ICAT Brazil Project

CBC - Centro Brasil no Clima

Report 1

GHG Emissions in Brazil up to 2030 under Current Mitigation Policies – Scenario A

Centro Clima / COPPE / UFRJ

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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 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. The 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 government and civil society representatives. Its members belong to government, 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 is 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 the 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 a 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 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 to propose 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 fulfil 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 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 a number of 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 action proposed by the Forum but being 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 a MRV framework proposal for the Brazilian NDC.

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

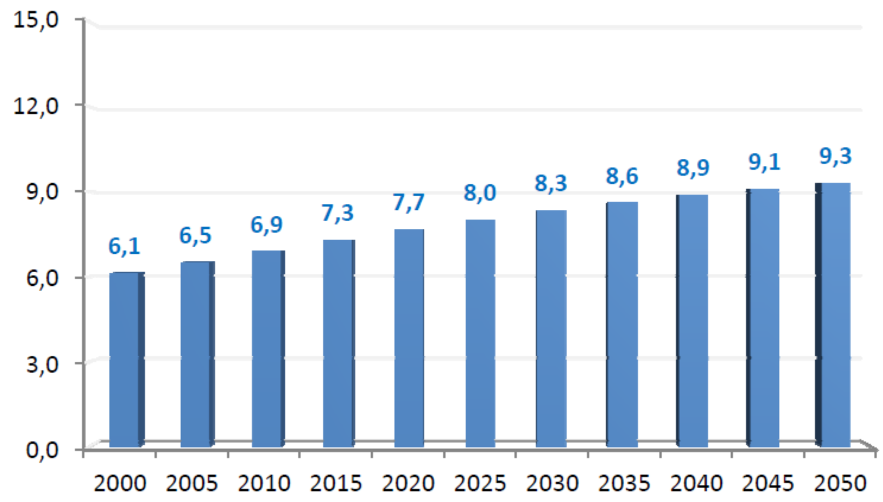
This section presents the set of assumptions used in the calibration of sectorial models and the IMACLIM-BR model. The IMACLIM-BR macroeconomic model was calibrated in order to reach the closest possible values of the numbers provided in this section. With the new equilibrium of the economy in 2030, 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.

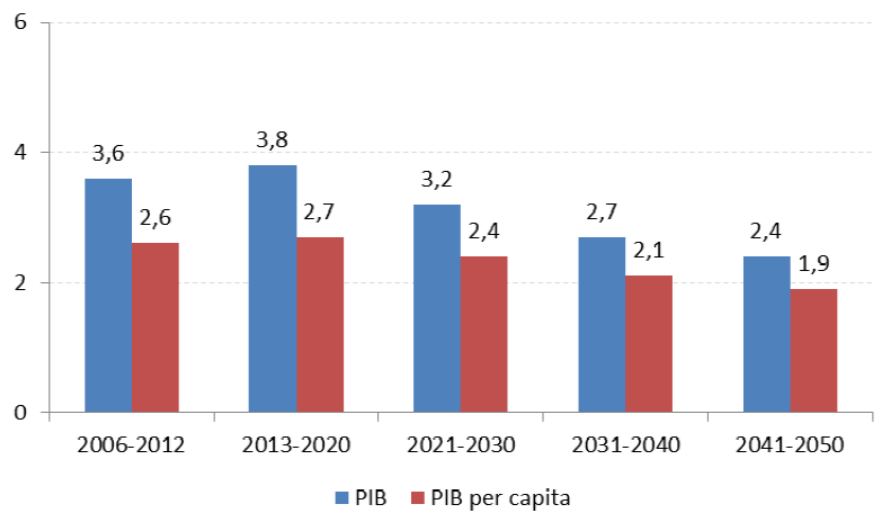


Source: EPE (2015)

Figure 1. World Population Projection

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)

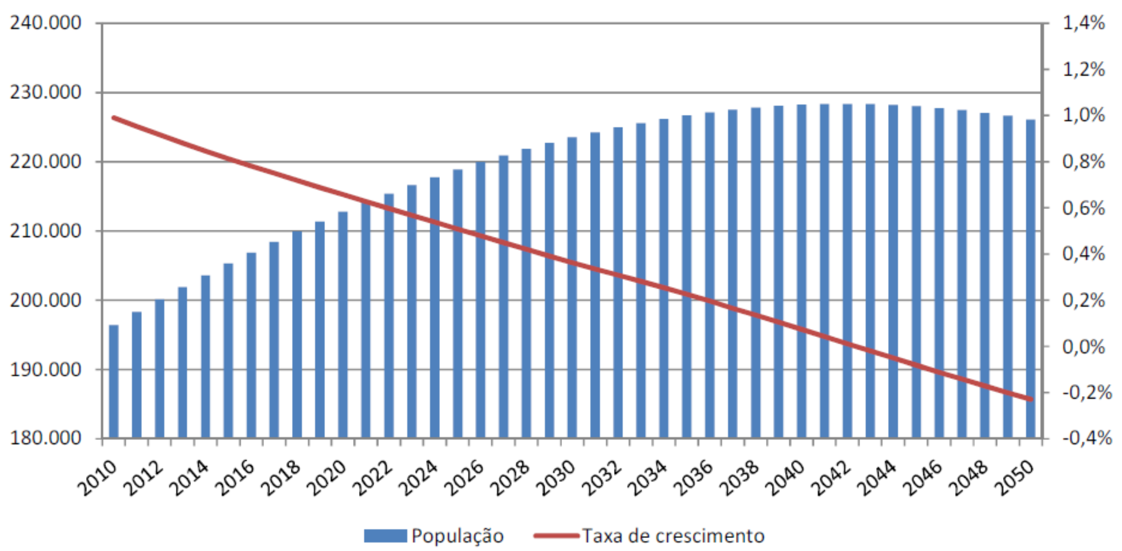
Figure 2. Average world economic growth per year

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 the level of 223 million people (IBGE, 2014).



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

Figure 3. Brazilian population (millions)

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.

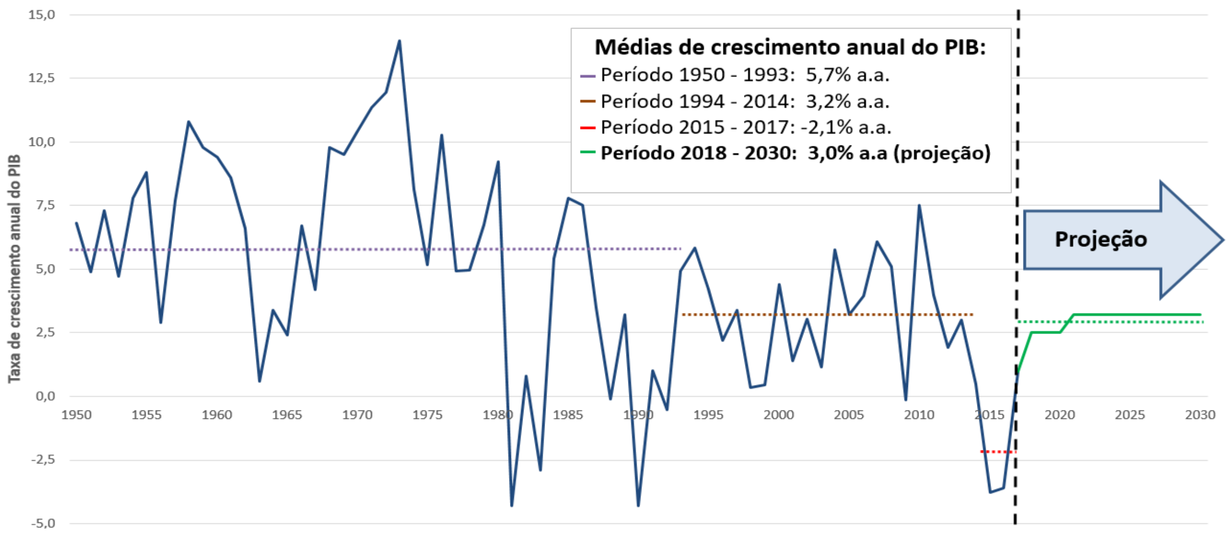
In this way, it is estimated that Brazil will grow at rates lower than the world average until 2020 when it would leave the current crisis. Between 2021 and 2030, reaping the fruits of the reforms initiated at the end of the previous decade, Brazil would grow in the average of the rest of the world: 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.

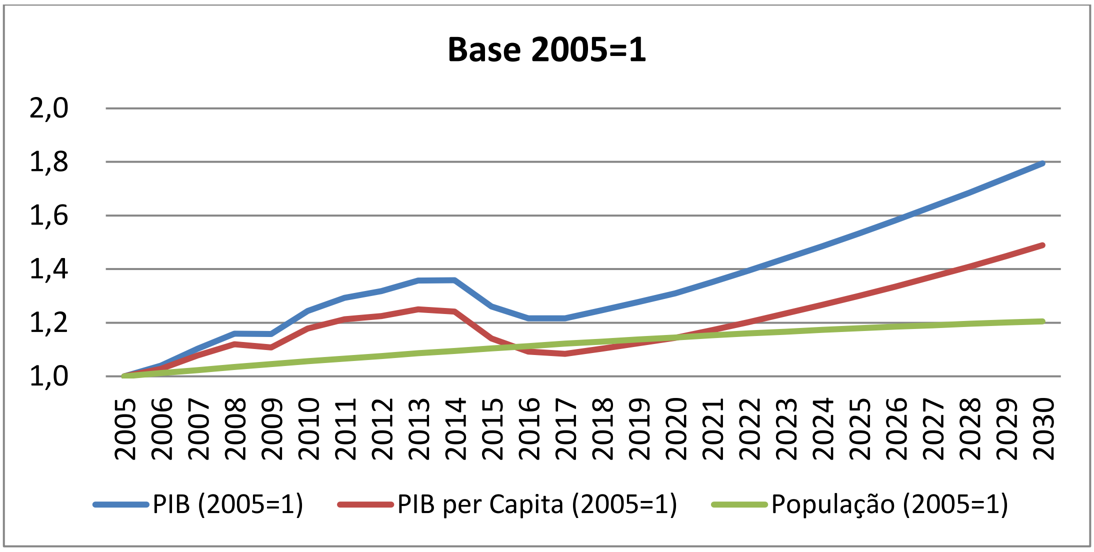


Figure 5. Evolution of selected indicators (Base 2005 = 1)

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, as a result 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, an 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 of the 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 segment is relevant due to the high cost that electric energy represents in its production process. These products are fundamental for the production of 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 has a tendency 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.

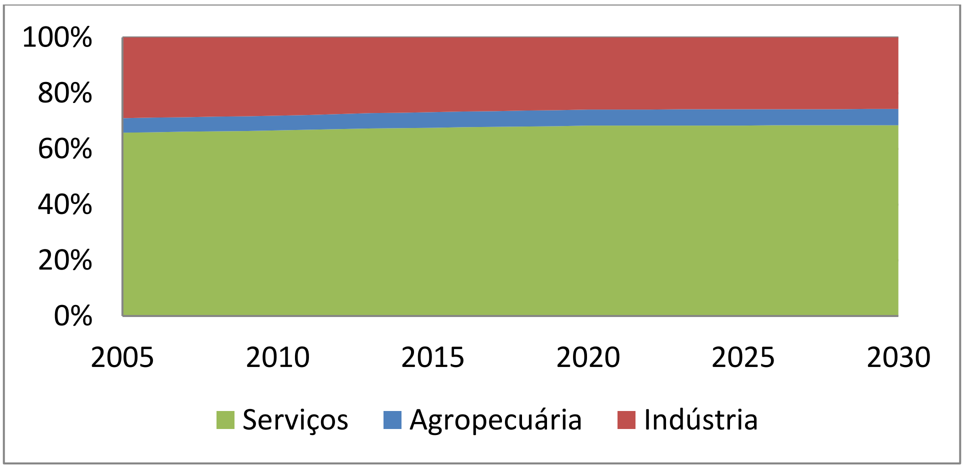


Figure 6. Participation of sectors in the Brazilian economy

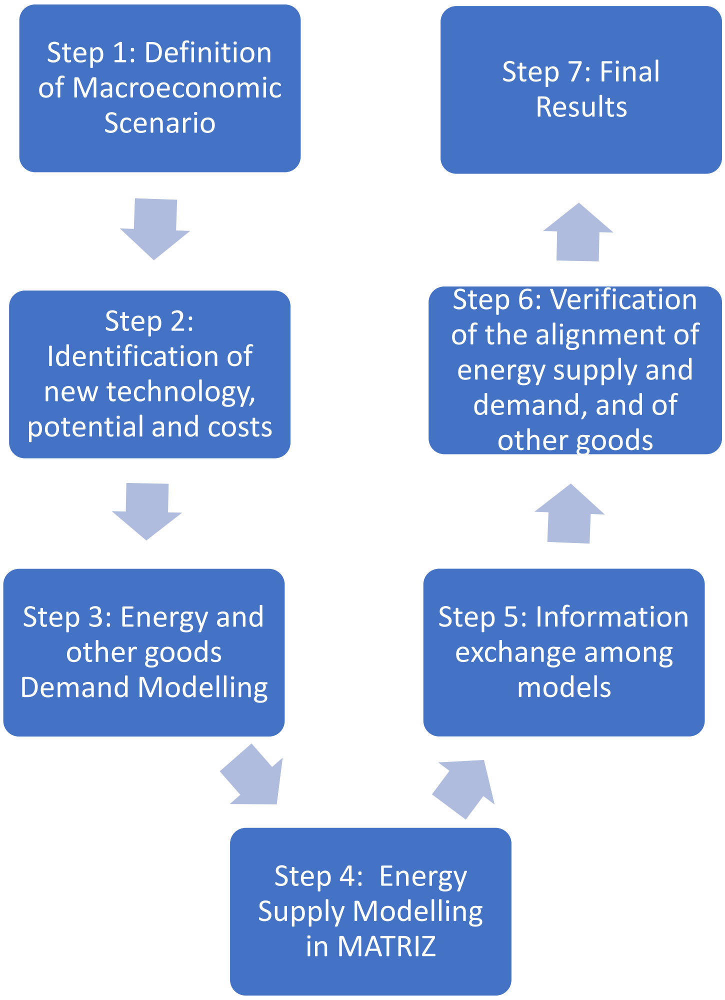
Further details on the assumptions and calibration of this economic scenario can be found in Wills & Lefevre (2016).

2.9. Sum-up of the Economic Premisses

- Demography:
  - Projection of 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).

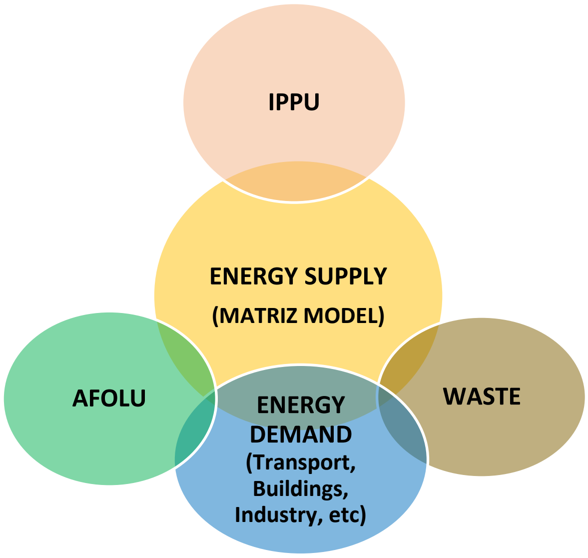


Figure 8. Methodological Approach: Integrated Modeling Diagram

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 Pinnus 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 land cover is changed to a 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 show 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 an amnesty to past illegal deforesters. 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 weakened 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 to 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 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 Pinnus 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 hectars 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: (i) …..; (ii)…..; (iii)

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 resulting 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 on emissions from rice cultivation from 2005 to 2016.

c) Burning of Agriculture Residues

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 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 others 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 increase 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 2005-2015 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, XXX). The assumptions for each mitigation measure are presented below and the respective penetration rate are in Table 1.

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[1], 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 levelled 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 $MtCO_2$-eq if the current deforestation trajectory is maintained until 2030.

b) Carbon Sink in Protected Areas (Conservation Units and Indigenous Lands)

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 overtime 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) Restoration of Native Forest

The area of native forest to be restored until 2030 covering all biomes (Amazonia, Mata Atlântica, 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 in 9.3 Mha (2013).

d) Conservation of secondary forest

Data published by SEEG (2018) about removals from secondary forest show an increase in removals between 2005-2010 and a 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.

[1] 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 area**

Forest planted areas (Eucalyptus e Pinnus) 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 tree 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) **Increase in forest-livestock integration systems (agroforestry)**

The area under forest-livestock integration systems 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-livestock integration 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 a lower performance than the period 2010-2015 (1,19 Mha/year).

g) **Restoration of degraded 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, what 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 the adoption of zero-tillage cropping system**

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 at 2020. Between 2020-2030 the assumption is zero-tillage in 100% of the expanded soybean area, totaling 45 Mha by 2030.

b) Increase in the adoption of Biological Nitrogen Fixation (BNF)

The agricultural area under BNF 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) Manure Management

The amount of animal waste treated until 2030 is estimated considering historical data of the annual populations (number of cattle, swine and others 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 during the period 2005-2015 and estimated values for 2016- 2030 period)

Table 2. Mitigation measures and penetration estimates (million ha).

Mitigation measure	Area (Million ha)							
	2005	2010	2015	2016	2017	2020	2025	2030
Protected areas (UC and TI)		191.6	247.0	258.1	269.2	269.2	269.2	269.2
Restoration of native forest				0.1	0.1	0.5	0.9	1.4
Commercial planted forest	5,3	6.5	6.9	6.7	6.4	6.3	6.7	7.4
Forest-livestock integration systems	0,3	0.9	2.0	2.1	2.2	2.6	3.2	3.8
Restoration of pasture			3.9	4.5	5.1	6.9	9.9	12.0

Mitigation measure	Area (Million ha)							
	2005	2010	2015	2016	2017	2020	2025	2030
Zero tillage cropping systems	25,5	30.8	34.1	34.1	36.2	39.3	42.9	45.1
Biological Nitrogen Fixation		23.3	32.2	32.3	32.4	32.7	36.3	38.4
Restoration of degraded pastureland			3.9	4.5	5.1	6.9	9.9	12.0
Manure Management		7.4	9.4	9.4	9.4	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 (livestock) area;
- CO_2-eq emissions and removals from the mitigation measures analyzed.

