1,780	1,864
Total	**7,713**	**8,016**	**8,555**	**8,957**	**9,346**	**10,131**	**10,195**	**10,003**	**10,574**	**11,173**	**11,729**

Source: Author based in EPE (2017)

4.3.1.10 Ceramic Industry

The ceramic industry has two main categories of products: red ceramic, *e.g.* bricks and roof tiles, and white ceramic, e.g. floors, tiles, tableware, sanitary ware, among other products with higher added value (Henriques, 2010). There are about 7,030 companies in the red ceramic branch with a production of over 40 million units per year and 675 companies in the white ceramic branch with a revenue of 13 billion reais per year (INT, 2012).

Table 45 shows the ceramic industry energy consumption by source between 2005 and 2015. The consumption in 2005 was 3,412 thousand toe of which 50% was firewood. In 2015, the consumption reached 4,614 thousand toe, an increase of 35% (EPE, 2017).

Table 45. Energy consumption in the Ceramic Industry in Brazil between 2005 and 2015 (1,000 toe).

SOURCES	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	831	901	960	1,007	977	1,141	1,288	1,314	1,354	1,339	1,324
Steam Coal	70	42	33	44	31	30	52	35	39	50	62
Firewood	1,710	1,762	1,885	2,122	2,081	2,275	2,387	2,458	2,631	2,657	2,312
Other Recovery	36	32	35	53	53	58	61	62	65	66	59
Diesel Oil	9	8	7	8	8	6	31	28	24	26	24
Fuel Oil	268	285	313	322	322	295	125	113	125	102	59
LPG	148	151	153	166	176	165	169	161	163	171	173
Other of Petroleum	71	76	170	173	178	195	270	275	289	292	262
Electricity	270	276	284	298	301	319	342	359	380	376	339
Total	**3,412**	**3,533**	**3,841**	**4,193**	**4,128**	**4,485**	**4,724**	**4,803**	**5,069**	**5,079**	**4,614**

Source: Author based in EPE (2017)

4.3.1.11 Other Industries

Other Industries comprises all other branches that were not previously covered. Figure 37 shows the value added of the Other Industries between 2005 and 2015. In 2005, it was 167 million reais, growing to 285 million reais in 2010, an increase of 70%. After 2013 the annual value added started to fell, reaching 218 million reais in 2015, 76% of the 2010 value, but still 30% higher than in 2005.

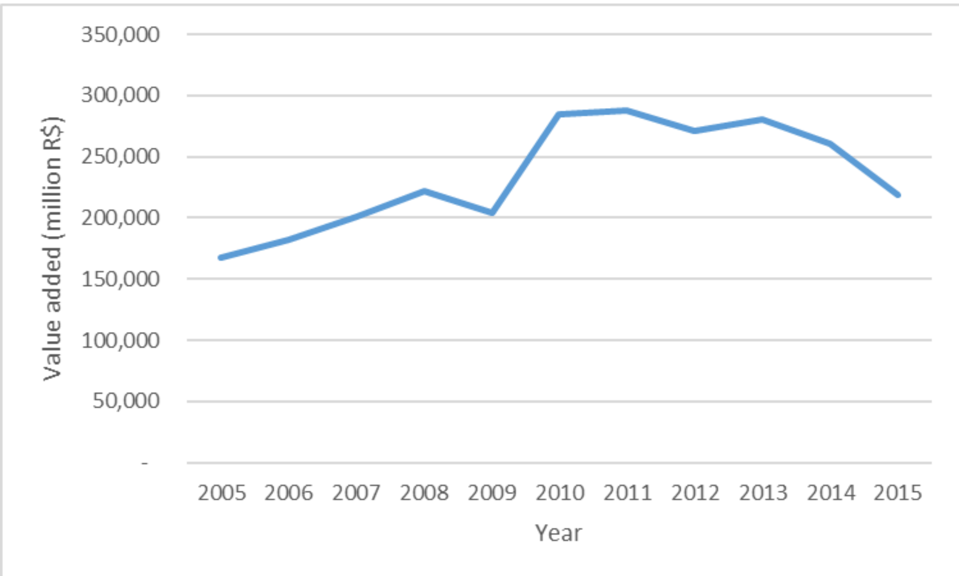


Figure 37. Annual value added in the Other Industries in Brazil between 2005 and 2015 (million R$).

Table 46 shows the energy consumption in Other Industries between 2005 and 2015. From 5,823 thousand toe in 2005, the energy consumption grew to 7,211 in 2010 and to 7,874 in 2015, an increase of 35% in the period. It`s worth noting that electricity is the main energy source in this branch with 50% of the total energy demand.

Table 46. Energy consumption in Other Industries in Brazil between 2005 and 2015 (1,000 toe)

SOURCES	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	984	1,063	1,186	1,425	1,368	1,901	2,079	1,856	1,890	1,832	2,057
Steam Coal	99	121	142	185	219	87	90	94	166	212	168
Firewood	703	724	752	798	783	874	898	889	907	898	871
Diesel Oil	113	116	124	129	129	144	154	162	188	198	162
Fuel Oil	358	226	301	310	310	177	170	101	111	111	71
Liquefied Petroleum Gas	148	171	184	192	200	153	196	215	257	262	188
Kerosene	5	3	2	1	1	1	1	1	0	0	0
Electricity	3,024	3,219	3,283	3,390	3,315	3,380	3,636	3,671	3,939	3,985	3,917
Charcoal	10	10	11	11	11	12	13	13	13	13	12
Other Secondary Petroleum	380	399	439	448	469	481	529	503	508	503	427
Total	**5,823**	**6,052**	**6,425**	**6,888**	**6,804**	**7,211**	**7,767**	**7,504**	**7,979**	**8,014**	**7,874**

Source: Author based in EPE (2017)

4.3.2. Scenarios A, B and C – Assumptions

Three different scenarios by 2030 look at future emissions paths in the industry sector. In Scenario A, each industrial branch would unfold following the current trend. In Scenario B mitigation measures are introduced but to a lesser extent than Scenario C that would lead to further mitigation in the industry sector to offset lower mitigation in the AFOLU sector.

The macroeconomic modeling supplied future activity level of each industrial branch, which is the same across all scenarios. It includes an increase in the demand for HFC and SF_6. Table 47 presents the annual growth rate for all industrial branches between 2015 and 2030.

Table 47. Activity level: industrial average annual growth rate between 2015 and 2030 (%).

Industrial branch	Activity level average annual growth rate 2015-2030
Cement	1.3%
Iron and Steel and Iron Alloy	0.4%
Mining and Pelleting	0.0%
Non-ferrous and other metals	0.1%
Chemical	0.4%
Food and beverage	1.0%
Textile	2.1%
Pulp and Paper	0.6%
Ceramics	0.1%
Other industries	0.7%
HFCs	3.5%
SF_6	2.8%
Total	2.1%

Source: Author

The mitigation measures that aim at reducing fuel consumption, in each industrial branch, are presented in Table 48. In general, three measures are used to reduce this consumption: (i) optimization of combustion; (ii) heat recovery systems; (iii) steam recovery systems. The difference between the three scenarios lies in different energy intensity gains up to 2030.

Table 48. Energy intensity reduction by industrial branch between 2015 and 2030 (%)

Industrial branch	Mitigation measure	Energy intensity reduction (toe/t product) in 2015-2030		
		Scenario A	Scenario B	Scenario C
Cement	Optimization of combustion	1.0%	4.0%	6.0%
	Heat recovery systems	2.8%	6.0%	9.0%
Iron and steel	Optimization of combustion	2.8%	5.0%	14%
Iron alloy	Heat recovery systems	3.0%	10.0%	14.0%
Non-ferrous metals	Optimization of combustion and Heat recovery systems	-	5.0%	9.0%
Pulp and paper	Optimization of combustion and Steam recovery systems	-	5.0%	8.0%
Mining and pelleting	Optimization of combustion	2.0%	8.0%	14.0%
Chemical	Optimization of combustion	1.5%	5.0%	7.0%
	Heat recovery systems	1.5%	5.0%	8.0%
Food and beverage	Optimization of combustion	1.0%	3.0%	5.0%
	Steam recovery systems	1.5%	4.5%	7.0%
Textile	Optimization of combustion	0.5%	4.0%	5.0%

Industrial branch	Mitigation measure	Energy intensity reduction (toe/t product) in 2015-2030		
		Scenario A	Scenario B	Scenario C
	Heat recovery systems	0.5%	4.0%	5.0%
Ceramic	Optimization of combustion	0.5%	3.0%	4.0%
	Heat recovery systems	1.0%	5.0%	7.0%
Other industry	Optimization of combustion	1.0%	3.0%	5.0%
	Heat recovery systems	1.0%	4.0%	7.0%

Source: Author

Scenario A, which follows the current trend, considers that the share of charcoal in the Iron and Steel branch would be reduced by 2.4% per year, the same rate observed between 2000 and 2016 when it went down from 25% in 2000 to 17% in 2016 (EPE, 2017).

Scenarios B and C considers that there would be a replacement of current fossil fuels by natural gas and by renewable biomass. Gains in the share of these fuels in each industrial branch between 2015 and 2030 are presented in Table 49.

Table 49. Replacement of fossil fuels by natural gas and by renewable biomass in Scenarios B and C (%)

Industrial Branch	Substitution of other fossil fuels for natural gas		Substitution of fossil fuels for renewable biomass	
	Scenario B	Scenario C	Scenario B	Scenario C
Cement	-	1.5%	-	-
Iron and Steel	-	-	5%	7%
Iron alloys	-	-	1%	2%
Mining and pelleting	-	5%	-	-
Chemical	2%	4%	-	-
Non-ferrous and other metals	0%	5%	0%	7%
Pulp and paper	2%	4%	1.5%	2%
Textile	-	1.5%		
Ceramic	0%	2%	0%	3%

Source: Author

For specific processes and product use, Table 50 presents the mitigation measures in Scenarios B and C. In the cement production, the use of additives could reduce GHG emissions due to the lower clinker/cement ratio. In respect to product use, like fluorinated greenhouse gases, the replacement or leakage control of gases and the end-of-life recollection could lead to substantial emission reductions.

Table 50. Mitigation measures and reduction potential between 2015 and 2030 (%).

Branch	Mitigation Measure	Emission reduction between 2015 and 2030	
		Scenario B	Scenario C
Cement	Add additives (reduction of clinker/cement ratio)	7%	11%
HFCs	Replacement for low GWP refrigerant	58%	76%
SF_6	Leakage control and end-of-life recollection	43%	58%
PFCs	Optimization and process control	10%	20%

Source: Author

4.3.3. Scenario A – Results

Table 51 shows the GHG emissions from energy consumption estimated up to 2030 in Scenario A. In 2005, the amount emitted from all the industrial branches was 61.5 Mt CO_2eq. In 2030, these emissions would grow up to 86.1 Mt CO_2eq, which represents 40% growth in the period. It is worth noting that the cement emissions would increase 102% in the period 2005-2030, rising from 9.2 to 18.5 Mt CO_2eq.

Table 51. Emission from energy consumption by industrial branch between 2005 and 2030, in Scenario A (Mt CO_2-eq)

Industrial branch	Emissions (Mt CO_2eq)					
	2005	2010	2015	2020	2025	2030
Cement	9.2	15	16	15	17	19
Iron and steel	5.3	5.6	5.6	5.7	6.1	6.5
Iron alloy	0.2	0.1	0.1	0.1	0.2	0.2
Mining and pelleting	6.7	7.3	7.7	8.4	9.9	11.5
Non-ferrous and other metals	4.9	5.5	5.5	6.4	7.5	8.8
Chemical	14.6	14	14	14	14	14
Food and beverage	5.0	5.5	5.6	5.4	5.6	5.8
Textile	1.2	1.0	0.70	0.70	0.70	0.70
Pulp and paper	4.2	4.2	4.1	4.6	5.1	5.6
Ceramic	4.0	5.2	5.0	5.0	5.3	5.7
Other industries	6.3	8.3	8.2	8.0	8.2	8.4
Total	**62**	**72**	**73**	**74**	**80**	**86**

Source: Author

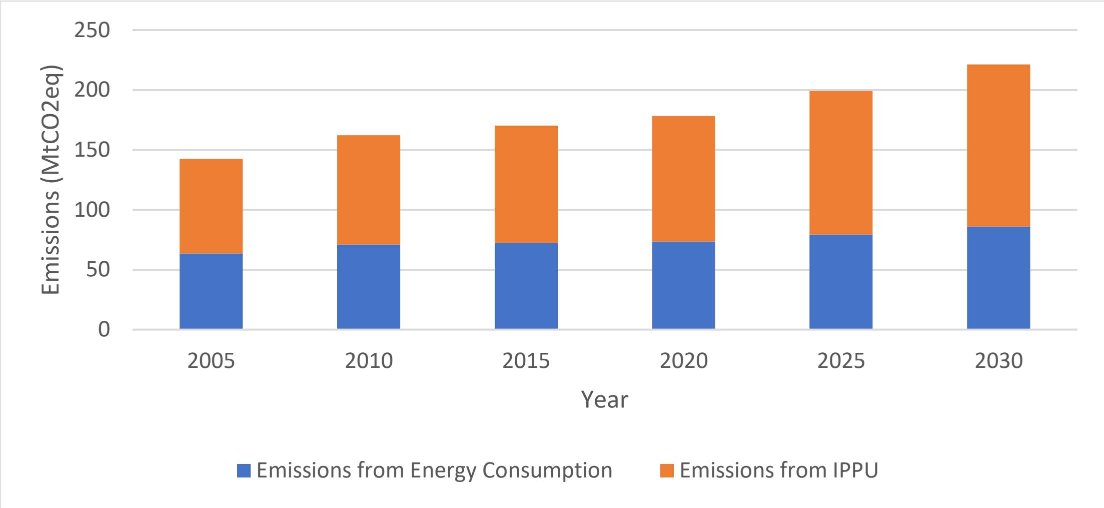
Table 52 presents the estimated emissions in Industrial Processes and Product Use (IPPU) between 2005 and 2030 in Scenario A. The total amount of IPPU emissions would increase from 79.0 Mt CO_2eq in 2005 to 135.7 Mt CO_2eq in 2030, approximately 71%. The results indicate that the emissions in the mineral industry would grow 77% in this period (from 21.8 up to 37.7 Mt CO_2eq), while the emissions in the iron and steel branch from 36.7 Mt CO_2eq to 52.6 Mt CO_2eq. In addition, HFCs and SF_6 emissions would increase more than six times, from 3.1 Mt CO_2eq in 2005 to 20.0 Mt CO_2eq in 2030.

Table 52. Emissions from IPPU by industrial branch between 2005 and 2030 in Scenario A (Mt CO_2-eq)

Branch	Emissions (Mt CO_2eq)					
	2005	2010	2015	2020	2025	2030
Mineral industry	22	30	32	29	33	38
Iron and steel	37	40	42	44	48	53
Iron alloy	1.2	1.2	0.90	1.2	1.5	1.9
Non-ferrous and other metals	2.9	5.4	5.7	6.8	7.9	9.3
Aluminum	3.4	3.1	3.1	6.4	8	9.7
Chemical	9.3	3.3	3.2	3.6	3.7	3.9
Non-energy use products	0.70	0.60	0.60	0.60	0.60	0.60
HFCs and SF_6	3.1	7.6	10	14	17	20
Total	79	91	98	105	120	136

Source: Author

Figure 38 presents the results for the industry sector Scenario A, differentiating the total emissions in (i) emissions from energy consumption and (ii) emissions from industrial processes and product use for the 2005-2030 period. The results indicate that, in this scenario, the GHG emissions would rise from 142 Mt CO_2eq in 2005 reaching 170 Mt CO_2-eq in 2015 and 221 Mt CO_2-eq in 2030, which represents an increase of 20% and 56% respectively, in comparison to 2005.



Source: Author

Figure 38. Emissions from energy consumption and IPPU in the Industrial Sector between 2005 and 2030, in Scenario A (Mt CO_2-eq).

4.3.4. Scenario B – Results

The results of the emissions from energy consumption in Scenario B are presented in Table 53 in Mt CO_2-eq from 2005 to 2030 per industrial branch. In 2005, the total emissions from energy consumption were 62 Mt CO_2-eq and, in Scenario B, the emissions grew 29%, to 81 Mt CO_2-eq.

Table 53. Emission from energy consumption by industrial branch between 2005 and 2030, in Scenario B (Mt CO_2-eq)

Industrial branch	Emissions (Mt CO_2-eq)					
	2005	2010	2015	2020	2025	2030
Cement	9.2	15	16	15	16	17
Iron and steel	5.3	5.6	5.6	5.7	5.8	6.0
Iron alloy	0.20	0.10	0.10	0.10	0.10	0.20
Mining and pelleting	6.7	7.3	7.7	8.3	9.5	11
Non-ferrous and other metals	4.9	5.5	5.5	6.3	7.2	8.3
Chemical	15	14	14	14	14	13
Food and beverage	5.0	5.5	5.6	5.2	5.3	5.4
Textile	1.2	1.00	0.70	0.60	0.70	0.70
Pulp and paper	4.2	4.2	4.1	4.5	4.9	5.4
Ceramic	4.0	5.2	5.00	4.9	5.1	5.3
Other industries	6.3	8.3	8.2	7.8	7.9	8.0
Total	**62**	**72**	**73**	**72**	**76**	**81**

Source: Author.

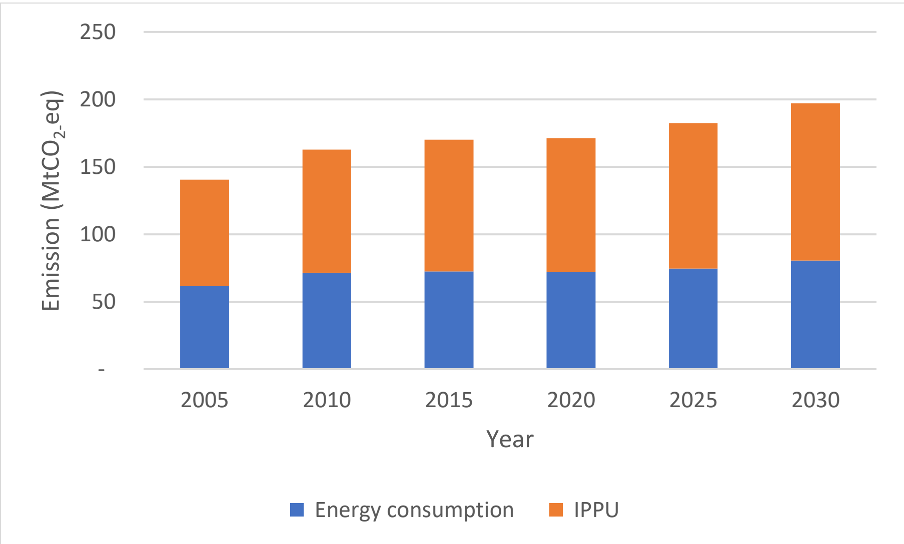
Table 54 shows the emissions from Industrial Process and Product Use in Mt CO_2-eq from 2005 to 2030 for the second Scenario, B. From 79 Mt CO_2-eq emitted in 2005, the emissions from IPPU grew 48%.

Table 54. Emissions from IPPU by industrial branch between 2005 and 2030 in Scenario B (Mt CO_2-eq)

Industrial Branch	Emissions (Mt CO_2-eq)					
	2005	2010	2015	2020	2025	2030
Mineral industry	22	30	32	29	32	36
Iron and steel	37	40	42	42	45	48
Iron alloy	1.2	1.2	0.90	1.2	1.5	2
Non-ferrous and other metals	2.9	5.4	5.7	6.7	7.7	9
Aluminum	3.4	3.1	3.1	6.4	8	10
Chemical	9.3	3.3	3.2	3.6	3.6	4
Non-energetic usage products	0.70	0.60	0.60	0.60	0.60	0.50
HFCs and SF6	3.1	7.6	10	9.5	8.7	8.1
Total	**79**	**91**	**98**	**99**	**108**	**116**

Source: Author

The total amount of GHG emitted between 2005 and 2030 by the Brazilian industry is shown in Figure 39, in Mt CO_2-eq. In 2005, the GHG emission was equivalent to 140.5 Mt CO_2-eq, and in 2015, the emissions grew to 170.1 Mt CO_2-eq, a relative growth of 21%. In Scenario B, the total emissions in the industry reached 197 Mt CO_2-eq in 2030, about 16% higher when compared to 2015 and 40% higher when compared to 2005.



Source: Author.

Figure 39. Emissions from energy consumption and IPPU in the Industrial Sector between 2005 and 2030, in Scenario B (Mt CO_2-eq).

4.3.5. Scenario C – Results

The present section shows the results of Scenario C, which has considered the highest effort of the Brazilian Industry to mitigate the GHG emissions when compared to the other scenarios. The emissions from energy consumption in Scenario C are presented in Table 55, from 2005 and 2030 in Mt CO_2-eq. From 61.5 Mt CO_2-eq in 2005 and 72.4 Mt CO_2-eq in 2015, the emissions from energy consumption in Scenario C shown a slight growth to 74.3 Mt CO_2-eq in 2030, a relative growth of 2.6% when compared to 2015 and 21% when compared to 2005.

Table 55. Emissions from energy consumption by industrial branch between 2005 and 2030 in Scenario C (Mt CO_2-eq)

Industrial branch	Emissions (Mt CO_2-eq)					
	2005	2010	2015	2020	2025	2030
Cement	9.2	15	16	15	16	16
Iron and steel	5.3	5.6	5.6	5.7	5.6	5.8
Iron alloy	0.2	0.1	0.1	0.1	0.1	0.2
Mining and pelleting	6.7	7.3	7.7	8.1	9	9.9
Non-ferrous and other metals	4.9	5.5	5.5	6.1	6.7	7.5
Chemical	15	14	14	13	13	12
Food and beverage	5.0	5.5	5.6	5.2	5.2	5.3
Textile	1.2	1.0	0.7	0.6	0.6	0.6
Pulp and paper	4.2	4.2	4.1	4.2	4.4	4.8
Ceramic	4	5.2	5.0	4.5	4.4	4.5
Other industries	6.3	8.3	8.2	7.7	7.6	7.6
Total	**62**	**72**	**73**	**70**	**72**	**74**

Source: Author.

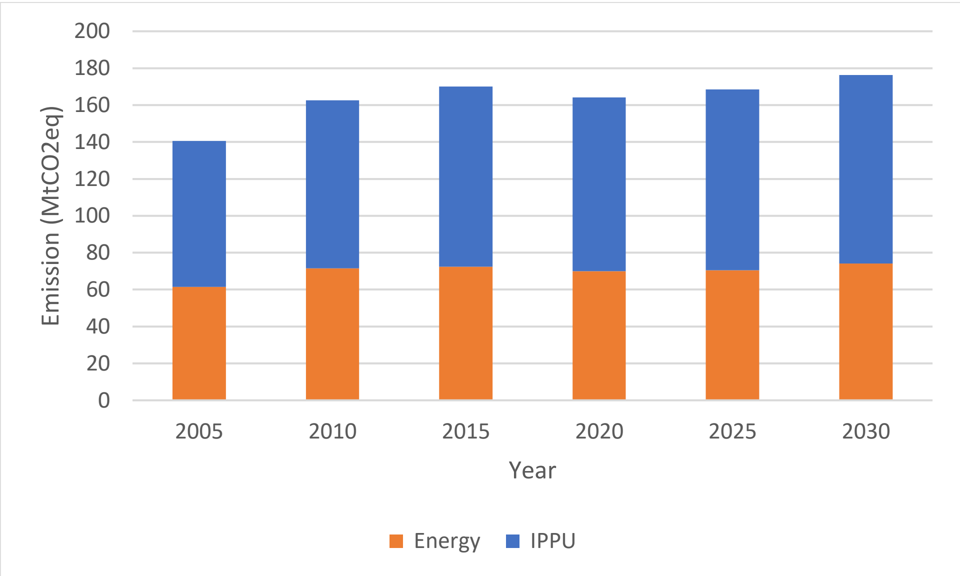
Table 56 shows the results of GHG emissions from Industrial Process and Product Use, in Mt CO_2-eq, from 2005 and 2030 in Scenario C. In 2030, the total amount of GHG emitted from IPPU, in Scenario C, were 102.0 Mt CO_2-eq, a relative growth of 4.1% when compared to 2015 and 29.1% when compared to 2005.

Table 56. Emissions from IPPU by industrial branch between 2005 and 2030 in Scenario C (Mt CO_2-eq)

Industrial Branch	Emissions (Mt CO_2-eq)					
	2005	2010	2015	2020	2025	2030
Mineral industry	22	30	32	29	32	35
Iron and steel	37	40	42	41	41	42
Iron alloy	1.2	1.2	0.9	1.1	1.3	1.5
Non-ferrous and other metals	2.9	5.4	5.7	6.5	7.4	8.4
Aluminum	3.4	3.1	3.1	6.3	7.7	9.1
Chemical	9.3	3.3	3.2	3.6	3.4	3.3
Non-energetic usage products	0.7	0.6	0.6	0.6	0.5	0.4
HFCs and SF6	3.1	7.6	10.3	8.0	6.0	4.5
Total	**79**	**91**	**98**	**96**	**99**	**104**

Source: Author.

The results of all emissions, energy consumption and IPPU, in the Brazilian industry, are shown in Figure 40. In 2030, the total emissions were 176.2 Mt CO_2-eq, a relative growth of 3.5% when compared to 2015 and 26% when compared to 2005.



Source: Author.

Figure 40. Total emissions from the industrial sector (Mt CO_2-eq) between 2005 and 2030, in Scenario C (Mt CO_2-eq).

4.3.6. Comparative Analysis of Scenarios A, B and C – Avoided Emissions by Mitigation Actions

In this section, the results of the scenarios A, B and C are compared. We analyze the emissions in energy consumption and industrial process and product use up to 2030 and also, the emissions mitigated by each branch and scenario.

Table 57 shows the Brazilian industry emissions from energy consumption and IPPU between 2005 and 2030, in Mt CO_2-eq, for each scenario. The emissions from energy consumption, in comparison to 2005, which GHG emissions from this source were 61.5 Mt CO_2-eq, presented a relative growth of 40% (85.9 Mt CO_2-eq), 31% (80.5 Mt CO_2-eq) and 21% (74.2 Mt CO_2-eq) in Scenarios A, B and C, respectively, in 2030. With regards to IPPU emissions, in 2005 they were equivalent to 79.0 Mt CO_2-eq and in 2030, the total amount of GHG emitted from this source was 135.4 Mt CO_2-eq, 111.6 Mt CO_2-eq and 102.0 Mt CO_2-eq in scenarios A, B and C, respectively, a relative growth of 71%, 48% and 29%.

Comparing the emissions in the scenarios which present mitigation measures, B and C, with the scenario that represents the current trend scenario A, in 2030, the Scenario B presents a reduction of 24.2 Mt CO_2-eq emitted and Scenario C presents a reduction of 45.1 Mt CO_2-eq or 20.9 Mt CO_2-eq in comparison to Scenario B.

Table 57. Brazilian Industry emissions (energy consumption and IPPU) from 2005 to 2030, in Scenarios A, B and C. (Mt CO_2-eq)

Emission Source	Emissions (Mt CO_2-eq)											
	2005	2010	2015	2020			2025			2030		
				A	B	C	A	B	C	A	B	C
Energy	62	72	73	74	72	70	80	76	72	86	81	74
IPPU	79	91	98	105	99	96	120	108	99	136	116	104
Total	**141**	**163**	**170**	**178**	**171**	**166**	**199**	**184**	**171**	**222**	**197**	**178**

Source: Author.

Table 58 shows the results of the emissions from energy consumption by branch in 2005 and in 2030 in the three scenarios, A, B and C. The growth of emissions from cement sector can be highlighted, from 9.21 Mt CO_2-eq in 2005, the emissions reached 18.50 Mt CO_2-eq in 2030 in Scenario A, a 106% relative growth, 17,31 Mt CO_2-eq in Scenario B and 16,22 in

Scenario C. Another important information is the emissions in the second most emitter branch, Chemical Industry, the only branch that presented reduction in their emissions, from 14.59 Mt CO_2-eq in 2005 to 14.27 Mt CO_2-eq in 2030, in Scenario A, 13.24 Mt CO_2-eq in Scenario B and 11.97 in Scenario C. This reduction in Scenario A, and consequently in B and C, has as the main cause the energy intensity reduction in the period 2005-2015.

Table 58. Emissions from energy consumption per industrial branch in 2005 and in 2030, in Scenarios A, B and C (Mt CO_2-eq)

Industrial Branch Emissions from energy consumption (Mt CO_2-eq)	2005	2030		
		Scenario A	Scenario B	Scenario C
Cement	9.2	19	17	16
Chemical Industry	15	14	13	12
Mining and pelleting	6.7	11	11	10
Other Industries	6.3	8.4	8.0	7.6
Non-ferrous and other metals	4.9	8.8	8.3	7.5
Iron and steel	5.3	6.6	6.4	5.8
Food and Beverage	5.0	5.9	5.4	5.3
Pulp and Paper	4.2	5.6	5.4	4.8
Ceramic	4.0	5.7	5.3	4.5
Textile	1.2	0.71	0.66	0.63
Iron alloys	0.24	0.20	0.19	0.18
Total	**62**	**86**	**81**	**74**

Source: Author

The results of the emissions in Industrial Processes and Product Use by branch are presented in Table 59 for the years 2005 and 2030 in Scenarios A, B and C. It is worth noting that the Iron and Steel branch has presented the largest emissions in IPPU, from 36.7 Mt CO_2-eq in 2005 to 52.6 Mt CO_2-eq in 2030 in Scenario A, 49.1 Mt CO_2-eq in Scenario B and 41.8 Mt CO_2-eq in Scenario C. Another highlight is the HFCs and SF_6 emissions growth, from 3.1 Mt CO_2-eq in 2005 to 20.0 Mt CO_2-eq in Scenario A, a relative growth of 545%. It can be justified due to the growth in the number of air conditioning and refrigeration equipment that contains HFCs instead of CFCs.

Table 59. Emissions from IPPU per branch in 2005 and in 2030 in Scenarios A, B and C (Mt CO_2-eq)

Industrial Branch Emissions from IPPU (Mt CO_2-eq)	2005	2030		
		A	B	C
Mineral Industry	22	38	36	35
Iron and Steel	37	53	49	42
Aluminum	3.4	9.7	9.6	9.1
Non-ferrous and other metals	2.9	9.3	8.8	8.4
HFCs and SF6	3.1	20	8.1	4.5
Chemical Industry	9.3	3.9	3.6	3.3
Iron alloys	1.2	1.9	1.8	1.5
Non-energetic usage products	0.7	0.6	0.5	0.4
Total	**79**	**136**	**118**	**104**

Source: Author

The Table 60 shows the amount of GHG mitigated in 2030 by each mitigation measure (Mt CO_2-eq) in every industrial branch in comparison to Scenario A and, regarding Scenario C, also in comparison to Scenario B.

It is worth noting the GHG mitigation in the Iron and Steel industry by optimization of combustion, with a reduction of 4.85 Mt CO_2-eq in Scenario B and 8.67 Mt CO_2-eq in Scenario C in 2030. The substitution of fossil fuels has presented the mitigation of 2.80 Mt CO_2-eq in 2030.

The leakage control and substitution of HFCs have reduced, in 2030, 11.0 Mt CO_2-eq in Scenario B and 14.5 in Scenario C. The main reason to this reduction is related to the high GWP of the fluorinated greenhouse gases and the mitigation potential by leakage control and the substation of these gases by other refrigerants.

Table 60. GHG mitigation from industrial branches by mitigation measure in Scenarios B and C (Mt CO_2-eq)

Industrial Branch	Mitigation measure	GHG mitigation in 2030 (Mt CO_2-eq)		
		Scenario B in relation to Scenario A	Scenario C in relation to Scenario A	Scenario C in relation to Scenario B
Cement	Optimization of combustion	0.48	0.86	0.38
	Heat recovery systems	0.72	1.3	0.57
	Clinker reduction	0.66	1.6	0.91
	Substitution of fossil fuel	-	0.13	0.13
Iron and steel	Optimization of combustion	3.8	8.7	4.9

Industrial Branch	Mitigation measure	GHG mitigation in 2030 (Mt CO_2-eq)		
		Scenario B in relation to Scenario A	Scenario C in relation to Scenario A	Scenario C in relation to Scenario B
	Substitution of fossil fuel	0.88	2.8	1.9
Iron alloy	Heat recovery systems	0.14	0.27	0.13
	Substitution of fossil fuel	0.01	0.17	0.16
Non-ferrous metals	Optimization of combustion and Heat recovery systems	0.91	1.59	0.68
	Optimization and process control (Aluminum)	0.14	0.55	0.41
	Substitution of fossil fuel	-	0.57	0.57
Pulp and paper	Optimization of combustion and Steam recovery systems	0.28	0.41	0.13
	Substitution of fossil fuel	-	0.46	0.46
Mineral Industry (Cement excluded)	Optimization of process	0.70	1.54	0.84
Mining and pelleting	Optimization of combustion	1.1	1.6	0.50
Chemicals	Optimization of combustion	0.65	1.53	0.88
	Heat recovery systems	0.65	1.3	0.69
Food and beverage	Optimization of combustion	0.18	0.24	0.06
	Steam recovery systems	0.27	0.33	0.06
Textile	Optimization of combustion	0.02	0.03	0.01
	Heat recovery systems	0.02	0.03	0.01
	Substitution of fossil fuel	-	0.02	0.02
Ceramics	Optimization of combustion	0.14	0.17	0.03
	Heat recovery systems	0.23	0.31	0.07
	Substitution of fossil fuel	-	0.67	0.67
HFCs	Leakage control and end-of-life recollection	12	16	3.3
SF6	Leakage control and end-of-life recollection	0.13	0.17	0.04

Industrial Branch	Mitigation measure	GHG mitigation in 2030 (Mt CO_2-eq)		
		Scenario B in relation to Scenario A	Scenario C in relation to Scenario A	Scenario C in relation to Scenario B
Other industries	Optimization of combustion	0.18	0.36	0.19
	Heat recovery systems	0.25	0.49	0.24

Source: Author.

4.4. ENERGY SUPPLY

4.4.1. Emission sources

Emission sources from energy supply can be labeled into four main groups: electricity production, energy consumption, charcoal production and fugitive emissions from oil and coal industry. Fugitive emissions are discussed in section 4.4.2.

Historically, electricity production in Brazil relies on renewable sources, mainly hydropower plants. Recently, new technologies are being introduced such as wind, solar photovoltaic and biomass power plants. Nevertheless, GHG emissions have been growing in recent years due to greater use of existing fossil fuel power plants. This increase is partially explained by the bad hydrological conditions in recent years, harming hydropower plants production. Although some people believe this river inflow reduction is permanent, in this study, it is considered that rainfall and river inflows would return to the historical average.

4.4.2. Scenario A

4.4.2.1 Assumptions

Scenario A is based upon current GHG emission trends. As mentioned in the previous section, there is a great perspective of higher levels of penetration of new renewable technologies. Still, Scenario A allows the expansion of fossil fuel power plants, such as natural gas and coal.

Oil and gas production was assumed to be equal to EPE’s study “Decennial Energy Plan 2026”. After this year, it is assumed that the same growth rate will be maintained until 2030. Figures 41 e 42 show the historical and projected production of natural gas and oil.

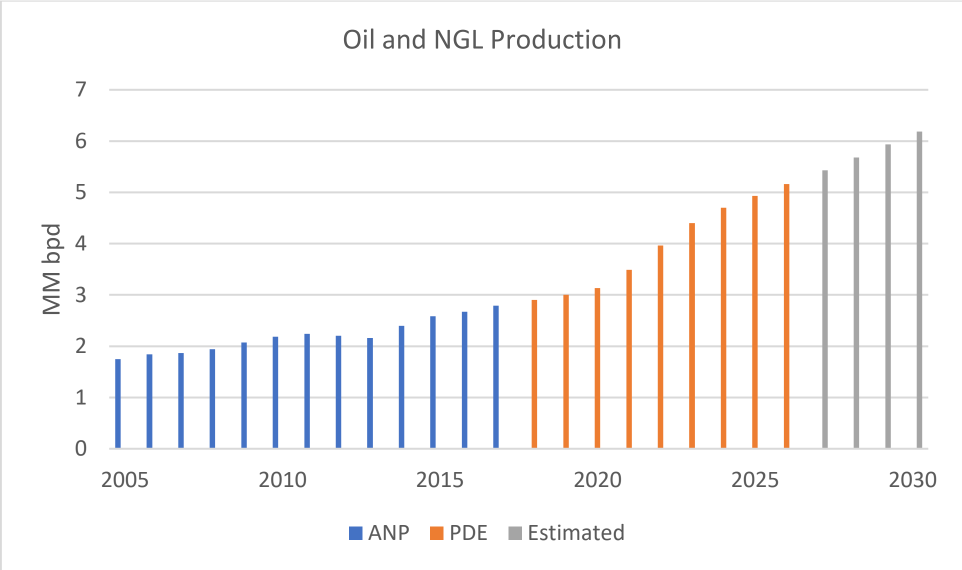


Figure 41. Oil and NGL production (million bpd)

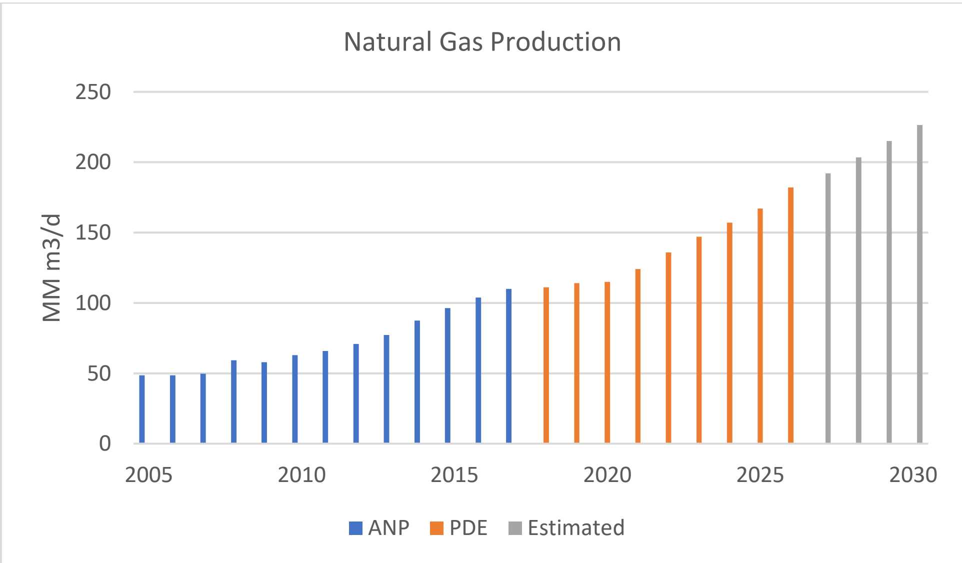


Figure 42. Natural gas production (million m^3/day)

4.4.2.2 Results

Scenario A total energy consumption, including the energy sector is presented in Table 61.

Table 61. Total energy consumption between 2005 and 2030 in Scenario A (k toe)

Ktoe	2005	2010	2015	2016	2017	2020	2025	2030
Natural gas	13,410	16,887	18,765	18,868	19,111	21,353	23,415	25,808
Coal	2,828	3,238	3,855	3,258	3,495	3,966	4,674	5,434
Firewood	16,119	17,052	16,670	15,997	16,687	14,601	14,596	14,455
Sugar cane products	21,147	30,066	28,667	29,791	30,477	28,229	31,870	34,046
Other primary sources	4,249	6,043	7,013	7,418	7,640	8,186	9,552	11,028
Diesel oil	32,643	41,498	48,033	46,247	46,738	49,386	53,500	59,123
Fuel oil	6,583	4,939	3,256	3,100	2,822	4,032	4,598	5,260
Gasoline	13,638	17,578	23,306	24,225	24,856	23,306	24,918	26,604
Liquefied petroleum gas	7,121	7,701	8,258	8,267	8,304	9,269	10,006	10,660
Naphtha	7,277	7,601	6,929	6,258	7,132	7,223	9,026	10,829
Kerosene	2,602	3,202	3,615	3,310	3,301	3,523	4,278	5,175
Coke oven gas	1,329	1,434	1,336	1,320	1,387	1,428	1,533	1,646
Coal coke	6,420	7,516	7,886	7,114	7,749	7,909	8,542	9,230
Electricity	32,267	39,964	45,096	44,820	45,238	50,269	56,127	61,938
Charcoal	6,248	4,648	4,101	3,529	3,332	3,809	3,828	3,859
Ethyl alcohol	7,324	12,628	15,927	14,332	14,348	14,335	16,712	18,961
Other oil secondaries	9,589	11,164	11,529	10,552	10,831	10,394	11,297	12,311
Non-energy oil products	4,500	7,797	6,731	6,917	6,308	8,532	9,785	11,639
Tar	197	238	229	226	255	93	100	107
Total	**195,491**	**241,194**	**261,202**	**255,549**	**260,011**	**269,843**	**298,357**	**328,115**

Based on that energy consumption, MATRIZ model simulations were performed to determine the energy supply in the time horizon. Table 62 shows the installed capacity, in GW, in the electricity sector.

Table 62. Electricity installed capacity between 2005 and 2030 in Scenario A (GW)

Installed capacity (GW)	2005	2010	2015	2016	2020	2025	2030
Hydro	71.1	80.7	91.7	96.9	108.6	111.0	115.1
Natural gas	9.6	11.3	12.4	13.0	14.2	16.3	18.3
Coal	1.4	1.9	3.4	3.4	3.5	3.5	3.5
Nuclear	2.0	2.0	2.0	2.0	2.0	2.0	3.4
Other non-renewable	5.4	8.6	10.5	10.8	4.7	1.8	1.6
Biomass	3.3	7.9	13.3	14.1	14.9	18.0	19.4
Wind	0.0	0.9	7.6	10.1	16.8	20.8	23.8
Solar	0.0	0.0	0.0	0.0	4.1	7.6	12.2
Total	**92.9**	**113.3**	**140.9**	**150.3**	**168.7**	**181.0**	**197.3**

There is a large increment of renewables installed capacity, but there is also an increase in natural gas (2 GW in the last five years) and nuclear power plants (Angra III).

Table 63 shows the power generation by source, in GWyr and the expected capacity factor. We can observe that the capacity factor of natural gas and coal power plants increases until 2030.

The solar capacity factor decreases because, initially, in the time horizon, most of its installed capacity is from utility-scale plants, which are projected in such a way that maximizes solar production, including the use of solar trackers. In the later years, distributed photovoltaics generation share increases, which, typically, has a smaller energy yield. Therefore, the aggregated capacity factor decreases. It is also important to notice that the installed capacity from photovoltaics showed here refers to and not DC power (solar panel STC capacity, in Wp).

Table 63. Electricity generation and capacity factor between 2005 and 2030 in Scenario A (GWyr and %)

	Generation (GWyr)					Expected generation (GWyr)			Expected capacity factor (%)		
	2005	2010	2015	2016	2017	2020	2025	2030	2020	2025	2030
Hydro	38.5	46.0	41.1	43.5	42.3	49.7	52.8	56.1	45.8%	47.5%	48.7%
Natural gas	2.1	4.2	9.1	6.4	7.5	4.9	7.1	8.4	34.5%	43.5%	45.8%
Coal	0.7	0.8	2.2	1.9	1.9	2.0	2.1	2.4	57.6%	59.1%	68.2%
Nuclear	1.1	1.7	1.7	1.8	1.8	1.7	1.7	3.1	87.8%	83.2%	90.2%
Other non-renewable	1.9	2.4	4.3	2.7	2.9	0.7	0.1	0.1	14.5%	7.1%	6.8%
Biomass	1.6	3.6	5.6	5.8	5.9	6.6	8.5	9.4	43.9%	47.1%	48.4%
Wind	0.0	0.2	2.5	3.8	4.8	7.1	8.8	10.0	42.1%	42.2%	42.2%
Solar	0.0	0.0	0.0	0.0	0.1	1.0	1.7	2.5	24.6%	22.0%	20.8%
Total	**46.0**	**58.9**	**66.4**	**66.1**	**67.1**	**73.7**	**82.7**	**92.0**			

As a result of the increase in gas and coal generation, the total emissions from the electricity sector increase until 2030, although it remains relatively low. The total emissions, in CO_2-eq, are shown in Table 64.

Table 64. Total emissions between 2005 and 2030 in Scenario A (Mt CO_2-eq)

Mt CO_2-eq	2005	2010	2015	2020	2025	2030
Electricity generation	27	37	68	41	47	55
Energy sector consumption	22	24	30	28	30	34
Charcoal power plants	1.0	0.70	0.60	0.50	0.50	0.50
Total	**49**	**61**	**99**	**69**	**78**	**89**

Note: fugitive emissions not included in the total

The share of electricity consumption in total energy demand increases in this Scenario time horizon, as in Table 65. This is a trend that reduces total emissions in the country, as electricity probably replaces a fossil fuel, such as gasoline.

Table 65. Share of electricity consumption in total energy demand between 2005 and 2030 in Scenario A (%)

	2005	2010	2015	2016	2017	2020	2025	2030
Scenario A	16.5%	16.6%	17.3%	17.5%	17.4%	18.6%	18.8%	18.9%

Table 66 shows the Domestic Energy Supply for Scenario A and historical data.

Table 66. Domestic Energy Supply between 2005 and 2030 in Scenario A (10^3 toe)

Ktoe	2005	2010	2015	2016	2017	2020	2025	2030
Non-renewable	**121,819**	**148,644**	**175,903**	**162,975**	**166,808**	**163,537**	**181,532**	**205,654**
Petroleum and oil products	84,553	101,714	111,626	105,354	106,276	107,767	116,756	128,713
Natural gas	20,526	27,536	40,971	35,569	37,938	33,942	42,034	48,786
Coal and coke	12,991	14,462	17,625	15,920	16,570	17,470	18,561	20,680
Other non-renewable	3,749	4,932	5,681	6,132	6,024	4,358	4,181	7,475
Renewable	**96,117**	**120,152**	**123,672**	**125,345**	**126,685**	**134,894**	**149,342**	**160,779**
Hydraulic and electricity	32,379	37,663	33,897	36,265	35,023	40,176	42,115	44,157
Firewood and charcoal	28,468	25,998	24,900	23,095	23,424	20,828	21,392	22,540
Sugar cane products	30,150	47,102	50,648	50,318	51,116	51,705	59,639	64,080
Other renewable	5,120	9,389	14,227	15,667	17,122	22,186	26,196	30,002
Total	**217,936**	**268,796**	**299,574**	**288,319**	**293,492**	**298,431**	**330,874**	**366,433**

4.4.3. Scenario B

4.4.3.1 Assumptions

In Scenario B, the mitigation efforts are focused in the AFOLU sector. So, all the assumptions in the energy sector from Scenario A are the same in Scenario B. It should be noted that the results might vary between Scenarios, as the energy demand is different.

4.4.3.2 Results

The total energy consumption in Scenario B including the energy sector is in Table 67. The total energy consumption is lower than in Scenario A.

Table 67. Total energy consumption between 2005 and 2030 in Scenario B (10^3 toe)

Ktoe	2005	2010	2015	2016	2017	2020	2025	2030
Natural gas	13,410	16,887	18,765	18,868	19,111	21,108	22,806	24,861
Coal	2,828	3,238	3,855	3,258	3,495	3,666	3,990	4,344
Firewood	16,119	17,052	16,670	15,997	16,687	14,452	14,272	13,925
Sugar cane products	21,147	30,066	28,667	29,791	30,477	28,502	31,735	35,006
Other primary sources	4,249	6,043	7,013	7,418	7,640	8,053	9,211	10,547
Diesel oil	32,643	41,498	48,033	46,247	46,738	49,361	53,634	58,134
Fuel oil	6,583	4,939	3,256	3,100	2,822	3,979	4,475	5,048
Gasoline	13,638	17,578	23,306	24,225	24,856	22,632	22,881	20,373
Liquefied petroleum gas	7,121	7,701	8,258	8,267	8,304	9,244	9,953	10,574
Naphtha	7,277	7,601	6,929	6,258	7,132	7,223	9,026	10,829
Kerosene	2,602	3,202	3,615	3,310	3,301	3,523	4,033	4,735
Coke oven gas	1,329	1,434	1,336	1,320	1,387	1,419	1,511	1,609
Coal coke	6,420	7,516	7,886	7,114	7,749	7,853	8,405	9,000
Electricity	32,267	39,964	45,096	44,820	45,238	49,907	55,344	60,644
Charcoal	6,248	4,648	4,101	3,529	3,332	4,033	4,330	4,637
Ethyl alcohol	7,324	12,628	15,927	14,332	14,348	14,885	17,689	22,247
Other oil secondaries	9,589	11,164	11,529	10,552	10,831	10,185	10,839	11,534
Non-energy oil products	4,500	7,797	6,731	6,917	6,308	8,532	9,785	11,639
Tar	197	238	229	226	255	92	99	103
Total	195,491	241,194	261,202	255,549	260,011	268,650	294,018	319,790

Table 68 shows the installed capacity in Scenario B, as simulated by the Matriz model.

Table 68. Electricity installed capacity between 2005 and 2030 in Scenario B (GW)

Installed capacity (GW)	2005	2010	2015	2016	2020	2025	2030
Hydro	71.1	80.7	91.7	96.9	108.6	111.0	112.3
Natural gas	9.6	11.3	12.4	13.0	14.2	16.3	18.4
Coal	1.4	1.9	3.4	3.4	3.5	3.5	3.5
Nuclear	2.0	2.0	2.0	2.0	2.0	2.0	3.4
Other non-renewable	5.4	8.6	10.5	10.8	4.7	1.8	1.6
Biomass	3.3	7.9	13.3	14.1	14.9	17.8	18.9
Wind	0	0.9	7.6	10.1	16.8	20.8	23.8
Solar	0	0	0	0	4.1	7.6	12.2
Total	**92.9**	**113.3**	**140.9**	**150.3**	**168.7**	**180.8**	**194.1**

Scenario B does not differ much from Scenario A in terms of capacity expansion and all differences can be explained by the lower electricity demand in the current scenario. As a result, the expected generation is also very similar (Table 69), in which the greatest variations are observed in hydro generation.

Table 69. Electricity generation and capacity factor between 2005 and 2030 in Scenario B (GWyr and %)

	Generation (GWyr)					Expected generation (GWyr)			Expected capacity factor (%)		
	2005	2010	2015	2016	2017	2020	2025	2030	2020	2025	2030
Hydro	38.5	46.0	41.1	43.5	42.3	49.4	52.3	54.5	45.5%	47.1%	48.5%
Natural gas	2.1	4.2	9.1	6.4	7.5	4.8	7.0	8.9	33.7%	43.2%	48.6%
Coal	0.7	0.8	2.2	1.9	1.9	2.0	1.9	2.1	57.6%	54.4%	59.1%
Nuclear	1.1	1.7	1.7	1.8	1.8	1.7	1.6	2.8	85.2%	82.8%	82.8%
Other non-renewable	1.9	2.4	4.3	2.7	2.9	0.7	0.1	0.1	14.5%	6.9%	6.0%
Biomass	1.6	3.6	5.6	5.8	5.9	6.5	8.0	9.1	43.5%	45.1%	48.0%
Wind	0.0	0.2	2.5	3.8	4.8	7.1	8.8	10.0	42.1%	42.2%	42.2%
Solar	0.0	0.0	0.0	0.0	0.1	1.0	1.7	2.5	24.6%	22.0%	20.8%
Total	46.0	58.9	66.4	66.1	67.1	73.2	81.5	90.0			

Table 70 shows the total emissions, in Mt CO_2-eq

Table 70. Total emissions between 2005 and 2030 in Scenario B (Mt CO_2-eq)

Mt CO_2-eq	2005	2010	2015	2020	2025	2030
Electricity generation	27	37	68	41	45	55
Energy sector consumption	22	24	30	28	30	32
Charcoal power plants	1.0	0.70	0.60	0.48	0.52	0.55
Total	49	61	99	69	75	88

Although Scenario B considers that the consumers would take some efficiency measures, the share of electricity in total energy demand does not change from Scenario A, as can be seen in Table 71.

Table 71. Share of electricity consumption in total energy demand between 2005 and 2030 in Scenario B (%)

	2005	2010	2015	2016	2017	2020	2025	2030
Scenario B	16.5%	16.6%	17.3%	17.5%	17.4%	19.6%	20.0%	20.3%

Table 72 shows the Domestic Energy Supply in Scenario B and historical data.

Table 72. Domestic Energy Supply between 2005 and 2030 in Scenario B (10^3 toe)

Ktoe	2005	2010	2015	2016	2017	2020	2025	2030
Non-renewable	**121,819**	**148,644**	**175,903**	**162,975**	**166,808**	**165,429**	**179,547**	**196,772**
Petroleum and oil products	84,553	101,714	111,626	105,354	106,276	110,577	116,073	122,343
Natural gas	20,526	27,536	40,971	35,569	37,938	33,511	41,944	48,812
Coal and coke	12,991	14,462	17,625	15,920	16,570	17,106	17,384	18,754
Other non-renewable	3,749	4,932	5,681	6,132	6,024	4,236	4,146	6,862
Renewable	**96,117**	**120,152**	**123,672**	**125,345**	**126,685**	**131,597**	**147,139**	**161,092**
Hydraulic and electricity	32,379	37,663	33,897	36,265	35,023	39,934	41,731	42,956
Firewood and charcoal	28,468	25,998	24,900	23,095	23,424	20,878	21,258	22,882
Sugar cane products	30,150	47,102	50,648	50,318	51,116	52,529	60,491	68,360
Other renewable	5,120	9,389	14,227	15,667	17,122	18,256	23,659	26,894
Total	**217,936**	**268,796**	**299,574**	**288,319**	**293,492**	**297,026**	**326,686**	**357,864**

4.4.4. Scenario C

4.4.4.1 Assumptions

In Scenario C, the main assumption is that no additional fossil fuel power capacity would be added, besides those that won energy auctions until 2017. Efforts would be made to foster a higher penetration of renewable sources, like photovoltaics, wind power, sugarcane bagasse and firewood thermal power plant.

4.4.4.2 Results

The total energy consumption in Scenario C, including the energy sector, is in Table 73 below.

Table 73. Total energy consumption between 2005 and 2030 in Scenario C (10^ toe)

ktoe	2005	2010	2015	2016	2017	2020	2025	2030
Natural gas	13,410	16,887	18,765	18,868	19,111	21,590	23,530	25,595
Coal	2,828	3,238	3,855	3,258	3,495	3,481	3,551	3,625
Firewood	16,119	17,052	16,670	15,997	16,687	14,476	14,256	13,820
Sugar cane products	21,147	30,066	28,667	29,791	30,477	29,627	33,158	36,975
Other primary sources	4,249	6,043	7,013	7,418	7,640	8,042	9,131	10,335
Diesel oil	32,643	41,498	48,033	46,247	46,738	49,193	51,609	53,597
Fuel oil	6,583	4,939	3,256	3,100	2,822	3,350	3,389	3,646
Gasoline	13,638	17,578	23,306	24,225	24,856	22,287	19,405	12,212
Liquefied petroleum gas	7,121	7,701	8,258	8,267	8,304	9,227	9,917	10,518
Naphtha	7,277	7,601	6,929	6,258	7,132	7,223	9,026	10,829
Kerosene	2,602	3,202	3,615	3,310	3,301	3,442	4,032	4,734
Coke oven gas	1,329	1,434	1,336	1,320	1,387	1,379	1,417	1,457
Coal coke	6,420	7,516	7,886	7,114	7,749	7,639	7,900	8,176
Electricity	32,267	39,964	45,096	44,820	45,238	49,620	54,893	60,580
Charcoal	6,248	4,648	4,101	3,529	3,332	4,061	4,395	4,743
Ethyl alcohol	7,324	12,628	15,927	14,332	14,348	15,900	20,011	24,888
Other oil secondaries	9,589	11,164	11,529	10,552	10,831	9,740	9,878	10,066
Non-energy oil products	4,500	7,797	6,731	6,917	6,308	8,532	9,785	11,639
Tar	197	238	229	226	255	90	92	95
Total	**195,491**	**241,194**	**261,202**	**255,549**	**260,011**	**268,900**	**289,376**	**307,530**

The total installed capacity in Scenario C is greater than in Scenarios A and B, even though the electricity demand is lower. This is due to the lower capacity factor of most renewable sources and some over installation in order to guarantee peak load supply.

Table 74. Electricity installed capacity between 2005 and 2030 in Scenario C

Installed capacity (GW)	2005	2010	2015	2016	2020	2025	2030
Hydro	71.1	80.7	91.7	96.9	108.6	111.0	114.0
Natural gas	9.6	11.3	12.4	13.0	14.2	16.3	16.3
Coal	1.4	1.9	3.4	3.4	3.5	3.5	3.5
Nuclear	2.0	2.0	2.0	2.0	2.0	2.0	3.4
Other non-renewable	5.4	8.6	10.5	10.8	4.7	1.8	1.6
Biomass	3.3	7.9	13.3	14.1	14.9	18.4	22.6
Wind	0.0	0.9	7.6	10.1	16.8	20.8	24.8
Solar	0.0	0.0	0.0	0.0	4.1	8.0	13.5
Total	**92.9**	**113.3**	**140.9**	**150.3**	**168.7**	**181.8**	**199.6**

The expected generation by source is shown in Table 75. The sources with greater generation reduction compared to Scenario A are hydro, coal and nuclear. Among those, only coal emits greenhouse gases. As a result, total emissions are lower only by a small amount in Scenario C compared to Scenario A (Table 78). It is worth mentioning that emissions in the electricity sector in Brazil are already low compared to other countries due to its relatively high renewable share.

One of the reasons that natural gas electricity production does not decrease more in this scenario is the peak load requirement. Although the Matriz model has a limited time resolution and its results are not totally conclusive, the results show that flexible technologies will be important in the next years. There are some technologies that could improve the system flexibility -- like batteries, pumped hydro, demand-side management -- but the assumptions in this study are conservative and therefore those technologies were not considered in the 2030 horizon.

Anyway, the results show that there is an inertia in the electricity sector as most of the installed capacity will not be decommissioned in the short term. Therefore, the decisions made in this decade will have a higher impact on the long-term emissions trends.

Table 75. Electricity generation and capacity factor between 2005 and 2030 in Scenario C (GWyr and %)

	Generation (GWyr)					Expected generation (GWyr)			Expected capacity factor (%)		
	2005	2010	2015	2016	2017	2020	2025	2030	2020	2025	2030
Hydro	38.5	46.0	41.1	43.5	42.3	49.1	51.8	53.9	45.2%	46.7%	47.3%
Natural gas	2.1	4.2	9.1	6.4	7.5	4.7	6.5	8.3	33.1%	40.1%	50.6%
Coal	0.7	0.8	2.2	1.9	1.9	2.0	2.0	1.9	57.6%	56.9%	54.9%
Nuclear	1.1	1.7	1.7	1.8	1.8	1.7	1.6	2.8	85.2%	82.8%	82.8%
Other non-renewable	1.9	2.4	4.3	2.7	2.9	0.7	0.1	0.0	14.0%	5.5%	1.9%
Biomass	1.6	3.6	5.6	5.8	5.9	6.5	8.2	9.6	43.6%	44.4%	42.7%
Wind	0.0	0.2	2.5	3.8	4.8	7.1	8.8	10.5	42.1%	42.2%	42.2%
Solar	0.0	0.0	0.0	0.0	0.1	1.0	1.8	2.9	24.6%	22.1%	21.1%
Total	**46.0**	**58.9**	**66.4**	**66.1**	**67.1**	**72.7**	**80.8**	**89.9**			

Table 76. Total emissions between 2005 and 2030 in Scenario C (Mt CO_2-eq)

Mt CO_2-eq	2005	2010	2015	2020	2025	2030
Electricity generation	27	37	68	40	44	50
Energy sector consumption	22	24	30	27	29	31
Charcoal power plants	1.0	0.7	0.6	0.5	0.5	0.6
Total	49	61	99	68	74	82

In this scenario, the electricity share in total energy demand is higher than in the other scenarios (Table 77). This is due to electrical vehicles replacing some internal combustion vehicles.

Table 77. Share of electricity consumption in total energy demand between 2005 and 2030 in Scenario B (%)

	2005	2010	2015	2016	2017	2020	2025	2030
Scenario C	16.5%	16.6%	17.3%	17.5%	17.4%	18.5%	19.0%	19.7%

Table 78 shows the Domestic Energy Supply for Scenario C and historical data.

Table 78. Domestic Energy Supply between 2005 and 2030 in Scenario C (10^3 toe)

Ktoe	2005	2010	2015	2016	2017	2020	2025	2030
Non-renewable	**121,819**	**148,644**	**175,903**	**162,975**	**166,808**	**159,799**	**165,200**	**171,383**
Petroleum and oil products	84,553	101,714	111,626	105,354	106,276	105,047	102,685	99,197
Natural gas	20,526	27,536	40,971	35,569	37,938	33,850	41,837	48,564
Coal and coke	12,991	14,462	17,625	15,920	16,570	16,671	16,544	16,779
Other non-renewable	3,749	4,932	5,681	6,132	6,024	4,231	4,134	6,842
Renewable	**96,117**	**120,152**	**123,672**	**125,345**	**126,685**	**137,345**	**156,572**	**173,899**
Hydraulic and electricity	32,379	37,663	33,897	36,265	35,023	39,665	41,379	42,534
Firewood and charcoal	28,468	25,998	24,900	23,095	23,424	20,997	21,406	22,050
Sugar cane products	30,150	47,102	50,648	50,318	51,116	54,671	64,240	74,889
Other renewable	5,120	9,389	14,227	15,667	17,122	22,013	29,547	34,426
Total	**217,936**	**268,796**	**299,574**	**288,319**	**293,492**	**297,144**	**321,772**	**345,282**

4.4.5. Comparative Analysis of Scenarios A, B and C – Avoided Emissions by Mitigation Actions

The Brazilian NDC presents some measures in the energy sector that should be implemented by 2030. The values achieved in Scenarios B and C and the Brazilian NDC goals for the energy sector are in Table 79. In those scenarios, apart from the share of biofuels and of renewables in the energy mix in Scenario A, all other goals would be met in 2030.

Table 79. NDC targets in the energy sector in Scenarios B and C (%)

Goal	2005	Scenario A 2030	Scenario B 2030	Scenario C 2030	NDC Target
% biofuels in energy mix	13.8%	18.7%	21.0%	23.7%	**18.0%**
% renewable in energy mix	44.1%	43.9%	46.9%	50.4%	**45.0%**
% renewable in energy mix, except hydro	29.2%	31.8%	34.9%	38.0%	**28.0%**
% electricity from renewables, except hydro (in total power supply)	3.1%	23.3%	23.4%	24.8%	**23.0%**

One of the Brazilian NDC's goals is to achieve 45% of renewables in the energy mix by 2030. Scenario A would not meet this goal, showing that more efforts are required.

The avoided emissions in Scenarios B and C, compared to Scenario A, are in Table 80 and Table 81 below.

Table 80. Avoided emissions in Scenario B, compared to Scenario A (Mt CO_2-eq)

Avoided emissions	2020	2025	2030
	Mt CO_2-eq		
Increased renewable power generation	0.47	1.7	0.18
Increased efficiency in Energy sector consumption	0.24	0.79	1.2
Emissions from charcoal kilns	-0.027	-0.060	-0.093
Total	0.68	2.4	1.3

Table 81. Avoided emissions in Scenario C, compared to Scenario A (Mt CO_2-eq)

Avoided emissions	2020	2025	2030
	Mt CO_2-eq		
Increased renewable power generation	1.0	3.2	4.5
Increased efficiency in Energy sector consumption	0.45	1.5	2.6
Emissions from charcoal kilns	-0.030	-0.068	-0.11
Total	1.4	4.6	7.0

In Table 82, it is possible to observe the emissions differences between scenarios B and C. It is possible to see that most part of the avoided emissions in Scenario C, compared to B, come from electricity generation sector.

Table 82. Avoided emissions in Scenario C, compared to Scenario B (Mt CO_2-eq)

Avoided emissions	2020	2025	2030
	Mt CO_2-eq		
Increased renewable power generation	0.50	1.1	4.5
Increased efficiency in Energy sector consumption	0.20	0.70	1.3
Emissions from charcoal kilns	-0.019	0.016	-0.05
Total	0.68	1.82	5.75

The emission factors from the electricity grid are in Table 83.

Table 83. Grid emission factors (kgCO_2-eq/MWh of electricity demand)

	2005	2010	2015	2020	2025	2030
	kgCO_2-eq/MWh					
Scenario A	71.1	78.7	130.0	70.1	72.4	76.1
Scenario B				69.8	70.8	77.4
Scenario C				69.3	69.0	71.4

We calculated which factors have contributed to reducing emissions in Scenarios B and C. We considered that, if a technology generated more electricity in an emission reduction scenario, that generation increase has a share in the total avoided emission. Likewise, a reduction in demand also contributes to lower total emissions. So, Table 84 shows avoided emissions in each scenario compared to Scenario A. Comparing to Table 83 we can see that the avoided emissions per TWh are greater than the average grid emission factor.

As technologies have different capacity factors, we calculated the amount of avoided emissions per year that each extra MW installed would provide[5]. The results are in Table 85 and Table 86. As Table 84 shows, all avoided emissions in Scenario B are due to demand reduction.

Table 84. Avoided emissions per TWh of increased electricity generation and demand reduction in Scenarios B and C, compared to Scenario A (kg CO_2-eq/MWh)

kg CO_2-eq/MWh	2020	2025	2030
Scenario B	0.10	0.16	0.01
Scenario C	0.11	0.18	0.13

Table 85. Additional installed capacity and avoided emissions per year, for each TWh of demand reduction in Scenario B over A (TWh and (Mt CO_2-eq /TWh).

	Demand reduction (TWh)			Avoided emissions (Mt CO_2-eq /TWh)		
	2020	2025	2030	2020	2025	2030
Demand reduction	4.8	10.4	17.1	96.5	160.5	8.3

[5] Demand reduction is considered a “technology” in this analysis. However, there is no installed capacity for this technology. So, the results should be interpreted as avoided emissions per TWh of demand reduction.

Table 86. Additional installed capacity and avoided emissions per year, for each extra GW installed in Scenario C over Scenario A (tCO_2-eq/MW per year)

	Additional installed capacity (GW)			Avoided emissions (Mt CO2-eq/GW per year)		
	2020	2025	2030	2020	2025	2030
Sugarcane bagass	0.0	0.0	2.7	0.0	0.0	0.5
Wind	0.0	0.0	1.0	0.0	0.0	0.5
Distributed photovoltaic	0.0	0.2	0.3	0.0	0.3	0.2
Utility scale photovoltaic	0.0	0.3	1.0	0.0	0.4	0.3
Demand reduction*	8.8	16.5	18.2	110.7	181.6	127.7

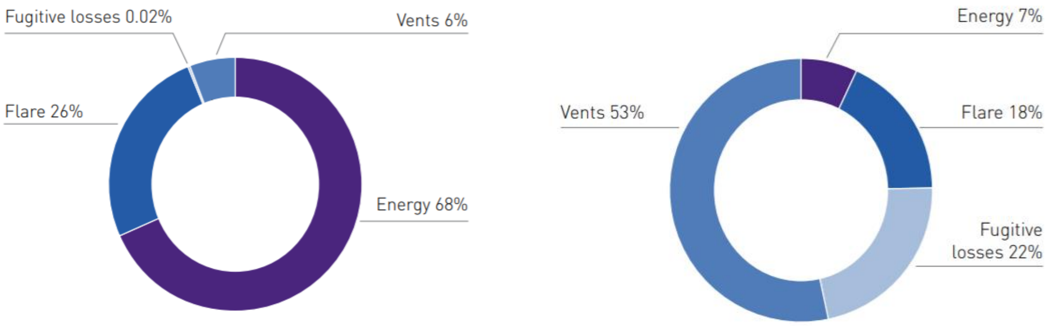
* In demand reduction line, the units are TWh and Mt CO_2-eq /TWh.