The agricultural production and area with crops, commercial planted forests and pasture (livestock), between 2005 and 2030 are presented in Tables 2 and 3, 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 3. Agricultural and livestock production (million ton, m^3 and head)

Production	2005	2010	2015	2016	2017	2020	2025	2030
Crops (Million ton)								
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
Other grains	28	26	29	29	29	30	31	34
Planted Forest (Million m^3)								
Wood production (homogeneous forest)	197	229	230	234	224	222	235	256
Wood production (integrated systems)	5	14	28	30	32	37	46	55
Total wood production	202	242	258	264	256	259	281	311
Livestock (Million of heads)								
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 4. Agricultural land area (2010-2030)

Agricultural Area (million ha)	2005	2010	2015	2016	2017	2020	2025	2030
Crops								
Crops (sugarcane, maize, soybean, other grains)	51.06	51.17	58.06	52.30	52.47	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 $MtCO_2$-eq. Emissions from agriculture amounted 460 $MtCO_2$-eq and Land Use Change and Forestry 1922 $MtCO_2$-eq. Emissions and Removals of CO_2-eq from the AFOLU sector in the period 2005-2030 is presented in Table 5.

Table 5. Gross Emissions, Removals and Net Emissions from AFOLU ($MtCO_2$-eq)

Emission AFOLU ($MtCO_2$-eq)	2005	2010	2015	2020	2025	2030
Land Use Change and Forestry						
Gross Emission	**2,671**	**668**	**913**	**925**	**927**	**928**
Deforestation and other land use change			883	896	896	896
Liming and forest residues			30	30	31	32
Removals	**-749**	**-313**	**-489**	**-511**	**-531**	**-546**
Commercial planted forest			-12	0	-14	-22
Restoration of native forest			0	-6	-15	-23
Restoration of pastureland			-14	-25	-22	-22
Forest-livestock integrated systems			-13	-8	-8	-8
Protected areas (UC and TI)			-354	-382	-382	-382

Emission AFOLU ($MtCO_2$-eq)	2005	2010	2015	2020	2025	2030
Secondary forest			-95	-90	-90	-90
Total Net Emission	**1,922**	**355**	**424**	**415**	**395**	**382**
Agriculture						
Enteric Fermentation		312	358	349	355	364
Manure Management		21	22	22	23	24
Agricultural soils		120	129	125	129	135
Rice Cultivation		13	14	10	8	7
Burning of agriculture residues		6	7	3	3	3
Zero tillage		0	-6	-16	-16	-11
Total Emission	**460**	**473**	**522**	**495**	**502**	**522**
AFOLU – Net Emission	**2,381**	**828**	**946**	**910**	**897**	**904**

AFOLU net GHG emissions in 2015 totaled 946 $MtCO_2$-eq, of which 382 $MtCO_2$-eq came from Land Use Change and Forestry and 522 $MtCO_2$-eq from the agricultural sector. In the period 2005-2015 there was a 40% reduction in the total net emissions (Table 4), 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 $MtCO_2$-eq in 2030 (Table 4). Although there is an increase in CO_2-eq removal in the Land Use Change and Forestry sector in this period (from -313 to -546 $MtCO_2$-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 were reduced in 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 4).

The Brazilian Nationally Appropriate Mitigation Actions (NAMAs) (Decree xxx 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 $MtCO_2$-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 $MtCO_2$-eq, in 2020);

v) the establishment and the improvement of 5.5 Mha of Biological Nitrogen Fixation cropping technique (with and estimated mitigation range of 16-20 $MtCO_2$-eq, in 2020).

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

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 achieve, in the Brazilian Amazonia, 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 – data from SEEG-2018) the deforestation area in the Amazon biome would be 591,5 mil ha in 2020, 50% higher than the target established (392,5 Mha). The emission reduction in relation to the average rate in the period 1996–2005 amounts 1Mt CO_2-eq[2], in 2020.

[2] 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).

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 according to the SEEG estimates (average of the period 2012-2016) while the NAMA value is 942 Mha.

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) Carbon Sinks in Protected Areas (Conservation Units and Indigenous Lands)

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 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) Restoration of Native Forest

Native forest to be restored covering all biomes (Amazonia, Mata Atlântica, 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) Conservation of secondary forest

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 area (commercial tree)

In Scenario B, planted forest area would be in accordance to 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) Increase of forest-livestock integration systems (agroforestry systems)

The total area under agroforestry 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) Restoration of degraded 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 in zero-tillage cropping systems

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 the adoption of Biological Nitrogen Fixation (BNF)

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) Manure Management

The amount of waste treated in the *Scenario B* by 2020 is according to the target established in ABC Plan (Brazil, 2010), reaching 4.4 million cubic meters of treated manure. For the subsequent period, values reach 13.7milliom m^3 by 2030, as a result of the policies for waste biogas recovery and power generation.

d) Intensification of 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 (Strassburg , 2014).

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.

4.1.5. 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 ambitious is to reach 60% of the emission reduction potential proposed in Scenario B (reduction of 57% in deforestation in Amazon biome, instead of 95%) according to the recommendation of the Brazilian Climate Change Forum (FBMC).

b) Carbon Sinks in Protected Areas (Conservation Units and Indigenous Lands)

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 Brazilian Forest Service (http://www.florestal.gov.br). The protected area by 2030 would then be 287.1 Mha in Scenario C.

c) Restoration of Native Forest

Native forest to be restored covering all biomes (Amazonia, Mata Atlântica, 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 in 9.3 Mha (2013).

d) Conservation of secondary forest

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 area (commercial tree)

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

f) Increase in forest-livestock integration systems (agroforestry)

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

g) Restoration of degraded pasture

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 the adoption of zero-tillage cropping system

The same as in Scenario A.

b) Increase the adoption of Biological Nitrogen Fixation (BNF)

The same as in Scenario A.

c) Manure Management

The same as in Scenario A.

d) Intensification of livestock productivity

The Intensification of 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 (Strassburg, 2014).

4.2. INDUSTRY

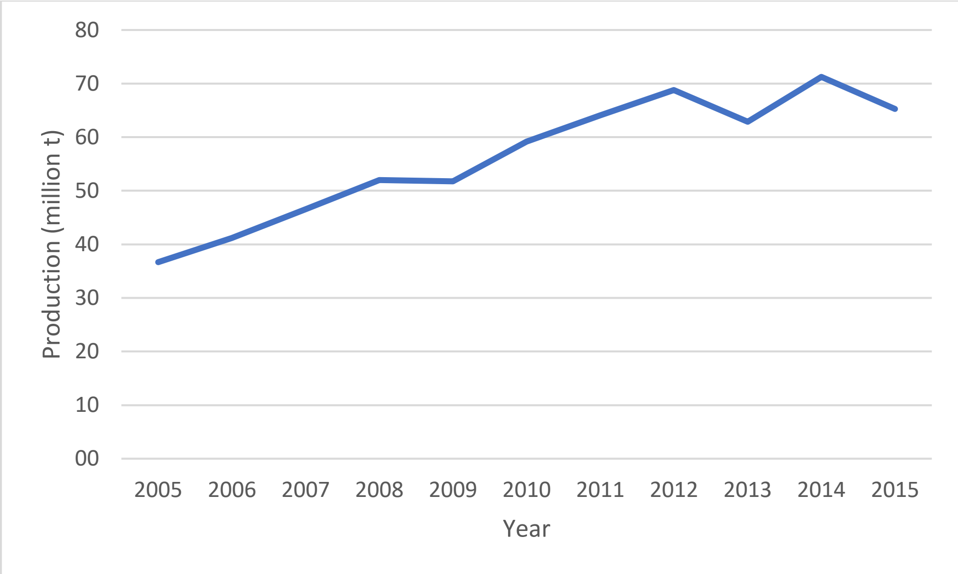
4.2.1. Emission sources

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 releases 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 CO_2). 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, sulphur hexafluoride (SF_6) and N_2O are used in a number of products used in industry (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 for 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 the generation of electricity consumed in the industrial sector are accounted for in the energy supply section.

4.21.1 Cement

The Brazilian cement industry is the sixth largest in the world with 100 factories and an annual cement production capacity of 100 million tons. Figure 9 shows the Brazilian annual cement production, in million tons, between 2005 and 2015. In 2005, the cement production was 37 million tons, growing to 59 million tons in 2010 and 65 million tons in 2015, an increase of 75% in 10 years (SNIC, 2017).



Source: based on SNIC (2017)

Figure 9. Annual cement production in Brazil between 2005 and 2015 (Million ton)

Table 6 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 segment, accounting for 71% of the total energy consumed in 2016 (EPE, 2017).

Table 6. Energy consumption in the cement industry between 2005 and 2016 (1,000 toe)

SOURCES	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
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: based on EPE (2017)

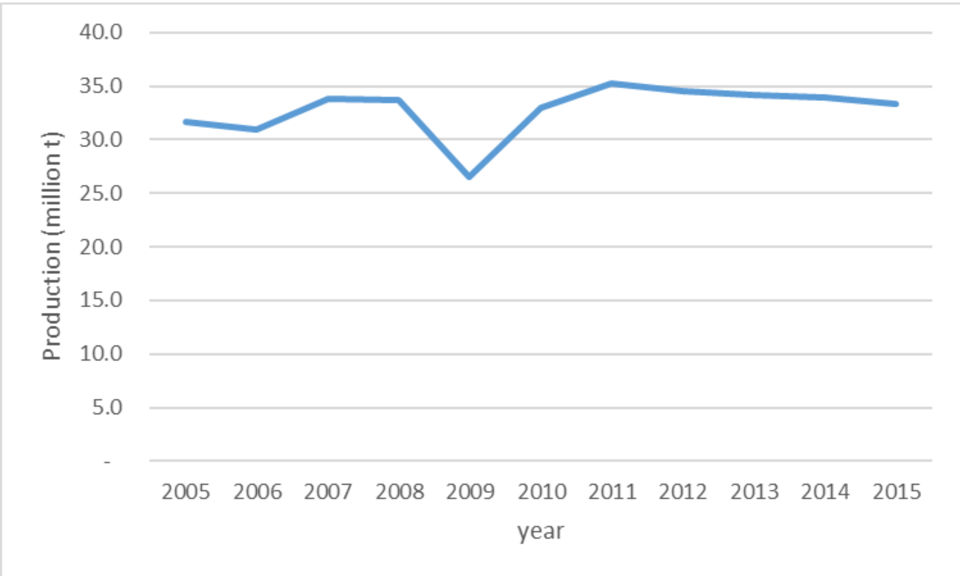
Cement production process consists of three stages. The first is the preparation of the raw material, usually limestone and clay, through grinding and sifting. The second, calcination, consists in taking the product of the preparation to the calcination kiln, where temperatures can reach 1,500ºC, obtaining 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 segment 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 ($CaCO_3$) decarbonation producing lime (CaO) and CO_2 (Henriques, 2010; MCTIC, 2010).

4.2.1.2 Iron and steel

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 million tons of steel per year, representing 2% of the world and 52% of the Latin American (MME, 2017).

Figure 10 shows the Brazilian iron and steel production between 2005 and 2015, that grew 5.7% (from 31.6 to 33.3 million tons) in the period with no significant variation in the shares of iron and steel (EPE, 2017).



Source: based on SNIC (2017)

Figure 10. Iron and steel production in Brazil between 2005 and 2015 (Million ton)

Table 7 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 7. Energy consumption in the iron and steel industry between 2005 and 2015 (1,000 toe)

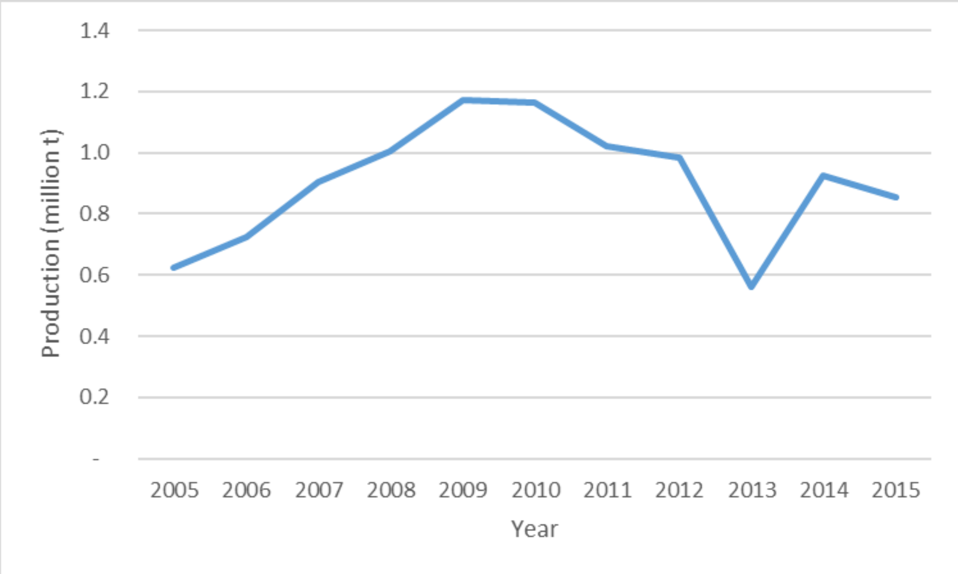
Sources	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	1,113	1,105	1,214	1,158	695	897	997	1,067	1,020	1,036	1,223
Mineral Coal	1,829	1,813	1,939	2,052	1,578	1,772	1,924	1,854	1,808	2,053	2,124
Diesel Oil	44	40	14	14	14	15	35	38	37	35	29
Fuel Oil	82	107	145	142	114	168	29	29	40	35	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
Others 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: based on 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).

4.2.1.2 Iron alloy

The production of iron alloys in Brazil has been decreasing over the recent years, as shown in Figure 11, from 0.6 million tons in 2005 to 1.2 million tons 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: based on MME (2009, 2010, 2017)

Figure 11. Annual iron alloy production in Brazil between 2005 and 2015 (Million ton).

The energy consumption between 2005 and 2015 is shown in Table 8. 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 segment are (i) electricity representing 43% of the total amount and (ii) charcoal and firewood with 38%.

Table 8. Energy consumption in the Iron alloy industry between 2005 and 2015 (1,000 toe)

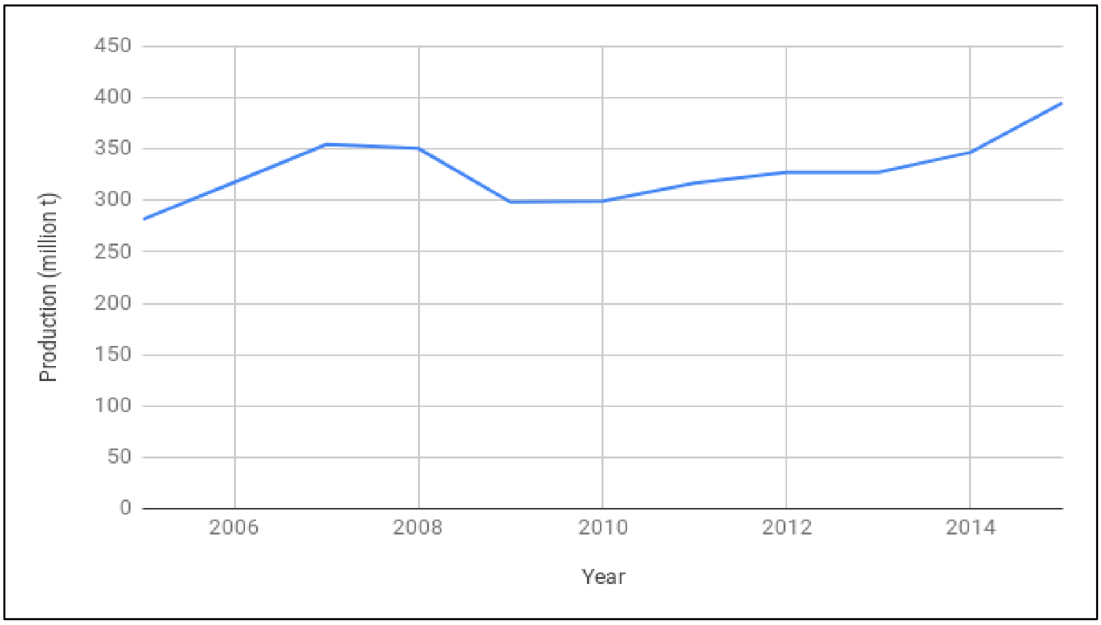
Sources	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	2	2	29	2	2	2	3	3	22	20	6
Coal of Mineral Coal	92	93	104	119	92	107	96	93	84	78	70
Electricity	665	662	746	751	580	728	678	666	626	582	524
Coal and Wood Coal	662	668	715	730	564	660	592	580	544	506	455
Other Not Specified	192	187	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: based on EPE (2017)

4.2.1.3 Mining and pelleting

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



Source: based on DNPM (2006; 2016)

Figure 12. Annual mining and pelleting production in Brazil between 2005 and 2015 (Million ton).

Table 9 presents the amount of energy consumed in the mining and pelleting segment 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 9. Energy consumption in the mining and pelleting production between 2005 and 2015 (1,000 toe).

SOURCES	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

SOURCES	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
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: based on EPE (2017)

4.2.1.4 Non-ferrous and other metals

Non-ferrous and other metals segment comprehends the production of aluminum, copper, zinc, silicon metal and other metals presented on Table 10. The total amount of non-ferrous and other metals produced per year had a reduction of 30%, from 2,449 million tons in 2005 to 1,694 million tons 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 10. Annual production in the non-ferrous and other metals between 2005 and 2015 (million ton).

Metal	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
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: based on MME (2010, 2017)

Table 11 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 segment 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 11. Energy consumption in the non-ferrous metals and other metals industry between 2005 and 2015 (1,000 toe).