4.5. FUGITIVE EMISSIONS (FROM ENERGY SUPPLY)

4.5.1. Oil and Natural Gas Systems

The term fugitive emissions is broadly applied to mean all greenhouse gas emissions from oil and gas systems except contributions from fuel combustion. Oil and natural gas systems comprise all infrastructure required to produce, collect, process or refine and deliver natural gas and petroleum products to the market. The system begins at the wellhead, or oil and gas source, and ends at the final sales point to the consumer (IPCC, 2006). The primary sources of these emissions may include fugitive equipment leaks, evaporation losses, venting, flaring and accidental releases.

Fugitive emissions from oil and natural gas systems occur from fugitive equipment leaks, evaporation losses, venting, flaring and accidental releases. In IOGP (2017), world carbon dioxide (CO_2) emissions from activities of exploration and production (E&P) were 68% from energy consumption and 26% from flares in 2016. Methane (CH_4) emissions were 53% from vents, 22% fugitive losses and 18% flare.



Source: IOGP (2017).

Figure 43. CO_2 (left) and CH_4 (right) emissions by source in E&P activities (%)

GHG emissions occur in three different segments of the oil or gas system: Exploration and Production (E&P), Refining and Transportation.

Exploration and Production includes onshore and offshore activities and emissions vary with oil and gas supply. In Brazil, gas production is mostly associated with natural gas (AG) and occurs alongside all crude oil production. AG production varies according to the gas to oil ratio (GOR) and methane is the predominant compound.

The refining segment includes oil refining and gas processing. Petroleum refining processes are the chemical engineering processes and other facilities used in petroleum refineries (also referred to as oil refineries) to transform crude oil into useful products such as liquefied petroleum gas (LPG), gasoline or petrol, kerosene, jet fuel, diesel oil and fuel oils. Emissions vary with the demand for such oil products and the main sources are leaks, flares, hydrocracking and fluid catalytic cracking units. Natural gas is processed in specific units (UPGN – Unidade de Processamento de Gás Natural) usually involving several processes, or stages, to remove oil, water, hydrocarbon gas liquids (HGL) and other impurities. HGL goes to petrochemical plants, oil refineries, and other HGL consumers (EIA, 2018).

The world refining industry faces challenges associated with the trade-off between pollutant emissions with local and global impacts. Production of diesel or gasoline with extremely low sulfur contents normally requires more energy, resulting in higher energy consumption and higher emissions of GHG (Szklo & Schaeffer, 2007).

In EPA (2013), the largest sources of GHG emissions in the Refineries Sector is stationary fuel combustion (68%), Catalytic Cracking/Reforming (27%) and flares (3%). These three sources are detailed:

- Stationary combustion sources are heaters, boilers, combustion turbines, and similar devices, that produce primarily CO_2 and small amounts of CH4 and nitrous oxide (N2O) emissions. The predominant fuel used at petroleum refineries is refinery fuel gas (RFG), which is also known as still gas. RFG is a mixture of light hydrocarbons, hydrogen, hydrogen sulfide (H_2S), and other gases.
- Catalytic cracking is the process where heat and pressure are used with a catalyst to break large hydrocarbons into smaller molecules and FCCU (fluid catalytic cracking unit) is the most common type of unit. GHG are emitted through the combustion of coke, CO_2 is the primary GHG emitted and small quantities of CH4 and N_2O are also emitted during "coke burn-off." An FCCU catalyst regenerator might be designed to operate in complete-combustion or partial combustion, varying CO_2 emission. The FCCU catalyst regeneration or coke burn-off vent is often the largest single source of GHG emissions at a refinery.
- Another source are flares, such as in E&P, in refineries are commonly used as safety devices to receive gases during periods of process upsets, equipment malfunctions, and unit start-up and shutdowns. Combustion of gas in a flare results in emissions of predominately CO_2 and small amounts of CH_4 and N_2O.

Refineries and Gas Processing Units in Brazil are under ANP rules and environmental licensing is usually coordinated by state authorities. According to ANP (2018), the Petroleum processing capacity was of 2.4 Mbpd distributed in 17 refineries with a utilization factor of 76.2%, in 2017. Petrobras owns 13 refineries, controlling 98.2% of the refining capacity. São Paulo state was responsible for 38.7% and Rio de Janeiro for 12.8%. Most refineries date back to the 1970s and these old-fashioned ones are responsible for 93% of the current processing capacity. In 2017, Brazilian associated natural gas was processed in 14 units and the total capacity was of 95.7 M m3/d. Processed volume was 64.9 M m3/d, 67.8% of the total capacity. Of total processed gas, Cabiunas (RJ) was responsible for 29%, Caraguatatuba (SP) for 19% and Urucu (AM) 18%.

According to Azevedo & Pereira (2010), adaptations in processes and equipment of the Brazilian refineries have been made since the mid-1980s to adjust them to the National

Petroleum standard, especially to amplify processing plants and to allow the production of cleaner fuels. Some programs were: PROAMB (Environmental Technology Program) in 1993, PROTER (Strategic Refining Development Program) in 1994 and INOVA (Program for Fuels Innovation) in 2000. After two huge oil spill incidents in 2000, in Baía de Guanabara/Rio de Janeiro and Paraná, a new program to improve environmental management, PEGASO (Program for Excellence in Environmental Management and Operational Safety) was created.

Most of the refineries are in São Paulo State, where CETESB, the environmental agency CETESB, published a Good Practice Book to Reduce Air Pollution (CETESB, 2017). Despite the actions in this guideline are to improve local air quality as energy efficiency improvement, reduction in stationary fuel combustion, fuels change, flare management and others in an LDAR program (in some cases combined with SmartLDAR) they also reduce GHG. The State Decree # 59113/2013 requires that refineries established in certain must elaborate specific plans.

Transportation includes storage, transportation and distribution for E&P and refining products. Transportation for E&P products includes vessels and pipelines. Distribution is the phase between refining and consumers, and some possible ways are by trucks or pipes.

Based on the Brazilian Oil and Gas Agency (ANP – Agência Nacional de Petróleo, Gás Natural e Biocombustíveis) data, since 2005 oil and gas production and related emissions increased with pre-salt production. In 2005, oil production was 1.75 million barrel per day (MM bpd) and in 2017, 2.79 MM bpd. In the Refining sector, processed oil increased from 1.76 MM bpd to 2.13 in 2014 but decreased to 1.76 MM bpd in 2017.

Table 87. Activity level from the oil and gas Industry between 2005 and 2017 (M bpd and M m^3/day).

Activity	Unit	2005	2010	2015	2016	2017
Oil and LNG Production	M bpd	1.8	2.2	2.6	2.7	2.8
Gas Production	M m^3/d	48	63	96	104	110
Oil Refining	M bpd	1.8	1.8	2.0	1.9	1.8

Source: ANP (2018).

Estimates of CO_2, CH_4 and N_2O emissions follow the methodology presented in MCTIC (2016) and vary with the activity levels. Table 88 presents the values for the 2005 – 2017 period when E&P represented approximately 60% and Refining, 40% of the total fugitive emissions. From 2015 to 2017 data were estimated with the average emission factor from 2003 to 2012.

Table 88. Fugitive emissions from the oil and gas industry, 2005 – 2017 (Mt CO_2-eq).

Segment	2005	2010	2015	2016	2017
Mt CO_2-eq					
E&P	5.9	6.2	6.8	7.1	7.4
Refining	6.5	7.1	8.0	7.4	7.0
Transportation	0.08	0.07	0.08	0.08	0.08
kt CH_4					
E&P	141	124	144	149	156
Refining	9.0	10.0	11.0	10.0	9.0
Transportation	7.0	8.0	9.0	9.0	10.0
Kt N_2O					
E&P	0.20	0.20	0.22	0.22	0.23
Refining	0.010	0.010	0.010	0.010	0.010
Transportation	0.0	0.0	0.0	0.0	0.0
Mt CO_2-eq					
E&P	10	10	11	12	12
Refining	6.8	7.4	8.4	7.7	7.3
Transportation	0.29	0.31	0.35	0.35	0.38
TOTAL	**17**	**18**	**20**	**20**	**20**

This study analyses the emissions from flaring. According to the World Bank (2016), there are three categories of flaring: routine flaring, safety flaring, and non-routine flaring. Routine flaring in oil production operations occurs in the absence of enough facilities or amenable geology to re-inject the produced gas, utilize it on-site, or dispatch it to a market. Safety flaring of gas is flaring to ensure safe operations of the facility, for example, to remove gas stemming from an accident or incident that could jeopardize the facility. Non-routine gas flaring is all flaring other than routine and safety flaring and it is either planned or unplanned, for example, initial plant/field start-up, facility shutdowns schedule, preventive maintenance, etc.

4.5.1.1. Scenario A

4.5.1.1.1 Assumptions

Based on the activity level expected for oil and gas production and oil refining from 2018 to 2030, Scenario A estimates the oil and gas fugitive emissions, taking into account ongoing mitigation efforts. Estimates on the oil and gas activity level for the 2018-2026 period is based on the Decennial Energy Plan elaborated by the Energy Research Office (EPE – Empresa de Pesquisa Energética). For the 2027 – 2030 period, it is the trend.

Table 89. Activity level of the oil and gas industry between 2005 and 2030 in Scenario A (M bpd and M m^3/day).

Activity	Unit	2005	2010	2015	2020	2025	2030
Oil and LNG Production	M bpd	1.8	2.2	2.6	3.1	4.9	6.2
Gas Production	M m^3/d	48	63	96	115	167	227
Oil Refining	M bpd	1.8	1.8	2.0	2.3	2.4	2.7

In 2000, ANP, through resolution number 249, established that all new oil and gas fields in the production stage should obtain authorization to flaring or venting more than 3% of the associated natural gas. This study analyzed the evolution of Brazilian production (Figure 44) and the flaring percentage from 2005 to 2017 with ANP data (Figure 45). The starting year is 2005 due to the average delay of 5 years between the exploration and the production stages. Data show the effort the industry has been making to diminish flaring. Flaring reached 13.98% of the associated gas production in 2005. It went down to 10,54% in 2010 but 75% of the production was still associated with projects before 2005. It was reduced to 3,43% in 2017 although 48% of the activity was also associated with projects before 2005.

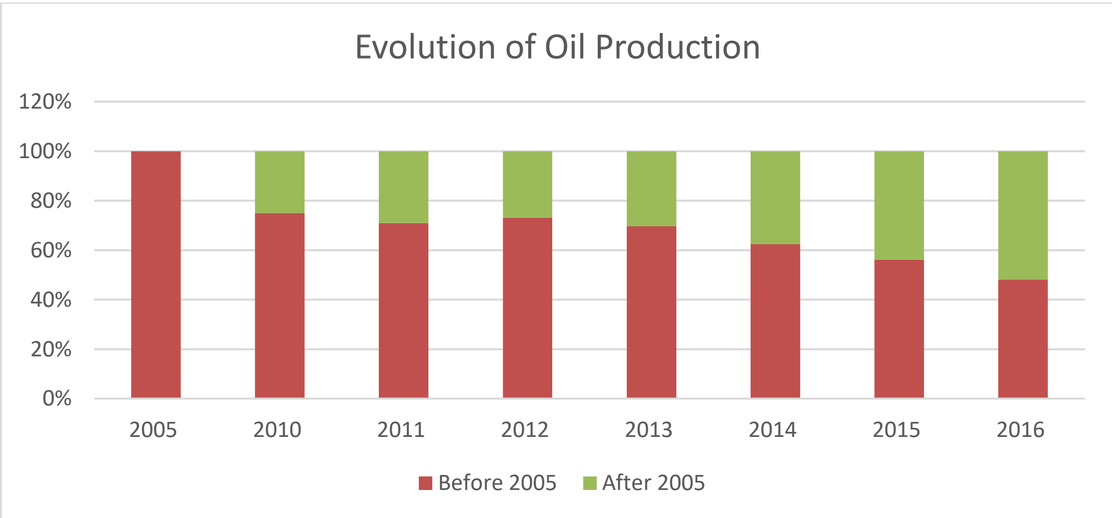


Figure 44. Brazilian oil production under the ANP resolution # 249 of 2000 between 2005 and 2016 (%)

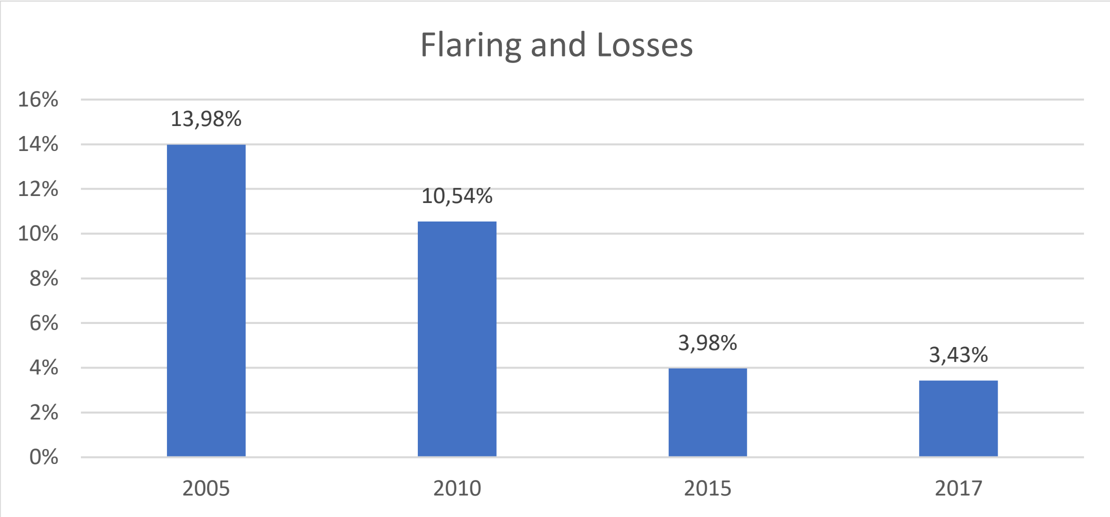


Figure 45. Gas flaring and losses of associated gas production from 2005 to 2017 (%)

Based on these results, we estimated a linear trend for E&P in Scenario A, when NG flaring and venting would be limited to 3.2% in 2020 and 3.0% in 2025 and 2030. In conclusion, E&P emissions estimates consider the activity level and the emission factor but discounting the envisaged improvements in flaring. In Refining and Transportation, estimates of fugitive emissions consider the activity level and the emission factor only, since there isn't any regulation on that. Data on flaring in the refining segment are not available making it impossible to draw up estimates.

4.5.1.1.2 Results

For the oil and gas industry, there isn`t any specific NAMA or NDC commitment and without any further incentive or restriction, emissions from 2005 to 2030 would be 2.5 times higher in E&P and Transportation segments and 1.6 in the Refining segment.

Table 90. Fugitive emissions in the oil and gas industry between 2005 and 2030 in Scenario A (Mt CO_2-eq).

Segment	2005	2010	2015	2020	2025	2030
Mt CO_2						
E&P	5.9	6.2	6.8	8.0	12	15
Refining	6.5	7.1	8.0	9.3	9.7	11
Transportation	0.08	0.07	0.08	0.10	0.12	0.15
kt CH_4						
E&P	141	124	144	175	276	346

Segment	2005	2010	2015	2020	2025	2030
Refining	9.0	9.9	10.6	12.3	12.8	14.2
Transportation	6.9	8.2	8.9	10.7	16.5	20.6
kt N_2O						
E&P	0.20	0.20	0.22	0.26	0.41	0.52
Refining	0.008	0.007	0.013	0.015	0.016	0.018
Transportation	0.003	0.002	0.003	0.003	0.005	0.006
Mt CO_2-eq						
Total E&P	9.9	9.7	11	13	20	25
Total Refining	6.8	7.4	8.3	9.6	10.1	11
Total Transportation	0.27	0.30	0.33	0.40	0.58	0.73
Total Mt CO_2-eq						
Total Oil and Gas Industry	**17**	**17**	**20**	**23**	**31**	**37**

4.5.1.2 Scenario B

4.5.1.2.1 Assumptions

No efforts are made in Scenario B to mitigate fugitive emissions. Changes in fuel demand would impact the refining segment that, in turn, would emit marginally less (a reduction of 0,036%). No changes are associated with E&P or the Transport segment.

4.5.1.2.2 Results

Emissions from 2005 to 2030 would be 2.5 times higher in the E&P and Transportation segments and 1.6 in the Refining Segment, as in Scenario A. Table 91 shows the emissions estimated in Scenario B.

Table 91. Fugitive emissions in the oil and gas industry between 2005 and 2030 in Scenario B (Mt CO_2-eq).

Segment	2005	2010	2015	2020	2025	2030
Mt CO_2						
E&P	5.9	6.2	6.8	8.0	12	15
Refining	6.5	7.1	8	9.3	9.7	11
Transportation	0.08	0.07	0.08	0.10	0.12	0.15
Kt CH_4						
E&P	141	124	144	175	276	346
Refining	9.0	9.9	10.6	12.3	12.8	14.2
Transportation	6.9	8.2	8.9	10.7	16.5	20.6
Kt N_2O						
E&P	0.20	0.20	0.22	0.26	0.41	0.52

Segment	2005	2010	2015	2020	2025	2030
Refining	0.008	0.007	0.013	0.015	0.016	0.018
Transportation	0.003	0.002	0.003	0.003	0.005	0.006
Mt CO_2-eq						
Total E&P	9.9	9.7	11	13	20	25
Total Refining	6.8	7.4	8.3	9.6	10	11
Total Transportation	0.27	0.30	0.33	0.40	0.58	0.73
Total Mt CO_2-eq						
Total Oil and Gas Industry	**17**	**17**	**20**	**23**	**31**	**37**

4.5.1.3 Scenario C

4.5.1.3.1 Assumptions

Scenario C includes major efforts to reduce emissions from the energy sector. The activity level is the same in Oil, LNG and gas production and reaches 2.69 M bpd in 2030.

Mitigation efforts in the E&P segment for flare reduction are based on the flare levels in the United Kingdom. Stewart (2014) assessing more than 200 UK offshore oil fields, “found that 3% of produced AG was flared or vented at offshore fields. This value drops to 2% when only fields developed after 1998 are included. Of the 99 fields developed after 1998 a large range of mean flaring/venting percentages (0-90%) exists at individual fields, indicating that a number of fields flare high fractions of the AG produced”.

Based on this study results, we assumed that 2.0%, the current value in practice in the UK, would be a viable target for Brazil by 2030. We set the values for the intermediate years by interpolation. Therefore, the mitigation efforts in Scenario C to the E&P segment would then limit flaring and venting to 3.2% in 2020, 2.6% in 2025 and 2.0 in 2030.

In respect to refining, as mentioned, emissions in the refinery segment result of leakages from piping connectors, valves, compressors and pumps. According to EPA (2018), valves and connectors account for more than 90% of emissions from leaking equipment with valves being the most significant source.

Therefore, potential mitigation actions are: improvement of leak detection and repair (LDAR) programs; improvement of block valves packing; optimization of valve stuffing box and stem finishes; installation of a second valve on cap or plug on open-ended lines; use of low emission type control valves; upgrade of pump seals; use of low emission quarter-turn valves;

and use of lof leakless technology (bellow valves; canned and magnetic drive pumps). Still, according to EPA, fugitive emissions in the US were reduced from 50-90% with LDAR.

Refineries in Europe are under phase III of the EU emissions trading system (EU ETS), since 2013. Based on the 2010 cap, 1.74% will be reduced annually, limiting the number of EUAs available to 21% below the 2005 level, by 2020. Opportunities to reduce emissions in 2050 are in energy efficiency actions: refinery process efficiency (e.g. catalyst improvements), use of low carbon energy sources (reduction of liquid fuel, increase gas and electricity grid) and CO_2 capture (CONCAWE, 2018).

Although CO_2 capture is not operational yet, Brazilian refineries should assess this option, along with energy efficiency measures and changes in energy sources. Other mitigation alternatives are improving flare efficiency and reducing venting and leakages. Flare efficiency can be improved with correct steam volume and by improving seal in the compressor. Leak monitoring and repair could be improved with LDAR or SMART LDAR procedures. Studies with these options are summarized below.

Robinson et al. (2007) tested the SMART LDAR, another leak gas detection technology. This technology consists of a portable Infrared camera that scans components more quickly and produces images of gas leaks in real time. The study concluded that the camera can detect emissions from piping components with leak rates as low as 2 gr/hr. The faster scanning rate allows operators to get a better return on repair efforts because it is easier to identify large leaks. The same technology was studied in Vidal (2006) for two Brazilian refineries that concluded that results were satisfied only in large leaks and the advantage is the faster response to identify large leaks and repair the components.

Some flaring reduction options are also reported in IPIECA (2012), like reducing the amount of material sent to the flare, processes operation improvement by reducing the number of emergency flaring episodes, installation of flare gas recovery systems to recycle the hydrocarbons back into the processing system.

Comodi, Renzi & Rossi (2016) investigated methods to improve energy efficiency in an Italian oil refinery with ejector and liquid ring compressor technologies and the amount of flare gas that can be recovered yearly corresponds to 6600 t CO_2-eq.

Silva et al. (2016) studied the optimal steam flowrate used in flares in a large refinery in Brazil by monitoring hydrocarbon emissions using an infrared camera. Results show that the flares were not working on the 98% efficiency, as specified by manufacturers with the steam flow being higher than the optimal. Results show that the optimal steam would be 44% and 78% smaller than the current flow and that adjusting the steam flow would increase combustion efficiency, reducing costs and black smoke.

Based on these studies, we assume that Petrobras can reduce leaks in the refining segment. Petrobras CDP inventory (2017) reported a reduction of 374,157 t CO_2-eq (AR4 GWP) or 0.5 Mt CO_2-eq (AR5 GWP) in fugitive emission due to leakages monitoring and reduction and improvements in management losses of gas flare in refineries, in 2016.

We estimate that refineries can save the same amount of fugitive emissions from leakage, venting and flaring reported in 2016 every 5 years, resulting in the annual mitigation of 0.5 Mt CO_2-eq (AR5 GWP) in 2020, 2025 and 2030.

4.5.1.3.2 Results

Emissions from 2005 to 2030 would be 2.0 times higher in the E&P and Transportation segments and 1.6 in the Refining Segment. Table 92 shows the emissions estimated in Scenario C.

Table 92. Fugitive emissions in the oil and gas industry between 2005 and 2030 in Scenario C (Mt CO_2-eq).

Segment	2005	2010	2015	2020	2025	2030
Mt CO_2						
E&P	5.9	6.2	6.8	8.0	12	13
Refining	6.5	7.1	8.0	8.8	8.7	9.3
Transportation	0.08	0.07	0.08	0.10	0.12	0.15
Kt CH_4						
E&P	141	124	144	175	276	346
Refining	9.0	9.9	10.6	10.5	9.2	8.9
Transportation	6.9	8.2	8.9	10.7	16.5	20.6
Kt N_2O						
E&P	0.20	0.20	0.22	0.26	0.41	0.52
Refining	0.008	0.007	0.013	0.015	0.016	0.018
Transportation	0.003	0.002	0.003	0.003	0.005	0.006
Mt CO_2-eq						
Total E&P	9.9	9.7	11	13	20	23
Total Refining	6.8	7.4	8.3	9.1	9.0	9.6
Total Transportation	0.27	0.30	0.33	0.40	0.58	0.73
Total Mt CO_2-eq						
Total Oil and Gas Industry	**17**	**17**	**20**	**23**	**29**	**34**

4.5.2. Fugitive emissions from mining, processing, storage and transportation of coal

4.5.2.1 Emission Sources

Mining and post-mining activities are sources of methane (CH_4) and carbon dioxide (CO_2) emissions. Coal normally continues to emit even after it has been mined, although more slowly than during the coal breakage stage (IPCC, 2006). Underground mines are characterized by seam gas emissions vented to the atmosphere from coal mine ventilation air and degasification systems. Surface coal mines have CH_4 and CO_2 emitted during mining from breakage of coal and associated strata and leakage from the pit floor and highwall, post-mining emissions, low-temperature oxidation and uncontrolled combustion in waste dumps.

This study follows the III National Communication of Brazil to the United Station Framework Convention to Climate Change (MCTIC, 2016) that accounts for emissions from mining of Run Of Mine (ROM) coal, processing and waste pile.

In Brazil, coal mining activities take place in three different states: Rio Grande do Sul, Santa Catarina and Paraná. According to MCTIC (2016), in Rio Grande do Sul there are only surface mines left while in Santa Catarina and Paraná they are underground.

Coal emissions estimates are based on coal production data that varies with the demand. According to the Coal Brazilian Association (ABCM – Associação Brasileira de Carvão Mineral), Run-Of-Mine (ROM) coal production increased in Rio Grande do Sul from 4.25 to 6.26 Mt and decreased in Santa Catarina, from 7.81 to 6.51 Mt, from 2005 to 2015. Currently, national coal production provides about 20% of domestic demand and is mainly used in power plants (EPE, 2017).

Table 93. Coal Run-Of-Mine (ROM) production in Brazil between 2005 and 2016 (kt).

State	2005	2010	2015	2016
	(kt)			
Rio Grande do Sul	4,250	5,011	6,260	4,841
Santa Catarina	7,809	6,278	6,508	6,207
Paraná	339	293	0	210
Total	12,398	11,582	13,107	11,257

Source: ABCM (2018).

Table 94 shows the emissions in the period.

Table 94. Fugitive emissions from mining, processing, storage and transportation of coal between 2005 and 2016 (Mt CO_2-eq)

Activity	2005	2010	2015	2016
Coal mining, processing, storage and transportation	Mt CO_2			
	1.4	1.9	1.8	1.8
	kt CH_4			
	49	39	52	30
	Mt CO_{2-}eq			
	2.9	**3.0**	**3.4**	**2.8**

4.5.2.2. Scenario A

4.5.2.2.1 Assumptions

The shares of surface and underground coal in mining show a trend towards 50% for each type, considering the period from 2005 to 2015, as in Figure 46. Considering these data, Scenario A assumes a constant share of 50-50% up to 2030.

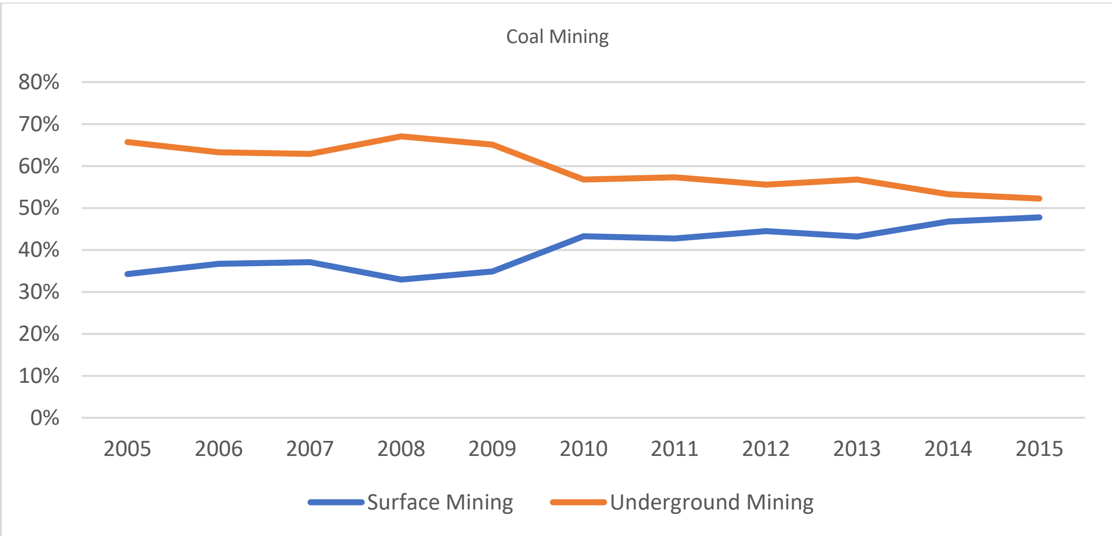


Figure 46. Trends in coal mining types between 2005 and 2015 (%)

The demand for coal in the 2018-2030 period was estimated by the Matriz model with outputs showing that most of the domestic coal production would keep on supplying power plants.

Matriz results are in 10^3 toe. The factor used to convert toe into tons of coal was 3.23 (due to the average coal type). Data from 2006 to 2015 shows that in average 51% of the production was rejected, therefore a factor of 1.96 was used to account for this loss of ROM coal.

Table 95. Coal mining production estimates up to 2030 in Scenario A (1,000 toe and ton)

Unit	2005	2010	2015	2020	2025	2030
10^3 toe	2,483	2,161	3,066	3,381	3,340	3,643
10^3 ton	6,045	5,415	6,354	10,906	10,774	11,752
ROM 10^3 ton (total coal production)	12,398	11,582	13,107	21,385	21,126	23,042

4.5.2.2.2 Results

Without any additional mitigation action, emissions in 2030 would be 1.8 times higher than in 2005, varying from 2.85 to 5.2 Mt CO_2-eq, as in Table 96.

Table 96. Fugitive emissions from coal between 2005 and 2030 in Scenario A (Mt CO_2-eq)

Activity	2005	2010	2015	2020	2025	2030
mining, processing, storage and transportation of coal	**Mt CO_2**					
	1,4	1,8	1,8	2,4	2,4	2,6
	kt CH_4					
	49	39	52	80	79	86
	Mt CO_2-eq					
	2.8	**2.9**	**3.3**	**4.6**	**4.6**	**5.0**

4.5.2.3 Scenario B

4.5.2.3.1 Assumptions

No mitigation actions envisaged. Emissions vary according to the demand for coal

4.5.2.3.2 Results

Without any additional mitigation action, emissions in Scenario B in 2030 would be 1.7 times higher than in 2005, varying from 2.9 to 4.9 Mt CO_2-eq, as in Table 97.

Table 97. Fugitive emissions from coal between 2005 and 2030 in Scenario B (Mt CO_2-eq)

Activity	2005	2010	2015	2020	2025	2030
mining, processing, storage and transportation of coal	Mt CO_2					
	1.4	1.8	1.8	2.4	2.1	2.5
	Kt CH_4					
	49	39	52	80	70	80
	Mt CO_2-eq					
	2.8	**2.9**	**3.3**	**4.6**	**4.1**	**4.7**

4.5.2.4 Scenario C

4.5.2.4.1 Assumptions

No mitigation actions envisaged. Emissions vary according to the demand for coal.

4.5.2.4.2 Results

Without any additional mitigation action, emissions in Scenario C in 2030 would be 1.5 times higher than in 2005, varying from 2.9 to 4.2 Mt CO_2-eq, as in Table 98.

Table 98. Fugitive emissions from coal between 2005 and 2030 in Scenario C (Mt CO_2-eq)

Activity	2005	2010	2015	2020	2025	2030
mining, processing, storage and transportation of coal	Mt CO_2					
	1.4	1.8	1.8	2.4	2.2	2.1
	Kt CH_4					
	49	39	52	78	72	69
	Mt CO_2-eq					
	2.8	**2.9**	**3.3**	**4.6**	**4.2**	**4.0**

4.5.3. Comparative Analysis of Scenarios A, B and C – Avoided Emissions by Mitigation Actions

As described in the previous sections, the results of scenarios A and B showed the trends for both oil and coal fugitive emissions, with differences reflecting only changes in the activity levels.

For the Exploration and Production (E & P) segment, there is a trend towards lower levels of flaring and gas losses as new platforms come on stream. Thus, it is estimated that by 2025 the flaring loss would be of 3.0%, 0.5% lower than in 2017.

In scenario C, some mitigation measures reduce the fugitive emissions in the E & P and refining segments, two major sources. Reducing demand for coal also reduces its production and thus emissions.

For E & P the proposed measure is a linear reduction in flaring between 2020 and 2030, starting with a 2.6% limit in 2020 and reaching 2% in 2030 (Table 99).

In the refining segment, the mitigation measure consists of reducing losses from oil and gas leakages through improving monitoring and flare efficiency. Based on Petrobras CDP (2017), we assumed that this measure would reduce 0.5 Mt CO_2-eq every 5 years or a mitigation amount of 0.5 Mt CO_2-eq in 2020, 1.0 Mt CO_2-eq in 2025 and 1.5 Mt CO_2-eq in 2030.

Table 99. Summary of the mitigation measures in Scenario C (Mt CO_2-eq and %)

Measure	2020	2025	2030
Flaring limits in E&P (%)	2.6%	2.0%	2.0%
Leak reduction in refining (Mt CO2-eq)	0.5	1.0	1.5

Emissions in all the scenarios are concentrated in the Oil and Gas industries. Of the total, they corresponded to 85% in 2005 and in both scenarios A and B, this share reached 89% in 2030 and a little less in Scenario C where O&G emits 87% in the end f the period.

Considering only the O&G industry, the E&P segment increases 170% in scenarios A and B and 140% in Scenario C, in 2030 relatively to 2005. In the refining segment the values increase 62% in scenarios A and B and 41% in Scenario C. In transport, emissions increase in the same magnitude as of the E&P segment, which is 166% in A and B and 159% in C, although in absolute term, values are quite lower than in E&P.

In coal mining, processing, storage and transportation emissions increase 79% in Scenario A, 69% in B and 45% in C, in 2030 relatively to 2005, reflecting a lower increase in coal demand in C than in A and B.

The emissions evolution in all scenarios in absolute values is in Table 100.

Table 100. Fugitive emissions in Scenarios A, B and C per segment – 2005-2030 (Mt CO_2-eq).

Segment	2005	2010	2015	2016	Scenario A			Scenario B			Scenario C		
					2020	2025	2030	2020	2025	2030	2020	2025	2030
Mt CO_2-eq **Oil and Natural Gas Systems**													
E&P	10	10	11	12	13	20	25	13	20	25	13	20	23
Refining	6.8	7.4	8.3	7.7	9.6	10	11	9.6	10	11	9.1	9.0	9.6
Transport	0.29	0.31	0.35	0.32	0.40	0.58	0.73	0.40	0.58	0.73	0.40	0.58	0.73
Total	17	18	20	20	23	31	37	23	31	37	23	29	34
Mining, processing, storage and transportation of coal													
Total	2.8	2.9	3.3	2.8	4.6	4.6	5.0	4.6	4.1	4.7	4.6	4.2	4.0
Total Fugitive Emissions													
Total	20	21	23	23	28	35	42	28	35	42	27	33	38

Fugitive emissions in scenarios A and B are close, so there is no avoided emission between scenarios A and B and emissions avoided between scenarios C and A are quite similar to scenario C in relation to B.

A flaring limit reduces up to 2.9 Mt CO_2-eq in 2030 from a total of 4.5 Mt CO_2-eq, being the main mitigation measure. Reduction of oil and gas leaks reduce up to 1.6 Mt CO_2-eq by 2030. Table 101 shows the mitigation potential between scenarios.

Table 101. Mitigation Measures and Avoided Emissions in each Scenario (Mt CO_2-eq)

Mitigation Measure	Emissions avoided in scenario B in relation to A			Emissions avoided in scenario C in relation to A			Emissions avoided in scenario C in relation to B		
	2020	2025	2030	2020	2025	2030	2020	2025	2030
	Mt CO_2-eq								
Flaring in E&P	-	-	-	-	0.50	2.0	-	0.50	2.0
Leak reduction in Refining	-	-	-	0.55	1.1	1.5	0.55	1.1	1.5
Coal minning & transport	-	0.55	0.27	0.06	0.40	0.98	0.06	-0.16	0.71
TOTAL	-	0.55	0.27	0.61	2.0	4.5	0.61	1.4	4.3

Fugitive emissions from the E & P segment in scenario C represent 48% of the total fugitive emissions in 2020 and 62% in 2030. This growth is due to an increase in the activities in the pre-salt, with production levels that going from 3.14 to 6.19 million barrels per day between 2020 and 2030.

In refining, in all the scenarios, the volume of petroleum processing increases from 2.3 to 2.6 million barrels per day. In scenario C, we have the lowest level of emissions due to more mitigation efforts, corresponding to 9.59 Mt CO_2-eq in 2030, or 28% of the total.

From scenario A to C, total fugitive emissions reduced from 43.03 to 38.47 Mt CO_2-eq, resulting in 4.49 Mt CO_2-eq of avoided emissions, or 10%. Emissions avoided in E & P because of flaring limitation would achieve 2.89 Mt CO_2-eq in 2030. In Refining, the reduction of leaks could mitigate 1.58 Mt CO_2-eq in this year.

Coal represents a small share of the total emissions (around 11%) and varies between scenarios according to the demand as no mitigation action is envisaged.

These results show that if a higher level of mitigation effort is needed, new measures should be studied for the E&P segment in face of it`s biggest share of emissions. More promising options are limit and monitoring of venting and flaring and leakage reduction.

4.6. WASTE

The Waste Sector is divided into two main subsectors: solid waste and wastewater. In the solid waste subsector, the analysis includes urban wastes (MSW), industrial (ISW) and health services (HSW), all class II-A (non-hazardous and non-inert). Hazardous wastes are not considered as they are stored according to the legislation and specific standards, whose treatments do not emit GHG, except incineration. In the wastewater subsector, the analysis considers domestic and commercial sewage as well as organic industrial effluents. Options for the energy use of methane from biogas to reduce GHG emissions are also included.

According to the National Basic Sanitation Research and the National Household Sample Research (IBGE, 2008, 2017), in larger cities with a population of more than 500,000 inhabitants and metropolitan areas, in general, the solid waste collection rate is over 90% with the waste being disposed of in controlled and sanitary landfills. Higher rates of sewage collection- on average around 50% with 10% treatment in plants – are also present. In medium-sized cities with more than 100,000 inhabitants and small towns, the collection efficiency is not that high, and less garbage is disposed of in managed landfills. Less sewage is also collected with large quantities being treated in decentralized tanks or thrown into water bodies.

The National Basic Sanitation Policy, Law No. 11,445 / 2007 (BRAZIL, 2007) and the National Solid Waste Policy, Law No. 12,305 / 2010 (BRAZIL, 2010a) and regulatory decrees establish competencies, management models and instruments able to improve the sanitation levels countrywide.

The targets defined in the national plans, instruments of these policies, are far from achievement. An example is the amount of waste still being dumped on unmanaged sites especially in small municipalities and in the North, Northeast and Midwest regions that should have been phased out before August 2014. Anyway, significant progress has been made in waste collection, especially in medium- and large-sized cities and in metropolitan areas, where most of the solid waste is disposed of in landfills. However, when all the municipalities are considered, more than half still deposit their waste in unmanaged open dumps, maintaining large environmental and public health liabilities in the country.

The waste sector was the second largest source of methane in Brazil, corresponding to 11.4% and 15.0%, in 2005 and 2010, respectively, based on the Third Brazilian GHG Inventory (MCICT, 2015). Table 102 shows the evolution of GHG emissions from waste treatment in Brazil, according to that document.

Table 102. Evolution of GHG emissions from waste treatment in Brazil between 1990 and 2010 (10^3ton)

Emissions	1990	2000	2005	2010	2015	Variation (%) 2015/1990
kt CH_4	1,173.7	1,754.2	2,062.0	2,462.7	2,860.8	143
kt CO_2	19.0	95.0	128.0	175.0	222.0	1068
kt N_2O	4.3	5.7	6.6	7.2	7.7	79
Mt CO_2-eq	**34**	**51**	**60**	**71**	**82,**	**142**

Source: MCTIC (2015, 2017).

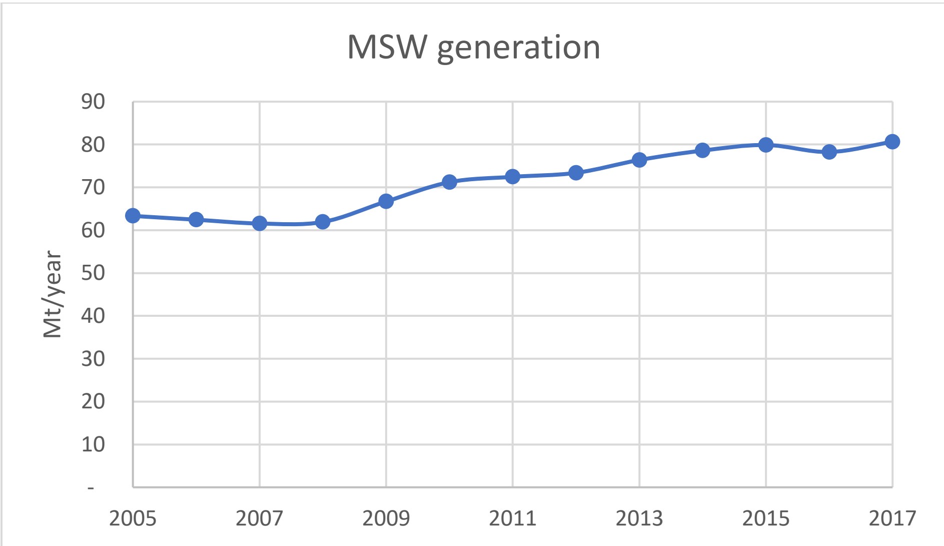
If totally implemented, the national policies could significantly increase emissions due to an improvement in the collection and treatment of urban solid waste and wastewater, that would become emission sources if some mitigation measures are not adopted. From 1990 to 2015 CH_4 per capita emissions from the waste sector already increased by 150%, from 5.5 to 14.2 kgCH_4/inhab.year, which corresponds to 0.4 tCO_2-eq/inhab.year. The increase, associated to the expansion of basic sanitation services (even with the reduction of population growth rates in the last decades), is attributed to a greater accumulation of waste in landfills and increased levels in wastewater treatment, which produce more methane.

Although landfills in developed countries are not the predominant practice, with incineration, thermal plants, recycling and composting common options, in Brazil, they are the most cost-effective technology available.

4.6.1. Solid Waste

4.6.1.1 Emission sources

According to the National Solid Waste Overview (ABRELPE, 2017), approximately 78 Mt of Urban Solid Waste (MSW) were generated in 2016, an increase of 24% since 2005. Figure 47 shows the evolution of MSW produced in recent years.



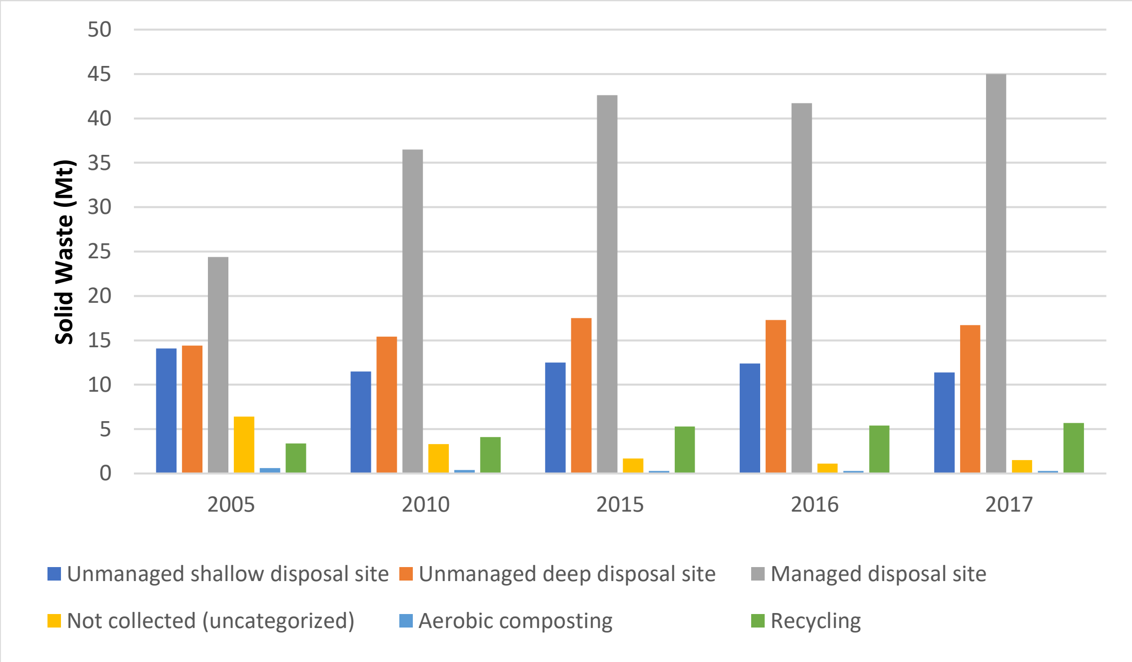
Source: ABRELPE (2005, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017). 2017 estimated by the authors.

Figure 47. MSW generation historical series in Brazil from 2005 to 2017 (Mt /year)

The average waste generation was of 1,213 kg/inhab.day, with 89% collection efficiency, or 1.079 kg/inh.day collected, in 2010 (ABRELPE, 2011). In 2016, the average was 1.040 kg/inhab.day with 91% collection efficiency, therefore a collection rate of 0.948 kg/inh.day (ABRELPE, 2017)[6]. This value varies by regions, states and municipalities, according to the population income level. In the State of Rio de Janeiro, for example, the average is 1.295 kg/inhab.day and in the city of Rio de Janeiro, it increases to 1.861 kg/inhab.day.

[6] This fall in the average waste generation is probably due to the economic crises.

Still according to ABRELPE (2017) about 60% of the garbage collected in the country is disposed of in landfills, a percentage still below the targets established by the National Solid Waste Policy determining that unmanaged landfills should be closed in August 2014. Figure 48 shows the evolution of solid waste subsector in recent years[7].



Source: Landfilling and paper/cardboard/cellulose recycling (ABRELPE, 2005, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017); aerobic composting (IBGE, 2000, 2008); uncategorized and 2017 estimated by the authors.

Figure 48. Solid waste destination in Brazil between 2005 and 2017(Mt)

Solid waste disposal sites, whether unmanaged, semi-managed, managed or even uncategorized produce greenhouse gases, mainly methane (CH_4), through the anaerobic decomposition of organic matter. Such a condition causes a managed landfill to generate more CH_4 than an open unmanaged site.

Thermal treatments are sources of CO_2, N_2O and CH_4, and biological treatments of CO_2, N_2O and CH_4 (from the non-biogenic origin). Incineration is commonly used for the treatment of both health (HSW) and industrial wastes (ISW). Recycling still has a modest contribution to emissions avoidances but includes only paper, cardboard and wood.

[7] Data from the National xxxx of 2008 is inconsistant with the historical series data available and therefore were disregarded in our estimates.

Future waste production as in scenarios A, B and C follows the population growth estimates, as presented in the macroeconomic chapter, and waste production per capita growth trends associated to a per capita GDP growth rate. Health waste generation grows according to population growth. The industrial waste production follows the energy demand estimated, a proxy for the activity levels of the food and beverage industry.

The parameters considered in the emissions estimates, such as carbon in the residues, fossil carbon fraction, biogas recovery rate, incinerator efficiency and methane and nitrous oxide emission factors, are those presented in the III National Inventory (MCTIC, 2015).

4.6.1.2 Scenario A

4.6.1.2.1 Assumptions

In scenario A, the activity levels were estimated by extending the respective waste treatment and final disposal trends from 2000 to 2016 up to 2030, still complying in part with the PNRS and PNSB aiming at reducing inadequate waste disposal. Regarding the share of methane recovered and burned, even though the Brazilian standard establishes a minimum of 20% in managed landfills, the study assumed 0.0%, the same rate adopted in the III National Inventory (MCTIC, 2015).

The numbers presented in Table 103 translate the set of the following parameters, adopted for Scenario A:

- Estimates of IBGE population growth;
- Per capita solid waste generation per GDP per capita;
- Scope and treatment methods for solids collection;
- Final disposal in landfills based on ABRELPE (2007 to 2016);
- Percentage of composting based on PNSB (IBGE, 2000, 2008);
- Percentage of paper recycling, based on BRACELPA (2000, 2014);
- Methane burning in landfills 0.0%, according to National Inventory (MCTIC, 2010, 2015);
- Incineration treatment for ISW and HSW following the IES Brasil 2050 Project.

Table 103. Evolution of the solid waste activity levels by subsector between 2005 and 2030 in Scenario A (Mt and %)

Activity Level		2005		2010		2015		2016		2017		2020		2025		2030	
		Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%
MSW and ISW (II-A) Generation		63.3	100.0	71.2	100.0	79.8	100.0	78.3	100.0	80.6	100.0	85	100	92.3	100	99.7	100
MSW and ISW(II-A) collected for disposal sites		52,9	83.5	63.4	89.0	72.5	90.8	71.3	91.2	73.1	90.7	77.1	90.6	83.4	90.3	89.6	89.9
Disposal Sites	Unmanaged Shallow	14.1	26.7	11.5	18.1	12.5	17.2	12.4	17.4	11.4	15.6	11.4	14.8	11.5	13.7	11.6	13.0
	Unmanaged deep	14.4	27.2	15.4	24.3	17.5	24.1	17.3	24.2	16.7	22.8	14.8	19.3	14.3	17.2	13.9	15.5
	Managed (landfills)	24.4	46.1	36.5	57.6	42.6	58.7	41.7	58.4	45.0	61.6	50.8	65.9	57.6	69.1	64.1	71.5
Not collected (uncategorized)		6.4	10.0	3.3	4.7	1.7	2.2	1.2	1.5	1.5	1.9	1.3	1.6	1.2	1.3	1.1	1.1
Aerobic composting		0.6	1.0	0.4	0.6	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.3	0.2	0.3	0.2	0.2
Paper Recycling		3.4	5.4	4.1	5.7	5.3	6.6	5.4	7.0	5.7	7.1	6.3	7.5	7.5	8.1	8.7	8.8

Source: Landfilling and paper/cardboard/cellulose recycling(ABRELPE, 2005, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017); aerobic composting (IBGE, 2000, 2008); uncategorized and 2017 up to 2030 estimated by the authors.

4.6.1.2.2 Results

Table 104 and Figure 49 show the emissions from the solid waste subsector by source per year in Scenario A.

Table 104. Emissions from the solid waste treatment systems up to 2030 in scenario A (Mt CO_2-eq)

Emissions		2005	2010	2015	2016	2017	2020	2025	2030
kt CH_4	MSW + ISW (II-A)	1,237	1,327	1,989	2,065	2,112	2,307	2,610	2,896
	Composting			1.3	1.3	1.2	1.1	1.0	0.90
kt CO_2	ISW	128	175	139	132	131	140	167	195
	MSW			41	42	44	47	51	55
kt N_2O	Composting			0.10	0.10	0.10	0.10	0.10	0.10
	ISW	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	MSW			0.003	0.003	0.003	0.003	0.004	0.004
Kt CO_2-eq	MSW + ISW (II-A)	34,770	37,334	55,681	57,829	59,131	64,588	73,088	81,076
	Composting			63	60	58	53	46	41
	ISW			141	134	133	142	170	198
	MSW			42	43	44	48	52	56
Mt CO_2-eq	**TOTAL**	**35**	**37**	**56**	**58**	**59**	**65**	**73**	**81**

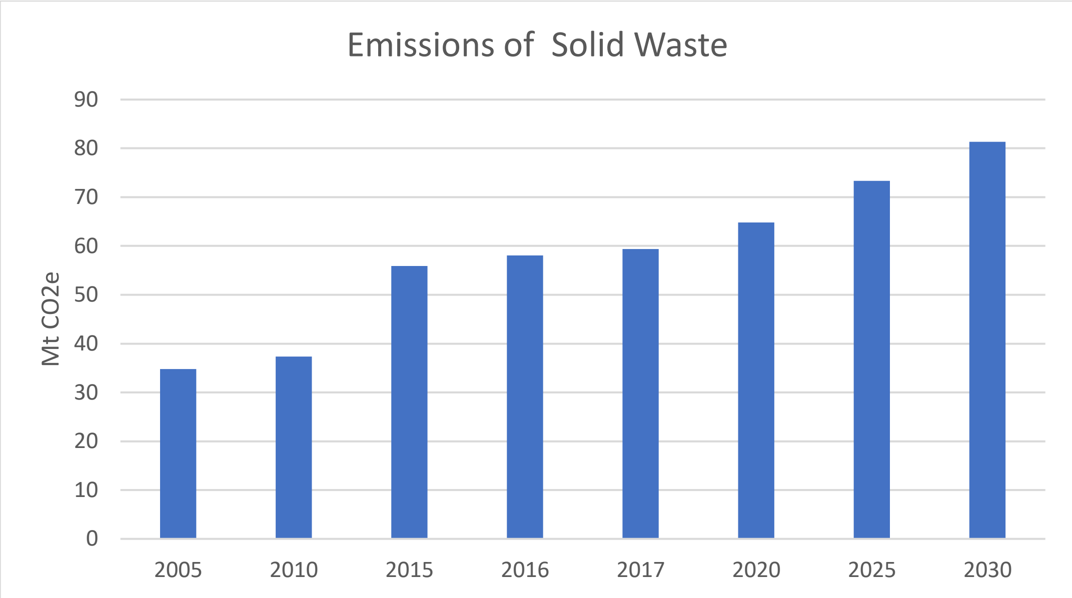


Figure 49. Evolution of solid waste treatment emissions in scenario A

The results indicate a 134% growth in methane emissions and other 1040% in nitrous oxide from solid waste treatment in 2030 with respect to 2005. Carbon dioxide emissions would also increase by 95%. Total annual emissions would increase 134% in the period.

4.6.1.3 Scenario B

4.6.1.3.1 Assumptions

In Scenario B, some additional investment in sanitation was simulated when comparing to Scenario A, increasing the sector compliance to the PNRS and the PNSB. In this scenario, not only there would be a reduction in the levels of inadequate waste disposal, but also in the emissions. From 2021 on, in the state capitals, there would be an annual increase of 10% in methane recovery for flaring until it stabilizes at 80%. The numbers are presented in Table 105 and reflect the following assumptions:

- MSW and ISW (II-A) disposal in landfill: from 46.1% in 2005 to 75% in 2030, an increase of 62.7% in the landfill rate;
- Methane destruction in landfills: a gradual increase by 10% per year from 2021 until reaching 80% for electricity generation in capitals only;
- Composting: increase in the total collected waste from 1.0% in 2005 to 2.0% in 2030;
- Recycling of paper, cardboard and cellulose: increases from 5.4% in 2005 to 12.0% in 2030

Table 105. Evolution of the solid waste activity levels by subsector between 2005 and 2030 in Scenario B (Mt and %)

Activity Level		2005		2010		2015		2016		2017		2020		2025		2030	
		Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%
MSW and ISW(II-A) generation		63.3	100.0	71.2	100.0	79.8	100.0	78.2	100.0	80.6	100.0	85.0	100.0	92.3	100.0	99.7	100.0
MSW and ISW(II-A) collected for disposal sites		52.9	83.5	63.4	89.0	72.5	90.8	71.4	91.2	73.1	90.7	76.8	89.9	82.0	88.8	86.9	84.9
Disposal Sites	Unmanaged Shallow	14.1	26.7	11.5	18.1	12.5	17.2	12.4	17.4	11.4	15.6	11.2	14.6	11.0	13.4	10.8	12.5
	Unmanaged deep	14.4	27.2	15.4	24.3	17.5	24.1	17.3	24.0	16.7	22.8	16.2	21.1	14.5	17.7	10.9	12.5
	Managed (landfills)	24.4	46.1	36.5	57.6	42.6	58.7	41.7	58.4	45.0	61.6	49.4	64.2	56.5	68.9	65.2	75.0
Not collected (uncategorized)		6.4	10.0	3.3	4.7	1.7	2.2	1.1	1.5	1.5	1.9	1.3	1.6	1.2	1.3	1.1	1.1
Aerobic composting		0.6	1.0	0.4	0.6	0.3	0.4	0.3	0.4	0.3	0.4	0.2	0.3	1.0	1.2	1.9	2.0
Recycling		3.4	5.4	4.1	5.7	5.3	6.6	5.4	7.0	5.7	7.1	6.5	7.7	8.0	8.7	9.7	12.0

4.6.1.3.2 Results

Table 106 and Figure 50 show the emissions result of the solid waste subsector by source per year in Scenario B.

Table 106. Emissions from the solid waste treatment systems up to 2030 in scenario B (Mt CO_2-eq)

Emissions		2005	2010	2015	2016	2017	2020	2025	2030
kt CH_4	MSW + ISW (II-A)	1,237	1,327	1,989	2,065	2,112	2,295	2,246	2,456
	Composting			1.3	1.3	1.2	2.9	5.3	8.0
kt CO_2	ISW	128	175	139	132	131	140	167	195
	HSW			41	42	44	47	51	55
kt N_2O	Composting			0.10	0.10	0.10	0.20	0.40	0.60
	ISW	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	HSW			0.003	0.003	0.003	0.003	0.004	0.004
kt CO_2-eq	MSW + ISW (II-A)	34,770	37,334	55,681	57,829	59,131	64,272	62,893	68,780
	Composting			63	60	58	140	253	382
	ISW			141	134	133	142	170	198
	HSW			42	43	44	48	52	56
Mt CO_2-eq	**TOTAL**	**35**	**37**	**56**	**58**	**59**	**65**	**63**	**70**

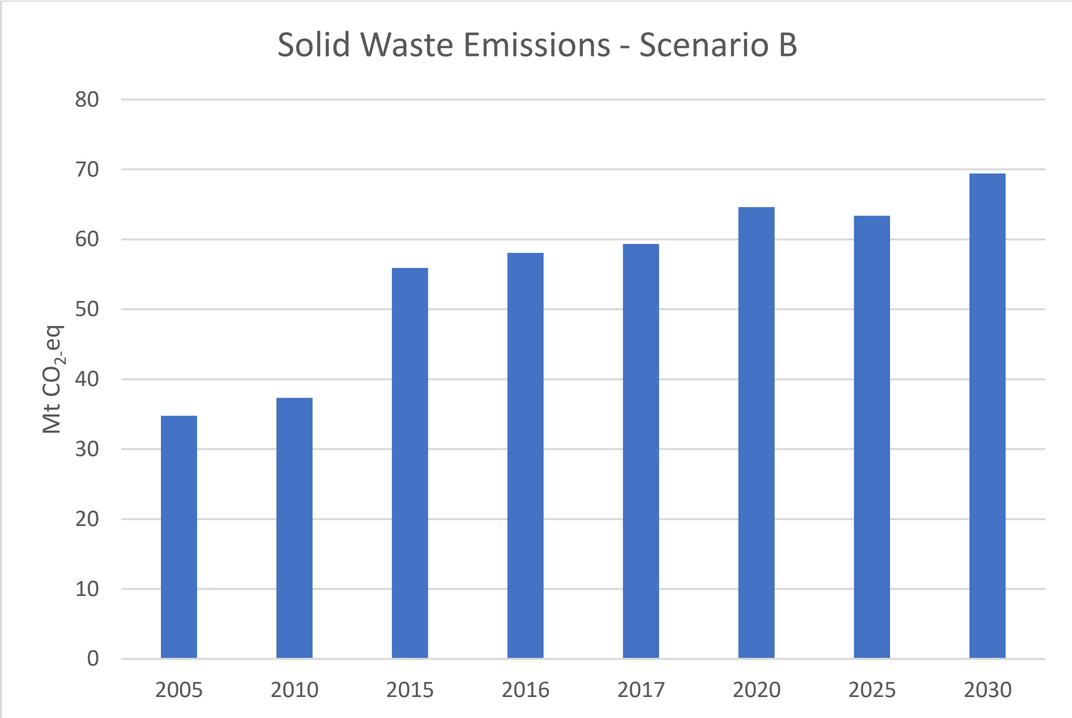


Figure 50. Evolution of solid waste treatment emissions in scenario B

The results indicate a 99% growth in methane emissions from solid waste treatment in 2030 compared to 2005. There would also be a huge increase of 6,037%, although in absolute terms not significant, in nitrous oxide emissions from waste composting and from health services and industrial wastes treated by incineration, a technology that also increases carbon dioxide emissions by 95%. The total increase in solid waste emissions is almost 100% in scenario B.

4.6.1.4 Scenario C

4.6.1.4.1 Assumptions

According to the Brazilian Climate Change Forum, the following set of mitigation measures could reduce about 20.8 Mt CO_2-eq in 2030 compared to the emissions in Scenario A, in the same year. These measures are:

- Expansion of the collection/use of methane from unmanaged dumps managed landfills: implementation of methane recovery infrastructure;
- Increase of the composting volume of organic waste segregated at source: large-scale waste systems with food, urban pruning leaves and branches, etc.,

producing an organic compost for soil carbon fixation (this isolated action has a little-perceived potential, but joined with the previous one it can reach a mitigation potential by 8 Mt CO_2-eq);

- Conversion of methane from landfills into biogenic CO_2, in flares: considerable mitigation potential in managed and controlled landfills where it is not possible to reuse; and
- Reverse logistics programs, reduction at source and selective collection of waste: federal support to local and regional programs associated with environmental education programs of wide reach and participation of different school's levels.

Therefore, in scenario C, the simulations consider the penetration of the mitigation measures suggested that were also assumed in Scenario B, but modestly. The collection and treatment levels were maintained but with greater efforts in emissions reduction. For example, the annual increase of 10% in methane recovery for flaring from 2021 on until it stabilizes at 80% that in Scenario B was restricted to capitals, is adopted in all metropolitan regions and large cities, in Scenario C. The set of the following assumptions is considered:

- MSW and ISW (II-A) disposal in landfill: from 46.1% in 2005 to 75% in 2030, an increase of 62.7% in the landfill rate, the same as in Scenario B;
- Methane recovery in landfills for:
  - destruction in flairs (95% efficiency): from 70% in 2021 down to 0% in 2028 in capitals and metropolitan areas;
  - destruction in flairs (95% efficiency): from 75% in 2021 down to 40% in 2028 in big cities (over 500,000 inhabitants);
  - electricity generation: from 0% in 2020 up to 80% in 2028 with a 10% annual increase in capitals and metropolitan áreas;
  - electricity generation: from 0% in 2020 up to 40% in 2028 with 5% annual increase in big cities (over 500,000 inhabitants);
  - replacement of natural gas used in vehicular fleet: from 2.5% of the total methane generated in 2025 up to 3.5% in 2030, in accordance to the demand envisaged to the states of São Paulo and Rio de Janeiro, as simulations in the transportation section;

- Composting: increases in the total collected waste from 1.0% in 2005 to 2.0% in 2030, the same as in Scenario B;
- Recycling of paper, cardboard and cellulose: increase from 5.4% in 2005 to 12.0% in 2030, the same as in Scenario B;

Table 107. Evolution of the solid waste activity levels by subsector between 2005 and 2030 in Scenario C (Mt and %)

Activity Level		2005		2010		2015		2016		2017		2020		2025		2030	
		Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%
MSW and ISW(II-A) generation		63.3	100.0	71.2	100.0	79.8	100.0	78.2	100.0	80.6	100.0	85.0	100.0	92.3	100.0	99.7	100.0
MSW and ISW(II-A) collected for disposal sites		52.9	83.5	63.4	89.0	72.5	90.8	71.4	91.2	73.1	90.7	76.8	89.9	82.0	88.8	86.9	84.9
Disposal Sites	Unmanaged Shallow	14.1	26.7	11.5	18.1	12.5	17.2	12.4	17.4	11.4	15.6	11.2	14.6	11.0	13.4	10.8	12.5
	Unmanaged deep	14.4	27.2	15.4	24.3	17.5	24.1	17.3	24.0	16.7	22.8	16.2	21.1	14.5	17.7	10.9	12.5
	Managed (landfills)	24.4	46.1	36.5	57.6	42.6	58.7	41.7	58.4	45.0	61.6	49.4	64.2	56.5	68.9	65.2	75.0
Not collected (uncategorized)		6.4	10.0	3.3	4.7	1.7	2.2	1.1	1.5	1.5	1.9	1.3	1.6	1.2	1.3	1.1	1.1
Aerobic composting		0.6	1.0	0.4	0.6	0.3	0.4	0.3	0.4	0.3	0.4	0.2	0.3	1.0	1.2	1.9	2.0
Recycling		3.4	5.4	4.1	5.7	5.3	6.6	5.4	7.0	5.7	7.1	6.5	7.7	8.0	8.7	9.7	12.0

Note: the same values as in Scenario B

4.6.1.4.2 Results

Table 108 and Figure 51 show the emissions results of the solid waste subsector by source per year, in Scenario C.

Table 108. Emissions from the solid waste treatment systems up to 2030, in scenario C (Mt CO_2-eq)

Emissions		2005	2010	2015	2016	2017	2020	2025	2030
Kt CH_4	MSW + ISW (II-A)	1,237	1,327	1,989	2,065	2,112	2,292	1,959	2,122
	Composting			1.3	1.3	1.2	2.9	5.3	8.0
Kt CO_2	ISW	128	175	139	132	131	140	167	195
	HSW			41	42	44	47	51	55
Kt N_2O	Composting			0.10	0.10	0.10	0.20	0.40	0.60
	ISW	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	HSW			0.003	0.003	0.003	0.003	0.004	0.004
Kt CO_2-eq	MSW + ISW (II-A)	34,770	37,334	55,681	57,829	59,131	64,179	54,847	59,414
	Composting			63	60	58	140	253	382
	ISW			141	134	133	142	170	198
	HSW			42	43	44	48	52	56
Mt CO_2-eq	**TOTAL**	**35**	**37**	**56**	**58**	**59**	**64**	**55**	**60**

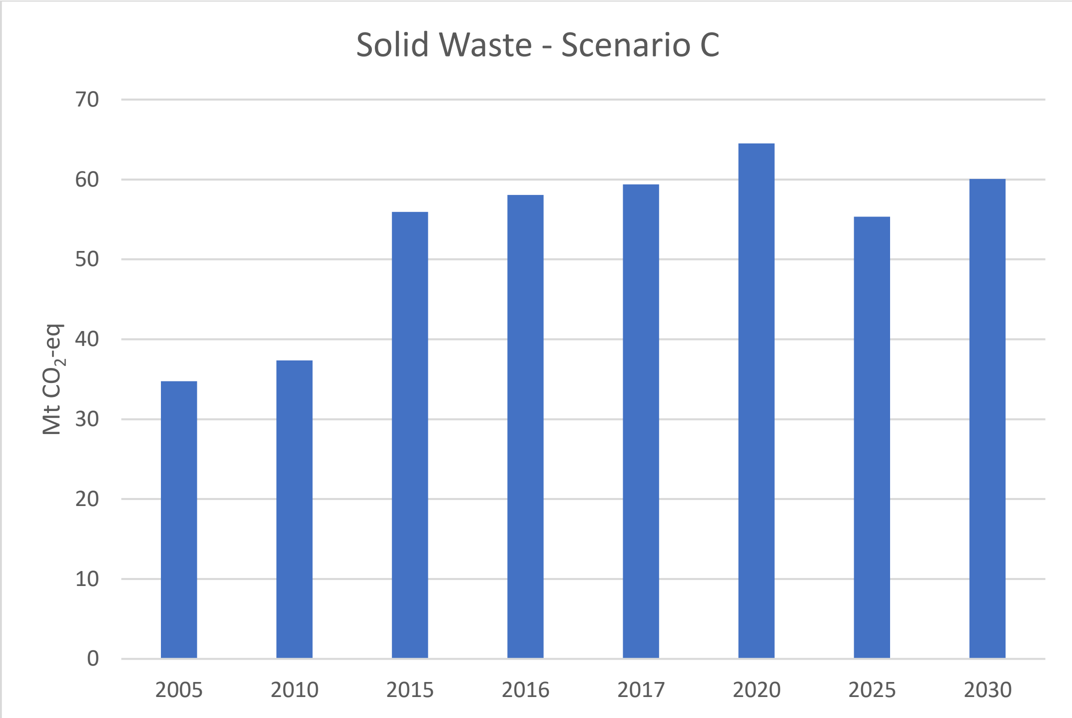


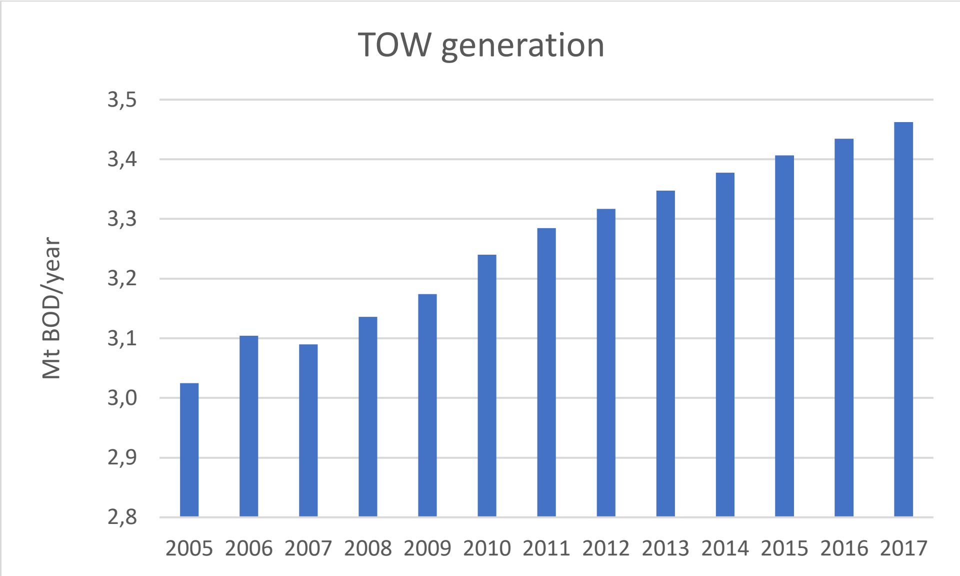
Figure 51. Evolution of solid waste treatment emissions in scenario C

The results indicate a 72% growth in methane emissions from solid waste treatment in 2030 compared to 2005. The results for the other GHG are the same as in Scenario B.