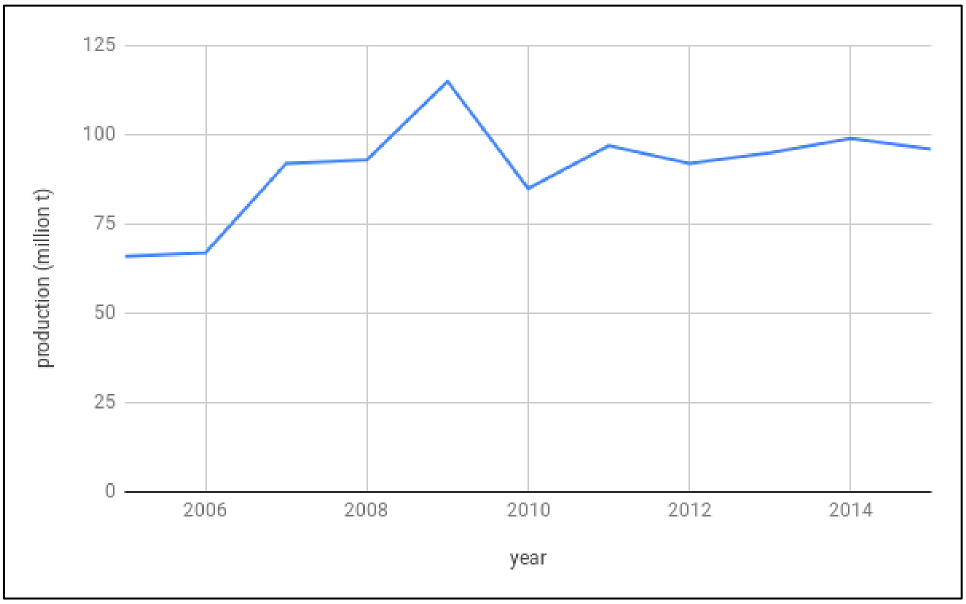
Source	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas	490	528	632	675	405	727	776	857	942	896	593
Fuel Oil	1,147	1,091	1,124	1,062	987	1,098	1,177	1,163	1,148	1,200	1,238
LNG	18	85	91	85	86	79	47	44	53	51	45
Coal and Coke	228	233	243	178	165	768	1,022	1,030	1,023	1,062	935
Electricity	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: based on EPE (2017)

4.2.1.5 Chemical industry

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

Figure 13 shows the total amount of chemical products made in Brazil between 2005 and 2015. The production went from 66 million tons, reaching 115 million tons in 2009 and decreasing to 96 million tons in 2015. In the period the total increase was about 45%.



Source: based on IBGE, (2005 - 2015)

Figure 13. Chemical industry production in Brazil between 2005 and 2015 (Million ton)

Table 12 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 4%.

Table 12. Energy consumption in the chemical industry between 2005 and 2015 (1,000 toe)

SOURES	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: based on EPE (2017)

4.2.1.6 Food and Beverage

Food and beverage is a major industry segment 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).

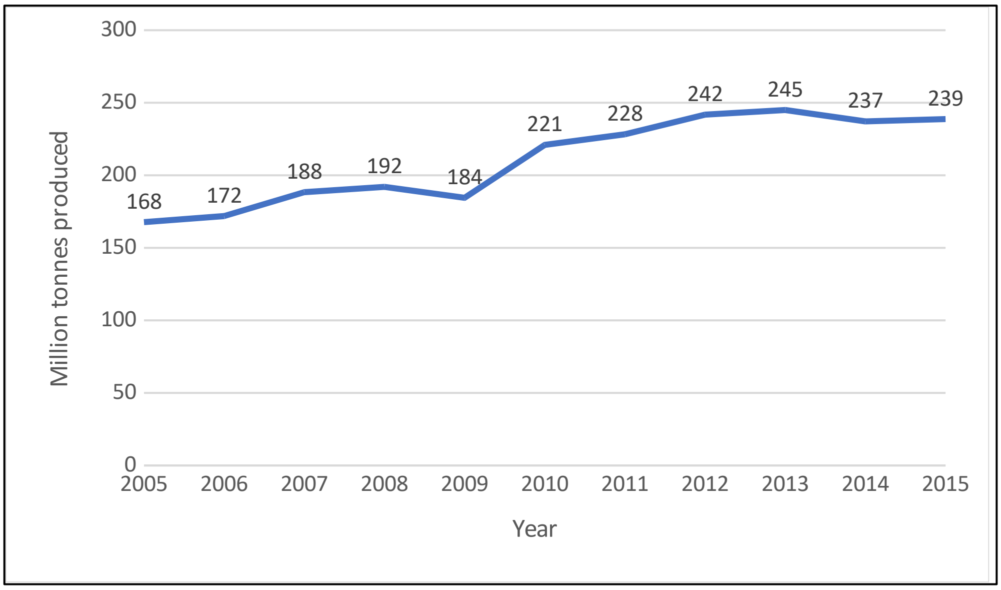
This segment is highly diversified, with 850 different food and beverage products (CNI 2010). Main products in 2010 are shown in Table 13.

Table 13. Food and beverage production by 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: based on IBGE (2014)

The total amount of food and beverage produced from 2005 to 2015 is presented in Figure 14. In the first year, 2005, the total amount was 168 million tons, growing 9.5% by 2010, and reaching 239 million tons in 2015, an increase of 42% in the total period.



Source: based on IBGE (2005-2015)

Figure 14. Annual production in Food and Beverage industry between 2005 and 2015 (Million ton)

Table 14 presents the energy consumption in this segment 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 14. Energy consumption in the food and beverage industry between 2005 and 2016 (1,000 toe)

SOURCES	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: based on EPE (2017)

Table 15 shows the main final energy use in food and beverage industry.

Table 15. Examples of final energy use in the food and beverage industry

Final energy use	Exemples
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: based on HENRIQUES (2010) *apud* COUTO (2017)

4.2.1.7 Textile

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

Figure 15 shows the value added of the textile industry between 2005 and 2015 in Brazil. In 2005 the value added by the textile industrial segment 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.

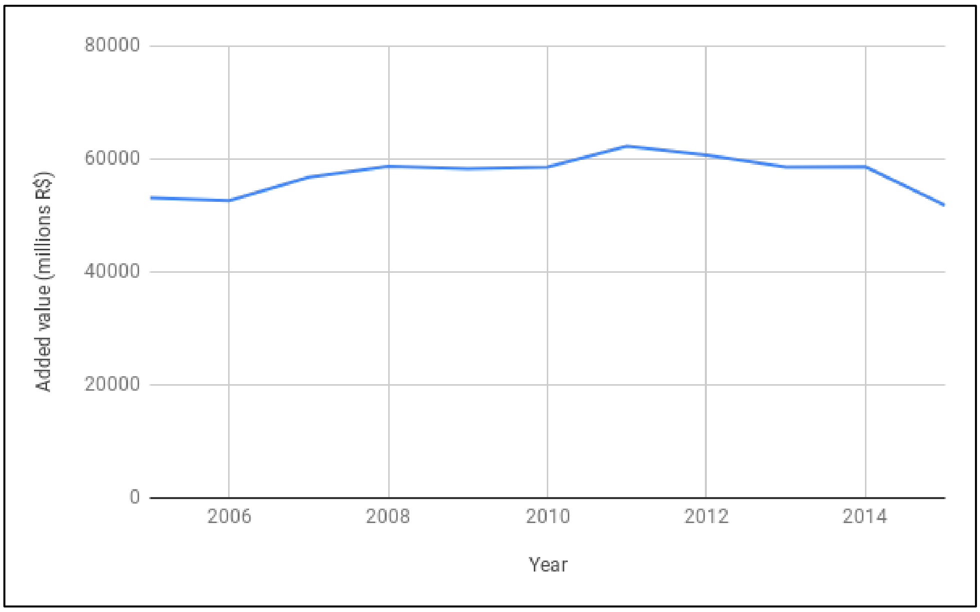


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Figure 15. Value added in Textile industry in Brazil between 2005 and 2015 (Million R$).

Table 16 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 16. Energy consumption in the textile industry between 2005 and 2015 (1,000 toe)

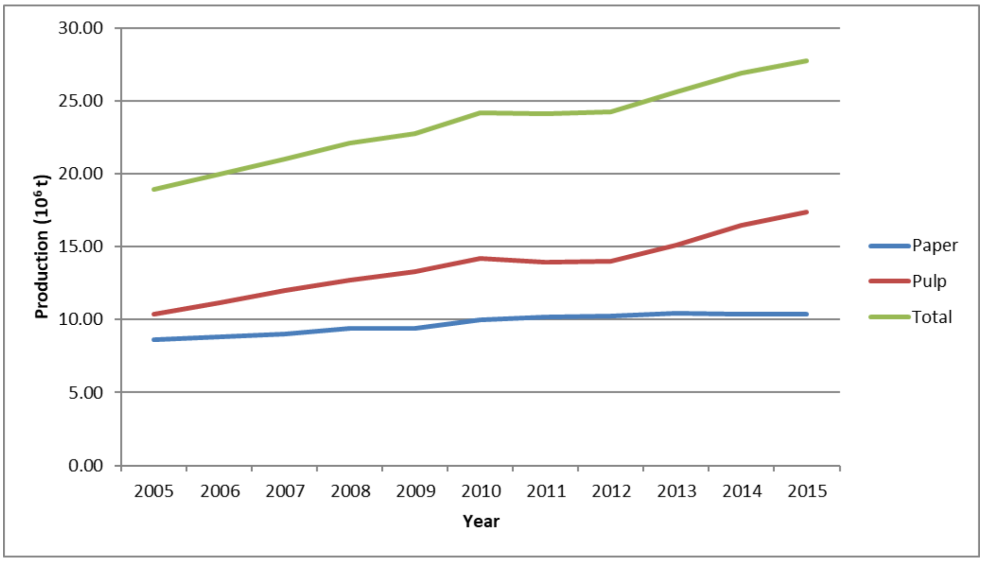
SOURCE	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
NATURAL GAS	327	334	372	322	300	329	327	317	312	248	215
FIREWOOD	93	94	96	95	88	92	76	73	71	69	62
DIESEL	2	2	3	3	3	3	6	8	6	5	2
FUEL OIL	112	105	108	106	106	64	55	45	46	34	19
LPG	9	9	11	10	10	10	29	28	31	40	37
ELECTRICITY	660	669	685	672	665	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: based on EPE (2017)

4.2.1.8 Pulp and Paper

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

Figure 16 shows the production of pulp and paper between 2005 and 2015. This industrial segment grew 46% between 2005 and 2015, from 19 million tons of pulp and paper to 28 million tons.



Source: based on IBA (2017)

Figure 16. Annual Pulp and Paper production between 2005 and 2015 (Million ton).

Table 17 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 worth noting the increase in the black liquor consumption, a source that reached a share of 50% of total energy demanded in 2015.

Table 17. Energy consumption in the pulp and paper industry between 2005 and 2015 (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: based on EPE (2017)

4.2.1.9 Ceramic

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 segment with a production of over 40 million units per year and 675 companies in the white ceramic segment with a revenue of 13 billion reais per year (INT, 2012).

Table 18 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 18. Energy consumption in the ceramic industry 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
Others 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: based on EPE (2017)

4.2.1.10 Other industries

Other Industries comprises all other segments that were not previously covered. Figure 17 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.

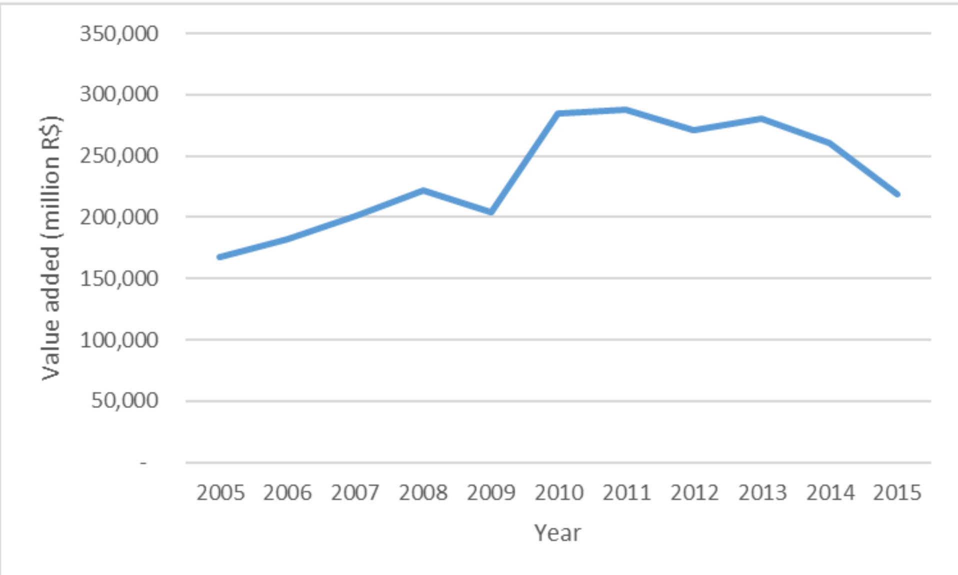


Figure 17. Value added in other industries between 2005 and 2015 (Million R$).

Table 19 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 segment with 50% of the total energy demand.

Table 19. Energy consumption in the other industries 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: based on EPE (2017)

4.2.2. 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 segment 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 a lower mitigation in the AFOLU sector.

The macroeconomic modelling supplied future activity level of each industrial segment, which is the same across all scenarios. It includes the increase in the demand for HFC and SF_6. Table 20 presents the annual growth rate for all industrial segments between 2015 and 2030.

Table 20. Activity level: industrial average annual growth rate between 2015 and 2030 (%).

Industrial segment	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%**

The mitigation measures that aim at reducing fuel consumption, in each industrial segment, are presented in Table 16. 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 2030.

Table 21. Energy intensity reduction by industrial segment between 2015 and 2030 (%)

Industrial segment	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%	10.0%	14.0%
Iron alloy	Heat recovery systems	3.0%	10.0%	14.0%
Non-ferrous metals	Optimization of combustion e Heat recovery systems	-	5.0%	9.0%
Pulp and paper	Optimization of combustion e 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%

Industrial segment	Mitigation measure	Energy intensity reduction (toe/t product) in 2015-2030		
		Scenario A	Scenario B	Scenario C
Textile	Optimization of combustion	0.5%	4.0%	5.0%
	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%

Scenario A, which follows the current trend, considers that the share of charcoal in the Iron and Steel segment 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 segment between 2015 and 2030 are presented in Table 22.

Table 22. Replacement of fossil fuels by natural gas and by renewable biomass in Scenarios B and C (%)

Industrial Segment	Substitution of other fossil fuels for natural gas	Substitution of fossil fuels for renewable biomass
Cement	1.5%	-
Iron and Steel	-	2.0%
Iron alloys	-	2.0%
Mining and pelleting	5.0%	-
Chemical	7.0%	-
Non-ferrous and other metals	7.0%	-
Pulp and paper	2.0%	0.5%
Textile	2.0%	-
Ceramic	2.0%	3.0%

For specific processes and product use, Table 23 presents the mitigation measures in Scenarios B and C. In the cement production, the use of additives could reduce GHG emissions due 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 23. Mitigation measures and potential in IPPU between 2015 and 2030 (%).

Segment	Mitigation Measure	Emission reduction between 2015 and 2030	
		Scenario B	Scenario C
Cement	Add additives (reduction of clinker/cement ratio)	11%	17%
HFCs	Replacement for low GWP refrigerant	-	55%
	Leakage control and end-of-life recollection	20%	40%
SF_6	Leakage control and end-of-life recollection	40%	50%
PFCs	Optimization and process control	10%	20%

4.2.3. Scenario A - Results

Table 24 shows the GHG emissions from energy consumption estimated up to 2030 in Scenario A. In 2005, the amount emitted from all the industrial segments was 61.5 $MtCO_2$-eq. In 2030, these emissions would grow up to 85.9 $MtCO_2$-eq, which represents 40% growth in the period. It is worth noting that the cement emissions would increase 107% in the period 2005-2030, rising from 9.2 to 19.0 $MtCO_2$-eq.

Table 24. Emissions from the energy consumption by industrial segment between 2005 and 2030 (Mt CO_2-eq)

Industrial segment	Emissions (Mt CO_2-eq)					
	2005	2010	2015	2020	2025	2030
Cement	9.2	14.8	16.1	15.6	17.2	19.0
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	9.8	11.4
Non-ferrous and other metals	4.9	5.5	5.5	6.4	7.5	8.8
Chemical	14.6	14.0	13.9	14.0	14.1	14.2
Food and beverage	5.0	5.5	5.6	5.4	5.6	5.8
Textile	1.2	1.0	0.7	0.7	0.7	0.7
Pulp and paper	4.2	4.2	4.1	4.3	4.8	5.3
Ceramic	4.0	5.2	5.0	4.9	5.2	5.5
Other industries	6.3	8.3	8.2	7.9	8.1	8.4
Total	**61.5**	**71.5**	**72.4**	**73.4**	**79.3**	**85.9**

Table 25 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 $MtCO_2$-eq in 2005 to 135.4 $MtCO_2$-eq 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 $MtCO_2$-eq), while the emissions in the iron and steel segment from 36.7 $MtCO_2$eq to 52.3 $MtCO_2$-eq. In addition, HFCs and SF_6 emissions would increase more than six times, from 3.1 $MtCO_2$-eq in 2005 to 20.0 $MtCO_2$-eq in 2030.

Table 25. Emissions from IPPU by industrial segment between 2005 and 2030 ($MtCO_2$-eq)

Segment	Emissions ($MtCO_2$-eq)					
	2005	2010	2015	2020	2025	2030
Mineral industry	21.8	30.1	31.6	29.2	33.4	37.7
Iron and steel	36.7	39.7	42.3	43.4	47.7	52.3
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	9.2
Aluminum	3.4	3.1	3.1	6.4	8.0	9.7
Chemical	9.3	3.3	3.2	3.6	3.7	3.9
Non-energy use products	0.7	0.6	0.6	0.6	0.6	0.6
HFCs and SF_6	3.1	7.6	10.3	13.5	16.8	20.0
Total	**79.0**	**91.2**	**97.7**	**104.8**	**119.7**	**135.4**

Figure 18 presents the results for the industry sector Scenario A, differentiating the total emissions in (i) emissions from energy consumption and (ii) emissions from industrial process and product use for the 2005-2030 period. The results indicate that, in this scenario, the GHG emissions would rise from 142 $MtCO_2$-eq in 2005 reaching 170 $MtCO_2$-eq q in 2015 and 221 $MtCO_2$-eq in 2030, which represents an increase of 20% and 56% respectively, in comparison to 2005.

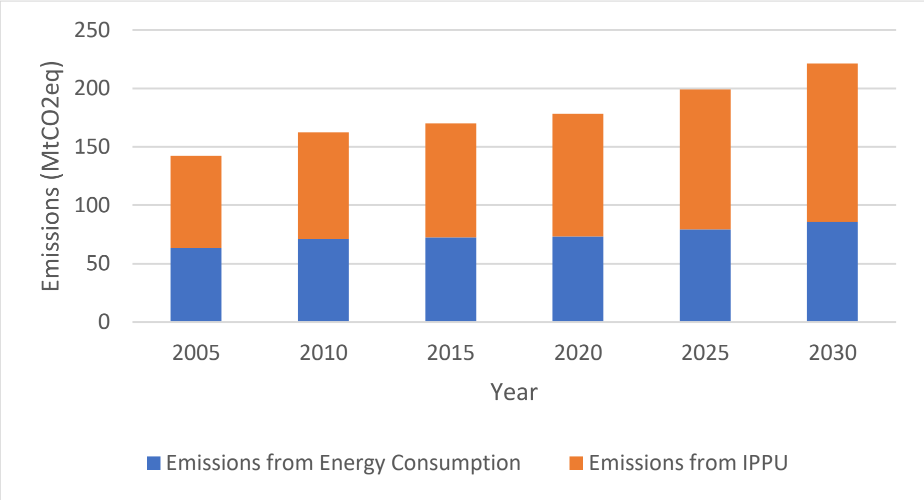


Figure 18. Emissions from energy consumption and from IPPU in the Industrial Sector between 2005 and 2030 ($MtCO_2$-eq).

4.3. TRANSPORT

This section presents the assumptions and results of the scenario A, as well as the assumptions of the scenarios B and C considering the transport sector.

4.3.1. 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 the road transport, the 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 19.

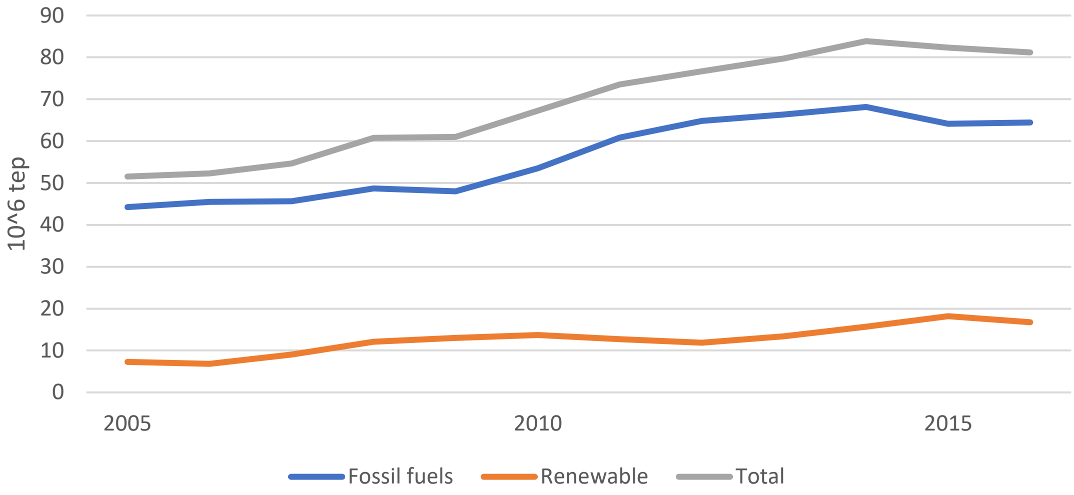


Figure 19. Energy consumption from the transport sector (Million toe).

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 43% in the meantime as shown in Figure 20.

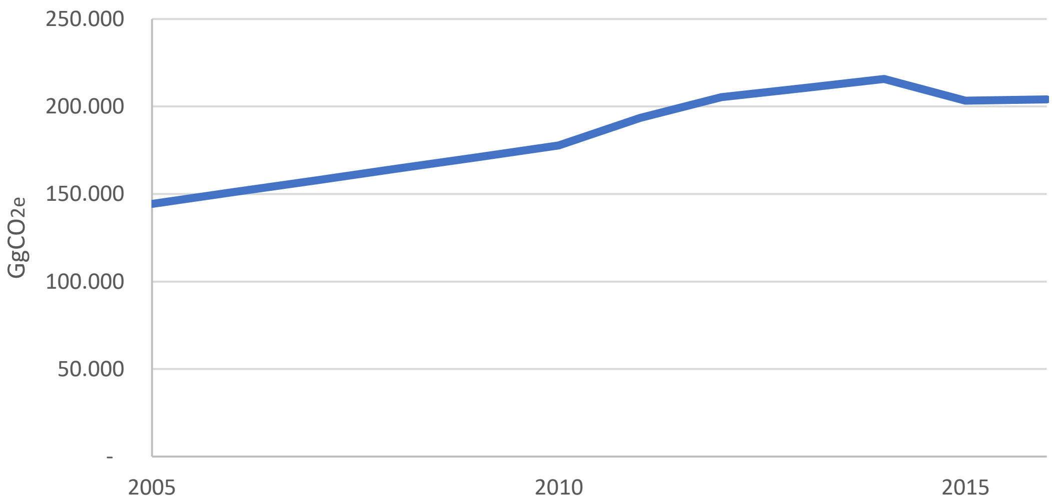


Figure 20. GHG emissions from the transport sector (Gg CO_2-eq).

As evidenced, all figures show 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 (2017) and to project future energy and GHG emissions by 2030. Next section describes the assumptions and results of the Scenario A.

4.3.2. 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 the Scenario A.

4.3.2.1 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 the 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 26). 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 26. Remaining works of the current transport infrastructure programs.

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 participation of the electromobility in the fleet is restricted, and thus being 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 acknowledge 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 the 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 8.

Table 27. Transport targets and assumptions considered 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 the 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 to 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)

4.3.2.2 Results

From the perspective of energy use, Figure 21 shows the projection. In the baseline, the participation of renewable sources of energy is 20,7% of the total energy consumption. At the end of the projection, the participation is 22,6% (1,8% higher than 2017).

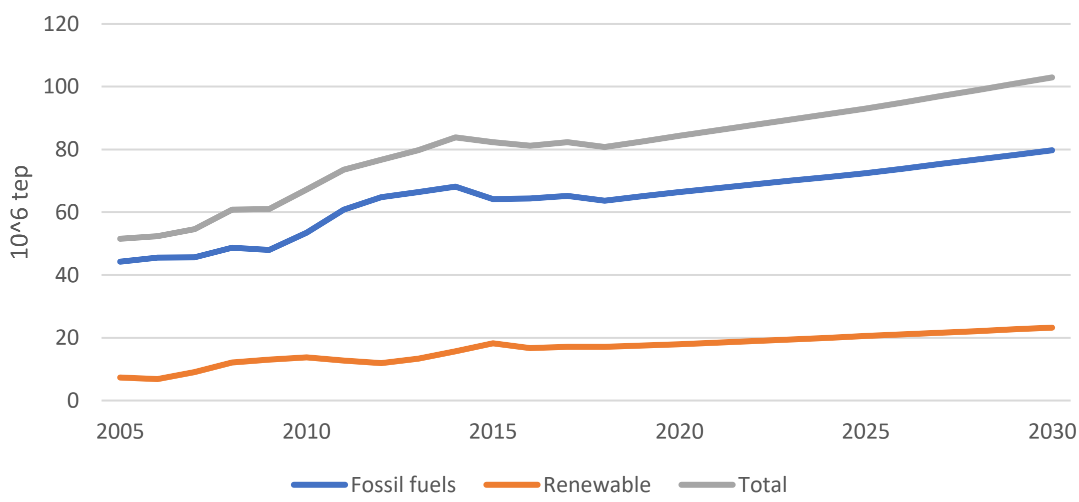


Figure 21. Energy consumption from the transport sector in Scenario A (Million toe).

To expose the disaggregated energy use, Figure 22 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 54% by 2030 compared to the baseline (2017). Nevertheless, it has minor effects on the energy consumption.

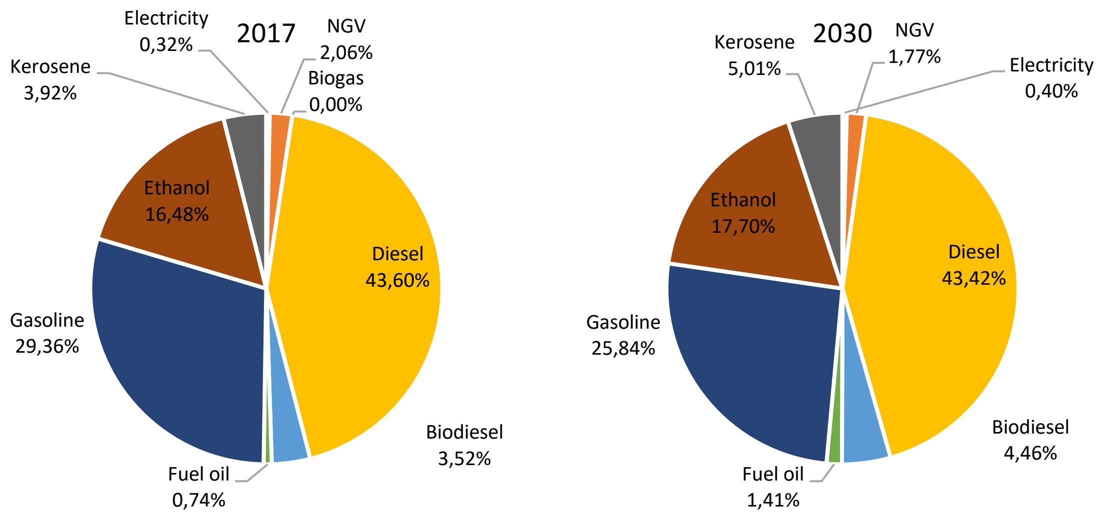


Figure 22. Energy consumption by source (% of toe).

Respecting the CO_2-eq emission, Figure 23 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 emission grows 19,1% up to 2030 (compared to the baseline), in other words, from 206,970 Gg CO_2-eq to 246,592 Gg CO_2-eq. At the end of the period, 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.

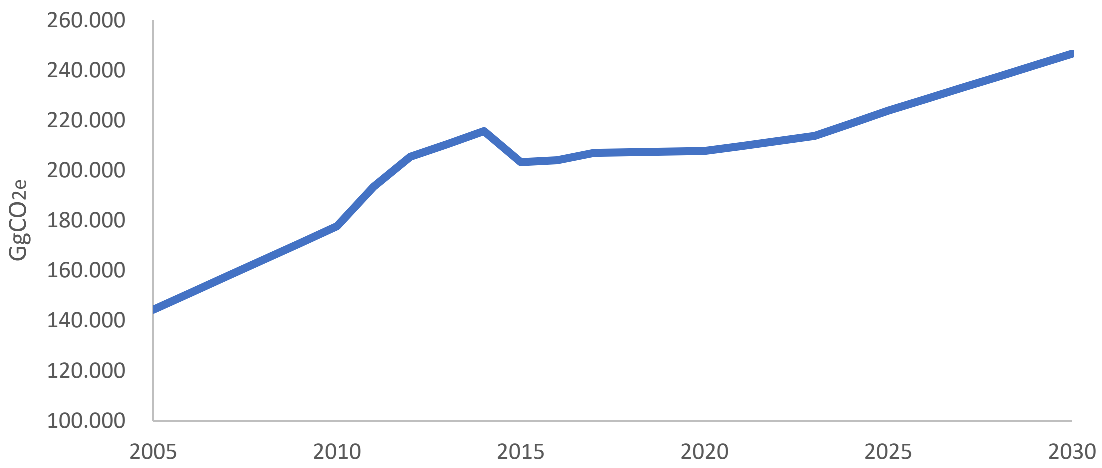


Figure 23. GHG emissions from the transport sector in Scenario A (Gg CO_2-eq).

4.3.3. Scenario B

Scenario B considers more incentives to public policies and private initiatives, simulating a more efficient use of transport modes and renewable fuels.

4.3.3.1 Assumptions

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

There is a greater capture of passenger for urban public transport 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 the 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 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 the 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 around 12% up to 2030. The "Efficiency of Urban Mobility – EEMU" technical booklet for passenger transportation is implemented by Brazilian municipalities on 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 the air transportation is not included. Table 9 indicates the targets and assumptions considered in Scenario B.

Table 28. Transport targets and assumptions considered in Scenario B.

FBMC (NDC/NAMA)	Assumptions
Optimizing and diversifying freight transport	Adjust concessions or renewal contracts for railways in the scope of the Investment Partnership Program (PPI), to ensure greater integration between the lines.

FBMC (NDC/NAMA)	Assumptions
	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 of all ongoing works (PAC and Avançar) with an average delay of three years.
	Qualification of buses and expansion of exclusive bus lanes.
	Measures to increase all aspects of active transport (40.10^9 p.km)
	Integrating policies in urban passenger transport
Energy efficiency gains for the fossil fuel fleet, considering passengers and freight transport	Rota 2030 Program (12% 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).
Expansion of alternative vehicles fleet and the supply of biofuels	RenovaBio, increasing the supply of ethanol to 42 billion liters; Market share of flexible-fuel vehicles at 40%.
	Participation of electric vehicles in the fleet of 2% for light vehicles; 4.5% motorcycles and 6% urban buses.
	Biodiesel Blend at 15% (B15)

4.3.4. 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.

4.3.4.1 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).

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 a 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 the international trend toward electrification (IEA, 2018), with incentives for resale and production, except for batteries, of light and heavy vehicles (buses). In addition, there is a greater participation of sustainable programs for the freight transport (e.g. PLVB) and passengers (e.g. EEMU). Nonetheless, there is 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 the air transportation from 2025 and biomethane in the 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 29 shows the targets and assumptions considered in Scenario C.

Table 29. Transport 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 p.km)
	Integrating policies in urban passenger transport
	Effective participation of the vehicle and ride sharing segment (Carsharing, Carpooling and Ridesharing)

FBMC (NDC/NAMA)	Assumptions
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).

4.4. 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 has 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 the recent years, harming hydro power 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 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 24 e 25 show the historical and projected production of natural gas and oil.

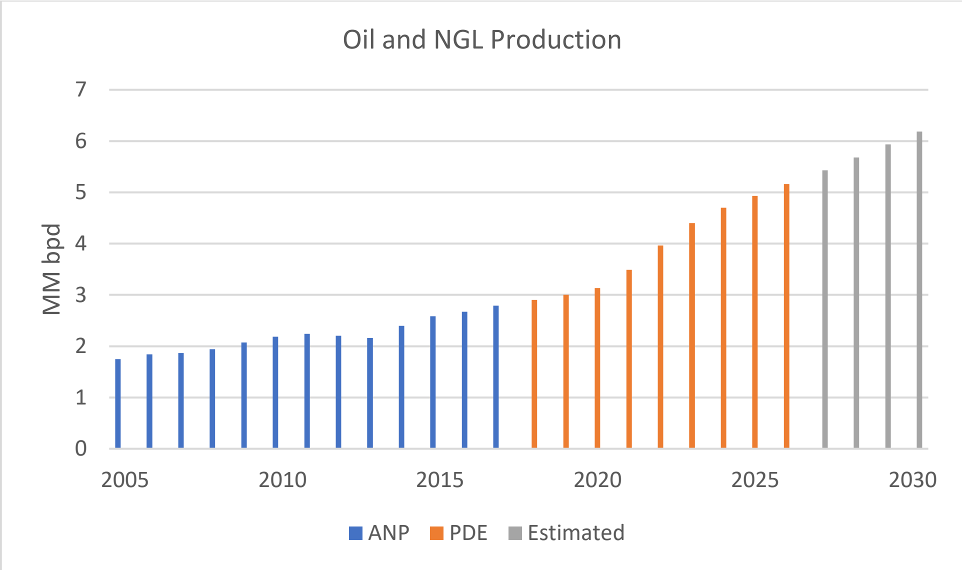


Figure 24. Oil and NGL production (Million bpd)

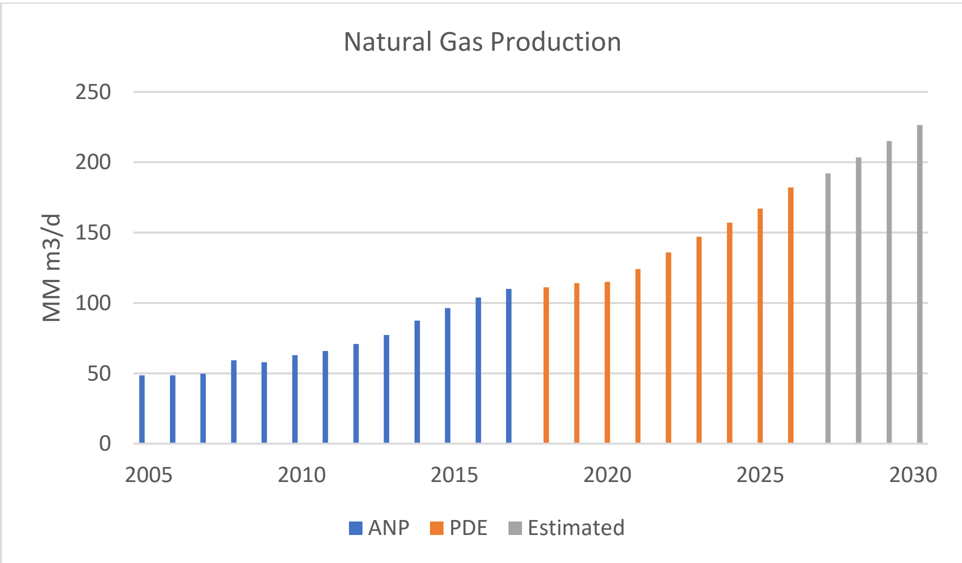


Figure 25. Natural gas production (Million m^3/day)

4.4.2.2 Results

The Scenario A total energy consumption, including the energy sector is presented in Table 30.

Table 30. Total energy consumption between 2005 and 2030 in Scenario A

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 31 shows the installed capacity, in GW, in the electricity sector.

Table 31. Electricity installed capacity between 2005 and 2030 in Scenario A

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
Others non-renewables	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 32 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 with 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 AC power (inverter nameplate capacity) and not DC power (solar panel STC capacity, in Wp).