4.6.2. Wastewater

4.6.2.1 Emission Sources

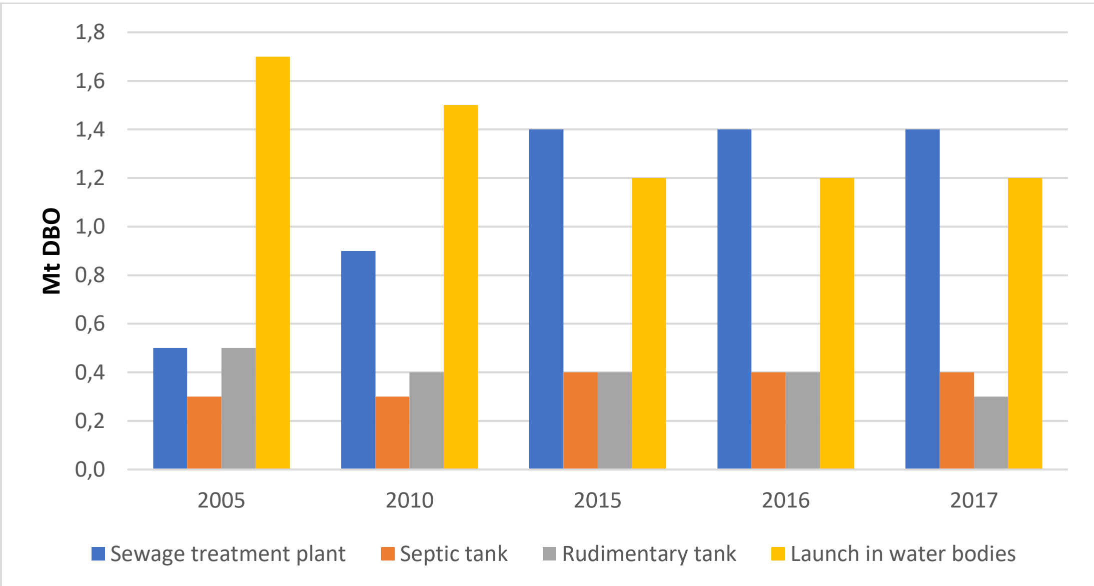
According to National Water Agency (ANA, 2017), approximately 3.3 Mt of biochemical oxygen demand (BOD) – the parameter used to measure the organic component of the wastewater – were generated in urban cities in2013, an estimated increase of 10% since 2005, following the population and the industry growths. Figure 52 shows the estimated evolution of BOD produced in recent years.



Source: 2000 National Basic Sanitation Research (IBGE, 2000); 2013 Wastewater Atlas (ANA, 2017); 2005 up to 2012 and 2014 up to 2017 estimated by the authors.

Figure 52. Total organic discharge in Brazil from 2005 to 2017 (Mt BOD)

According to the 2013 Wastewater Atlas (ANA, 2017), only 61% of the urban domestic effluent is collected in the country and only 43% of it is treated in centralized plants. Figure 53 shows the estimated evolution of the wastewater subsector in recent years.



Source: 2000 National Basic Sanitation Research (IBGE, 2000); 2013 Wastewater Atlas (ANA, 2017); 2005 up to 2017 estimated by the authors.

Figure 53. Domestic wastewater destination in Brazil between 2005 and 2017 (Mt BOD)

Sewage treatment systems can be classified as preliminary, primary, secondary and tertiary. The preliminary treatment removes coarse solids, while the primary treatment removes sedimentary solids. In both, physical treatment mechanisms predominate – grids and deposition – and in the primary treatment, part of suspended organic matter and floating materials is removed (oils and greases). In the secondary treatment, the mechanisms are biological, since the main objective of this level is removing the organic matter through biodegradation by microorganisms. The treatment systems used may include anaerobic and aerobic stabilization lagoons, anaerobic reactors, biological filters, activated sludge, among others. Tertiary treatment is used to process the effluent in relation to pathogens and other contaminants, as well as to provide nutrient withdrawal through one or more maturation lagoons, filtration, bioadsorption, ion exchange and disinfection processes (VON SPERLING et al., 2005).

Sludge is also produced in primary, secondary and tertiary treatment systems. The primary consists of solids removal while the secondary and the tertiary include biological growth in the biomass and aggregation of small particles. Sludge should also be treated under either anaerobic or aerobic digestion, densification, dewatering, composting or final disposal in landfills (IPCC, 2006).

Both the wastewater and the sludge treatments, under anaerobic conditions, result in CH_4 emissions, with the amount varying according to the effluent characteristics, the temperature and the type of treatment. The main factor defining the amount of methane to be produced is the amount of degradable organic matter in the sewage measured by BOD and COD (the chemical oxygen demand). The higher the BOD or COD, the higher the methane production. Regarding temperature, methane production increases, especially in hot climates and in systems without adequate control of this parameter.

Nitrous oxide is associated with the degradation of the nitrogenous components present in the effluents (urea, nitrate and proteins) and other processes involving the treatment, mainly in the tertiary systems, that can remove these nitrogenous compounds. Direct emissions of N_2O are generated both in the nitrification processes (an aerobic process that converts ammonia and other nitrogenous compounds into nitrate – NO3) and denitrification (an anaerobic process in which the nitrate is converted to nitrogen gas – N2), as they are intermediate products of both processes. N_2O emissions can occur both in treatment plants and in water bodies where the effluent is discharged.

Methane emissions from industrial wastewater treatment plants reflect the evolution of the segments where the wastewater with significant carbon loading is treated under intended or unintended anaerobic conditions. Therefore, emissions from industrial effluents are estimated with a function that correlates the amount of organic matter to be treated, with the GDP growth rate of the food and beverage industry. In 2010, beer production accounted for 62% of the emissions, followed by the raw milk industry with 14% (MCTIC, 2015). Although "vinhoto", the byproduct of the sugar and ethanol industry, has the highest content of organic matter in all the industrial sector, it is applied directly to the soil and does not produce methane. N2O is also produced in the industrial waste sector.

Future urban wastewater production as in scenarios A, B and C follows urban population estimates, as presented in the macroeconomic chapter.

The parameters considered in the emissions estimates, such as carbon in the wastewater, fossil carbon fraction, biogas recovery rate, incinerator efficiency and methane and nitrous oxide emission factors, are those presented in the III National Inventory (MCTIC, 2015).

4.6.2.2 Scenario A

4.6.2.2.1 Assumptions

As in the subsector of solid wastes, additional mitigation measures were not considered in Scenario A. Future activity levels are merely extensions of the trends from 2000 to 2016 in effluent treatment and disposal types, complying in part with the PNSB. In the anaerobic treatment processes equipped with flares, the CH_4 produced is considered partially destroyed, with an efficiency of approximately 55% as adopted in the Third National Inventory (MCTI, 2015).

The numbers presented in Table 109 reflect the following assumptions:

- Wastewater per capita generation per GDP per capita;
- Total organic matter expressed in BOD of the effluents;
- Scope and type of wastewater treatment systems;
- Percentages of wastewater treatment on PNSB (IBGE, 2000, 2008) and Sanitation Atlas (ANA, 2017);
- The current trend in methane destruction from anaerobic plants (MCTIC, 2010, 2015);

- Wastewater treated in plants: growing from 16,7% of the total generated in 2005 to 45.9% in 2030, the growth trend;
- Wastewater treated in anaerobic plants: from 3.8% of the total treated in 2005 to 21.5% of that generated in 2030, the growth trend;
- Share of the biomethane destruction in domestic anaerobic treatment plants constant until 2030 (60% at an efficiency rate of 55%);
- Wastewater treatment in septic and rudimentary tanks decreases according to the historical trend of 27% in 2005 to 21% in 2030;
- Methane flaring in industrial ETE grows according to the historical trend up to 43.7% of the biomethane produced in 2030 (with 55% efficiency rate)

Table 109. Evolution of the wastewater subsector activity levels between 2005 and 2030 in Scenario A (Mt and %)

Activity Level	2005		2010		2015		2016		2017		2020		2025		2030	
	Mt BDO	%	Mt BDO	%	Mt BDO	%	Mt BDO	%	Mt BDO	%	Mt BDO	%	Mt BDO	%	Mt BDO	%
Wastewater generation	3.0	100	3.2	100	3.4	100	3.4	100	3.5	100	3.5	100	3.7	100	3.8	100
Sewage treatment plant	0.5	16.7	0.9	27.5	1.4	39.9	1.4	40.5	1.4	41	1.5	42.4	1.6	44.3	1.7	45.9
Emission-free processes	0.1	2.3	0.1	1.8	0	1.5	0	1.5	0	1.4	0	1.3	0	1.1	0	1
Sludge activated	0.2	6.6	0.4	11.8	0.5	14.4	0.5	14.7	0.5	15	0.6	15.7	0.6	16.7	0.7	17.5
Anaerobic Treatments	0.1	3.8	0.3	9.2	0.6	18.2	0.6	18.5	0.6	18.8	0.7	19.6	0.8	20.7	0.8	21.5
Facultative lagoons	0.1	3.4	0.1	3.4	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5
Other treatments, unspecified	0.0	0.5	0.0	1.3	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4
Septic tank	0.3	10.5	0.3	10.8	0.4	12.2	0.4	12.5	0.4	12.9	0.5	14	0.6	16	0.7	18.1
Rudimentary tank	0.5	16.4	0.4	13.7	0.4	11	0.4	10.5	0.3	10	0.3	8.3	0.2	5.6	0.1	2.9
Launch in water bodies	1.7	56.4	1.5	48	1.2	36.8	1.2	36.5	1.2	36.2	1.2	35.3	1.2	34.1	1.2	33.1

4.3.2.2.2 Results

Table 110 and Figure 54 present the emissions results of effluent subsector by source per year in Scenario A.

Table 110. Wastewater treatment emissions by source between 2005 and 2030 in scenario A (Mt CO_2-eq)

Emissions		2005	2010	2015	2016	2017	2020	2025	2030
kt CH_4	Domestic wastewater	437	513	517	525	534	558	598	612
	Industrial wastewater	388	621	660	662	664	670	815	958
kt N_2O	Domestic wastewater	6.6	7.2	8.7	8.7	8.8	8.9	9.1	9.3
kt CO_2-eq	Domestic wastewater	13,974	16,266	16,772	17,018	17,262	17,995	19,160	19,600
	Industrial wastewater	10,872	17,394	18,486	18,537	18,589	18,753	22,825	26,829
Mt CO_2-eq	**TOTAL**	**25**	**34**	**35**	**36**	**36**	**37**	**41**	**46**

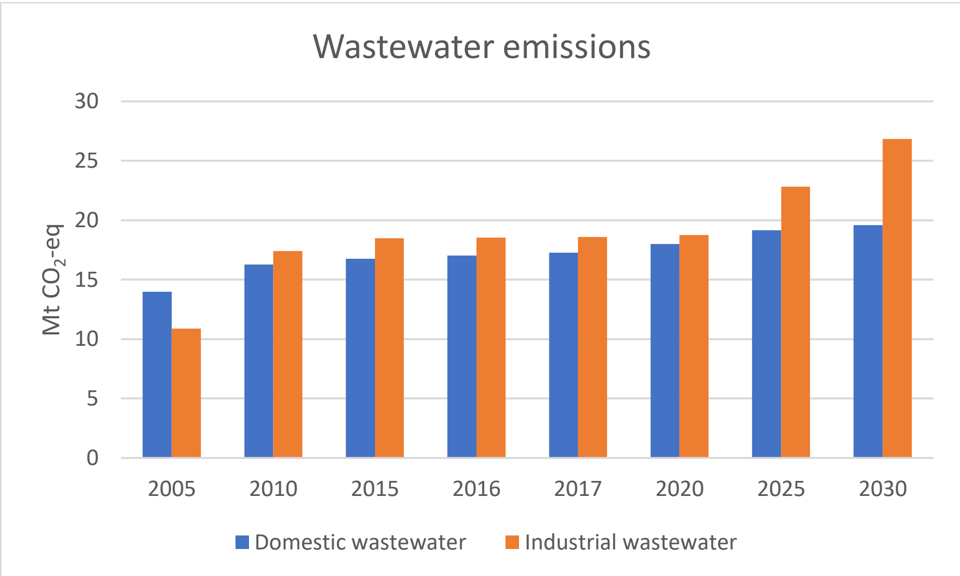


Figure 54. Evolution of wastewater treatment emissions in scenario A

Methane emissions from sewage systems would grow 40.2% and nitrous oxide 41.0% in the 2005-2030 period in Scenario A. From the industrial wastewater systems, there would be a 146.8% growth in methane emissions.

4.6.2.3 Scenario B

4.6.2.3.1 Assumptions

In Scenario B, the sector investment is higher than in Scenario A and complies on a larger scale with the PNSB, not only reducing the sanitation deficit but also yielding fewer emissions, with an increase in the methane recovery for flaring in treatment plants from 2021 on. According to the Brazilian Climate Change Forum, using the methane as a substitute for fossil fuels in transportation and electricity generation is a mitigation measure that should be part of the sanitation efforts.

The numbers presented in Table 111 reflect the following set of assumptions in Scenario B:

- Wastewater treated in plants: reaches 50.8% of total generated in 2030;
- Wastewater treated in anaerobic plants: displacement of 5% from septic tanks to anaerobic plants up to 26.5% in 2030;
- Biomethane destruction in anaerobic plants: flaring increase from 60% to 70% in anaerobic plants from 2021 to 2030 (efficiency rate of 55%);
- Domestic wastewater treatment in septic and rudimentary tanks: decreases to 16.0% in 2030, due to a 5% displacement for anaerobic treatment systems;
- Methane destruction in industrial wastewater treatment plants: increase in capital cities, metropolitan regions and other large cities (above 500 thousand inhabitants) to 45.3% of the biomethane produced in 2030. (55% efficiency).

Table 111. Evolution of the wastewater subsector activity levels between 2005 and 2030 in Scenario B (Mt and %)

Activity Level	2005		2010		2015		2016		2017		2020		2025		2030	
	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%
Wastewater generation	3.0	100	3.2	100	3.4	100	3.4	100	3.5	100	3.5	100	3.7	100	3.8	100
Sewage treatment plant	0.5	16.7	0.9	27.5	1.4	39.9	1.4	40.5	1.4	41	1.5	42.4	1.6	44.3	1.7	50.8
Emission-free processes	0.1	2.3	0.1	1.8	0	1.5	0	1.5	0	1.4	0	1.3	0	1.1	0	1
Sludge activated	0.2	6.6	0.4	11.8	0.5	14.4	0.5	14.7	0.5	15	0.6	15.7	0.6	16.7	0.7	17.5
Anaerobic Treatments	0.1	3.8	0.3	9.2	0.6	18.2	0.6	18.5	0.6	18.8	0.7	19.6	0.8	20.7	1	26.5
facultative lagoons	0.1	3.4	0.1	3.4	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5
Other treatments, unspecified	0.0	0.5	0.0	1.3	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4
Septic tank	0.3	10.5	0.3	10.8	0.4	12.2	0.4	12.5	0.4	12.9	0.5	13.1	0.5	13.8	0.5	13.1
Rudimentary tank	0.5	16.4	0.4	13.7	0.4	11	0.4	10.5	0.3	10	0.3	8.3	0.2	5.6	0.1	2.9
Launch in water bodies	1.7	56.4	1.5	48	1.2	36.8	1.2	36.5	1.2	36.2	1.3	36.1	1.3	36.2	1.2	33.1

4.6.2.3.2 Results

Table 112 and Figure 55 presents the emission results of effluent subsector by source per year in Scenario B.

Table 112. Wastewater treatment emissions by source between 2005 and 2030 in scenario B (Mt CO_2-eq)

Emissions		2005	2010	2015	2016	2017	2020	2025	2030
Kt CH_4	Domestic wastewater	437	513	517	525	534	551	569	589
	Industrial wastewater	388	621	660	662	664	663	807	947
Kt N_2O	Domestic wastewater	6.6	7.2	8.7	8.7	8.8	8.9	9.1	9.3
Kt CO_2-eq	Domestic wastewater	13,974	16,266	16,772	17,018	17,262	17,803	18,349	18,963
	Industrial wastewater	10,872	17,394	18,486	18,537	18,589	18,575	22,585	26,523
Mt CO_2-eq	**TOTAL**	**25**	**34**	**35**	**36**	**36**	**37**	**41**	**46**

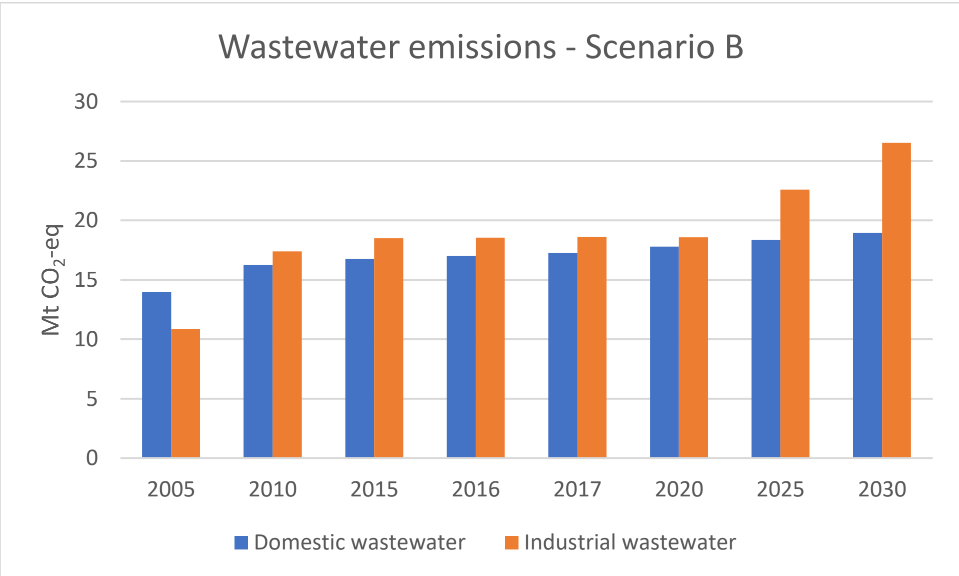


Figure 55. Evolution of wastewater treatment emissions in scenario B (Mt CO_2-eq)

In this scenario B, the results of GHG emissions evolution due to the treatment of sanitary sewage indicate a 35% and 41.0% increase in the methane and nitrous oxide emissions, respectively, in 2030 compared to 2005. In the treatment of industrial wastewater, there is 144% growth in methane emissions in 2030 compared to 2005. The total increase in wastewater emissions is 83%, less 4% than in scenario A.

4.6.2.4 Scenario C

4.6.2.4.1 Assumptions

In scenario C, mitigation measures were considered in addition to those already underway in Scenario B, from 2018 to 2030, maintaining the level of collection and treatment and complying on a larger scale with the PNSB, with greater efforts in reduce emissions, for example, with an increase in the methane recovery for flare burning, from 2021 to stabilize by 80% in anaerobic Plants. The numbers presented in Table 113 translate the set of following assumptions, adopted to build Scenario C:

- Wastewater treatment in plants: 50.8% of generated in 2030;
- Treatment in anaerobic plants: Displacement of 5% of treatment from septic tanks to anaerobic plants up to 26.5% in 2030;
- Destruction of biomethane in flares of anaerobic plants: increases from 60% to 80% from 2021 to 2030 (efficiency rate of 55%);
- Domestic sewage treatment in septic and rudimentary tanks decreases from 21% to 16% in 2030, due to the displacement of 5% for anaerobic treatment;
- Methane destruction in industrial plants of the capitals, metropolitan regions, large cities (> 500 thousand inhabitants) and medium size (> 100 thousand inhabitants) to 46.9% of the biomethane produced in 2030 (55% efficiency).

Table 113. Evolution of the wastewater subsector activity levels between 2005 and 2030 in Scenario C (Mt and %)

Activity Level	2005		2010		2015		2016		2017		2020		2025		2030	
	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%	Mt BOD	%
Wastewater generation	3.0	100	3.2	100	3.4	100	3.4	100	3.5	100	3.5	100	3.7	100	3.8	100
Sewage treatment plant	0.5	16.7	0.9	27.5	1.4	39.9	1.4	40.5	1.4	41	1.5	42.4	1.6	44.3	1.7	50.8
Emission-free processes	0.1	2.3	0.1	1.8	0	1.5	0	1.5	0	1.4	0	1.3	0	1.1	0	1
Sludge activated	0.2	6.6	0.4	11.8	0.5	14.4	0.5	14.7	0.5	15	0.6	15.7	0.6	16.7	0.7	17.5
Anaerobic Treatments	0.1	3.8	0.3	9.2	0.6	18.2	0.6	18.5	0.6	18.8	0.7	19.6	0.8	20.7	1	26.5
facultative lagoons	0.1	3.4	0.1	3.4	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5	0.1	3.5
Other treatments, unspecified	0.0	0.5	0	1.3	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4	0.1	2.4

Septic tank	0.3	10.5	0.3	10.8	0.4	12.2	0.4	12.5	0.4	12.9	0.5	13.1	0.5	13.8	0.5	13.1
Rudimentary tank	0.5	16.4	0.4	13.7	0.4	11	0.4	10.5	0.3	10	0.3	8.3	0.2	5.6	0.1	2.9
Launch in water bodies	1.7	56.4	1.5	48	1.2	36.8	1.2	36.5	1.2	36.2	1.3	36.1	1.3	36.2	1.2	33.1

According to the Brazilian Forum on Climate Change, the mitigation measures considered the expansion of methane capture in treatment plants, through the implementation of sanitation policies, and the energetic use of methane from plants without installed infrastructure for recovery, use in transportation and electric generation. The difference between them is the implementation level of the increase of methane capture/use in plants as shown above.

4.6.2.4.2 Results

Table 114 and Figure 56 presents the wastewater emissions by source per year in Scenario C.

Table 114. Wastewater treatment emissions by source between 2005 and 2030 in scenario C (Mt CO_2-eq)

Emissions (kt)		2005	2010	2015	2016	2017	2020	2025	2030
Kt CH_4	Domestic wastewater	437	513	517	525	534	551	559	579
	Industrial wastewater	388	621	660	662	664	657	798	936
Kt N_2O	Domestic wastewater	6.6	7.2	8.7	8.7	8.8	8.9	9.1	9.3
kt CO_2-eq	Domestic wastewater	13,974	16,266	16,772	17,018	17,262	17,803	18,069	18,671
	Industrial wastewater	10,872	17,394	18,486	18,537	18,589	18,396	22,346	26,218
Mt CO_2-eq	**TOTAL**	**25**	**34**	**36**	**36**	**36**	**36**	**40**	**45**

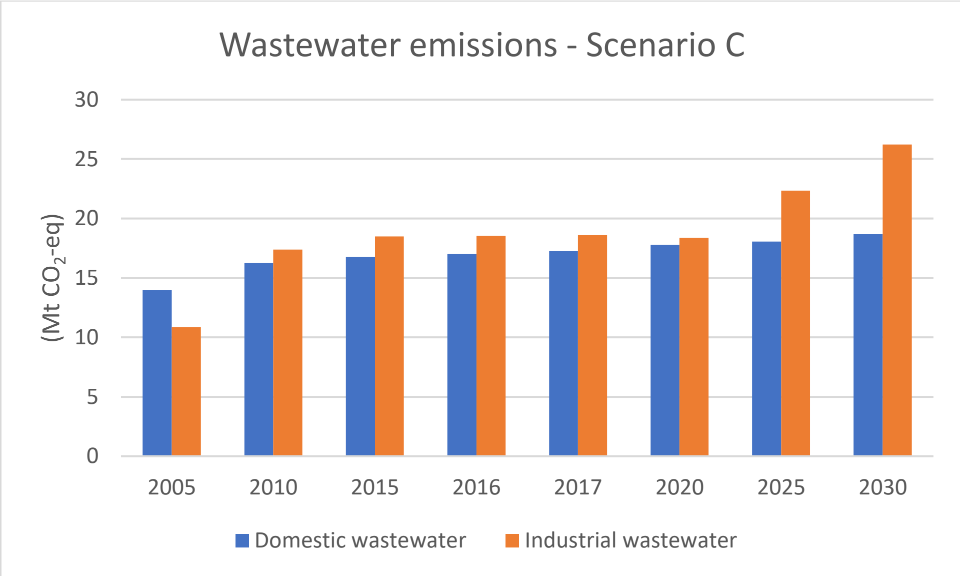


Figure 56. Evolution of wastewater treatment emissions in scenario C (Mt CO_2-eq)

In scenario C, emissions from sewage would increase by 33% and 41% in methane and nitrous oxide, respectively, in 2030 compared to 2005. From industrial wastewater, there would be a growth of 141% in methane emissions in 2030 compared to 2005. The total increase in wastewater emissions would be of 81%, 3% less than in scenario B and 6% than in scenario A.

4.6.3. Comparative Analysis of Scenarios A, B and C – Avoided Emissions by Mitigation Actions

This section presents a comparative analysis of emissions in the waste treatment between scenarios, containing total emissions by source in the three scenarios and avoided emissions by each mitigation action in scenario B (in relation to A), scenario C (in relation to A), and the increase in avoided emissions from scenario C in relation to B. Table 115, 116, 117 and 118 present the results and Figures 57, 58, 59 and 60 illustrate the contributions of each mitigation measure between scenarios A-B and B-C in the waste sector.

Table 115. Total emissions by source in scenarios A, B and C in the waste sector (Mt CO_2-eq)

Emission sources (Mt CO2-eq)	National Inventory	Estimative	Scenario A			Scenario B			Scenario C		
	2010	2015	2020	2025	2030	2020	2025	2030	2020	2025	2030
MSW and ISW(II-A) landfilling		56	65	73	81	64	63	69	64	55	59
ISW and HSW incineration		0.20	0.20	0.20	0.30	0.20	0.20	0.30	0.20	0.20	0.30
Aerobic composting		0.10	0.10	0.05	0.04	0.10	0.20	0.40	0.10	0.20	0.40
Total solid waste (Mt CO_2eq)	37	56	65	73	81	65	67	69	65	55	60
Domestic wastewater	16	17	18	19	20	18	18	19	18	18	19
Industrial wastewater	17	19	19	23	27	19	23	27	18	22	26
Total wastewater (Mt CO_2eq)	34	35	37	42	46	36	41	46	36	40	45
Total Waste Sector (Mt CO_2-eq)	**71**	**91**	**102**	**115**	**128**	**101**	**104**	**116**	**100**	**95**	**105**

Table 116. Avoided emissions – scenarios A-B by mitigation action in the waste sector (Mt CO_2-eq)

Avoided Emissions (Mt CO_2-eq)	**2020**	**2025**	**2030**
Solid Waste Treatment	**0.32**	**10**	**12**
Disposal of MSW and ISW (II-A) in landfills	0.32	10	12
Reduced disposal of USW in unmanaged shallow landfills	0.03	0.14	0.27
Reduced disposal of USW in unmanaged deep landfills	-0.67	-0.61	0.38
Decreased disposal of USW in managed deep landfills without methane destruction	0.95	1.4	0.82
Increased disposal of USW in managed deep landfills with methane destruction	0.00	3.5	0.0
Increased disposal of USW in managed deep landfills with methane recovery for power generation	0.0	5.8	11
Increase of disposal of USW in managed deep landfills with methane recovery for vehicular use	0.0	0.0	0
Increase of paper, cardboard and cellulose recycling	0.0	0.0	0.0
Increase of aerobic composting	0.0	-0.16	-0.34
Domestic wastewater treatment	**0.19**	**0.81**	**0.64**
Decrease of UDW treatment in septic and rudimentary tanks	0.24	0.66	1.6
Increase of UDW treatment in urban anaerobic plants with methane destruction in flares	0.0	0.28	-0.94
Increase of UDW sent to activated sludge systems and lagoons, launched in nature and unspecified	-0.05	-0.13	0.0
Decrease of wastewater treatment in rural households	0.0	0.0	0.0
Industrial wastewater treatment	**0.18**	**0.24**	**0.31**
TOTAL	**0.69**	**11**	**13**
Non-disposal of recycled waste in landfills	0.01	0.10	0.10
Non-disposal of composted waste in landfills	0.00	0.30	0.90
Non-use of natural gas in thermoelectric plants	0.00	0.10	0.30
Non-use of natural gas in vehicles	0.00	0.00	0.00

Avoided Emissions (Mt CO_2-eq)	2020	2025	2030
PLUS SUBTOTAL	**0.01**	**0.50**	**1.3**
PLUS TOTAL	**0.70**	**12**	**14**

Table 117. Avoided emissions – scenarios A-C by mitigation actions in the waste sector (Mt CO_2-eq)

Avoided Emissions (Mt CO_2-eq)	2020	2025	2030
Solid Waste Treatment	**0.32**	**18**	**21**
Disposal of MSW and ISW (II-A) in landfills	0.41	18	22
Reduced disposal of USW in unmanaged shallow landfills	0.03	0.14	0.27
Reduced disposal of USW in unmanaged deep landfills	-0.66	-0.60	0.39
Decreased disposal of USW in managed deep landfills without methane destruction	1.0	1.5	0.93
Increased disposal of USW in managed deep landfills with methane destruction	0.0	6.8	0.66
Increased disposal of USW in managed deep landfills with methane recovery for power generation	0.0	8.6	17
Increase of disposal of USW in managed deep landfills with methane recovery for vehicular use	0.00	1.8	2.8
Increase of paper, cardboard and cellulose recycling	0.0	0.0	0.0
Increase of aerobic composting	-0.09	-0.16	-0.34
Domestic wastewater treatment	**0.19**	**1.1**	**0.93**
Decrease of UDW treatment in septic and rudimentary tanks	0.24	0.66	1.6
Increase of UDW treatment in urban anaerobic plants with methane destruction in flares	0.0	0.56	-0.20
Increase of UDW sent to activated sludge systems and lagoons, launched in nature and unspecified	-0.05	-0.13	-0.45
Decrease of wastewater treatment in rural households	0.0	0.0	0.0
Industrial wastewater treatment	**0.36**	**0.48**	**0.61**
TOTAL	**0.87**	**20**	**23**
Not disposal of recycled waste in landfills	0.01	0.1	0.1
Not disposal of composted waste in landfills	0.0	0.3	0.9
Non-use of natural gas in thermoelectric plants	0.0	0.3	0.6
Non-use of natural gas in vehicles	0.0	0.2	0.3
PLUS SUBTOTAL	**0.01**	**0.9**	**1.9**
PLUS TOTAL	**1.0**	**21**	**25**

Table 118. Avoided emissions – scenarios B-C by mitigation actions in the waste sector (Mt CO_2-eq)

Avoided Emissions (Mt CO_2-eq)	2020	2025	2030
Solid Waste Treatment	**0.09**	**8.0**	**9.4**
Disposal of MSW and ISW (II-A) in landfills	0.09	8.0	9.4
Reduced disposal of USW in unmanaged shallow landfills	0.00	0.00	0.00
Reduced disposal of USW in unmanaged deep landfills	0.01	0.01	0.01
Decreased disposal of USW in managed deep landfills without methane destruction	0.08	0.10	0.11
Increased disposal of USW in managed deep landfills with methane destruction	0.00	3.3	0.66
Increased disposal of USW in managed deep landfills with methane recovery for power generation	0.00	2.8	5.8
Increase of disposal of USW in managed deep landfills with methane recovery for vehicular use	0.00	1.8	2.8
Increase of paper, cardboard and cellulose recycling	0.00	0.00	0.00
Increase of aerobic composting	0.00	0.00	0.00
Domestic wastewater treatment	**0**	**0.28**	**0.29**
Decrease of urban domestic wastewater treatment in septic and rudimentary tanks	0.00	0.00	0.00
Increase of treatment in urban anaerobic plants with the destruction of biomethane in flares	0.00	0.28	0.74
Other treatments (activated sludge, lagoons, launch in nature and unspecified)	0.00	0.00	-0.45
Rural domestic wastewater treatment	0.00	0.00	0.00
Industrial wastewater treatment	**0.18**	**0.24**	**0.31**
TOTAL	**0.27**	**8.6**	**10**
No disposal of recycled waste in landfills	0	0	0
No disposal of composted waste in landfills	0	0	0
Non-use of natural gas in thermoelectric plants	0	0.20	0.30
Non-use of natural gas in vehicles	0	0.20	0.30
PLUS SUBTOTAL	**0**	**0.4**	**0.6**
PLUS TOTAL	**0.30**	**8.9**	**11**

5. ECONOMY-WIDE GHG EMISSIONS UNDER CURRENT MITIGATION POLICIES (SCENARIO A)

The emission pathways obtained for Scenario A in the model runs are presented by sectors in Table 119. We can see that there would be a strong reduction of emissions from Agriculture Forest and Other Land Use (AFOLU), particularly from Land Use, Land Use Change and Forestry (LULUCF) where both a reduction in deforestation rates and the extension of current levels of carbon removal in conservation units and indigenous lands would allow for a decrease of net emissions from LULUCF of 80% up to 2030. All other sectors and sub-sectors present emissions in 2030 substantially higher than in 2005, jeopardizing the achievement of the NDC targets, as discussed in chapter 8.