Table 32. Electricity generation and capacity factor between 2005 and 2030 in Scenario A

	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%
Others 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 electricity sector increase until 2030, although it remains relatively low. The total emissions, in CO_2-eq, are shown in Table 33.

Table 33. Total emissions between 2005 and 2030 in Scenario A

$MtCO_{2e}$	2005	2010	2015	2020	2025	2030
Electricity generation	26.7	36.6	68.2	41.0	47.2	54.8
Energy sector consumption	21.7	23.9	30.1	27.8	30.4	33.5
Charcoal power plants	1.0	0.7	0.6	0.5	0.5	0.5
Total		**81.9**		**97.5**	**114.2**	**131.8**

Note: fugitive emissions not included in the total

The share of electricity consumption in total energy demand increases in this Scenario time horizon, as can be seen in Table 34. This is a trend that reduces total emissions in the country, as electricity probably replaces a fossil fuel, such as gasoline.

Table 34. 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 35 shows the Domestic Energy Supply for Scenario A and historical data.

Table 35. Domestic Energy Supply between 2005 and 2030 in Scenario A

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**

The Brazilian NDC presents some measures in the energy sector that should be achieved by 2030. Although those in Table 7 are not NDC targets (the only target is absolute countrywide emissions reduction), they can help predict if the decisions are going in the right way. Table 36 shows the results for those goals in Scenario A.

Table 36. NDC targets in the energy sector in Scenario A

Goal	2005	Scenario A 2030	NDC Target
% biofuels in energy mix	13.8%	18.7%	**18.0%**
% renewable in energy mix	44.1%	43.9%	**45.0%**
% renewable in energy mix, except hydro	29.2%	31.8%	**28.0%**
% electricity from renewables, except hydro	3.4%	23.9%	**23.0%**

One of the Brazilian NDC's goals is to achieve 45% of renewables in the energy mix by 2030. This goal is not reached in Scenario A, showing that more efforts are required in both energy supply and demand.

4.4.3. Scenario B

4.4.3.1 Assumptions

In Scenario B, 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 may vary between those Scenarios, as the energy demand is different.

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, as photovoltaics, wind power, sugarcane bagasse and firewood thermal power plant.

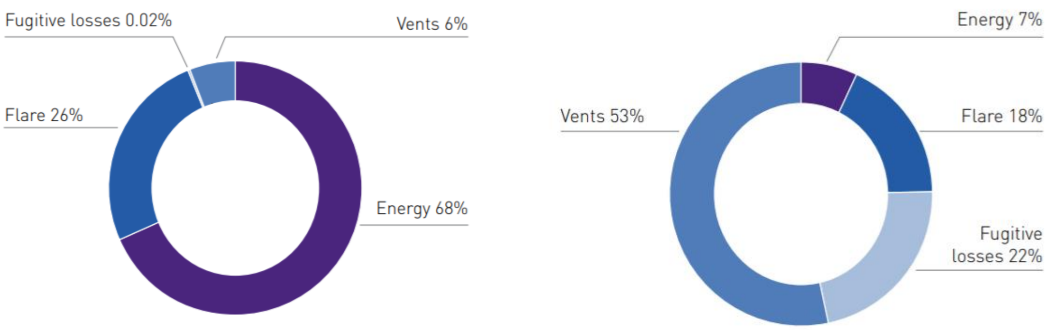
4.5. FUGITIVE EMISSIONS (FROM ENERGY SUPPLY)

4.5.1. Oil And Natural Gas Systems

Emissions occur in three different segments of the oil or gas system: Exploration and Production (E&P), Refining and Transportation. These segments are detailed below:

Exploration and Production includes projects onshore and offshore and emissions vary with oil and gas supply. Flaring is responsible for CO_2, CH_4 and N_2O emissions and leaks for CH_4 emissions. In Brazil, gas production corresponds to the production of associated natural gas (AG) and occurs alongside all crude oil production. Depending on the gas to oil ratio (GOR) low or high volumes of this natural gas will be produced. AG is comprised predominantly of methane.

Fugitive emissions from oil and natural gas systems reported include fugitive equipment leaks, evaporation losses, venting, flaring and accidental releases. In IOGP (2017), emissions in 2016 from exploration and production (E&P) activities presented most of the carbon dioxide (CO_2) emissions from energy consumption (68%) and flare (26%). The source of methane (CH_4) emissions are 53% from vents, 22% fugitive losses and 18% flare.



Source: IOGP (2017).

Figure 26. CO_2 (left) and CH_4 (right) emissions by source (%)

Refining segment includes oil refining and gas processing. In Refining crude oil is transformed in useful products such as gasoline, diesel and kerosene. Emissions are function of demand and some source are leaks, flaring, Hydrocracking and Fluid Catalytic Cracking Unit. Natural gas is processed in specific units (UPGN – Unidade de Processamento de Gás Natural), being complex and usually involves several processes, or stages, to remove oil, water, hydrogen gas liquids (HGL), and other impurities. HGL is separated and from the processing plant may be sent to petrochemical plants, oil refineries, and other HGL consumers (EIA, 2018).

Transportation includes storage, transportation and distribution for E&P and Refining products, this is why emissions vary with supply and demand. 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 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 of 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 37. Activity level from the oil and gas Industry between 2005 and 2017.

Activity	Unit	2005	2010	2015	2016	2017
Oil and LNG Production	MM bpd	1.75	2.19	2.59	2.67	2.79
Gas Production	MM m^3/d	48	63	96	104	110
Oil Refining	MM bpd	1.76	1.83	2.00	1.85	1.76

Source: ANP (2018).

Emissions were calculated according to the methodology presented in MCTI (2016) for CO_2, CH_4 and N_2O gases from 2005 to 2017 based on these activities. Emissions from the oil and gas industry vary with the activity level. In E&P, all emissions increased from 2005 to 2017, CO_2 values vary from 5933 to 7376 Gg CO_2, from 141 to 156 Gg CH_4 and from 0.20 to 0.23 Gg N_2O.

Refining had a maximum value in 2015 and emissions had the same evolution, with values from 6482 Gg CO_2 in 2005 to 7043 Gg CO_2 in 2015, 9 to 11 Gg CH_4.

Transportation varies from 82 Gg CO_2 in 2005 to 84 Gg CO_2 in 2015 and from 7 Gg CH_4 in 2005 to 10 Gg CH_4 in 2017.

Table 38. Fugitive emissions from the oil and gas industry (2005 – 2017).

Segment	2005	2010	2015	2016	2017
Gg CO_2					
E&P	5,933	6,196	6,832	7,063	7,376
Refining	6,482	7,107	8,023	7,427	7,043
Transportation	82	66	84	82	81
Gg CH_4					
E&P	141	124	144	149	156
Refining	9	10	11	10	9
Transportation	7	8	9	9	10
Gg N_2O					
E&P	0.20	0.20	0.22	0.22	0.23
Refining	0.01	0.01	0.01	0.01	0.01
Transportation	0.003	0.002	0.003	0.003	0.003

According to these results, E&P represents approximately 60% of the GHG emissions in CO_2-eq and Refining, 40%. In 2005 fugitive emissions from oil and natural gas systems were 17.3 Mt CO_2-eq and peaked at 19.9 Mt CO_2-eq in 2015.

Table 39. Fugitive emissions from the oil and gas industry between 2005 and 2017) (MtCO2e)

Segment	2005	2010	2015	2016	2017
Mt CO_2-eq					
E&P	10.2	10.0	11.2	11.6	12.1
Refining	6.8	7.4	8.3	7.7	7.3
Transportation	0.3	0.3	0.4	0.4	0.4
Total Mt CO_2-eq					
Oil and Natural Gas Systems	**17.3**	**17.7**	**19.9**	**19.7**	**19.8**

4.5.1.2. Scenario A

4.5.1.2.1 Assumptions

Scenario A estimates the oil and gas fugitive emissions from 2018 to 2030, taking into account ongoing mitigation efforts. An activity level was estimated for the oil and gas production and oil refining to calculate these emissions. The Oil and Gas activity from 2018 to 2026 is based on the Decennial Energy Plan elaborated by the Energy Research Office (EPE – Empresa de Pesquisa Energética) and from 2027 to 2030 the activity level is the trend.

Table 40. Activity level of the oil and gas industry between 2005 and 2030 in Scenario A.

Activity	Unit	2005	2010	2015	2020	2025	2030
Oil and LNG Production	MM bpd	1.75	2.19	2.59	3.14	4.93	6.19
Gas Production	MM m^3/d	48	63	96	115	167	227
Oil Refining	MM bpd	1.76	1.83	2.00	2.32	2.41	2.68

The manly trends analyzed were the activity growing level and the reduction in emissions from flaring. World Bank (2016) divide flaring in three categories: routine flaring, safety flaring, and non-routine flaring. Routine flaring oil production operations in the absence of sufficient facilities or amenable geology to re-inject the produced gas, utilize it on-site, or dispatch it to a market. Safety flaring is associated to ensure safe operation of the facility, for example to remove gas stemming from an accident or incident that could jeopardize the facility.

In 2000, ANP, through resolution number 249, established that all the new oil and gas fields in the production stage should obtain an authorization to flaring or venting more than 3% of the associated natural gas. This study analyzed the evolution of the Brazilian production (Figure 27) and the flaring percentage from 2005 to 2017 with ANP data (Figure 28). The starting year is 2005 due to the average delay of 5 years between the exploration and the production stages. This data shows the effort the industry has been making to diminish flaring. In 2005 flaring reached 13.98% of the associated gas production, in 2010 it went down to 10,54% but 75% of the production was still associated to projects before 2005 and in 2017 although 48% of the activity was also associated to projects before 2005, flaring was reduced to 3,43%.

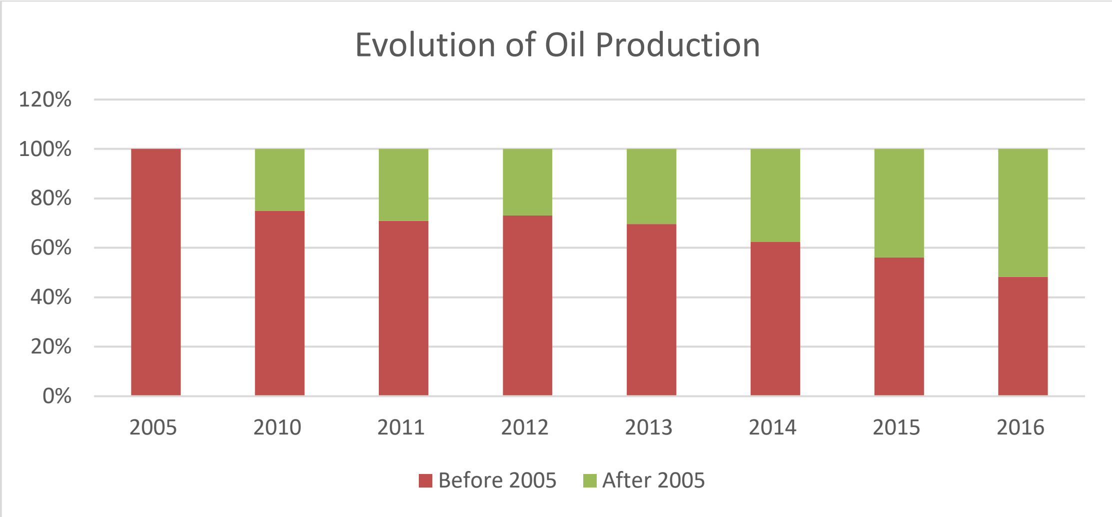


Figure 27. Brazilian oil production under the ANP resolution number 249 of 2000 between 2005 and 2016 (%)

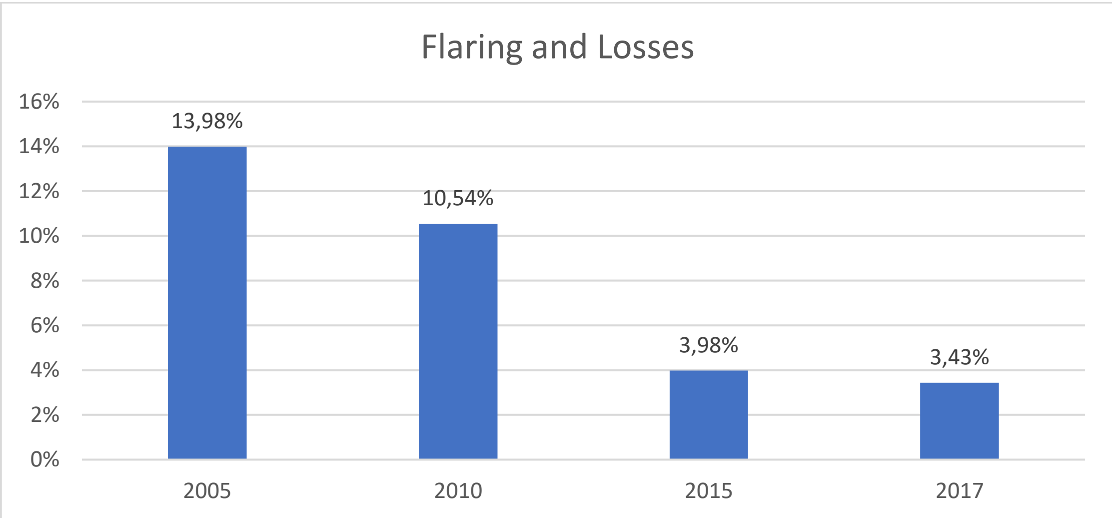


Figure 28. Gas flaring and losses of associated gas production from 2005 to 2017 (%)

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 were estimated considering the activity level and the emission factor but discounting the envisaged improvements in flaring. In Refining and Transportation, fugitive emissions were calculated considering the activity level and the emission factor only since there isn't any regulation on that. Data on flaring in Refining are not available and therefore no estimate was made regarding this stage.

4.5.1.2.2 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 Refining.

Table 41. 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
Gg CO_2						
E&P	5,933	6,196	6,832	8,282	13,030	16,336
Refining	6,482	7,107	8,023	9,287	9,656	10,746
Transportation	82	66	84	97	124	147
Gg CH_4						
E&P	141	124	144	175	276	346
Refining	9	10	11	12	13	14
Transportation	7	8	9	11	17	21
Gg N_2O						
E&P	0.20	0.20	0.22	0.26	0.41	0.52
Refining	0.01	0.01	0.01	0.02	0.02	0.02
Transportation	0.003	0.002	0.003	0.004	0.006	0.007
Mt CO_2-eq						
Total E&P	10.2	10.0	11.2	13.3	20.7	25.9
Total Refining	6.8	7.4	8.3	9.7	10.0	11.2
Total Transportation	0.3	0.3	0.4	0.4	0.6	0.8
Total Mt CO_2-eq						
Total Oil and Gas Industry	**17.26**	**17.67**	**19.92**	**23.69**	**32.08**	**38.79**

4.5.1.3 Scenario B

4.5.1.3.1 Assumptions

No efforts are made in Scenario B to mitigate fugitive emissions. Changes in the demand values for fuels would impact Refining that would, in turn, would have its emissions slightly reduced. No changes are associated to E&P or the Transport segment.

4.5.1.4 Scenario C

4.5.1.4.1 Assumptions

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

Mitigation effort in E&P segment is based on flaring reducing, based on flaring levels in the United Kingdom. Stewart (2014) studied flaring and venting from over 200 UK offshore oil fields and found that 3% of produced AG was flared or vented at UK offshore fields. This value is 2% when only fields developed after 1998 are included, but the most common flaring range of the 99 fields developed after 1998 is 0-1%.

Based on this study results, linear trend in natural gas flaring is adopted to reach 2.0% limit in 2030. Mitigation efforts in Scenario C to E&P segment are limiting flaring and venting to 3.2% in 2020, 2.6% in 2025 and 2.0 in 2030.

In Refining, Petrobras is looking for leakage monitoring and reduction, and also for improvement in managing flares in refineries to reduce gas losse. This mitigation action will be considered in this scenario

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

4.5.1.1 Emission Sources

Mining and post-mining activities are sources of methane (CH_4) and carbon dioxide (CO_2) emissions. Coal normally continues to emit gas 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 national emissions inventory report (MCTIC, 2016), that accounts for emissions from mining of Run Of Mine (ROM) coal, processing and waste pile.

Brazilian coal mining occurs 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 Parana the mines 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 from 2005 to 2015 increased in Rio Grande do Sul, from 4.25 to 6.26 million tons and decreased in Santa Catarina, from 7.81 to 6.51 million tons. Currently, national coal production provides about 20% of domestic demand and is mainly used in power plants (EPE, 2018).

Table 42. Coal Run-Of-Mine (ROM) production in Brazil between 2005 and 2016 (tons).

State	2005	2010	2015	2016
Rio Grande do Sul	4,250,367	5,010,779	6,259,740	4,840,599
Santa Catarina	7,808,680	6,278,327	6,507,617	6,207,149
Paraná	339,130	293,329	340,000	209,696
Total	**12,398,177**	**11,582,435**	**13,107,357**	**11,257,444**

Source: ABCM (2018).

Emissions from 2005 to 2016 shows a peak in 2015, as in Table 24.

Table 43. Fugitive emissions from mining, processing, storage and transportation of coal between 2005 and 2016 ($MtCO_2$-eq)

Activity	2005	2010	2015	2016
Coal mining, processing, storage and transportation	**Mt CO_2**			
	1.38	1.85	1.82	1.82
	Mt CH_4			
	0.05	0.04	0.05	0.03
	Mt CO_2-eq			
	2.85	**3.02**	**3.37**	**2.76**

4.5.1.2. Scenario A

4.5.1.2.1 Assumptions

Coal production from 2005 to 2015 shows a recent trend of 50% for surface mining and another 50% for underground mining, as in Figure 29. Considering these data, Scenario A assumes that up to 2030, this share would remain constant.