Table 119. GHG Emissions in Scenario A (Mt CO_2-eq)

Mt CO_2-eq	2005	2010	2015	2020	2025	2025/ 2005	2030	2030/ 2005
AFOLU	**2,381**	**828**	**935**	**899**	**887**	**-63%**	**894**	**-62%**
Land Use and Land Use Change and Forestry	1,922	355	413	408	388	**-80%**	375	**-80%**
Cropping Systems	127	139	143	124	124	**-2%**	134	**5%**
Livestock	333	333	379	368	374	**12%**	385	**16%**
Transport	144	178	203	208	223	**54%**	247	**71%**
Industry	141	163	170	178	199	**42%**	222	**58%**
Energy Supply	69	81	122	97	113	**64%**	131	**89%**
Fuel Combustion	49	61	99	69	78	**58%**	89	**80%**
Fugitive Emissions	20	20	23	28	35	**80%**	42	**114%**
Waste	**60**	**71**	**91**	**102**	**115**	**93%**	**128**	**114%**
Solid Waste	35	37	56	65	73	**109%**	81	**132%**
Wastewater	25	34	35	37	42	**68%**	47	**88%**
Others (energy use sectors)	**46**	**47**	**47**	**51**	**54**	**17%**	**54**	**19%**
Total	**2,841**	**1,367**	**1,568**	**1,535**	**1,591**	**-44%**	**1,675**	**-41%**

These results for Scenario A are further disaggregated in Table 120, allowing for a more detailed presentation of emissions split by driving forces and economic sectors.

Table 120. Detailed Presentation of GHG Emissions in Scenario A (Mt CO_2-eq**)**

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
AFOLU – Agriculture, Forestry and Other Land Use	2,381	828	935	899	887	894
Land Use and Land Use Change	1,922	355	413	408	388	375
Gross Emissions	2,171	668	913	925	927	928
Deforestation and other land use	-	-	883	896	896	896
Liming and forest residues	-	-	30	30	31	32
Removals	-249	-313	-500	-518	-538	-553
Planted Forests	-	-	-12	-	-14	-22
Restoration of Native Forest	-	-	-	-5.8	-15	-23
Recovery of Degraded	-	-	-14	-25	-22	-22
Livestock-Forest Systems	-	-	-25	-15	-15	-15
Protected Areas and Indigenous	-	-	-354	-382	-382	-382
Secondary forests	-	-	-95	-90	-90	-90
Agriculture	460	473	522	491	498	519
Livestock	333	333	379	368	374	385
Enteric Fermentation	-	312	358	349	355	364
Manure management	-	21	22	18	19	21
Cropping Systems	127	139	143	124	124	134
Agricultural Soils	-	120	129	125	129	135
Rice Cultivation	-	13	14	10	8.2	6.9
Burning of Agricultural Residues	-	6.5	6.6	3.4	3.0	2.8
Zero Tillage	-	-	-6.1	-16	-16	-11
Energy	321	378	444	429	469	518
Energy Supply (Fuel Combustion)	49	61	99	69	78	89
Energy Sector Consumption	22	24	30	28	30	34
Transformation Centers	28	37	69	42	48	55
Power Generation	27	37	68	41	47	55
Charcoal Production	1.0	0.70	0.60	0.50	0.50	0.50
Residential	26	26	26	29	31	32
Commercial & Public	3.7	2.8	2.6	2.9	3.6	4.2
Agriculture	16	18	18	19	19	18
Transportation	144	178	203	208	223	247
Road	131.6	160	186	190	202	221
Railways	2.8	3.3	2.8	3.2	3.5	3.7
Airways	6.4	10	11	11	12	16
Waterways	3.6	4.5	3.1	4.2	5.1	6.3
Industry	61.6	71.5	72.5	73.5	79.5	86
Cement	9.2	15	16	15	17	19
Pig iron and steel	5.3	5.6	5.6	5.7	6.1	6.5
Iron-Alloys	0.2	0.1	0.1	0.1	0.2	0.2
Mining/Pelletization	6.7	7.3	7.7	8.4	9.9	12
Non-Ferrous/Other Metallurgical	4.9	5.5	5.5	6.4	7.5	8.8

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
Chemical	15	14	14	14	14	14
Food and Beverage	5	5.5	5.6	5.4	5.6	5.8
Textile	1.2	1	0.7	0.7	0.7	0.7
Pulp & Paper	4.2	4.2	4.1	4.6	5.1	5.6
Ceramics	4	5.2	5	5	5.3	5.7
Other Industries	6.3	8.3	8.2	8.0	8.2	8.4
Energy Supply (Fugitive Emissions)	20	20	23	28	35	42
E&P	10	10	11	13	20	25
Oil Refining	6.8	7.4	8.3	10	10	11
Fuel Transport	0.27	0.30	0.33	0.40	0.58	0.73
Coal Production	2.8	2.9	3.3	4.6	4.6	5.0
Waste	**60**	**71**	**91**	**102**	**115**	**128**
Solid Waste	**35**	**37**	**56**	**65**	**73**	**81**
Urban Solid Wastes	-	-	56	65	73	81
Other	-	-	0.06	0.24	0.27	0.29
Wastewater Treatment and	25	34	35	37	42	47
Domestic Wastewater	14	16	17	18	19	20
Industrial Wastewater	11	17	18	19	23	27
Industrial Processes and Product	79	91	98	105	120	136
Mineral Industry	22	30	32	29	33	38
Pig Iron and steel	37	40	42	44	48	53
Iron-Alloy	1.2	1.2	0.9	1.2	1.5	1.9
Non-ferrous and other metals	2.9	5.4	5.7	6.8	7.9	9.3
Aluminum	3.4	3.1	3.1	6.4	8.0	9.7
Chemical industry	9.3	3.3	3.2	3.6	3.7	3.9
Non-energy products	0.70	0.60	0.60	0.60	0.60	0.60
HFCs e SF_6	3.1	7.6	10	14	17	20
TOTAL	2,841	1,367	1,568	1,535	1,591	1,675

6. ECONOMY-WIDE GHG EMISSIONS UNDER MITIGATION SCENARIOS (SCENARIOS B AND C)

The emission pathways obtained for Scenario B in the model runs are presented by sectors in Table 121. We reach negative net emissions from Land Use, Land Use Change and Forestry (LULUCF) in 2030, with both a reduction in deforestation rates and an increase in carbon removals in conservation units and indigenous lands that are particularly relevant to the overall mitigation targets. Emissions from agriculture also decrease along the period due to efficiency gains and a reduction of average cattle slaughtering age allows to curb down emissions from livestock at the end of the period. Although all other sectors present increasing emissions, the success of strong mitigation efforts in the AFOLU sector would be decisive for Brazil to meet its Paris commitment with a good margin to increase its ambition in future updates of the NDC, as discussed in chapter 8.

Table 121. GHG Emissions in Scenario B (Mt CO_2-eq)

Mt CO2-eq		2005	2010	2015	2020	2025	2025/2005	2030	2030/2005
AFOLU		**2,381**	**828**	**935**	**679**	**500**	**-79%**	**320**	**-87%**
	Land Use and Land Use Change and Forestry	1,922	355	413	193	33	**-98%**	-109	**-106%**
	Cropping Systems	127	139	143	124	116	**-9%**	113	**-11%**
	Livestock	333	333	379	363	352	**6%**	315	**-5%**
Transport		**144**	**178**	**203**	**204**	**211**	**46%**	**218**	**51%**
Industry		**141**	**163**	**170**	**171**	**184**	**31%**	**197**	**40%**
Energy Supply		**69**	**81**	**122**	**96**	**111**	**59%**	**129**	**87%**
	Fuel Combustion	49	61	99	69	75	**52%**	88	**77%**
	Fugitive Emissions	20	20	23	28	35	**77%**	42	**112%**
Waste		**60**	**71**	**91**	**101**	**104**	**74%**	**116**	**93%**
	Solid Waste	35	37	56	64	63	**81%**	70	**98%**
	Wastewater	25	34	35	37	41	**64%**	46	**82%**
Others (energy use sectors)		**46**	**47**	**47**	**51**	**54**	**17%**	**54**	**19%**
Total		**2,841**	**1,367**	**1,568**	**1,302**	**1,164**	**-59%**	**1,035**	**-64%**

These results for Scenario B are further disaggregated in Table 122, allowing for a more detailed presentation of emissions split by driving forces and economic sectors.

Table 122. Detailed Presentation of GHG Emissions in Scenario B (Mt CO_2-eq)

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
AFOLU – Agriculture, Forestry and Other Land Use	2,381	828	935	679	500	320
Land Use, Land Use Change and Forestry (net emissions)	1,922	355	413	193	33	-109
Gross Emissions	2,171	668	913	760	655	626
Deforestation and other land use changes	-	-	883	729	622	592
Liming and forest residues	-	-	30	31	33	35
Removals	-249	-313	-500	-567	-622	-735
Planted Forests	-	-	-12	-33	-31	-31
Restoration of Native Forest	-	-	-	-20.9	-55	-145
Recovery of Degraded Pasturelands	-	-	-14	-34	-39	-39
Livestock-Forest Systems	-	-	-25	-25	-25	-24
Protected Areas and Indigenous Lands	-	-	-354	-382	-410	-437
Secondary forests	-	-	-95	-73	-62	-59
Agriculture	460	473	522	486	468	429
Livestock	333	333	379	363	352	315
Enteric Fermentation	-	312	358	349	340	304
Manure management	-	21	22	13	12	11
Cropping Systems	127	139	143	124	116	113
Agricultural Soils		120	129	125	125	119
Rice Cultivation	-	13	14	10	8.2	6.9
Burning of Agricultural Residues	-	6.5	6.6	3.4	3.1	3.1
Zero Tillage	-	-	-6.1	-16	-20	-16
Energy	321	377	444	423	451	482
Energy Supply (Fuel Combustion)	49	61	99	69	76	88
Energy Sector Consumption	22	24	30	28	30	32
Transformation Centers	28	37	69	41	46	55
Power Plants	27	37	68	41	46	55
Charcoal Production	1.0	0.70	0.60	0.48	0.52	0.55
Residential	26	26	26	29	31	32
Commercial & Public	3.7	2.8	2.6	2.9	3.6	4.2
Agriculture	16	18	18	19	19	18
Transportation	144	178	203	204	211	218
Road	131.6	160	186	186	190	194
Railways	2.8	3.3	2.8	3.2	3.3	3.5
Airways	6.4	9.8	11	11	13	15
Waterways	3.6	4.5	3.1	4.2	5.1	6.1
Industry	62	72	73	72	76	81
Cement	9.2	15	16	15	16	17
Pig iron and steel	5.3	5.6	5.6	5.7	5.8	6
Iron-Alloys	0.2	0.1	0.1	0.1	0.1	0.2
Mining/Pelletization	6.7	7.3	7.7	8.3	9.5	11
Non-Ferrous/Other Metallurgical	4.9	5.5	5.5	6.3	7.2	8.3
Chemical	15	14	14	13.6	14	13
Food and Beverage	5.0	5.5	5.6	5.2	5.3	5.4
Textile	1.2	1.0	0.7	0.6	0.7	0.7

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
Pulp & Paper	4.2	4.2	4.1	4.5	4.9	5.4
Ceramics	4	5.2	5	4.9	5.1	5.3
Other Industries	6.3	8.3	8.2	7.8	7.9	8
Energy Supply (Fugitive Emissions)	20	20	23	28	35	42
E&P	10	10	11	13	20	25
Oil Refining	6.8	7.4	8.3	10	10	11
Fuel Transport	0.27	0.30	0.33	0.40	0.58	0.73
Coal Production	2.8	2.9	3.3	4.6	4.1	4.7
Waste	**60**	**71**	**91**	**101**	**104**	**115**
Solid Waste	**35**	**37**	**56**	**65**	**63**	**69**
Urban Solid Wastes	-	-	56	64	63	69
Others			0.10	0.33	0.47	0.64
Wastewater Treatment and Discharge	**25**	**34**	**35**	37	41	46
Domestic Wastewater	-	16	17	18	18	19
Industrial Wastewater	-	17	18	19	23	27
Industrial Processes and Product Use	**79**	**91**	**98**	**99**	**108**	**116**
Mineral Industry	22	30	32	29	32	36
Pig Iron and steel	37	40	42	42	45	48
Iron-Alloy	1.2	1.2	0.9	1.2	1.5	1.8
Non-ferrous and other metals	2.9	5.4	5.7	6.7	7.7	8.8
Aluminum	3.4	3.1	3.1	6.4	8.0	9.6
Chemical industry	9.3	3.3	3.2	3.6	3.6	3.6
Non-energy products	0.70	0.60	0.60	0.60	0.60	0.50
HFCs e SF_6	3.1	7.6	10	10	8.7	8.1
TOTAL	**2,841**	**1,367**	**1,568**	**1,302**	**1,164**	**1,035**

The emission pathways obtained for Scenario C in the model runs are presented by sector in Table 123. Compared to 2005, we reach a reduction of 95% in 2030 emissions from Land Use, Land Use Change and Forestry (LULUCF), where both a reduction in deforestation rates and an increase in carbon removals in conservation units and indigenous lands, although to a lesser extent than in Scenario B, are again decisive. The agriculture and livestock sector also presents GHG emissions in 2030 lower than in 2005. Even with more mitigation efforts than in Scenario B, emissions from all other sectors would still be growing up to 2030. Again, from an economy-wide perspective, the efforts would be more than enough for Brazil to meet its Paris commitment, allowing to increase its ambition in future NDC updates, as discussed in chapter 8.

Table 123. GHG Emissions in Scenario C (Mt CO_2-eq)

Mt CO_2-eq		2005	2010	2015	2020	2025	2025/ 2005	2030	2030/ 2005
AFOLU		**2,381**	**828**	**935**	**741**	**614**	**-74%**	**533**	**-78%**
	LandUseandLand UseChangeandFo restry	1,922	355	413	249	137	**-93%**	91	**-95%**
	CroppingSystems	127	139	143	124	119	**-7%**	118	**-7%**
	Livestock	333	333	379	368	359	**8%**	324	**-3%**
Transport		**144**	**178**	**203**	**201**	**193**	**34%**	**175**	**21%**
Industry		**141**	**163**	**170**	**166**	**171**	**22%**	**178**	**26%**
Energy Supply		**69**	**81**	**122**	**95**	**107**	**55%**	**119**	**73%**
	FuelCombustion	49	61	99	68	74	**49%**	82	**66%**
	FugitiveEmissions	20	20	23	27	33	**70%**	38	**91%**
Waste		**60**	**71**	**91**	**100**	**95**	**59%**	**105**	**74%**
	SolidWaste	35	37	56	64	55	**58%**	60	**70%**
	Wastewater	25	34	35	36	40	**60%**	45	**80%**
Others (energy use sectors)		**46**	**47**	**47**	**51**	**54**	**17%**	**54**	**19%**
Total		**2,841**	**1,367**	**1,568**	**1,354**	**1,235**	**-57%**	**1,164**	**-59%**

These results for Scenario C are further disaggregated in Table 124, allowing for a more detailed presentation of emissions split by driving forces and economic sectors.

Table 124. Detailed Presentation of GHG Emissions in Scenario C (Mt CO_2-eq)

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
AFOLU – Agriculture. Forestry and Other Land Use	2,381	828	935	741	614	533
Land Use. Land Use Change and Forestry (net emissions)	1,922	355	413	249	137	91
Gross Emissions	2,171	668	913	759	677	673
Deforestation and other land use changes	-	-	883	729	645	640
Liming and forest residues	-	-	30	30	32	33
Removals	-249	-313	-500	-510	-540	-582
Planted Forests	-	-	-12	-	-13	-12
Restoration of Native Forest	-	-	-	-7.0	-18	-48
Recovery of Degraded Pasturelands	-	-	-14	-29	-29	-29
Livestock-Forest Systems	-	-	-25	-20	-20	-20
Protected Areas and Indigenous Lands	-	-	-354	-382	-396	-410
Secondary forests	-	-	-95	-73	-64	-64
Agriculture	460	473	522	492	478	442
Livestock	333	333	379	368	359	324
Enteric Fermentation	-	312	358	349	340	304
Manure management	-	21	22	18	19	20
Cropping Systems	127	139	143	124	119	118
Agricultural Soils	-	120	129	126	127	123
Rice Cultivation	-	13	14	10	8.2	6.9
Burning of Agricultural Residues	-	6.5	6.6	3.7	3.5	3.5
Zero Tillage	-	-	-6.1	-16	-20	-16
Energy	321	377	444	417	425	423
Energy Supply (Fuel Combustion)	49	61	99	68	74	82
Energy Sector Consumption	22	24	30	27	29	31
Transformation Centers	28	37	69	41	45	51
Power Plants	27	37	68	40	44	50
Charcoal Production	1.0	0.70	0.60	0.50	0.50	0.60
Residential	26	26	26	29	31	32
Commercial & Public	3.7	2.8	2.6	2.9	3.6	4.2
Agriculture	16	18	18	19	19	18
Transportation	144	178	203	201	193	175
Road	131.6	160	186	183	172	151
Railways	2.8	3.3	2.8	3.1	3.2	3.6
Airways	6.4	10	11	11	13	14
Waterways	3.6	4.5	3.1	4.2	5.5	7.2
Industry	62	72	73	70	72	74
Cement	9.2	15	16	15	16	16
Pig iron and steel	5.3	5.6	5.6	5.7	5.6	5.8
Iron-Alloys	0.2	0.1	0.1	0.1	0.1	0.2
Mining/Pelletization	6.7	7.3	7.7	8.1	9	10
Non-Ferrous/Other Metallurgical	4.9	5.5	5.5	6.1	6.7	7.5
Chemical	15	14	14	13.2	13	12
Food and Beverage	5.0	5.5	5.6	5.2	5.2	5.3
Textile	1.2	1.0	0.7	0.6	0.6	0.6

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
Pulp & Paper	4.2	4.2	4.1	4.2	4.4	4.8
Ceramics	4	5.2	5	4.5	4.4	4.5
Other industries	6.3	8.3	8.2	7.7	7.6	7.6
Energy Supply (Fugitive Emissions)	20	20	23	27	33	38
E&P	10	10	11	13	20	23
Oil Refining	6.8	7.4	8.3	9	9	10
Fuel Transport	0.27	0.30	0.33	0.40	0.58	0.73
Coal Production	2.8	2.9	3.3	4.6	4.2	4.0
Waste	60	71	91	100	95	105
Solid Waste	35	37	56	64	55	60
Urban Solid Wastes	-	-	56	64	55	59
Others	-	-	0.10	0.33	0.47	0.64
Wastewater Treatment and Discharge	25	34	35	36	40	45
Domestic Wastewater	-	16	17	18	18	19
Industrial Wastewater	-	17	18	18	22	26
Industrial Processes and Product Use	**79**	**91**	**98**	**96**	**99**	**104**
Mineral Industry	22	30	32	29	32	35
Pig Iron and steel	37	40	42	41	41	42
Iron-Alloy	1.2	1.2	0.9	1.1	1.3	1.5
Non-ferrous and other metals	2.9	5.4	5.7	6.5	7.4	8.4
Aluminum	3.4	3.1	3.1	6.3	7.7	9.1
Chemical industry	9.3	3.3	3.2	3.6	3.4	3.3
Non-energy products	0.70	0.60	0.60	0.60	0.50	0.40
HFCs e SF_6	3.1	7.6	10	8.0	6.0	4.5
TOTAL	**2,841**	**1,367**	**1,568**	**1,354**	**1,235**	**1,164**

7. COMPARATIVE ANALYSIS OF SCENARIOS A, B AND C – AVOIDED EMISSIONS

A comparative analysis of the avoided emissions across scenarios and sectors is presented in Table 125. In 2030, economy-wide emissions in Scenario B are 37% lower than in Scenario A, mainly thanks to the strong mitigation efforts in AFOLU (89% of the total reduction), and particularly in LULUCF (77% of the total reduction).

In 2030, economy-wide emissions in Scenario C are 30% lower than in Scenario A. Again, the AFOLU sector provides a large majority (71%) of total avoided emissions, mainly thanks to the mitigation of LULUCF emissions (56%), although to a lesser extent than in Scenario B, according to the assumptions of lower ambition and success of mitigation policies and measures in AFOLU. However, this decrease is partially compensated by larger avoided emissions in other sectors, mainly Transport, reaching 14% of the total reductions in 2030, and Industry (9%).

Table 125. Comparative Analysis of GHG Emissions Across Scenarios and Sectors (Mt CO_2-eq)

Mt CO_2-eq	2020	2025	2030	2020	2025	2030	2020	2025	2030
	GHG Emissions in Scenario A – GHG Emissions in Scenario B			GHG Emissions in Scenario A – GHG Emissions in Scenario C			GHG Emissions in Scenario B – GHG Emissions in Scenario C		
AFOLU	**220**	**387**	**574**	**158**	**272**	**361**	**-62**	**-114**	**-213**
Land Use and Land Use Change and Forestry	215	356	484	159	252	284	-56	-104	-200
Cropping Systems	-0.03	8.5	20	-0.87	5	16	-0.8	-3.1	-4.4
Livestock	4.9	22	70	-0.10	15	61	-5.0	-7.1	-8.5
Transport	**4.0**	**12**	**28**	**7.1**	**30**	**71**	**3.1**	**18**	**43**
Industry	**7.2**	**16**	**25**	**13**	**28**	**44**	**5.6**	**13**	**19**
Energy Supply	0.72	2.9	1.6	2.0	6.6	11	1.3	3.7	9.9
Fuel Combustion	0.72	2.4	1.3	1.4	4.6	6.9	0.68	2.2	5.6
Fugitive Emissions	-	0.55	0.27	0.61	2.0	4.5	0.61	1.4	4.3
Waste	**0.9**	**11**	**13**	**1.9**	**20**	**24**	**1 .0**	**9.0**	**11**
Solid Waste	0.9	9.8	12	0.91	18	22	-	8.0	10
Waste water	-	1.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0
Others (energy use sectors)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Total	**233**	**428**	**641**	**182**	**357**	**511**	**-51**	**-71**	**-130**

7.1. Comparative Analysis of Scenarios A and B

The amount of avoided emissions in Scenario B compared to Scenario A is split by main mitigation actions in Table 126. We can see that the reduction of deforestation alone is responsible for nearly half (47%) of the total avoided emissions in 2030. Overall, six mitigation actions in the AFOLU sector account for 90% of total avoided emissions in 2030. The most relevant single mitigation action in the other sectors is the increased use of biofuels, allowing for 2% of total avoided emissions in 2030.

Table 126. Consolidated Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and B (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Reduction of Deforestation	160	69%	265	62%	293	46%
Increased Restoration of native forests	15	6%	40	9%	122	19%
Increase in livestock productivity	-	0%	15	4%	60	9%
Increase of protected areas (increased accounting of carbon sinks)	-	0%	28	7%	55	9%
Increased Restoration of pastureland	8.69	4%	17	4%	17	3%
Reduction in fertilizer application and in animal manure deposit on soil (due to a decrease in the average cattle slaughtering age)	0.00	0%	3.6	1%	14	2%
Increased use of biofuels	1.50	1%	6.7	2%	13	2%
HFCs leakage control and end-of-life recollection	3.91	2%	8.0	2%	12	2%
Increased disposal of USW in managed deep landfills with methane recovery for power generation	-	0%	5.8	1%	11	2%
Others in Transportation	2.3	1%	6.1	1%	17	3%
Others in Energy Supply	0.68	0%	3.0	1%	1.6	0%
Others in Industry	3.3	1%	7.5	2%	13	2%
Others in Waste	0.70	0%	5.7	1%	3.1	0%
Others in AFOLU	36	15%	18	4%	12	2%
TOTAL	**232**	100%	**429**	100%	**643**	100%

Note: Negative figures describe an increase in emissions in Scenario B compared to Scenario A.

The amount of avoided emissions in Scenario B compared to Scenario A is split by the complete set of mitigation actions grouped by sectors, in Tables 127 to 132.

Table 127. AFOLU – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and B (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Reduction of Deforestation	160	73%	265	68%	293	51%
Increased Restoration of native forests	15	7%	40	10%	122	21%
Increase in livestock productivity	0.0	0%	15	4%	60	10%
Increase of protected areas (increased accounting of carbon sinks)	0.0	0%	28	7%	55	10%
Increased Restoration of pastureland	8.7	4%	17	4%	17	3%
Reduction in fertilizer application and in animal manure deposit on soil (due to a decrease in the average cattle slaughtering age)	0.0	0%	3.6	1%	14.2	2%
Other land use change (net effect of crop switches)	6.1	3%	9.2	2%	10	2%
Increase of manure management (from cattle swine and other animals)	4.9	2%	7.3	2%	9.7	2%
Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)	9.6	4%	9.6	2%	9.5	2%
Increase in commercial planted forests	33	15%	16	4%	9.0	2%
Increase of zero-tillage practices (crops)	0.0	0%	4.3	1%	5.2	1%
Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)	0.0	0%	1.5	0%	2.1	0%
OTHER EMISSION SOURCES						
Burning of agriculture residues (in sugar cane pre-harvesting)	0.0	0%	-0.11	0%	-0.31	0%
Returning of agriculture residues to agricultural soil	0.0	0%	-0.69	0%	-0.94	0%
Liming for pH correction of agricultural soil	-0.7	0%	-1.8	0%	-2.4	0%
Carbon sinks in the natural regrowth of deforested areas	-17	-8%	-27	-7%	-30	-5%
Total	**220**	**100%**	**387**	**100%**	**574**	**100%**

*Livestock-Forest (IPF); Crop-Forest (ILF); and Crop-Livestock-Forest (IPF)
Note: Negative figures describe an increase in emissions in Scenario B compared to Scenario A, due to increased sugar cane production, liming in the additional agricultural area for energy crops and to the accounting of natural regrowth of deforested areas as new protected areas.

Table 128. Transport – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and B (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased use of biofuels	1.5	39%	6.7	52%	13	43%
Changes in freight transport patterns and infrastructure			1.8	14%	4.0	14%
Gains in energy efficiency in the transportation sector	1.5	39%	1.6	12%	3.8	13%
Expansion of the electric vehicles fleet (battery electric vehicles - BEV and hybrids)	0	0	0.4	3%	3.4	12%
Increased use of mass transportation systems	0.82	21%	1.0	8%	2.4	8%
Improved logistics of freight transportation			0.8	6%	2.0	7%
Improved logistics of passenger transportation and increased active transportation			0.6	5%	1.3	4%
Total	**3.8**	**100%**	**13**	**100%**	**30**	**100%**

Table 129. Industry – Avoided Emissions by Industrial Branch – Comparative Analysis of Scenarios A and B (Mt CO_2-eq and %)

INDUSTRIAL BRANCH	GHG Emissions in Scenario A – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
HFCs (product use)	3.9	54%	8.0	52%	12	49%
Iron and steel	1.3	18%	2.9	19%	4.7	19%
Cement	0.41	6%	1.08	7%	1.9	8%
Chemicals	0.40	6%	0.77	5%	1.3	5%
Non-ferrous metals	0.26	4%	0.60	4%	1.1	4%
Mining and pelleting	0.15	2%	0.39	3%	0.70	3%
Mineral industry (except Cement)	0.25	3%	0.60	4%	1.10	4%
Food and beverage	0.14	2%	0.29	2%	0.45	2%
Other industries	0.14	2%	0.28	2%	0.43	2%
Ceramics	0.09	1%	0.21	1%	0.37	2%
Pulp and paper	0.08	1%	0.17	1%	0.28	1%
Iron alloys	0.03	0%	0.08	0%	0.15	1%
SF_6 (product use)	0.04	1%	0.09	1%	0.13	1%
Textiles	0.02	0%	0.03	0%	0.04	0%
Total	**7.2**	**100%**	**16**	**100%**	**25**	**100%**

Table 130. Industry – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and B (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
HFCs leakage control and end-of-life recollection	3.9	54%	8.0	52%	12	49%
Energy efficiency	2.1	29%	5.6	36%	9.6	39%
Fuel shift	0.76	11%	0.82	5%	0.89	4%
Clinker reduction	0.13	2%	0.37	2%	0.66	3%
Process control & optimization	0.28	4%	0.68	4%	1.2	5%
SF_6 leakage control and end-of-life recollection	0.04	1%	0.09	1%	0.13	1%
Total	**7.2**	**100%**	**16**	**100%**	**25**	**100%**

Table 131. Energy Supply – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and B (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased efficiency in Energy sector consumption	0.24	35%	0.79	27%	1.2	77%
Reduced fugitive emissions due to lower coal mining & handling activities	0.0	0%	0.55	19%	0.27	17%
Reduced fugitive emissions due to leak reduction in oil refineries and natural gas processing plants	0.0	0%	0.0	0%	0.0	0%
Increased renewable power generation	0.47	68%	1.7	57%	0.18	0.12
Reduced fugitive emissions due to less Gas flaring in Oil and Gas E&P	0.0	0%	0.0	0%	0.0	0%
OTHER EMISSION SOURCES						
Emissions from charcoal kilns*	-0.027	-4%	-0.060	-2%	-0.093	-6%
Total	0.68	100%	3.0	100%	1.6	100%

*The mitigation effect of increased charcoal use is captured in Industry emissions (increased use of renewable charcoal to replace fossil fuels), but here increased charcoal production increases non-CO_2 emissions from charcoal manufacturing kilns.

Table 132. Waste – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and B (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased disposal of USW in managed deep landfills with methane recovery for power generation	-	0%	5.8	52%	11	84%
Decrease of UDW treatment in septic and rudimentary tanks	0.24	35%	0.66	6%	1.6	12%
Decreased disposal of USW in managed deep landfills without methane destruction	0.95	139%	1.37	12%	0.82	6%
Reduced disposal of USW in unmanaged deep landfills	-0.67	-98%	-0.61	-6%	0.38	3%
Increased industrial wastewater treatment with methane destruction	0.18	26%	0.24	2%	0.31	2%
Reduced disposal of USW in unmanaged shallow landfills	0.03	5%	0.14	1%	0.27	2%
OTHER EMISSION SOURCES						
Different ways of disposal and treatment of Urban Solid Waste – USW**	-	0%	3.3	30%	-0.34	-3%
Different ways of disposal and treatment of Urban Domestic Wastewater – UDW***	-0.05	-7%	0.15	1%	-0.94	-7%
Total	**0.69**	**100%**	**11**	**100%**	**13**	**100%**

* USW = Urban Solid Waste; UDW = Urban Domestic Wastewater
** Includes: Increased disposal of USW in managed deep landfills with methane destruction, increase of disposal of USW in managed deep landfills with methane recovery for vehicular use, Increase of paper, cardboard and cellulose recycling and Increase of aerobic composting of solid waste
*** Includes: Decrease of wastewater treatment in rural households, Increase of UDW sent to activated sludge systems and lagoons, launched in nature and unspecified and Increase of aerobic composting of solid waste
Note 1: Negative figures in 2020 and 2025 describe an increase in emissions in Scenario B due to an increase in waste collection and disposal for sanitation purposes before the Mitigation Action is implemented at the end of the period.
Note 2: Negative figures until 2030 describe an increase in emissions in Scenario B compared to Scenario A.

7.2. Comparative Analysis of Scenarios A and C

The amount of avoided emissions in Scenario C compared to Scenario A is split by main mitigation actions in Table 133. Again, the reduction of deforestation alone is responsible for nearly half (49%) of the total avoided emissions in 2030. Overall, five mitigation actions in the AFOLU sector still account for 75% of total avoided emissions in 2030, but this share is lower than in Scenario B. Mitigation action in other sectors present higher relevance than in Scenario B, such as increased use of biofuels, energy efficiency in Industry and HFCs leakage control and end-of-life recollection, allowing for 5%, 4% and 3% respectively of total avoided emissions in 2030.

Table 133. Consolidated Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Reduction of Deforestation	160	89%	242	68%	247	48%
Increase in livestock productivity	-	0%	15	4%	60	12%
Increase of protected areas (increased accounting of carbon sinks)	-	0%	14	4%	28	5%
Increased use of biofuels	1.5	1%	15	4%	27	5%
Increased Restoration of native forests	1.2	1%	3.0	1%	26	5%
Energy efficiency in the industry sector	4.6	3%	12	3%	19	4%
Increased disposal of USW in managed deep landfills with methane recovery for power generation	-	0%	8.6	2%	17	3%
HFCs leakage control and end-of-life recollection	5.3	3%	11	3%	16	3%
Reduction in fertilizer application and in animal manure deposit on soil (due to a decrease in the average cattle slaughtering age)	0.0	0%	3.6	1%	14	3%
Others in Transportation	5.9	3%	15	4%	44	9%
Others in Energy Supply	2.0	1%	6.6	2%	11	2%
Others in Industry	3.0	2%	5.5	2%	8.7	2%
Others in Waste	0.88	0%	11	3%	7.2	1%
Others in AFOLU	-3.9	-2%	-5.6	-2%	-14	-3%
TOTAL	**181**	100%	**358**	100%	**512**	100%

Note: Negative figures describe an increase in emissions in Scenario C compared to Scenario A.

The amount of avoided emissions in Scenario C compared to Scenario A is split by the complete set of mitigation actions grouped by sectors, in Tables 134 to 139.

Table 134. AFOLU – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Reduction of Deforestation	160	102%	242	89%	247	68%
Increase in livestock productivity	0.0	0%	15	6%	60	17%
Increase of protected areas (increased accounting of carbon sinks)	0.0	0%	14	5%	28	8%
Increased Restoration of native forests	1.2	1%	3.0	1%	26	7%
Reduction in fertilizer application and in animal manure deposit on soil (due to a decrease in the average cattle slaughtering age)	0.0	0%	3.6	1%	14	4%
Other land use change (net effect of crop switches)	6.1	4%	8.6	3%	8.7	2%
Increased Restoration of pastureland	3.3	2%	6.6	2%	6.6	2%
Increase of zero-tillage practices (crops)	0.0	0%	4.1	2%	5.2	1%
Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)	4.8	3%	4.8	2%	4.8	1%
Increase of manure management (from cattle swine and other animals)	-0.10	0%	0.21	0%	1.2	0%
Burning of agriculture residues (in sugar cane pre-harvesting)	-0.27	0%	-0.47	0%	-0.77	0%
Liming for pH correction of agricultural soil	-0.46	0%	-0.85	0%	-1.1	0%
OTHER EMISSION SOURCES						
Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)	-0.42	0%	-0.88	0%	-1.3	0%
Returning of agriculture residues to agricultural soil	-0.19	0%	-0.88	0%	-1.4	0%
Increase in commercial planted forests	0.00	0%	-1.71	-1%	-9.9	-3%
Carbon sinks in the natural regrowth of deforested areas	-17	-11%	-25	-9%	-26	-7%
Total	**158**	**100%**	**273**	**100 %**	**361**	**100%**

*Livestock-Forest (IPF); Crop-Forest (ILF); and Crop-Livestock-Forest (IPF)
Note: Negative figures describe an increase in emissions in Scenario C compared to Scenario A, due to increased sugar cane production, liming in the additional agricultural area for energy crops and to the accounting of natural regrowth of deforested areas as new protected areas.

Table 135. Transport – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased use of biofuels	1.5	20%	15	50%	27	38%
Expansion of the electric vehicles fleet (battery electric vehicles - BEV and hybrids)	0.1	1%	1.5	5%	12	17%
Changes in freight transport patterns and infrastructure	0.0	0%	4.0	13%	12	16%
Gains in energy efficiency in the transportation sector	2.0	27%	3.6	12%	7.7	11%
Increased use of mass transportation systems	1.3	18%	1.7	6%	5.3	7%
Improved logistics of freight transportation	1.3	18%	2.3	8%	4.4	6%
Improved logistics of passenger transportation and increased active transportation	1.2	16%	2.2	7%	3.5	5%
Total	**7.4**	**100%**	**31**	**100%**	**71**	**100%**

Table 136. Industry – Avoided Emissions by Industrial Branch – Comparative Analysis of Scenarios A and C (Mt CO_2-eq and %)

INDUSTRIAL BRANCH	GHG Emissions in Scenario A – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
HFCs (product use)	5.3	41%	11	39%	16	63%
Iron and steel	3.0	24%	7.1	25%	11	47%
Cement	0.89	7%	2.2	8%	3.9	16%
Chemicals	0.83	6%	2	7%	2.9	12%
Non-ferrous metals	0.68	5%	1.6	6%	2.7	11%
Mining and pelleting	0.37	3%	0.91	3%	1.5	6%
Mineral industry (except Cement)	0.25	2%	0.62	2%	1.6	6%
Pulp and paper	0.38	3%	0.68	2%	0.87	4%
Ceramics	0.48	4%	0.85	3%	1.2	5%
Other industries	0.28	2%	0.56	2%	0.85	3%
Food and beverage	0.18	1%	0.37	1%	0.57	2%
Iron alloys	0.09	1%	0.24	1%	0.44	2%
SF6 (product use)	0.05	0%	0.12	0%	0.17	1%
Textiles	0.03	0%	0.05	0%	0.08	0%
Total	**13**	**100%**	**28**	**100%**	**44**	**100%**

Table 137. Industry – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Energy efficiency	4.6	55%	12	76%	19	79%
HFCs leakage control and end-of-life recollection	5.3	64%	11	71%	16	63%
Fuel shift	2.2	27%	3.5	23%	4.8	20%
Process control & optimization	0.38	5%	0.94	6%	2.2	9%
Clinker reduction	0.35	4%	0.92	6%	1.6	6%
SF6 leakage control and end-of-life recollection	0.05	1%	0.12	1%	0.17	1%
Total	**13**	**100%**	**28**	**100%**	**44**	**100%**

Table 138. Energy Supply – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased renewable power generation	1.0	50%	3.1	47%	4.5	39%
Increased efficiency in Energy sector consumption	0.40	20%	1.5	23%	2.5	22%
Reduced fugitive emissions due to leak reduction in oil refineries and natural gas processing plants	0.55	27%	1.1	17%	1.55	13%
Reduced fugitive emissions due to lower coal mining & handling activities	0.06	3%	0.40	6%	0.98	8%
OTHER EMISSION SOURCES						
Emissions from charcoal kilns*	-	0%	0.50	8%	2.0	17%
Total	**2.0**	**100%**	**6.6**	**100%**	**12**	**100%**

Note: Negative figures describe an increase in emissions in Scenario C compared to Scenario A as increased charcoal production increases non-CO_2 emissions from charcoal manufacturing kilns.

Table 139. Waste – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios A and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario A – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased disposal of USW in managed deep landfills with methane recovery for power generation	-	0%	8.6	44%	17	73%
Increase of disposal of USW in managed deep landfills with methane recovery for vehicular use	-	0%	1.8	9%	2.8	12%
Decrease of UDW treatment in septic and rudimentary tanks	0.24	28%	0.66	3%	1.6	7%
Decreased disposal of USW in managed deep landfills without methane destruction	1.0	119%	1.5	7%	0.93	4%
Increased disposal of USW in managed deep landfills with methane destruction	-	0%	6.82	35%	0.66	3%
Increased industrial wastewater treatment with methane destruction	0.36	41%	0.48	2%	0.61	3%
Reduced disposal of USW in unmanaged deep landfills	- 0.66	-76%	- 0.60	-3%	0.39	2%
Reduced disposal of USW in unmanaged shallow landfills	0.03	4%	0.14	1%	0.27	1%
OTHER EMISSION SOURCES						
Different ways of disposal and treatment of Urban Solid Waste – USW**	- 0.09	-10%	- 0.16	-1%	- 0.34	-1%
Different ways of disposal and treatment of Urban Domestic Wastewater – UDW***	- 0.05	-6%	0.43	2%	- 0.65	-3%
Total	**0.87**	**100%**	**20**	**100%**	**23**	**100%**

* USW = Urban Solid Waste; UDW = Urban Domestic Wastewater
** Includes: Increase of paper, cardboard and cellulose recycling and Increase of aerobic composting of solid waste
***Includes: Decrease of wastewater treatment in rural households, Increase of UDW treatment in urban anaerobic plants with destruction of methane in flares and
Increase of UDW sent to activated sludge systems and lagoons, launched in nature and unspecified.
Note: Negative figures describe an increase in emissions in Scenario C compared to Scenario A.

7.3. Comparative Analysis of Scenarios B and C

The amount of avoided emissions in Scenario C compared to Scenario B is split by main mitigation actions in Table 140. Overall, the total avoided emissions in Scenario C compared to Scenario B are negative, as by design Scenario B is more ambitious than Scenario C in the AFOLU sector, and the increased avoided emissions from mitigation actions in Scenario C only partially compensates for the decline in avoided emissions from AFOLU. We can see that Scenario C has tested a lower degree of success in increased restoration of native forests and in the reduction of deforestation, mainly, but also in the increase of protected areas, of commercial planted forests and of the restoration of pastureland.

In other sectors, the main increase in avoided emissions from single mitigation actions in Scenario C compared to Scenario B has come from the increased use of biofuels, energy efficiency in Industry, expansion of the electric vehicles fleet, changes in freight transport patterns and infrastructure, increased disposal of USW in managed deep landfills with methane recovery and increased renewable power generation.

Table 140. Consolidated Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios B and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario B – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased Restoration of native forests	-14	27%	-37	52%	-96	73%
Reduction of Deforestation	-	0%	-22	31%	-47	35%
Increase of protected areas (increased accounting of carbon sinks)	-	0%	-14	19%	-27	20%
Increase in commercial planted forests	-33	63%	-18	25%	-19	14%
Increased use of biofuels	-	0%	8.6	-12%	15	-11%
Increased Restoration of pastureland	-5.4	10%	-11	15%	-11	8%
Energy efficiency	2.5	-5%	6.2	-9%	9.8	-7%
Increase of manure management (from cattle swine and others animals)	-5.0	10%	-7.1	10%	-8.5	6%
Expansion of the electric vehicles fleet (battery electric vehicles - BEV and hybrids)	0.10	0%	1.1	-2%	8.5	-6%

Others in Transportation	3.5	-7%	8.1	-11%	19	-14%
Others in Energy Supply	1.3	-2%	3.7	-5%	9.9	-7%
Others in Industry	3.2	-6%	6.5	-9%	9.1	-7%
Others in Waste	0.27	-1%	8.6	-12%	10.0	-8%
Others in AFOLU	-5.3	10%	-5.1	7%	-4.3	3%
TOTAL	**-52**	100%	**-71**	100%	**-132**	100%

Note: By design, AFOLU has increased mitigation ambition in Scenario B compared to Scenario C, but in all other sectors (Industry, Transport, Energy Supply and Waste), Scenario C has increased mitigation ambition compared to Scenario B Avoided emissions in scenario C compared to B are positive for all sectors but AFOLU as in Scenario C, the degree of ambition/success of the mitigation actions is lower

The amount of avoided emissions in Scenario C compared to Scenario B is split by the complete set of mitigation actions grouped by sectors, in Tables 141 to 146.

Table 141. AFOLU – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios B and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario B– GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased Restoration of native forests	-14	22%	-37	32%	-96	45%
Reduction of Deforestation	-	0%	-22	20%	-47	22%
Increase of protected areas (increased accounting of carbon sinks)	-	0%	-14	12%	-27	13%
Increase in commercial planted forests	-33	52%	-18	16%	-19	9%
Increased Restoration of pastureland	-5.4	9%	-11	9%	-11	5%
Increase of manure management (from cattle swine and other animals)	-5.0	8%	-7.1	6%	-8.5	4%
Increased use of integrated cropland-livestock-forestry systems (ILF+ICF+ICLF)	-4.8	8%	-4.8	4%	-4.8	2%
Increase in Biological Nitrogen Fixation (replacement of chemical fertilizers)	-0.42	1%	-2.4	2%	-3.4	2%
Other land use change (net effect of crop switches)	-	0%	-0.67	1%	-1.4	1%
Returning of agriculture residues to agricultural soil	-0.16	0%	-0.19	0%	-0.47	0%
Burning of agriculture residues (in sugar cane pre-harvesting)	-0.27	0%	-0.36	0%	-0.45	0%

MITIGATION ACTIONS	GHG Emissions in Scenario B– GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increase of zero-tillage practices (crops)	-	0%	-	0%	-	0%
OTHER EMISSION SOURCES						
Increase in livestock productivity	-	0%	-	0%	-	0%
Reduction in fertilizer application and in animal manure deposit on soil (due to a decrease in the average cattle slaughtering age)	-	0%	-	0%	-	0%
Liming for pH correction of agricultural soil	0.28	0%	1.0	-1%	1.3	-1%
Carbon sinks in the natural regrowth of deforested areas	-	0%	2.3	-2%	4.8	-2%
Total	-62	100%	-114	100%	-213	100%

*Livestock-Forest (IPF); Crop-Forest (ILF); and Crop-Livestock-Forest (IPF)
Note 1: In AFOLU, by design Scenario B has increased mitigation ambition compared to Scenario C
Note 2: Positive figures describe an increase in emissions in Scenario B compared to Scenario C, due to liming in the additional agricultural area for energy crops and to the accounting of natural regrowth of deforested areas.

Table 142. Transport – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios B and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario B – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased use of biofuels	-	0%	8.6	48%	15	35%
Expansion of the electric vehicles fleet (battery electric vehicles - BEV and hybrids)	0.10	3%	1.1	6%	8.5	20%
Changes in freight transport patterns and infrastructure	-	0%	2.3	13%	7.5	18%
Gains in energy efficiency in the transportation sector	0.50	14%	2	11%	3.9	9%
Increased use of mass transportation systems	0.50	14%	0.70	4%	2.9	7%
Improved logistics of freight transportation	1.3	36%	1.5	8%	2.4	6%
Improved logistics of passenger transportation and increased active transportation	1.2	33%	1.6	9%	2.2	5%
Total	**3.6**	**100%**	**18**	**100%**	**42**	**100%**

Note: In Transportation, by design Scenario C has increased mitigation ambition compared to Scenario B

Table 143. Industry – Avoided Emissions by Industrial Branch – Comparative Analysis of Scenarios B and C (Mt CO_2-eq and %)

INDUSTRIAL BRANCH	GHG Emissions in Scenario B – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Iron and steel	1.8	31%	4.2	33%	6.8	36%
HFCs (product use)	1.4	25%	3	23%	3.3	17%
Cement	0.47	8%	1.2	9%	2.0	11%
Non-ferrous metals	0.42	7%	1.0	8%	1.7	9%
Chemicals	0.43	8%	1	10%	1.6	8%
Mining and pelleting	0.22	4%	0.51	4%	0.84	4%
Mineral industry (except Cement)	-	0%	0.02	0%	0.50	3%
Ceramics	0.39	7%	0.64	5%	0.77	4%
Pulp and paper	0.30	5%	0.51	4%	0.59	3%
Other industries	0.14	3%	0.29	2%	0.43	2%
Iron alloys	0.06	1%	0.16	1%	0.29	2%
Food and beverage	0.04	1%	0.08	1%	0.12	1%
SF6 (product use)	0.02	0%	0.03	0%	0.04	0%
Textiles	0.01	0%	0.02	0%	0.04	0%
Total	**5.7**	**100%**	**13**	**100%**	**19**	**100%**

Note: In Industry, by design Scenario C has increased mitigation ambition compared to Scenario B

Table 144. Industry – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios B and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario B – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Energy efficiency	2.5	44%	6	40%	10	40%
Fuel shift	1.4	25%	2.7	17%	3.9	16%
HFCs leakage control and end-of-life recollection	1.4	25%	3	19%	3.3	13%
Process control & optimization	0.10	2%	0.26	2%	0.9	4%
Clinker reduction	0.22	4%	0.54	3%	0.9	4%
SF6 leakage control and end-of-life recollection	0.02	0%	0.03	0%	0.04	0%
Total	**5.7**	**100%**	**13**	**100%**	**19**	**100%**

Note: In Industry, by design Scenario C has increased mitigation ambition compared to Scenario B

Table 145. Energy Supply – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios B and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario B – GHG Emissions in Scenario C					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased renewable power generation	0.50	39%	1.5	34%	4.3	45%
Reduced fugitive emissions due to less Gas flaring in Oil and Gas E&P	-	0%	0.50	15%	2.0	20%
Reduced fugitive emissions due to leak reduction in oil refineries and natural gas processing plants	0.55	43%	1.1	34%	1.5	15%
Increased efficiency in Energy sector consumption	0.20	16%	0.74	21%	1.3	13%
Reduced fugitive emissions due to lower coal mining & handling activities	0.06	4%	-0.16	-5%	0.71	7%
OTHER EMISSION SOURCES						
Emissions from charcoal kilns*	-0.02	-1%	0.02	1%	-0.05	0%
Total	**1.3**	**100%**	**3.7**	**100%**	**10**	**100%**

Note (1): In Energy Supply, by design Scenario C has increased mitigation ambition compared to Scenario B
Note (2): Negative figures describe an increase in emissions in Scenario C compared to Scenario B as increased charcoal production increases non-CO_2 emissions from charcoal manufacturing kilns.

Table 146. Waste – Avoided Emissions by Mitigation Action – Comparative Analysis of Scenarios B and C (Mt CO_2-eq and %)

MITIGATION ACTIONS	GHG Emissions in Scenario C – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased disposal of USW in managed deep landfills with methane recovery for power generation	-	0%	2.8	33%	5.8	58%
Increase of disposal of USW in managed deep landfills with methane recovery for vehicular use	-	0%	1.8	21%	2.8	28%
Increase of UDW treatment in urban anaerobic plants with destruction of methane in flares	-	0%	0.28	3%	0.74	7%
Increased disposal of USW in managed deep landfills with methane destruction	-	0%	3.3	39%	0.66	7%

MITIGATION ACTIONS	GHG Emissions in Scenario C – GHG Emissions in Scenario B					
	2020		2025		2030	
	Mt CO_2-eq	%	Mt CO_2-eq	%	Mt CO_2-eq	%
Increased industrial wastewater treatment with methane destruction	0.18	66%	0.24	3%	0.31	3%
Decreased disposal of USW in managed deep landfills without methane destruction	0.08	30%	0.10	1%	0.11	1%
OTHER EMISSION SOURCES						
Different ways of disposal and treatment of Urban Solid Waste – USW**	0.01	5%	0.01	0%	0.01	0%
Different ways of disposal and treatment of Urban Domestic Wastewater – UDW***	-	0%	0.00	0%	-0.44	-4%
Total	**0.27**	**100%**	**8.6**	**100%**	**10**	**100%**

* USW = Urban Solid Waste; UDW = Urban Domestic Wastewater
** Includes: Reduced disposal of USW in unmanaged deep landfills, Reduced disposal of USW in unmanaged shallow landfills, Increase of paper, cardboard and cellulose recycling and Increase of aerobic composting of solid waste
*** Decrease of wastewater treatment in rural households, Decrease of UDW treatment in septic and rudimentary tanks and Increase of UDW sent to activated sludge systems and lagoons, launched in nature and unspecified
Note (1): In Waste, by design Scenario C has increased mitigation ambition compared to Scenario B
Note (2): Negative figures describe an increase in emissions in Scenario C compared to Scenario B.

8. CONCLUSION

The Brazilian NDC targets are an economy-wide goal of 37% GHG emission reduction, in 2025 and an intended 43% reduction, in 2030, compared with 2005 as the base year. In its annex "for clarification purposes," it is specified that these goals translate into an aggregate limit of 1.3 Gt CO_2-eq in 2025 and 1.2 Gt CO_2-eq in 2030 (GWP-100, IPCC AR5). It also presents the 2005 values of the Second National Communication to the UNFCCC as the base year.

However, improvements in the methodology for an accounting of AFOLU emissions have led to economy-wide emission values for 2005 significantly higher in the Third National Inventory included as part of the Third National Communication of Brazil to the UNFCCC.

Table 147 shows both values for 2005 and the NDC targets for 2025 and 2030 if the same 37% and 43% of the reduction in economy-wide emissions would apply.

Table 147. Brazilian NDC targets with figures related to the Second National Communication and corrected by the Third National Communication (Mt CO_2-eq and %)

	2005	2025	2030
Second National Communication	2.1	1.3	1.2
Third National Communication	2.8	1.8	1.6
	100%	-37%	-43%

Source: Based on Brazil, 2015

In this report, we have calculated the GHG emission scenarios according to the most recently available data and methodology, using the Third National Inventory.

Brazilian NAMAs presented to the UNFCCC at COP15 in Copenhagen, adjusted to the IPCC AR5 GWP, would result in an economy-wide cap of 2.1 – 2.2 Gt CO_2-eq in 2020. This level is far higher than the results obtained for 2020 in Scenario B (1.3 Gt CO_2-eq), Scenario C (1.4 Gt CO_2-eq) and even in Scenario A (1.5 Gt CO_2-eq). Therefore, we can foresee no major difficulties for Brazil meeting its Copenhagen pledges if current trends are pursued.

However, in Scenario A, where no extra mitigation efforts would be made, besides those already in place, total emissions would reach 1.6 Gt CO_2-eq in 2025 and 1.7 Gt CO_2-eq in 2030. The level reached in 2030 is above the Paris commitment irrespectively of the metric adopted, either using the Second or the Third National Inventory. Therefore, the assessment of the potential results of current mitigation policies shows that they are not enough to meet Brazilian NDC targets for 2030.

Additional mitigation actions are required to put the country's GHG emission pathway back on track to meet the Brazilian commitment to the Paris agreement. According to the multiple stakeholders consulted by the Brazilian Forum on Climate Change during 2017, there are plenty of additional mitigation options that could be deployed to this end. Grouped in Scenarios B and C, they would allow not only to meet Brazilian Paris commitments, even under the stricter interpretation that sticks to the absolute emissions cap of 1.3 Gt CO_2-eq in 2025 and 1.2 Gt CO_2-eq in 2030, as illustrated by the results of Scenario C (1.2 Gt CO_2-eq in 2025 and 2030), but also to increase the ambition of next NDCs to reach even lower economy-wide emissions in 2025 (1.2 Gt CO_2-eq) and 2030 (1.0 Gt CO_2-eq), as illustrated by the results of Scenario B.

This scenario analysis also illustrates the crucial role of some key mitigation actions, as the reduction in deforestation. In Scenario C, that hits the NDC targets with an increased mitigation effort in other sectors than AFOLU, deforestation should emit no more than 0.6 Gt CO_2-eq in 2025 and 2030 (around half of the caps of 1.3 and 1.2 Gt CO_2-eq in 2025 and 2030, respectively), in order to meet the economy-wide targets. The translation of this deforestation emission level in different pathways of deforested surfaces in the main biomes as the Amazon and the Savannah ("cerrado") is a good example of the type of MRV indicators required to track the progress achieved in Brazilian mitigation policies towards meeting the NDC targets, as it will be further explored in the next phase of the study.

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APPENDIX – SECTORIAL METHODOLOGIES

AFOLU

1. Macroeconomic Scenario

The macroeconomic scenario underlying the AFOLU analysis considered the domestic GDP projected for the long-term and a compound annual growth rate (CAGR) of approximately 1.15% between the years 2014 and 2023 to compensate the recent fall in GDP due to the continuous growth of the sector. Growth rates for the global GDP published by EPE were also used (EPE, 2015).

2. Modeling of the Agricultural Sector (production and area estimates)

Projections are divided into agricultural and forestry production (grains, sugarcane, forest plantation (wood) and livestock) and planted area (sugarcane, soybeans, maize, other grains, planted forests and pasture). The crops considered were sugarcane, soybeans, maize (1st and 2nd crop), other grains, pine and eucalyptus. The livestock category is beef cattle, dairy cattle and swine.

The agricultural production in *Scenario A* was estimated from historical data up to 2015 or 2017. For the future, we used the demand for agricultural and livestock products and forestry from energy, transport and industry sectors. Estimates are also based on the domestic and global GDP from the IES Brazil project (LA ROVERE et al., 2018) adopted in the present study.

The projection of the planted area was calculated considering the annual production (ton) and the average productivity per hectare (ton/ha) as shown in Table 148.

Table 148. Productivity data

Productivity (ton/ha)	2005	2010	2015	2016	2017	2020	2025	2030
Crops								
Sugarcane	66.2	67.7	61.3	71.7	71.8	72.7	74.3	93.3
Maize	2.9	4.5	5.2	5.4	5.5	5.8	6.3	6.9
Soybean	2.2	3.0	3.0	3.3	3.2	3.3	3.4	3.6
Other grains	2.1	2.3	2.7	2.7	2.8	3.0	3.3	3.7
Cattle head/ha (no restorated pasture)	1.1	1.2	1.3	1.3	1.3	1.3	1.3	1.3
Cattle head/ha (restorated pasture)	1.1	1.2	1.4	1.4	1.4	1.5	1.7	1.9

Data sources: Sugarcane: IBGE (2016). Única. (2016) e EPE (2015); Maize and Soybean: IBGE (2016) e MCTI. GEF (2016); Other grains: IBGE (2016). CAGR; Cattle/ha: ABIEC (2016) e MCTI. GEF (2016).

3. Data source

Historical data used in the estimates of the agricultural production and areas and their respective sources are presented below:

Soybeans and soybeans products

- Historical series of the soybean production and area (2005-2015): IBGE (2017)
- Historical series of soybean production for processing (soybean oil, soybean meal and soybean biodiesel): for the period 2007-2016 ABIOVE (2017); for the years 2020. 2025 and 2030 (APROBIO and UBRABIO, 2016)
- Historical series of biodiesel production for the period 2005-2015: ANP (2016)
- Demand for biodiesel: data from the energy supply sector of this project
- Projections to produce soybean, soybean meal and the soybean yield: MAPA (2017)
- Soybean yield projection: MCTI, GEF (2016)

Maize

- Historical series of the maize production (1st and 2nd harvester) corresponding to the period 2005-2015: IBGE (2016)
- Production projections and area: MAPA (2017)
- Maize yield projection: MCTI, GEF (2016)

Other Grains

- Historical series of the grain production and grain area (14 crops) corresponding to the period 2005-2015: (IBGE, 2016).
- Other grains yield: estimated using the compound annual growth rate (approximately 2.2%) applied between 2015-2030.

Livestock

- Historical data of heads of cattle, pigs and birds corresponding to the period 2005-2015: IBGE (2016), ABIEC (2017).
- Projections of production and domestic, world GDP until 2030: LA ROVERE et al., (2018).
- Meat production: ABIEC (2017), MAPA (2017), OECD/FAO (2015)

- Restoration pasture areas: Observatório ABC (2015)
- Intensification of livestock productivity (productivity gain, genetic improvement and reduction of the slaughter age): adapted from Strassburg (2014).

Sugarcane

- Historical series of the sugarcane production and area (2005-2015): IBGE (2016), UNICA (2016).
- Demand for sugarcane products: demand for sugar estimated by industrial sector; demand for ethanol (energy, non-energy and transport) from the transport and energy sector of this study.
- Productivity: 2010 to 2015 (Única 2016); in the period 2016-2024 (MAPA, 2016) and from 2025 to 2030 (EPE, 2015).

Commercial Forest Planted

- Historical series of wood production and planted area of pine and eucalyptus forests: 2010-2012 (ABRAF,2013) and 2014-2017 (IBÁ, 2017).
- Forest production and planted area 2016-2030: estimated considering the demand for energy (charcoal and firewood) and for paper and pulp. For industrialized wood (sawn and plywood), wood panels according to growth rates extracted from the Mitigation Options study (MCTI, GEF, 2016).
- Forest planted productivity: ranged from 35 to 40 m3/ha.year-1 in the period from 2005 to 2015 and was considered constant from 2016 (CGEE, 2015; ABRAF,2013; 2016; CGEE,2015).

4. Balance of GHG Emission

The methodology to calculate GHG emissions balance is in accordance with the IPCC Guidelines for National Greenhouse Inventories (1996), IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) and the Third Brazilian Inventory of Anthropogenic Greenhouse Gas Emissions (Brazil, 2016). The emission data from IES Brazil project (LA ROVERE et al., 2018) were also used.

The net emissions from AFOLU include gross emissions and removals in Land Use Change and Forest and emissions from agriculture. Emissions from Land Use Change and Forest are associated with biomass gain or loss, for example, deforestation and other land use changes

(CO_2), emissions from burned forest residue (N_2O e CH_4) and liming (CO_2). Removal sources of CO_2 are provided by planted forests, restoration of native forests, restoration of degraded pasture, forest-livestock integrated systems, protected areas (conservation units and indigenous lands), and conservation of secondary forest. Emissions from the agricultural sector include the following sources: agricultural soils, rice cultivation, burning of agricultural residues, zero tillage system, enteric fermentation and manure management.

Emissions and removals were estimated for Scenario A considering the agricultural production and planted area by 2030 and the adoption of low carbon agriculture practices (mitigation measures). In the period 2005-2015 (or 2017, when available data) published data were used. Between 2016-2030 the values are estimates.

The estimates take into accounting the sectorial mitigation measures defined in the governmental commitments: Brazil's Nationally Appropriate Mitigation Actions – NAMA (Brazil, 2010) and Brazil’s Nationally Determined Contribution – NDC (Brazil, 2015); governmental policies for the agricultural sector Low-Carbon Agriculture – ABC Plan (Brazil, 2010) and; measure suggested by Brazilian Climate Change Forum (FBMC) . The mitigation measures considered are listed below:

- Reduction of deforestation
- Carbon account in Protected Areas (Conservation Units and Indigenous lands)
- Restoration of Native Forest
- Conservation of secondary forest
- Increase in commercial planted forest
- Increase in forest-livestock integration
- Restoration of degraded pasture
- Increase in the adoption of zero-tillage cropping system
- Increase in the adoption of Biological Nitrogen Fixation (BNF)
- Manure Management
- Intensification of livestock productivity

Industry

1. Emissions from energy consumption

Energy consumption was estimated through a bottom-up methodology, which describes a particular economic sector through the technologies and processes used for a particular energy purpose (Murphy, Rivers and Jaccard, 2007).

The Brazilian industry was segmented in eleven subsectors (branchs): (i) cement; (ii) iron and steel; (iii) iron alloys; (iv) mining and pelleting; (v) non-ferrous and other metals; (vi) food and beverage; (vii) chemical industry; (viii) paper and pulp; (ix) textile; (x) ceramic; (xi) other industries.

The energy demand by source in every industrial branch t is calculated by the product between the activity level and the energy intensity as shown in Equation 1:

$$D_{t,y} = IE_{t,y} \times NA_{t,y}$$

'*D*', the energy demand; *NA*, the activity level; '*T*', a certain technology; '*Y*' is the year; '*IE*', the final energy intensity.

Greenhouse gas emissions (GHG) from the energy consumption are calculated by the product of the quantity, in TJ, of each source consumed per year and its emission factor, in $kgCO_2/TJ$, kg CH_4/TJ and kg N_2O/TJ. Equation 2-1 shows how these emissions are calculated, where $E_{i,j}$ is the emission of fuel *j* in branch *i*, FE_j is the emission factor of fuel *j*, and $S_{i,j}$ is the amount of fuel *j* consumed in the branch *i*.

$$E_{i,j} = FE_j \times S_{i,j}$$

2. Emissions from IPPU

GHG emissions from industrial processes and product use were calculated based on the methodologies presented in the reference reports of the Third Brazilian Inventory of Anthropogenic Greenhouse Gas Emissions and Removals (MCTI 2015).

We used distinct emissions factors for each industrial process (those that are in place or new ones for mitigation purposes) times the estimated product output for each technology process for some activity level. This is applicable to the production of metals, which involves the production of pig iron and steel, ferroalloys, aluminum, and other non-ferrous; mineral products such as the manufacture of cement, lime, limestone; and products of the chemical industry (MCTI 2010).

Emissions related to the use of products come from the leakage of fluorinated gases, HFCs, in refrigeration and air conditioning equipment and SF6 in distribution and electrical transmission equipment. Emissions of these gases were estimated based on the expected demand up to 2030.

For some processes, the calculation is below:

i. Iron and Steel, iron alloys and non-ferrous metals

The equation below shows the emissions calculation in industrial processes for the pig iron and steel, ferroalloys and non-ferrous metals (except aluminum) branches. This equation is based on the consumption of reducing fuels, e.g. metallurgical coal, petroleum coke, coal steam, coal coke. It was considered that 100% of these fuels, when used for direct heating, served as reducing agents and therefore are considered process emissions.

$$E_{CO2} = \sum_i \frac{Reducing\ fuel_i \times FE_i \times F_{ox} \times \frac{44}{12} - C_{prod} \times \frac{44}{12}}{10^3} \quad Equation\ 3$$

Where, "E_{co2}" is GHG emissions in Gg CO_2-eq; "Reducing fuel" is the "*i*" reducing fuel consumption reported by the TJ Energy Balance for direct heating; "*FE* is the emission factor"; "F*ox*" corresponds to the oxidation factor; "C_{prod}" is the amount of carbon contained in the product (t) or the average percentage of carbon in the steel/pig iron multiplied by the production in tonnes.

Table 149 shows the emission factors and the oxidized fraction for each of the reducing fuels.

Table 149. Emission factors (tC / TJ) and oxidized fraction (%) of reducing fuels in pig iron and steel, ferroalloys and non-ferrous metals

Reducing Fuel	Emission Factor (tC/TJ)	oxidized fraction (%)
Petroleum Coke	27,5	1
Coal	25,8	1
Mineral Coke	29,5	1
Charcoal	29,1	1

Source: self-elaboration based MCTI (2015)

ii. Aluminum

Greenhouse gas emissions during the aluminum production process were calculated according to the Tier 1 methodology presented in MCTI (2015a), which uses only the technology classification, Prebake anode or Soderberg anode, and corresponding emission factors, such as can be seen in Equation 4:

$$E_{t,i} = FE_{t,i} \times Q_{t,i}$$ Equation 4

Where "E" corresponds to GHG emissions; "FE" is the emission factor, in t CO_2/tAl; "Q" is the amount of aluminum produced in t; "I" refers to the greenhouse gas emitted; "T" corresponds to the technology used in the production of aluminum. Table 150 presents the values of the emission factors, FE, for each of the abovementioned technologies.

Table 150. Emission factors for aluminum production technologies (t CO_2 / t, kg CF_4 / t and kg C_2F_6 / t)

Technology	Emission factor		
	t CO_2/t Al	**kg CF_4/ t Al**	**kg C_2F_6/t Al**
Soderberg – VSS	1,7	0,08	0,04
Soderberg – HSS	1,7	0,04	0,03
***Prebaked Anode* – CWPB**	1,6	0,04	0,04
***Prebaked Anode* – SWPB**	1,6	1,6	0,4

Source: self-elaboration based in MCTI (2015)

iii. Mineral Products

MCTI (2010) presents methodologies that estimate the emissions of greenhouse gases in mineral products, such as cement, lime, limestone and dolomite and bark. The calculation of these emissions is reduced to the product between the production of these minerals and a given emission factor.

iv. Chemical Industry

GHG emissions from the chemical industry were estimated based on the methodology presented in MCTI (2015b). This report presents the emission factors of the various GHGs that are emitted during the production of the various products of this industry in relation to the quantity produced.

v. HFCs and SF6

In MCTI (2015) a methodology is presented for the calculation of the emissions of fluorinated gases HFCs, used in refrigeration and air conditioning equipment, and SF6, used in transmission and electrical distribution equipment. The emissions here are the result of a simple estimation from a historical series that correlates these emissions with the evolution of GDP.

Transportation

Method

Three approaches are adopted simultaneously: two quantitative (top-down and bottom-up); and a qualitative (ASIF). The method for calculating energy consumption and emissions is based on a bottom-up approach, requiring multi-sectoral collaborative efforts not only to explain the direct energy use but also balance the transportation activity and energy between the transport modes, justifying each case in terms of development stage and energy supply capacity. Here, the transport sector has been further split up into the highest sector level detail available. Additionally, a top-down approach is used to calibrate the outcomes from the bottom-up approach. The protocol is based on the study of Gonçalves and D´Agosto (2017).