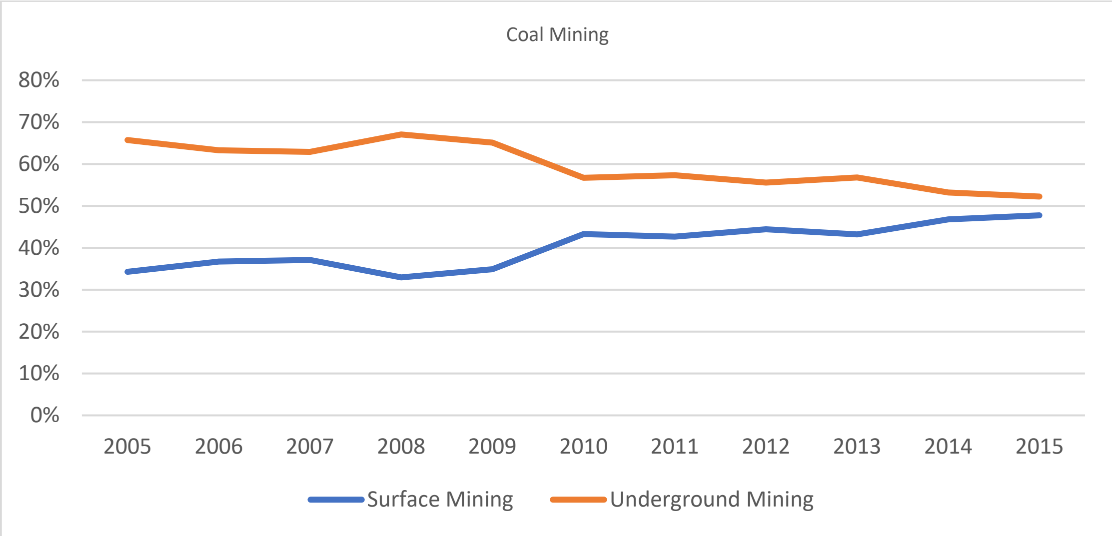


Figure 29. Trends in coal mining types between 2005 and 2015 (%)

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 tep. The factor used to convert tep into tons 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 ROM coal loss.

Table 44. 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

4.5.1.2.2 Results

Without any mitigation action, emissions in 2030 would be 2622 Gg CO_2 and 86 Gg CH_4, as in table 8. In total, 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 45.

Table 45. Fugitive emissions from coal between 2005 and 2030 in Scenario A ($MtCO_2$-eq)

Activity	2005	2010	2015	2020	2025	2030
mining, processing, storage and transportation of coal	**Gg CO_2**					
	1,381	1,846	1,822	2,434	2,404	2,622
	Gg CH_4					
	49	39	52	80	79	86
	Mt CO_2-eq					
	2.85	**3.02**	**3.37**	**4.83**	**4.77**	**5.20**

4.5.1.3 Scenario B

4.5.1.3.1 Assumptions

No mitigation actions envisaged. Emissions vary according to the demand

4.5.1.4 Scenario C

4.5.1.4.1 Assumptions

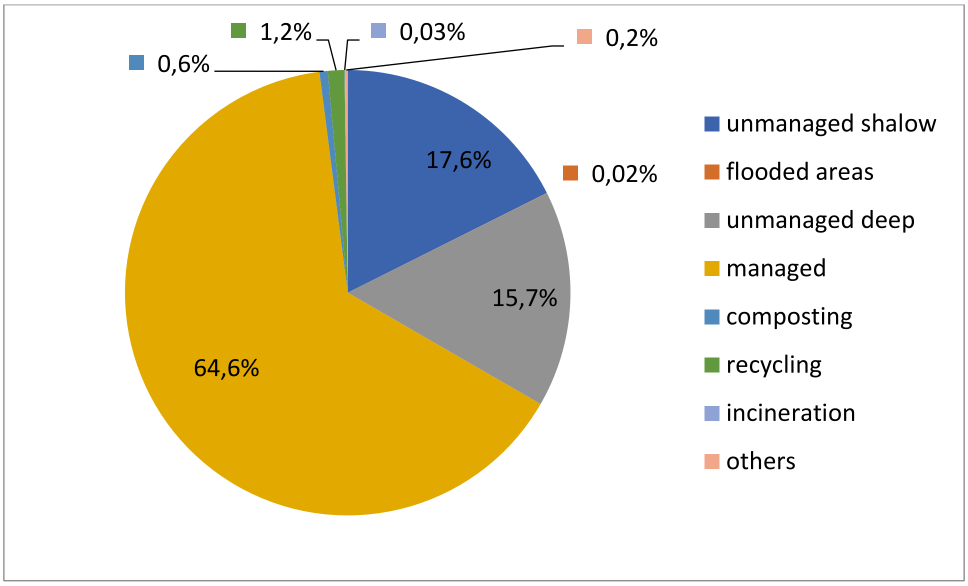
No mitigation actions envisaged. Emissions vary according to the demand

4.6. WASTE

The Waste Sector is divided into two main subsectors: solid wastes and liquid effluents. In the solid waste subsector, urban wastes (MSW), industrial (ISW) and health services (HSW), all class II-A (non-hazardous and non-inert) were investigated. Hazardous wastes are not counted, as they are stored according to the legislation and specific standards, whose treatments are not GHG emitters, except when they are treated by incineration. In the wastewater subsector, domestic and commercial sewage as well as organic industrial effluents were investigated. Options for energy use as a way to reduce GHG emissions were also considered.

The Waste Sector can also be divided into three substrates, by size of cities. 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, collection efficiency is not as 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.

According to the latest National Survey of Basic Sanitation (IBGE, 2010), more than half of the 240,000 tons of urban waste produced daily was released in open dumps, water bodies or environmental protection áreas, in 2008. Figure 30 shows the main treatments and final destinations of waste per collected mass unit, based on the results of this research.



Source: IBGE, 2010

Figure 30. Final Destination of MSW, in 2008 (%)

According to the same survey (IBGE, 2010), the final disposal of MSW per destination unit in the 5,565 Brazilian municipalities is 51% of unmanaged open dumps, 22% of controlled landfills and only 27 % of landfills. Table 46 shows the evolution of waste final disposal, referring to the last three sanitation surveys conducted by IBGE in 1989, 2000 and 2008.

Table 46. Share of municipalities by type of solid waste destination between 1989 and 2008 (%)

Waste final destination unit [3]	Year		
	1989	2000	2008
Unmanaged Shallow	88.2	72.3	50.8
Unmanaged Deep	9.6	22.3	22.5
Managed	1.1	17.3	27.7

Source: National Survey of Basic Sanitation (IBGE, 2010).

[3]There is no uniformity in the evaluation and classification of waste disposal landfills in Brazil, due to the lack of national standardization and the use of different classifications from universities, environmental agencies or other institutions (CETESB, 2016; FARIA, 2002; LOUREIRO, 2005; MONTEIRO, 2006). By the empirical character, two assessors with similar technical formation can reach different classifications for the same landfill. In addition, much research is done with the information provided by the municipal administrations that tend to overestimate their waste management.

Significant progress has been made in waste collection, especially in médium- and large-sized cities and in metropolitan areas, since most of them already send waste to licensed landfills. However, when all municipalities are considered, more than half still deposit their waste in unmanaged open dumps, maintaining large environmental and public health liabilities in the country.

In 2010, the average waste generation, according to the Brazilian Solid Waste Survey 2010 (ABRELPE, 2011) was of 1,213 kg/inhab.day, with 89% collection efficiency, or 1.079 kg/inhab.day collected. In 2016, the average was 1.040 kg/inhab.day, with 91% collection efficiency, therefore a collection rate of 0.948 kg/inhab.day (ABRELPE, 2017). However, there is a variation of this value considering the regions, the federation states and municipalities, mainly due to the income level of the population. In the State of Rio de Janeiro, for example, this average is 1.295 kg/inhab.day and in the city of Rio de Janeiro it increases to 1.861 kg/inhab.day.

Incineration is less commonly used for treatment of both health (HSW) and industrial wastes (ISW). In the present assumptions, health waste generation grows according to population growth and industrial waste to the energy demand of the food and beverage industry. The parameters considered in the 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. SolidWaste

4.6.1.1 Emission sources

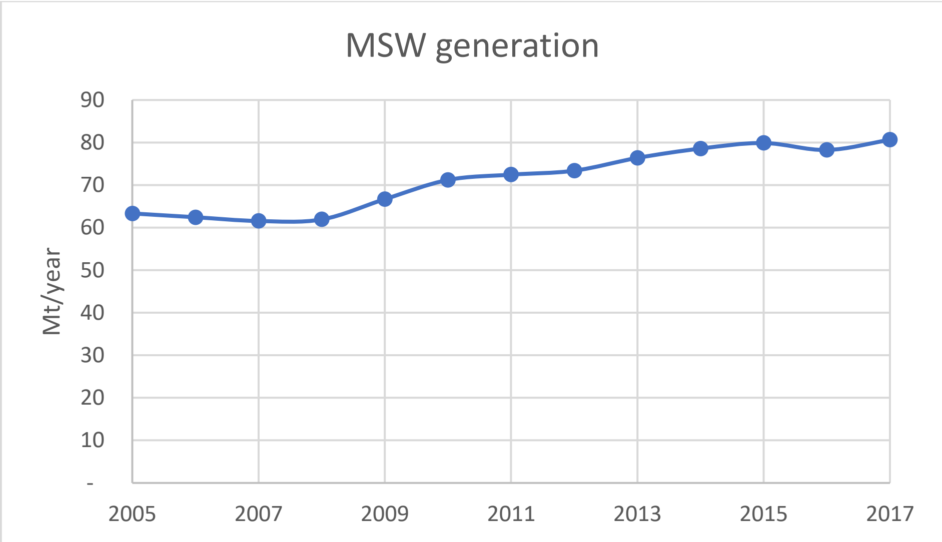
Emission source description

Landfilling, whether unmanaged, semi-managed, managed or even uncategorized generates greenhouse gases, mainly methane (CH_4), through the anaerobic decomposition of organic waste. Such a condition causes a managed landfill to generate more CH_4 than an open unmanaged one.

The thermal and biological treatments are sources of CO_2, N_2O and CH_4 emission, this one for non-biogenic origin. Regarding recycling, the share that contributes to avoid emissions is very small, because it is due only to the paper, cardboard and wood.

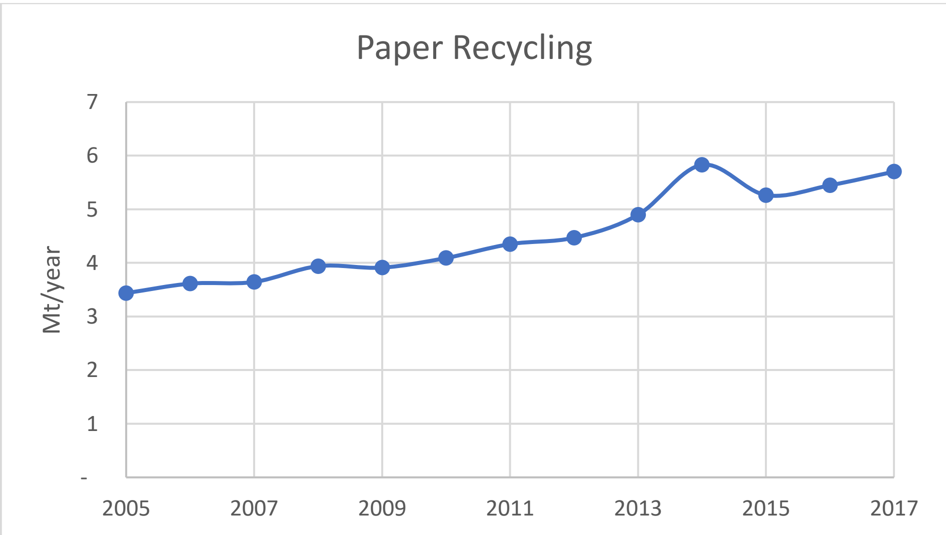
Analysis of historical evolution and recent trends: determinants of emissions from 2005 to date

According to ABRELPE (2017), approximately 80 million tonnes of Urban Solid Waste (MSW) are generated in Brazil, annualy. In order to estimate future production of urban waste, urban population estimates were used up to 2030, as presented in the macroeconomic chapter, and the trend of per capita waste production growth that relates waste production to per capita GDP growth. Figures 31, 32, and 33 presents waste generation, recycling and composting historical series from 2005 to 2017.



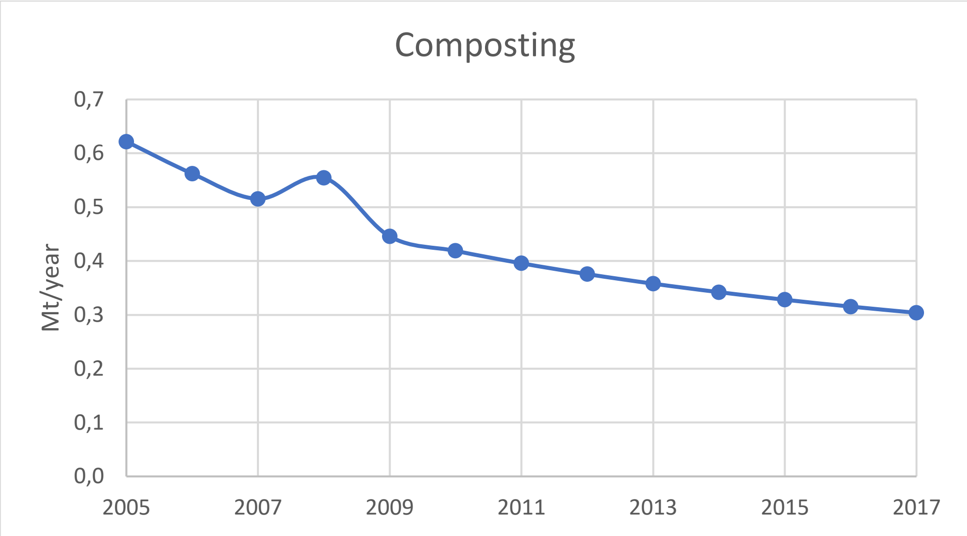
Source: (ABRELPE, 2018)

Figure 31. MSW generation historical series in Brazil from 2005 to 2017



Source: BRACELPA, 2017

Figure 32. Paper recycling historical series in Brazil from 2005 to 2017



Source: ABRELPE, 2018

Figure 33. MSW composting historical series in Brazil from 2005 to 2017

Unlike Brazil, landfills in developed countries are not the predominant practice, with incineration, thermal plants, recycling and composting common options. However, in Brazil, the increase in per capita emissions is mainly due to the expansion of basic sanitation services in cities (even with the reduction of population growth rates in the last decades), assuming that this increase is a consequence of a greater accumulation of waste in landfills and increased levels in wastewater treatment, which produce more methane.

Emissions from industrial sewage treatment reflect the evolution of the most productive activities involving organic matter what generates methane. In 2010, the beer sector accounted for 62% of the emissions, followed by the raw milk industry with 14% (MCTIC , 2015). Although "vinhoto" is the byproduct of the sugar and etanol industry with the highest organic matter in the industrial sector, it is applied directly to the soil and does not generate methane emissions. Table 47 shows the evolution of GHG emissions estimates for waste treatment in Brazil.

Table 47. Evolution of GHG emissions from waste treatment in Brazil between 1990 and 2010 (10^3 ton)

GHG (10^3ton)	1990	2000	2005	2010	Variation (%) 1990/2010
CH_4	1,173.6	1,754.1	2,117.3	2,651.9	126.0
CO_2	19.0	96.0	130.0	178.0	836.8
N_2O	4.3	5.7	6.6	7.2	67.4
CO_2-eq	**34,019.3**	**50,721.3**	**61,163.4**	**76,339.2**	**124.4**

Source: III Brazilian Inventory of GHG Emissions (MCTIC, 2015).

Based on the III Brazilian Inventory of Anthropogenic Emissions and Removals of Greenhouse Gases Not Controlled by the Montreal Protocol (MCICT, 2015), in 2005 and 2010, the waste sector was the second largest source of total emissions of CH_4 in Brazil, corresponding to 11.4% and 15.0% of totals, respectively.

According to this document, in 2010 the solid waste treatment subsector accounted for 1,516 thousand tons of CH_4, or 42.5 million tonnes of CO_2-eq, representing 7% of the country's total methane emissions. From 1990 to 2010, emissions per capita of CH4 from the waste sector increased by 150%, from 5.5 to 13.9 kgCH4/inhab.year, which corresponds to 0.39 tCO_2-eq/inhab.year.

Solid waste incineration and effluent treatment generated CO_2 and N_2O emissions due to non-renewable carbon-containing waste, estimated at 178.0 and 23.8 tons, respectively, in 2010 (MCICT, 2015).

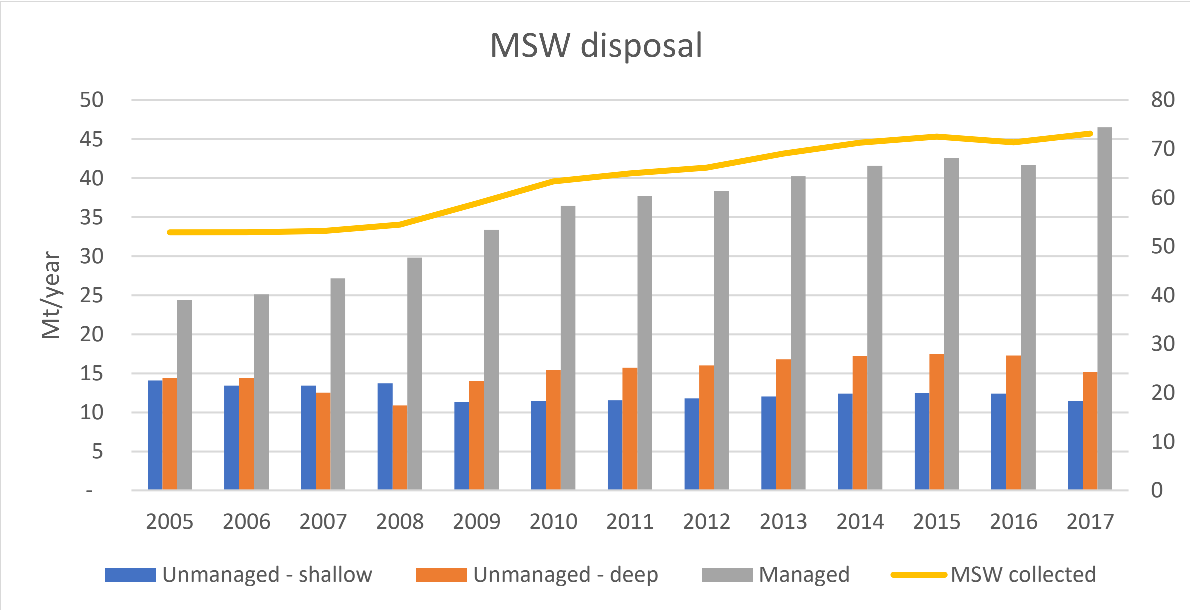
Table 48 shows the recent historical evolution of solid waste activity level subsector from 2005 to 2017.