Qualitative approach

The ASIF method is used to analyze and allocate assumptions and mitigation measures. It was developed by the Intergovernmental Panel on Climate Change (IPCC), considering four lines of action to reduce the consumption of fossil energy in transportation and consequently decrease GHG. 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).

This approach was used in the Greenpeace Energy Revolution Report (D´Agosto et al., 2015), in the study developed by the International Council on Clean Transportation (ICCT) (Façanha et al., 2012), the study Economic and Social Implications of the Governmental Plan Scenario (D'Agosto, Gonçalves and Oliveira, 2016) and the study entitled Future prospective scenarios for the use of energy in transportation in Brazil and GHG emissions (Gonçalves and D´Agosto, 2017).

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 is based on projections related to the GDP for freight transportation and GDP per capita for passenger transportation. Literature stresses that estimating the transport activity considering the economic growth (GDP and GDP per capita) can be more accurate than using only the population growth or other variable dissociated from the economic activity.

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 to estimate the energy consumption and GHG emission for rail, water, duct and air transportation. 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 activity and energy consumption. The data sources to estimate the energy consumption and GHG emissions, for both qualitative approaches are described in Table 151.

Table 151. Data sources considered for applying the procedures bottom-up and top-down.

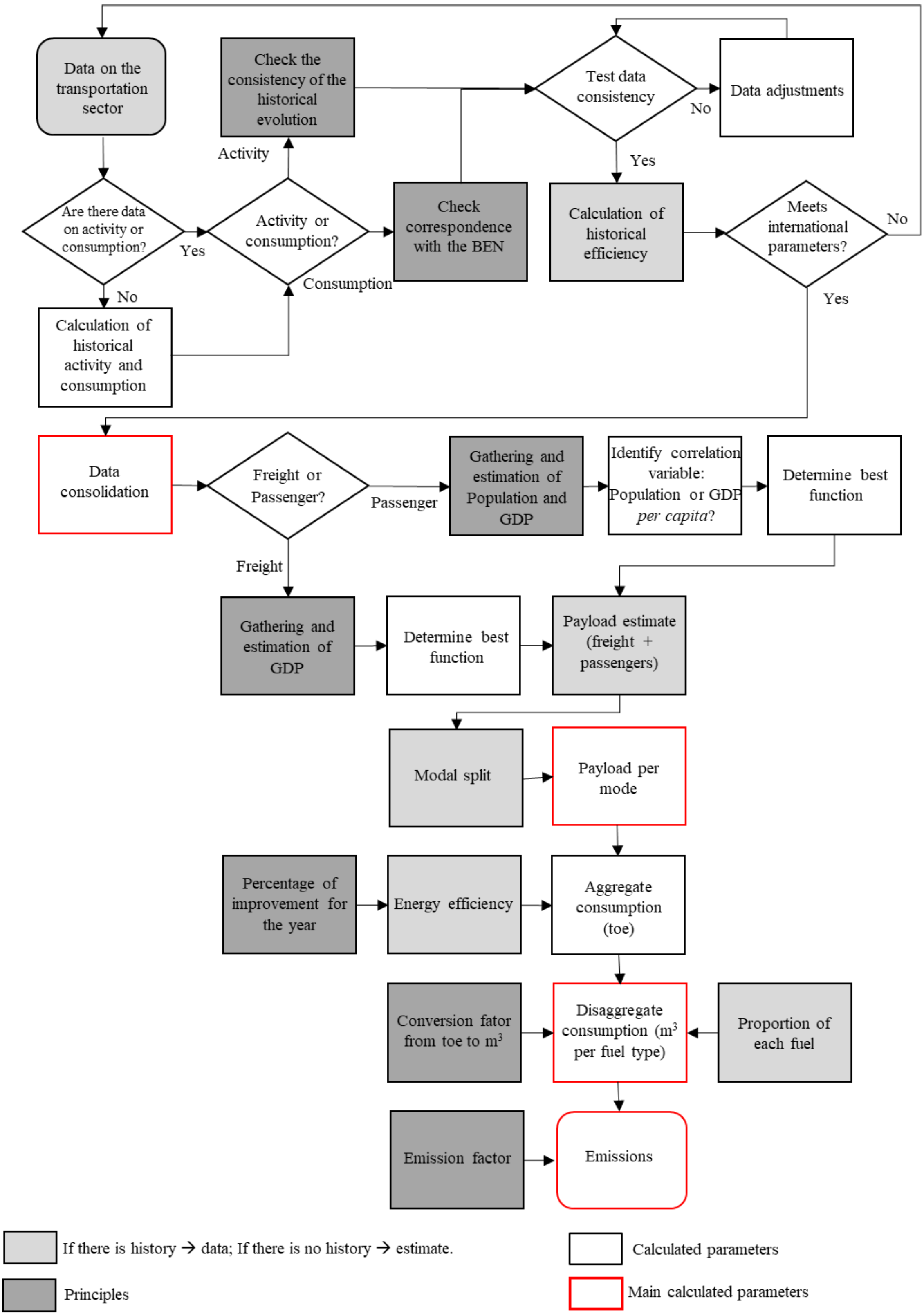
Output	Data	Source
Fleet	Sales	(ANVAVEA, 2018; ABRACICLO, 2018)
	Vehicle scrappage	(MMA, 2014; MCT; SINDIPEÇAS 2009)
Emission factors	g/km; kg/l; g/m³	PROCONVE; PROMOT; (CETESB, 2017)
Fuel economy	km/l; m³/year	(CETESB, 2017; MMA, 2014)
Vehicle-use intensity	km/year	(CETESB, 2017; MMA, 2014)
Energy consumption[8]	Joules; m³; l	(BEN, 2017)

Top-down approach

The top-down approach aims to quantify and identify, by mode and type of transport activity (passengers and freight), the trajectory of modal split and activity (pass-km and t-km), energy intensity (kJ/t-km and kJ/pass-km), energy consumption and GHG emissions in aggregate form, and thus providing an overview of energy use by source. It is used to estimate the emissions from transportation modes where there is no available data to estimate by the bottom-up approach and it is also used to calibrate and justify the results obtained from the bottom-up approach.

The detailed protocol is shown in Figure 57.

[8] For the top-down approach.

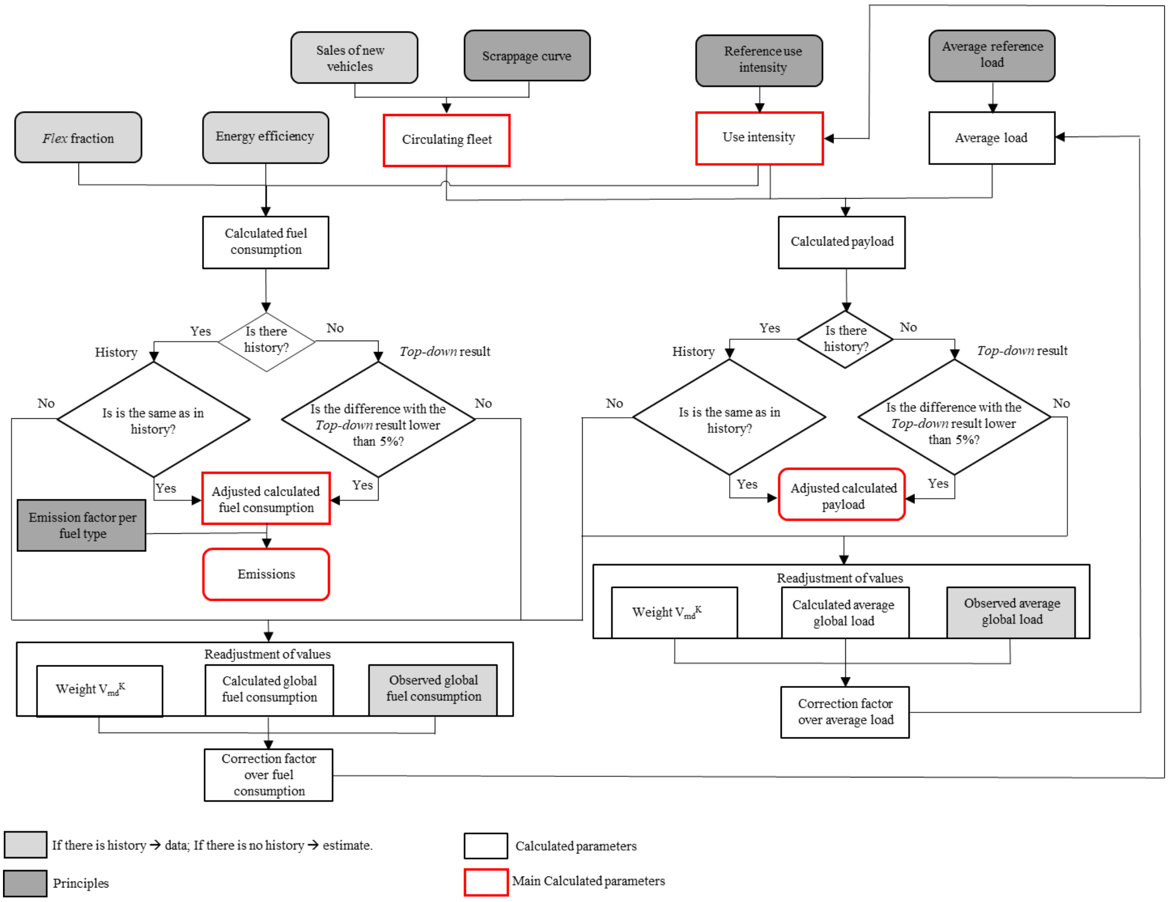


Source: Gonçalves and D´Agosto (2017).

Figure 57. Procedure adopted to estimate energy consumption using the top-down approach.

Bottom-up approach

For calculating energy consumption, four main data sets must be identified: (1) fleet, considering the year, vehicle´s model, age and energy source, considering also a scrappage curve; (2) vehicle-use intensity by fuel type and vehicle type; and (3) fuel economy by energy source. Figure 58 illustrates the procedure to estimate energy consumption and GHG emissions.



Source: Gonçalves and D´Agosto (2017).

Figure 58. Procedure adopted to estimate energy consumption using the bottom-line approach.

Historical trends

Considering the road transportation mode, Figure 59 illustrates the Brazilian car fleet, light commercial vehicles, motorcycles, buses and trucks.

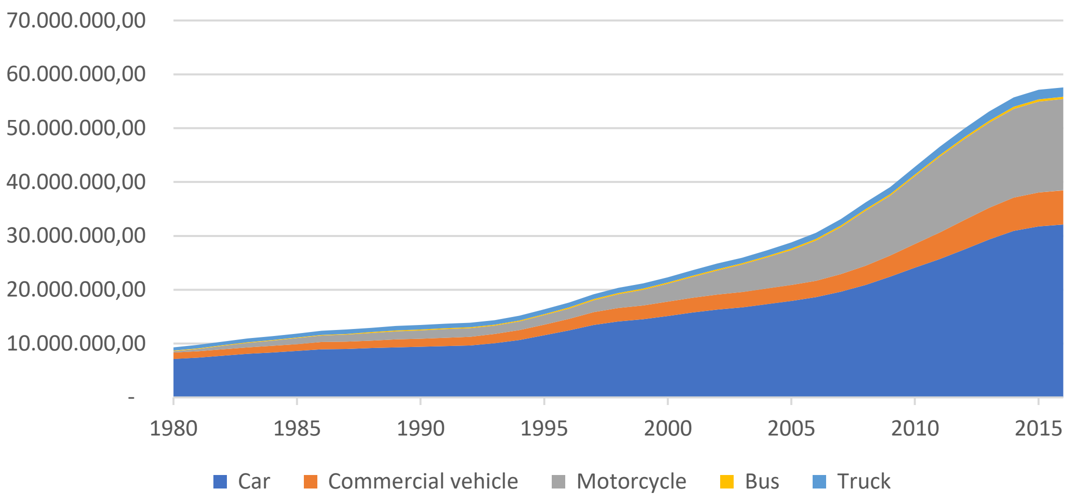


Figure 59. Historical of Brazilian fleet.

It is important to mention that road transportation is responsible for the greater participation in the modal split for both categories. The fleet is estimated according to sales (ANFAVEA, 2018; ABRACICLO, 2018) and scrapping (MMA, 2014; MCT; SINDIPEÇAS 2009) considering each type of vehicle.

Figure 60 shows the historical activity of transport. It is important to point out that energy consumption and GHG emissions are directly related to the activity.

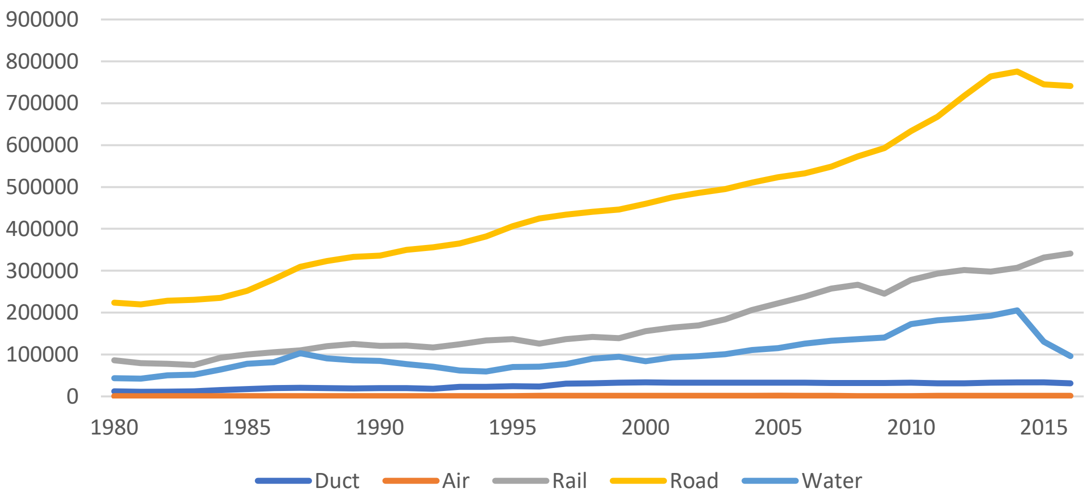


Figure 60. Transport activity of freight transportation (t-km).

From 2005, where the activity for all modes is around 366 billion tons per kilometer, transport activity expands 35% until 2016, reaching the amount of 1,21 billion of tons. As an observation, activity decreases between 2014 and 2016. This is expected since national GDP fell 9.1% during the period affecting transport widely. On the other hand, Figure 61 shows the transport activity of passenger transportation from 1980 to 2016.

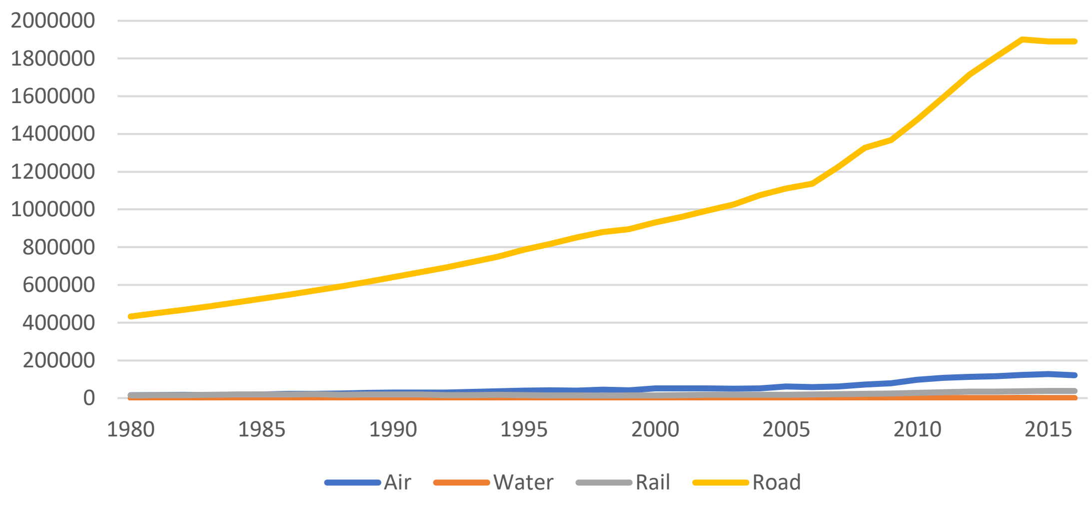


Figure 61. Transport activity of passenger transportation (pass-km).

In this case, the aggregate growth from 2005 to 2016 is 72%, the majority represented by road transportation. Under these circumstances, total activity is 1,19 billion of passenger per kilometer in 2005, while it reaches 2,05 billion of passenger per kilometer in 2016. At the end of the period, road mode represents 92.16% of the modal split of passenger transportation.

Energy Supply

To meet the energy demand, energy supply is estimated using the Energy Matrix Model (MATRIZ) developed by CEPEL (Research Center in Electricity), conceived as a tool to support long-term energy system expansion planning studies, such as the National Energy Plans (PNE), prepared by the Ministry of Mines and Energy (MME) and by the Energy Research Agency (EPE).

Briefly, this is a large computational model, based on linear programming which builds the complete energy chains from exogenous input data, such as, energy demand, energy resources, technologies, fuel prices etc. As results, it presents values of the electric generation, fuel production, power capacities and the optimum value of the energy flows in all energy chains considered, including eventual imports and exports, for the entire time horizon of study. In order to define the expansion optimization problem, some additions of production capacity and/or energy transport (electric or fuel) can be admitted as exogenous input data.

The MATRIZ model finds, among the numerous "viable solutions" to the expansion optimization problem, which solution minimizes the present value of the total cost of investment and operation of the energy system, also known as the "optimal solution" (there may be more than one solution of minimal cost). A viable solution is any supply alternative among different energy sources, capable of supplying an energy demand scenario (demands for subsystem electricity, fuels by type, etc.). This solution must satisfy all restrictions provided (Limits of capacity of electric power generation sources, minimum and maximum capacity factors by source, transport boundaries between regions, processing capacity and refining profiles of existing and new refineries, limits of processing capacity, import and/or regasification of natural gas, availability of sugarcane bagasse for thermoelectric generation, etc.).

In general, technologies are represented in aggregate form since individualized representation would significantly increase the complexity of integrated energy chain analysis. For the Brazilian energy system, integrated analysis becomes increasingly important due to the prospect of expanding the production of sugarcane for ethanol production and the supply of natural gas with the exploitation of the reserves of the Pre-salt. The expansion of these chains impacts the oil chain, the competition between ethanol and petroleum, the means of transportation and the electricity chain, through the sugarcane bagasse cogeneration plants and natural gas thermoelectric plants.

Long-term studies using the MATRIZ model allow us to define a strategy to expand energy chains considering their interdependencies, environmental constraints and government policies. This strategy can then be taken to expand sectoral planning for more detailed planning, considering the technical, economic and environmental impacts of individual technology projects.

The use of the MATRIZ makes it possible to consolidate the projections of the Brazilian Energy Matrix consistent with the assumptions established in the scenarios.

Waste

The basic equation for the first order decay model is:

(1) DDOCm = DDOCm(0) * e^-kton

where DDOCm(0) is the mass of decomposable degradable organic carbon (DOC) at the start of the reaction when t=0 and e^-kton=1, k is the reaction constant and t is the time in years. DDOCm is the mass of DDOC at any time.

From equation (I) it is easy to see that at the end of year 1 (going from point 0 to point 1 on the time axis) the mass of DDOC left not decomposed in the SWDS is:

(2) DDOCm(1) = DDOCm(0) * e^-k

and the mass of DDOC decomposed into CH_4 and CO_2 will be:

(3) DDOCmdecomp(1) = DDOCm(0) * (1 – e^-k)

In a first order reaction, the amount of product (here decomposed DDOCm) is always proportional to the amount of reactant (here DDOCm). This means that it does not matter when the DDOCm was deposited. This also means that when the amount of DDOCm accumulated in the SWDS, plus last year's deposit, is known, CH_4 production can be calculated as if every year is year number one in the time series. Then all calculations can be done by equations (2) and (3) in a simple spreadsheet.

The default assumption is that CH_4 generation from all the waste deposited each year begins on the 1st of January in the year after deposition. This is the same as an average six-month delay until substantial CH_4 generation begins (the time it takes for anaerobic conditions to become well established). However, the worksheet includes the possibility of an earlier start to the reaction, in the year of deposition of the waste. This requires separate calculations for the deposition year. For longer delay times than 6 months, DDOCmd in the columns F and G cells in the CH_4 calculating sheets, have to be readdressed one cell down, and the number 13 in exp2 has to be changed to 25 (7 to 18 months delay time).

The equations used in these spreadsheets are: (As the mathematics of every waste fraction/category is the same, indexing for fraction/category is omitted for equations 4-9.)

To calculate mass of decomposable DOC (DDOCm) from amount of waste material (W):

(4) DDOCmd(T), = W(T) • DOC * DOCf • MCF

The amount of deposited DDOCm remaining not decomposed at the end of deposition year T:

(5) DDOCmrem(T) = DDOCmd(T) • e^(-k • ((13-M)/12)

The amount of deposited DDOCm decomposed during deposition year T:

(6) $DDOCmdec(T) = DDOCmd(T) \bullet (1 – e^{(-k \bullet ((13-M)/12))})$

The amount of DDOCm accumulated in the SWDS at the end of year T

(7) $DDOCma(T) = DDOCmrem(T) + (DDOCma(T-1) \bullet e^{-k})$

The total amount of DDOCm decomposed in year T

(8) $DDOCmdecomp(T) = DDOCmdec(T) + (DDOCma(T-1) \bullet (1 – e^{-k}))$

The amount of CH_4 generated from DOC decomposed

(9) CH_4 generated(T) = DDOCmdecomp(T) • F • 16/12

The amount of CH_4 emitted

(10) CH_4 emitted in year T = ($\Sigma_x CH_4$ generated (x,T) – R(T)) • (1- OX(T))

Where:

T = the year of inventory

x = material fraction/waste category

W(T) = amount deposited in year T

MCF = Methane Correction Factor

DOC = Degradable organic carbon (under aerobic conditions)

DOCf = Fraction of DOC decomposing under anaerobic conditions

DDOC = Decomposable Degradable Organic Carbon (under anaerobic conditions)

DDOCmd(T) = mass of DDOC deposited year T

DDOCmrem(T) = mass of DDOC deposited in inventory year T, remaining not decomposed at the end of year.

DDOCmdec(T) = mass of DDOC deposited in inventory year T, decomposed during the year.

DDOCma(T) = total mass of DDOC left not decomposed at end of year T.

DDOCma(T-1) = total mass of DDOC left not decomposed at end of year T-1.

DDOCmdecomp(T) = total mass of DDOC decomposed in year T.

CH_4 generated(T) = CH_4 generated in year T

F = Fraction of CH_4 by volume in generated landfill gas

16/12 = Molecular weight ratio CH_4/C

R(T) = Recovered CH_4 in year T

OX(T) = Oxidation factor in year T (fraction)

k = rate of reaction constant

M = Month of reaction start (= delay time + 7)

Biological Treatment Of Solid Waste

The CH_4 and N_2O emissions of biological treatment can be estimated using the default method given in Equations 11 and 12 shown below:

(11) $$CH_4\ \text{Emissions} = \Sigma (M_i \bullet EF_i) \bullet 10\text{-}3 - R$$

Where:

CH_4 Emissions = total CH_4 emissions in inventory year, Gg CH_4

Mi = mass of organic waste treated by biological treatment type i, Gg

EF = emission factor for treatment i, g CH_4/kg waste treated

i = composting or anaerobic digestion

R = total amount of CH_4 recovered in inventory year, Gg CH_4

Emissions from flaring are not treated at Tier 1.

(12) $$N_2O\ \text{Emissions} = \Sigma_i (M_i \bullet EF_i) \bullet 10\text{-}3$$

Where:

N_2O Emissions = total N_2O emissions in inventory year, Gg N_2O

Mi = mass of organic waste treated by biological treatment type i, Gg

EF = emission factor for treatment i, g N_2O/kg waste treated

i = composting or anaerobic digestion

Incineration and Open Burning Of Waste

Incineration and open burning of waste are sources of greenhouse gas emissions, like other types of combustion. Relevant gases emitted include CO_2, methane (CH_4) and nitrous oxide (N_2O). Normally, CO_2 emissions from waste incineration are more significant than CH_4 and N_2O emissions.

Consistent with the 1996 Guidelines (IPCC, 1997), only CO_2 emissions resulting from oxidation, during incineration and open burning of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and should be included in the national CO_2 emissions estimate. The CO_2 emissions from combustion of biomass materials (e.g., paper, food, and wood waste) contained in the waste are biogenic emissions and should not be included in national total emission estimates.

For MSW, it is good practice to calculate the CO_2 emissions based on waste types/material (such as paper, wood, plastics) in the waste incinerated or open-burned as shown in Equation 13

(13) $$CO_2\ Emissions = MSW \cdot \Sigma_j (WF_j \cdot dm_j \cdot CF_j \cdot FCF \cdot OF_j) \cdot 44/12$$

Where:

CO_2 Emissions = CO_2 emissions in inventory year, Gg/yr

MSW = total amount of municipal solid waste as wet weight incinerated or open-burned, Gg/yr

WFj = fraction of waste type/material of component j in the MSW (as wet weight incinerated or open-burned)

dmj = dry matter content in the component j of the MSW incinerated or open-burned, (fraction)

CFj = fraction of carbon in the dry matter (i.e., carbon content) of component j

FCFj = fraction of fossil carbon in the total carbon of component j

OFj = oxidation factor, (fraction)

44/12 = conversion factor from C to CO_2

with: $\Sigma_j WF_j = 1$

j = component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste,

wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal,

glass, other inert waste.

The calculation of CH_4 emissions is based on the amount of waste incinerated/open-burned and on the related emission factor as shown in Equation 14.

(14) $$CH_4\ Emissions = \Sigma_i (IW_i \cdot EF_i) \cdot 10^{-6}$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, Gg/yr

IWi = amount of solid waste of type i incinerated or open-burned, Gg/yr

EFi = aggregate CH4 emission factor, kg CH_4/Gg of waste

10-6 = conversion factor from kilogram to gigagram

i = category or type of waste incinerated/open-burned, specified as follows:

MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste,

CW: clinical waste, SS: sewage sludge, others (that must be specified)

The calculation of N_2O emissions is based on the waste input to the incinerators or the amount of waste open-burned and a default emission factor. This relationship is summarized in the following Equation 15:

(15) $$N_2O \text{ Emissions} = \Sigma_i (IW_i \,.\, EF_i) \,.\, 10^{-6}$$

Where:

N_2O Emissions = N_2O emissions in inventory year, Gg/yr

IWi = amount of incinerated/open-burned waste of type i , Gg/yr

EFi = N_2O emission factor (kg N_2O/Gg of waste) for waste of type i

10^{-6} = conversion from kilogram to gigagram

i = category or type of waste incinerated/open-burned, specified as follows:

MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste,

CW: clinical waste, SS: sewage sludge, others (that must be specified)

Wastewater Treatment and Discharge

Wastewater can be a source of methane (CH_4) when treated or disposed of anaerobically. It can also be a source of nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emissions from wastewater are not considered in the IPCC Guidelines because these are of biogenic origin and should not be included in national total emissions. Wastewater originates from a variety of domestic, commercial and industrial sources and may be treated on site (uncollected), sewered to a centralized plant (collected) or disposed of of untreated nearby or via an outfall. Domestic wastewater is defined as wastewater from household water use, while industrial wastewater is from industrial practices only.

The activity data for this source category is the total amount of organically degradable material in the wastewater (TOW). This parameter is a function of human population and BOD generation per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year). The equation for TOW is:

(16) TOW = P . BOD . 0.001 . I . 365

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = country population in inventory year, (person)

BOD = country-specific per capita BOD in inventory year, g/person/day.

0.001 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00)

The emission factor for a wastewater treatment and discharge pathway and system is a function of the maximum CH_4 producing potential (B0) and the methane correction factor (MCF) for the wastewater treatment and discharge system, as shown in Equation 17.

(17) EFj = B0 . MCFj

Where:

EFj = emission factor, kg CH_4/kg BOD

j = each treatment/discharge pathway or system

Bo = maximum CH_4 producing capacity, kg CH_4/kg BOD

MCFj = methane correction factor (fraction).

The general equation to estimate CH_4 emissions from domestic wastewater is as follows:

(18) CH4 Emissions = [Σij (Ui . Tij . EFj)] . (TOW – S) – R

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr

TOW = total organics in wastewater in inventory year, kg BOD/yr

S = organic component removed as sludge in inventory year, kg BOD/yr

Ui = fraction of population in income group i in inventory year, See Table 6.5.

Ti,j = degree of utilization of treatment/discharge pathway or system, j, for each income group fraction i in inventory year, See Table 6.5.

i = income group: rural, urban high income and urban low-income

j = each treatment/discharge pathway or system

EFj = emission factor, kg CH_4 / kg BOD

R = amount of CH_4 recovered in inventory year, kg CH_4/yr

Industrial wastewater may be treated on-site or released into domestic sewer systems. If it is released into the domestic sewer system, the emissions are to be included with the domestic wastewater emissions. This section deals with estimating CH_4 emissions from on-site industrial wastewater treatment. Only industrial wastewater with significant carbon loading that is treated under intended or unintended anaerobic conditions will produce CH_4. Organics in industrial wastewater are often expressed in terms of COD, which is used here.

Assessment of CH_4 production potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater, and the propensity of the industrial sector to treat their wastewater in anaerobic systems. Using these criteria, major industrial wastewater sources with high CH_4 gas production potential can be identified as follows:

- pulp and paper manufacture,
- meat and poultry processing (slaughterhouses),
- alcohol, beer, starch production,
- organic chemicals production,
- other food and drink processing (dairy products, vegetable oil, fruits and vegetables, canneries, juice making, etc.).

The activity data for this source category is the amount of organically degradable material in the wastewater (TOW). This parameter is a function of industrial output (product) P (tons/yr), wastewater generation W (m3/ton of product), and degradable organics concentration in the wastewater COD (kg COD/m3). For each selected sector estimate total organically degradable carbon (TOW), as follows:

(19) TOWi = Pi . Wi . CODi

Where:

TOWi = total organically degradable material in wastewater for industry i, kg COD/yr

i = industrial sector

Pi = total industrial product for industrial sector i, t/yr

Wi = wastewater generated, m3/t product

CODi = chemical oxygen demand (industrial degradable organic component in wastewater), kg COD/m3

The general equation to estimate CH_4 emissions from industrial wastewater is as follows:

(20) CH_4 Emissions = Σi [(TOWi – Si) . EFi – Ri]

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr

TOWi = total organically degradable material in wastewater from industry i in inventory year, kg COD/yr

i = industrial sector

Si = organic component removed as sludge in inventory year, kg COD/yr

EFi = emission factor for industry i, kg CH_4/kg COD for treatment/discharge pathway or system(s) used in inventory year. If more than one treatment practice is used in an industry this factor would need to be a weighted average.

Ri = amount of CH_4 recovered in inventory year, kg CH_4/yr

Nitrous oxide (N_2O) emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea. Direct emissions from nitrification and denitrification at wastewater treatment plants may be considered as a minor source.

The activity data that are needed for estimating N_2O emissions are nitrogen content in the wastewater effluent, country population and average annual per capita protein generation (kg/person/yr). Per capita protein generation consists of intake (consumption) which is available from the Food and Agriculture Organization (FAO, 2004), multiplied by factors to account for additional 'non-consumed' protein and for industrial protein discharged into the sewer system. For developing countries using garbage disposals, the default for non-consumed protein discharged to wastewater pathways is 1.1. Wastewater from industrial or commercial sources that is discharged into the sewer may contain protein (e.g., from grocery stores and butchers). The default for this fraction is 1.25. The total nitrogen in the effluent is estimated as follows:

(21) Neffluent = (P . Protein . Fnpr . Fnon-com . Find-com) – Nsludge

Where:

Neffluent = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

Protein = annual per capita protein consumption, kg/person/yr

Fnpr = fraction of nitrogen in protein, default = 0.16, kg N/kg protein

Fnon-con = factor for non-consumed protein added to the wastewater

Find-com = factor for industrial and commercial co-discharged protein into the sewer system

Nsludge = nitrogen removed with sludge (default = zero), kg N/yr

The simplified general equation for N_2O emissions from wastewater effluent is as follows:

(22) N_2O Emissions = Neffluent. EFeffluent. 44/28

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

Neffluent = nitrogen in the effluent discharged to aquatic environments, kg N/yr

EFeffluent = emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

The Bo is the maximum amount of CH_4 that can be produced from a given quantity of organics (as expressed in BOD or COD) in the wastewater. For domestic wastewater, inventory compilers can compare country-specific values for Bo with the IPCC default value (0.25 kg CH_4/kg COD or 0.6 kg CH_4/kg BOD). The MCF indicates the extent to which the CH_4 producing capacity (B0) is realized in each type of treatment and discharge pathway and system. Thus, it is an indication of the degree to which the system is anaerobic.

Table 152. Default MCF values for domestic wastewater

Type of treatment and discharge pathway or system	MCF	EF
Sea, river and lake discharge	0,10	0,06
Stagnant sewer	0,50	0,30
Flowing sewer (open or closed)	0,00	0,00
Centralized, aerobic treatment plant (well managed)	0,00	0,00
Centralized, aerobic treatment plant (Not well managed)	0,30	0,18
Anaerobic digester for sludge	0,80	0,48
Anaerobic reactor	0,80	0,48
Anaerobic shallow lagoon	0,20	0,12
Anaerobic deep lagoon	0,80	0,48
Septic system	0,50	0,30
Latrine (Dry climate, groundwater table lower than latrine, small family)	0,10	0,06
Latrine (Dry climate, groundwater table lower than latrine, communal)	0,50	0,30
Latrine (Wet climate/flush water use, groundwater table higher than latrine)	0,70	0,42
Latrine (Regular sediment removal for fertilizer)	0,10	0,06

Source: IPCC (2006)

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ICAT Brazil Project

Report 2

GHG Emissions in Brazil up to 2030 under Current Mitigation Policies – Scenario A and under Additional Mitigation Actions – Scenarios B and C

PPE-21314

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