Table 48. Solid waste activity level subsector, by destination between 2005 and 2017 (Mt/year and %)

Solid Waste			2005	2010	2015	2016	2017
Waste generation		Mt/year	63.3	71.2	79.9	78.3	80.6
Uncategorized		Mt/year	6.4	3.3	1.8	1.2	1.5
		(%)	10%	5%	2%	1%	2%
Recycling		Mt/year	3.4	4.1	5.3	5.4	5.7
		(%)	5.4%	5.7%	6.6%	7.0%	7.1%
Composting		Mt/year	0.6	0.4	0.3	0.3	0.3
		(%)	1.0%	0.6%	0.4%	0.4%	0.4%
Colected		Mt/year	52.9	63.4	72.5	71.3	73.1
		(%)	83.5%	89.0%	90.8%	91.1%	90.7%
Landfills	Unmanaged Shallow	Mt/year	14.1	11.5	12.5	12.4	11.5
		(%)	26.7%	18.1%	17.2%	17.4%	15.7%
	Unmanaged Deep	Mt/year	14.4	15.4	17.5	17.3	15.2
		(%)	27.2%	24.3%	24.1%	24.2%	20.7%
	Managed	Mt/year	24.4	36.5	42.6	41.7	46.5
		(%)	46.1%	57.6%	58.7%	61.3%	63.6%

Source: IBGE (2011), MCTIC (2015), ABRELPE (2017), ANA (2017), SNIS (2018).

This scenario shows that in 2017 only 63% of the garbage collected in the country was already disposed of in landfills, a scenario still below that established in the National Solid Waste Policy, which provided for the closure of unmanaged landfills in August 2014. Figure 34 shows the final disposal landfills increase tendency, but does not show a reduction tendency for dumps and unmanaged ones.



Source: ABRELPE, 2018

Figure 34. Distribution of MSW final disposal in Brazil between 2005 and 2017

4.6.1.2 Scenario A

4.6.1.2.1 Assumptions

The set of regulatory framework and national and state policies and plans defined from 2007, if implemented, would significantly impact on the GHG reduction of the sanitation sector in the country, due to the treatment and adequate disposal of urban solid waste and the efficiency in wastewater treatment, increasing the energy recovery in both processes.

The federal laws of the National Basic Sanitation Policy, Law No. 11,445 / 2007 (BRASIL, 2007) and the National Solid Waste Policy, Law No. 12,305 / 2010 (BRAZIL, 2010a) and their respective regulatory decrees established competencies, management models and instruments able to proceed the necessary transformations in these fields.

The targets defined in the National Plans for Basic Sanitation and Solid Waste, even though the most conservative scenarios, are far to achieve. An extreme example concerns the total unmanaged dumps in the national territory, which should close before August 2014 and is still far from being achieved, especially in small municipalities and in the North, Northeast and Midwest regions.

In scenario A, additional mitigation measures were not considered to those already in progress. Activity levels were therefore 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 in order to reduce inadequate waste disposal. Regarding methane recovery to flare burning, even though the Brazilian standard establishes a minimum of 20% in managed landfills, was considered zero, the same rate adopted in the III National Inventory (MCTIC, 2015).

The numbers presented in Table 49 translate the set of following assumptions, adopted for Scenario A:

- Estimates of IBGE population growth;
- Per capita generation of solids 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%, according to National Inventory (MCTIC, 2010, 2015);
- Incineration treatment for ISW and HSW following the IES Brasil 2050 Project.

Table 49. 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) collect for landfilling		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
Landfill	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

Activity Level	2005		2010		2015		2016		2017		2020		2025		2030	
	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%
Managed	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
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

4.6.1.2.2 Results

Table 50 and Figure 35 shows the emissions results of the solid waste subsector by source per year in Scenario A.

Table 50. Emissions from the solid waste treatment systems up to 2030 in scenario A (kt CO_2-eq)

Emissions (kt)		2005	2010	2015	2016	2017	2020	2025	2030
CH_4	MSW + ISW (II-A)	1,237.1	1,327.0	1,988.6	2,065.3	2,111.8	2,306.7	2,610.3	2,895.6
	Composting			1.3	1.3	1.2	1.1	1.0	0.9
CO_2	ISW	128.0	175.0	139.1	132.1	130.9	139.7	167.3	195.0
	MSW			41.2	42.3	43.5	46.6	51.0	54.5
N_2O	Composting			0.1	0.1	0.1	0.1	0.1	0.1
	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
CO_2-eq	MSW + ISW (II-A)	34,769.5	37,333.7	55,680.8	57,828.5	59,130.7	64,588.0	73,088.3	81,075.9
	Composting			62.8	60.4	58.2	52.6	45.8	40.8
	ISW			141.4	134.2	133.0	141.9	170.0	198.2
	MSW			42.0	43.1	44.3	47.5	52.0	55.5
	TOTAL	**34,769.5**	**37,333.7**	**55,927.0**	**58,066.2**	**59,366.2**	**64,830.0**	**73,356.1**	**81,370.3**

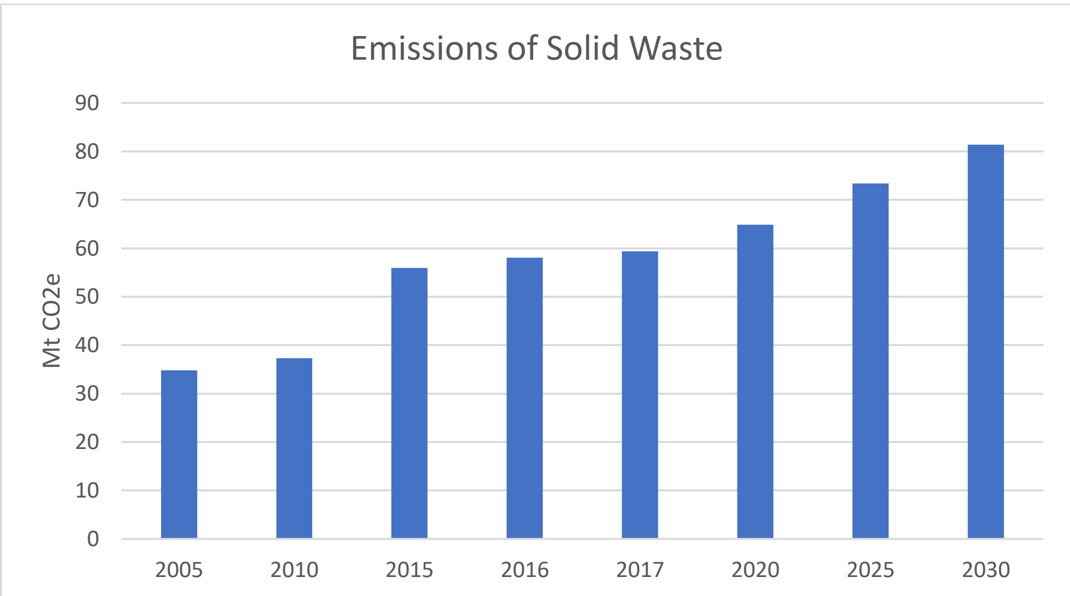


Figure 35. Evolution of solid waste treatment emissions in scenario A

The results indicate a growth of 134% in 2030 compared to 2005 in methane emissions from solid waste treatment; of 1,040% of nitrous oxide emissions from composting and treatment of waste from health services and industrial waste, both by incineration, and an increase in the emission of carbon dioxide by 95% for the treatment of waste from health services and industrial wastes by 2030 compared to 2005.

4.6.1.3 Scenário B

4.6.1.3.1 Assumptions

In scenario B, mitigation measures were considered in addition to those already in progress, from 2018 to 2030, complying on a larger scale with the PNRS and PNSB, not only reducing the inadequate waste disposal, but also the emissions, with annual increase of 10% in the recovery of methane for flaring in the Brazilian capitals, from 2021 until stabilize at 80%. The numbers presented in Table 51 translate the set of following assumptions, adopted for the construction of Scenario B:

- Equal expansion of sanitation measures in scenarios B and C (collection of MSW for landfilling and final disposal of MSW and ISW (II-A) to 75%;
- Methane destruction in landfills: gradual increase by 10% per year until reaching 80% only in capitals from 2021;
- Composting: increase to 2% by 2030;
- Recycling of paper, cardboard and cellulose: up to 12% in 2030
- Generation of electricity with biomethane recovered in landfills: annual increasing from 1.5% in 2021 to 13.6% in 2030.

Table 51. 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) collect for landfilling		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	87.2
Landfill	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	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
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
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

The mitigation measures to the waste sector, according to the Brazilian Forum on Climate Change, are the following:

- Expansion of the collection / use of methane from unmanaged dumps, managed landfills and effluent plants: through the implementation of waste policies and the energetic use of this methane still without installed infrastructure for recovery.
- Increasing composting volume of segregated organic wastes in source: large-scale waste from food, sewage, urban pruning leaves and branches, etc., producing an organic compost for soil carbon fixation, and biogas, which can be used for electricity production and transportation, replacing natural gas.
- Destruction of methane from landfill with flairs: with considerable potential for mitigation by burning in managed and controlled landfills where it is not possible to reuse, reducing CH_4 emissions;
- Reverse logistic programs, reduction in source and selective collection of waste: with federal support to local and regional programs, associated with environmental education programs of wide reach and participation of different schools levels in the implementation of this action.

4.6.1.4 Scenário C

4.6.1.4.1 Assumptions

In scenario C, mitigation measures were considered in addition to those already underway in Scenario B, from 2018 to 2030, maintaining the collection and treatment levels and complying on a larger scale with the PNRS, with greater efforts in reduce emissions, for example, with an annual increase of 10% in methane recovery for flaring, this time not only in Brazilian capitals, but metropolitan regions and large cities, from 2021 to stabilize at 80%. The numbers presented in Table 52 translate the set of following assumptions to construct Scenario C:

- Same extension of sanitation measures in scenarios B and C (collection of MSW for landfilling and final disposal of MSW and ISW (II-A) in landfills to 75%);
- Methane destruction in landfills: gradual increase from 10% per year in 2021 to 80% in capitals, metropolitan regions and large cities (over 500,000 inhabitants);
- Composting: increase to 2% in 2030
- Recycling of paper, cardboard and cellulose: up to 12% in 2030

- Generation of electricity with the recovered biomethane in managed landfills: annual increase from 2.8% in 2021 to 20.9% in 2030;
- Replacement of natural gás for vehicles by biomethane from 2.5% of the total generated in 2025 to 3.5% in 2030, according to the demand in the States of São Paulo and Rio de Janeiro, foreseen in Biofuels Program of Transport Sector.

Table 52. 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 landfilling		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	87.2
Landfill	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	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
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
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

According to the Brazilian Forum on Climate Change, the set of mitigation measures considered in the waste area would produce an estimated 2030 potential by 20 $MtCO_2$-eq, due to actions that could supply biogas for transportation and energy use. The proposed measures exist in scenarios B and C. The differences between them are the levels of implementation:

- Expansion of collection/use of methane from unmanaged dumps and managed landfills;
- Increasing on composting of segregated organic solid waste by source (this isolated action has a little perceived potential, but joined with the previous one it can reach a mitigation potential by 8 $MtCO_2$-eq);
- Methane destruction on managed landfill flairs (according to MCTIC, 2017, the mitigation potential of this measure could reach 20.8 $MtCO_2$-eq in 2030);
- Reverse logistics, reduction in Source and selective collection.

4.6.2. Wastewater

4.6.2.1 Emission Sources

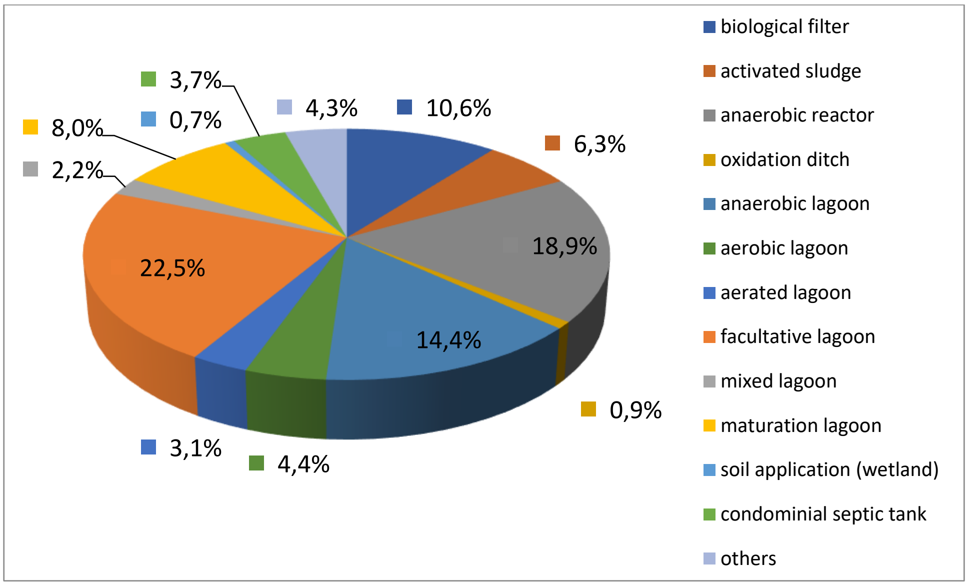
Sewage treatment systems can be classified as preliminary, primary, secondary and tertiary. The preliminary treatment aims to remove coarse solids, while the primary one also removes sedimentary solids. In both, physical treatment mechanisms predominate - grids and deposition - and in the primary part 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 remove 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).

Both the treatment of wastewater as the sludge produced, under anaerobic conditions, results in CH_4, and the amount of gas produced will depend on the effluent characteristics, the temperature and the type of treatment used. The main factor of methane generation is the amount of degradable organic matter measured by the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD). 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.

Sludge can be produced in both primary, secondary and tertiary treatment, with the primary consisting of the solids removed from wastewater and in the others is the result of biological growth in the biomass and aggregation of small particles. Sludge should also be treated and the treatment process includes anaerobic and aerobic digestion, densification, dewatering, composting or final disposal in landfills.

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

In 2005, according to PNAD (2008), in the population without collection, 54% of wastewater was treated by septic tanks, 37% by rudimentary tanks, 5% poured directly into water bodies and 4% in trenches. In the case of population with collecting, the participation adopted for each treatment or destination is shown in Figure 36.



Source: MCTIC, 2015

Figure 36. Sewage Treatment in Brazil in 2005

GHG emissions from treatment and disposal of urban sewage were estimated considering the prolongation of the historical trend by treatment types up to 2030 kept proportionally constant (share of technologies).

In the anaerobic treatment processes, with reactors and anaerobic digesters of activated sludge systems that have burners, the CH_4 emitted by these systems is considered partially destroyed, with an efficiency of approximately 55% (MCTI, 2015).

Emissions from industrial effluents are estimated with a function of organic matter production to the GDP of the food and beverage industry.

4.6.2.2 Scenario A

4.6.2.2.1 Assumptions

Similarly to the subsector of solids, additional mitigation measures were not considered to those already in progress. The activity levels were therefore estimated by the extension of the respective effluent treatments and disposal trends from 2000 to 2016 up to 2030, still complying in part with the PNSB in order to reduce the inadequate disposal. In relation to methane recovery for flare burning in anaerobic plants, was adopted 55% as the same efficiency of the III National Inventory (MCTIC, 2015).

The numbers presented in Table 53 translate the set of following assumptions, adopted to construct Scenario A:

- Wastewater per capita generation per GDP per capita;
- Total organic matter in BOD of the effluents;
- Scope and wastewater treating collected;
- Percentages of wastewater treatment on PNSB (IBGE, 2000, 2008) and Sanitation Atlas (ANA, 2017);
- Methane destruction in anaerobic plants following the growth trend (MCTIC, 2010, 2015);
- Wastewater treatment in plants: 45.9% of the generated in 2030, following the growth trend;
- Wastewater treatment in anaerobic plants Treatment of 21.5% of that generated in 2030, following the growth trend;
- Biometano destruction in anaerobic plants constant until 2030;
- Wastewater treatment in septic and rudimentary tanks decreases according to the historical trend of 27% to 21% in 2030;
- Methane burning in industrial ETE grows according to the historical trend up to 43.7% of the biometano produced in 2030 (with 55% efficiency)

Table 53. 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	
	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%
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 54 and Figure 37 presents the emission results of effluent subsector by source per year in Scenario A.

Table 54. Wastewater treatment emissions by source between 2005 and 2030 in scenario A (kt CO_2-eq)

	Emissions (kt)	2005	2010	2015	2016	2017	2020	2025	2030
CH_4	Domestic wastewater	436.6	512.8	517.1	525.3	533.5	558.2	589.7	611.9
	Industrial wastewater	388.3	621.2	660.2	662.0	663.9	669.8	815.2	958.2
N_2O	Domestic wastewater	6.6	7.2	8.7	8.7	8.8	8.9	9.1	9.3
CO_2-eq	Domestic wastewater	13,973.8	16,266.4	16,771.8	17,018.0	17,262.3	17,994.9	18,935.2	19,600.1
	Industrial wastewater	10,872.4	17,393.6	18,486.1	18,536.7	18,588.8	18,753.0	22,825.0	26,828.6
	TOTAL	**24,846.2**	**33,660.0**	**35,257.9**	**35,554.7**	**35,851.1**	**36,748.0**	**41,760.2**	**46,428.7**

In this effluent subsector, the results of GHG emissions evolution due to the treatment of sanitary sewage indicate a 40.2% and 41.0% increase in the methane and nitrous oxide emissions, respectively, in 2030 compared to 2005. In the treatment of industry wastewater, there is 146.8% growth in methane emissions in 2030 compared to 2005.

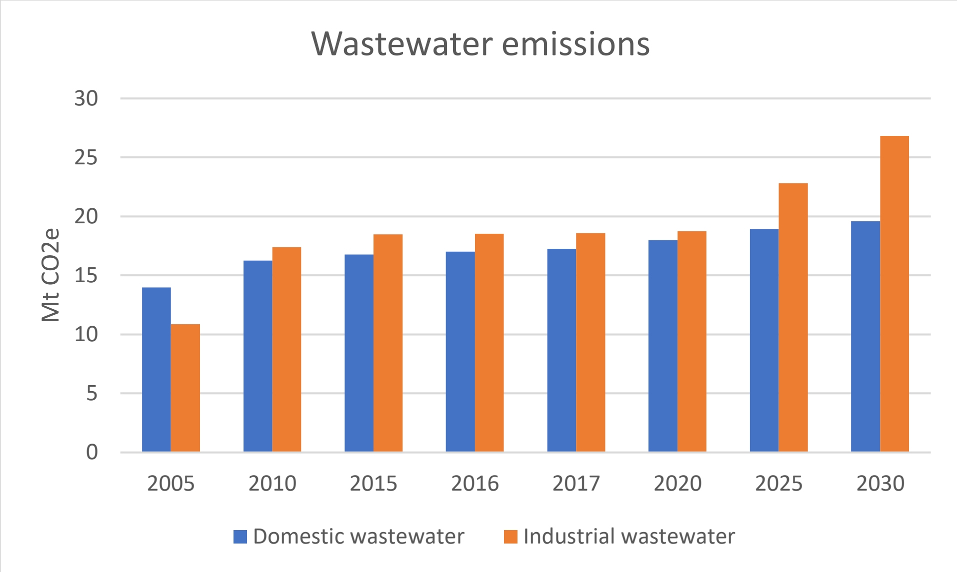


Figure 37. Evolution of wastewater treatment emissions in scenario A

4.6.2.3 Scenario B

4.6.2.3.1 Assumptions

In scenario B, mitigation measures were considered in addition to those that are already in progress, from 2018 to 2030, complying on a larger scale with the PNSB, not only reducing the inadequate disposal of sewage, but also emissions, with an increase in the methane recovery for flairing in Plants from 2021. The numbers presented in Table 55 reflect the following set of assumptions to construct Scenario B:

- Wastewater treatment in plants: 50.8% of sewage generated in 2030;
- Treatment in anaerobic plants: displacement 5% from septic tanks to anaerobic plants up to 26.5% in 2030;
- Biomethane destruction in anaerobic plants: Increase methane destruction in flairs from 60% to 70% of anaerobic plants from 2021 to 2030;
- Domestic wastewater treatment in septic and rudimentary tankss: Decreases to 16.0% in 2030, due to the 5% displacement for anaerobic treatment;
- Methane destruction in industrial wastewater treatment plants: Increase in the methane destruction in the capitals, metropolitan regions and large cities (above 500 thousand inhabitants) to 45.3% of the biomethane produced in 2030. (55% efficiency).

Table 55. 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	
	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%
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 implementation of sanitation policies, and the energetic use of methane from plants without installed infrastructure for recovery, for use in transportation and electric generation. These actions exist in scenarios B and C. The diference between them is the implementation level of the increase of methane capture / use in plants.

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 56 translate the set of following asumptions, adopted to constructof Scenario C:

- Wastewater freatment 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 anaerobic plants: increases from 60% to 80% from 2021 to 2030;
- 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 56. 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	
	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%	MtDBO	%
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

The set of mitigation measures, according to the Brazilian Forum On Climate Change, due to actions that offer biogas for use in transport and energy, exist in scenarios B and C. The diferencecs between them is the level of implementation of increased methane capture / use in plants, which could contribute to an estimated potential of 14 $MtCO_2$-eq in 2030 along with other mitigation measures in the treatment of solid waste.

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 57. We can see that there would be a reduction in 80% in emissions from Land Use, Land Use Change and Forestry, where both a reduction in deforestation rates and the extension of current levels of carbon removal in conservation units and indigenous lands are particularly relevant to the overall mitigation to be achieved up to 2030. All other sectors present increasing emissions, showing that if no extra mitigation efforts are made, Brazil would not meet its commitment.

Table 57. Detailed Presentation of GHG Emissions in Scenario A (Mt CO_2-eq)

	2005	2010	2015	2020	2025	2025/ 2005	2030	2030/ 2005
Land Use and Land Use Change and Forestry	1,921.7	355.0	424.0	414.6	395.4	-79%	381.8	-80%
Cropping Systems	127.1	139.4	142.9	123.6	124.2	-2%	133.7	5%
Livestock	332.6	333.4	379.5	371.4	377.8	14%	388.6	17%
Transport	144.4	177.7	203.3	207.7	223.9	55%	246.6	71%
Industry	140.5	162.7	170.1	178.2	199.0	42%	221.3	57%
Others (energy demand)	45.1	47.2	46.9	50.8	53.5	19%	54.3	20%
Energy Supply (Fuel Combustion)	49.3	61.2	99.0	69.3	78.1	58%	88.8	80%
Energy Supply (Fugitive Emissions)	20.1	20.7	23.3	28.0	35.9	78%	42.8	113%
Waste	59.6	71.0	91.2	101.6	115.1	93%	127.8	114%
Total	**2,841**	**1,368**	**1,580**	**1,545**	**1,603**	**-44%**	**1,686**	**-41%**

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These results for Scenario A are further disaggregated in Table 58, allowing for a more detailed presentation of emissions split by driving forces and economic sectors.

Table 58. Detailed Presentation of GHG Emissions in Scenario A (Mt CO_{2}-eq)

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
Energy	**320.4**	**378.2**	**444.9**	**429.1**	**470.7**	**518.4**
Energy Supply	**49.3**	**61.2**	**99.0**	**69.3**	**78.1**	**88.8**
Energy Sector Consumption	**21.7**	**23.9**	**30.1**	**27.8**	**30.4**	**33.5**
Transformation Centers	**27.6**	**37.3**	**68.8**	**41.4**	**47.7**	**55.3**
Power Plants	26.7	36.6	68.2	41.0	47.2	54.8
Charcoal Production	1.0	0.7	0.6	0.5	0.5	0.5
Residential	**25.7**	**26.2**	**26.4**	**29.1**	**30.7**	**31.8**
Commercial & Public	**3.7**	**2.8**	**2.6**	**2.9**	**3.6**	**4.2**
Agriculture	**15.7**	**18.2**	**17.9**	**18.8**	**19.2**	**18.3**
Transportation	**144.4**	**177.7**	**203.3**	**207.7**	**223.9**	**246.6**
Road	**131.6**	**160.2**	**186.4**	**189.9**	**202.3**	**220.9**
Railways	**2.8**	**3.3**	**2.8**	**3.2**	**3.5**	**3.7**
Airways	**6.4**	**9.8**	**11.0**	**10.5**	**13.0**	**15.7**
Waterways	**3.6**	**4.5**	**3.1**	**4.2**	**5.1**	**6.2**
Industry	**61.5**	**71.5**	**72.4**	**73.4**	**79.3**	**85.9**
Cement	**9.2**	**14.8**	**16.1**	**15.6**	**17.2**	**19.0**
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**	**9.8**	**11.4**
Non-Ferrous/Other Metallurgical	**4.9**	**5.5**	**5.5**	**6.4**	**7.5**	**8.8**
Chemical	**14.6**	**14.0**	**13.9**	**14.0**	**14.1**	**14.2**
Food and Beverage	**5.0**	**5.5**	**5.6**	**5.4**	**5.6**	**5.8**
Textile	**1.2**	**1.0**	**0.7**	**0.7**	**0.7**	**0.7**
Pulp & Paper	**4.2**	**4.2**	**4.1**	**4.3**	**4.8**	**5.3**
Ceramics	**4.0**	**5.2**	**5.0**	**4.9**	**5.2**	**5.5**
Other Industries	**6.3**	**8.3**	**8.2**	**7.9**	**8.1**	**8.4**
Fugitive Emissions	**20.1**	**20.7**	**23.3**	**28.0**	**35.9**	**42.8**
E&P	**10.2**	**10.0**	**11.2**	**13.3**	**20.7**	**25.9**
Oil Refining	**6.8**	**7.4**	**8.3**	**9.4**	**9.8**	**10.9**
Fuel Transport	**0.3**	**0.3**	**0.4**	**0.4**	**0.6**	**0.8**
Coal Production	**2.9**	**3.0**	**3.4**	**4.8**	**4.8**	**5.2**
AFOLU – Agriculture, Forestry and Other Land Use	**2381.4**	**827.7**	**946.4**	**909.7**	**897.4**	**904.0**
Land Use, Land Use Change and Forestry (net emissions)	**1921.7**	**355.0**	**424.0**	**414.6**	**395.4**	**381.8**
Gross Emissions	**-**	**667.8**	**913.0**	**925.3**	**926.6**	**927.6**
Deforestation and other land use changes	-	-	882.9	895.5	895.5	895.5
Liming and forest residues	-	-	30.0	29.8	31.1	32.1
Removals	**-**	**- 312.7**	**- 489.0**	**- 510.7**	**- 531.2**	**- 545.9**
Planted Forests	-	-	- 12.1	-	- 14.3	- 21.7

Sector	2005	2010	2015	2020	2025	2030
	Mt CO_2-eq					
Restoration of Native Forest	-	-	-	- 5.8	- 15.4	- 22.7
Recovery of Degraded Pasturelands	-	-	-14.3	- 25.3	-22.0	-22.0
Livestock-Forest Systems	-	-	-13.4	- 8.1	- 8.0	-8.0
Protected Areas and Indigenous Lands	-	-	-354.1	-381.9	-381.9	-381.9
Secondary forests	-	-	-95.1	-89.6	-89.6	-89.6
Forests Planted for Pellets	-	-	-	-	-	-
Agriculture	**459.7**	**472.7**	**522.4**	**495.0**	**502.0**	**522.2**
Livestock	**332.6**	**333.4**	**379.5**	**371.4**	**377.8**	**388.6**
Enteric Fermentation	-	312.4	357.6	349.2	354.9	364.4
Manure management	-	21.0	21.9	22.2	23.0	24.2
Cropping Systems	**127.1**	**139.4**	**142.9**	**123.6**	**124.2**	**133.7**
Agricultural Soils	-	119.9	128.8	125.4	129.1	134.6
Rice Cultivation	-	13.0	13.6	10.4	8.2	6.9
Burning of Agricultural Residues	-	6.5	6.6	3.4	3.0	2.8
Zero Tillage	-	-	- 6.1	- 15.6	- 16.2	- 10.5
Waste	**59.6**	**71.0**	**91.2**	**101.6**	**115.1**	**127.8**
Solid Waste	**34.8**	**37.3**	**55.9**	**64.8**	**73.4**	**81.4**
Industrial Solid Waste	-	-	0.1	0.1	0.2	0.2
Solid Waste from Health Systems	-	-	0.0	0.0	0.1	0.1
Composting	-	-	0.1	0.1	0.0	0.0
Urban Solid Wastes	-	-	55.7	64.6	73.1	81.1
Wastewater Treatment and Discharge	**24.8**	**33.7**	**35.3**	**36.7**	**41.8**	**46.4**
Domestic Wastewater	14.0	16.3	16.8	18.0	18.9	19.6
Industrial Wastewater	10.9	17.4	18.5	18.8	22.8	26.8
Industrial Processes and Product Use	**79.0**	**91.2**	**97.7**	**104.8**	**119.7**	**135.4**
Mineral Industry	**21.8**	**30.1**	**31.6**	**29.2**	**33.4**	**37.7**
Pig Iron and steel	**36.7**	**39.7**	**42.3**	**43.4**	**47.7**	**52.3**
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**	**9.2**
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	**0.7**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**
HFCs e SF_6	**3.1**	**7.6**	**10.3**	**13.5**	**16.8**	**20.0**
TOTAL	**2,841**	**1,368**	**1,580**	**1,545**	**1,603**	**1,686**

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6. CONCLUSION

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 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).

Table 59. Brazilian NDC targets (Mt CO_2-eq and %)

2005	2025	2030
2.1	1.3	1.2
100%	-37%	-43%

Source: Brazil 2015

In Scenario A, where no extra mitigation efforts would be made besides those already in place, total values in Scenario A would reach 1.6 million tons of CO_2-eq in 2025 and 1.7 million tons in 2030. These amounts are 31% and 42%, respectively above the commitment targets.

It is noteworthy that, at the time the country announced its pledges and signed the Paris Agreement, the second national inventory showed values for 2005, the base year, which are 25% lower than the values subsequently revised by the third national inventory. Both values for the base year are in Table 60, that also presents the Scenario A values until 2030.

Table 60. Consolidation of the Scenario A values (Mt CO_2-eq and %)

	2005	2010	2015	2020	2025	2025 / 2005	2030	2030 / 2005
Second National Inventory	2.1	1.4	1.6	1.5	1.6	-24%	1.7	-20%
Third National Inventory	2.8	1.4	1.6	1.5	1.6	-44%	1.7	-41%

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The assessment of the potential results of current mitigation policies shows that they are not sufficient to meet Brazilian NDC targets for 2030.

Additional mitigation actions will be required to put the country’s GHG emission pathway back on track to meet Brazilian commitment to the Paris agreement.

The results of Scenarios B and C including two different sets of additional mitigation actions will be presented in the next report.

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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 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 planted area was calculated considering the annual production (ton) and the average productivity per hectare (ton/ha) as shown in Table 32.

Table 61. 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 energy supply sector of this project
- Projections for the production of 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 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). Removals source 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 the 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 (razil, 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 taken into accounted 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: (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 segment 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 segment *i*, FE_j is the emission factor of fuel *j*, and $S_{i,j}$ is the amount of fuel *j* consumed in the segment *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 particular processes, the calculation are 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) segments. 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 of CO_2e; "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 62 shows the emission factors and the oxidized fraction for each of the reducing fuels.

Table 62. 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: based on 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:

$$E_{t,i} = FE_{t,i} \times Q_{t,i} \qquad \text{Equation 4}$$

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 63 presents the values of the emission factors, FE, for each of the abovementioned technologies.

Table 63. 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: based on 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 SF_6

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 were adopted simultaneously: two quantitative (top-down and bottom-up); and a qualitative (ASIF). 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.

The method 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, 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 top-down approach aims to quantify and identify, by mode and type of transport activity (passengers and freight), the evolution of modal split and activity (p-km and t-km), energy intensity (kJ/t.km and kJ/p.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 based on the study of D´Agosto et al. (2018).

Historical trends

Considering the road transportation mode, Figure 38 illustrates the Brazilian car fleet, light commercial vehicles, motorcycles, buses and trucks.

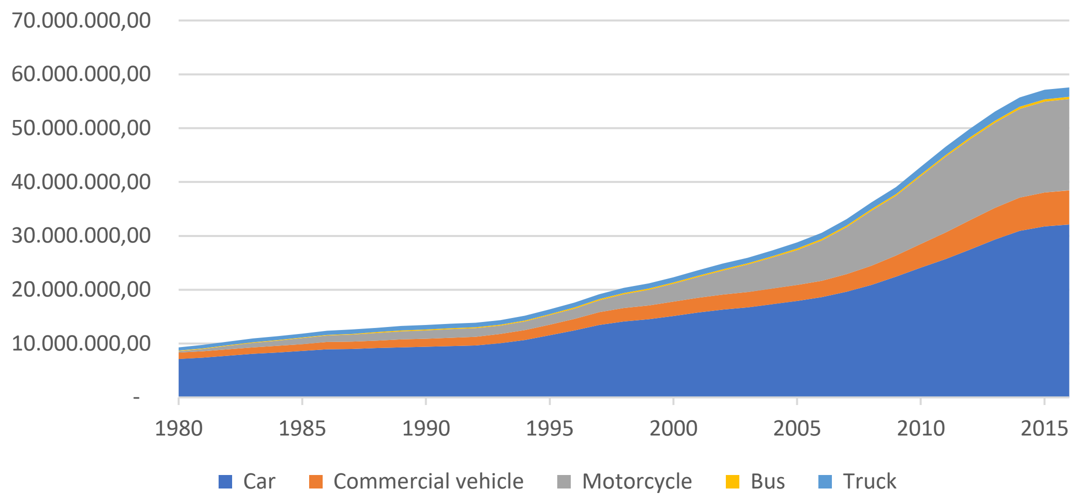

Figure 38. Historical of Brazilian fleet.

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) considering each type of vehicle.

Figure 39 shows the historical activity of transport. It is important to point out that energy consumption and GHG emissions are directly related to the activity.

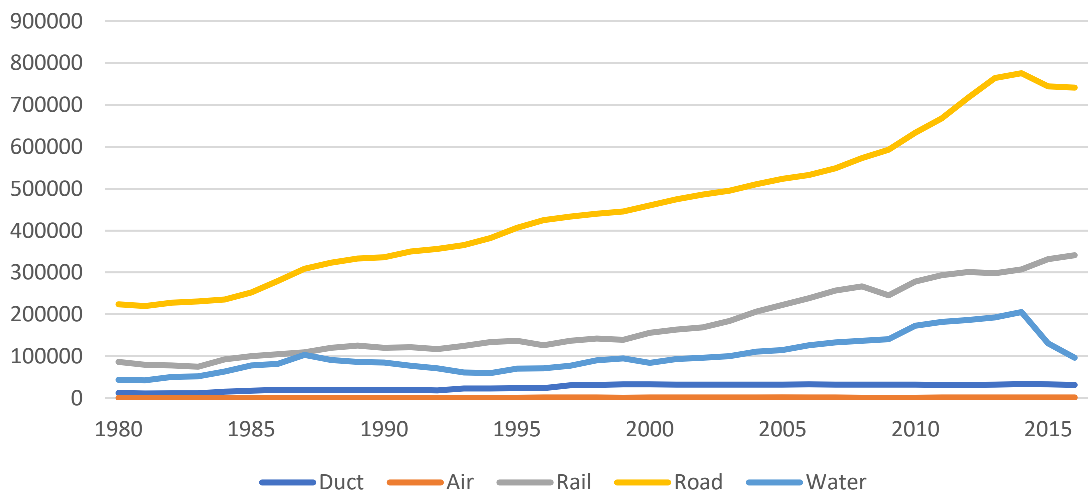

Figure 39. Transport activity of freight transportation (t.km).

From 2005, where the activity for all modes is around 366 billion of tons per kilometer, transport activity expands 35% until 2016, reaching the amount of 1,210 billion of tons. As 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 40 shows the transport activity of passenger transportation from 1980 to 2016.

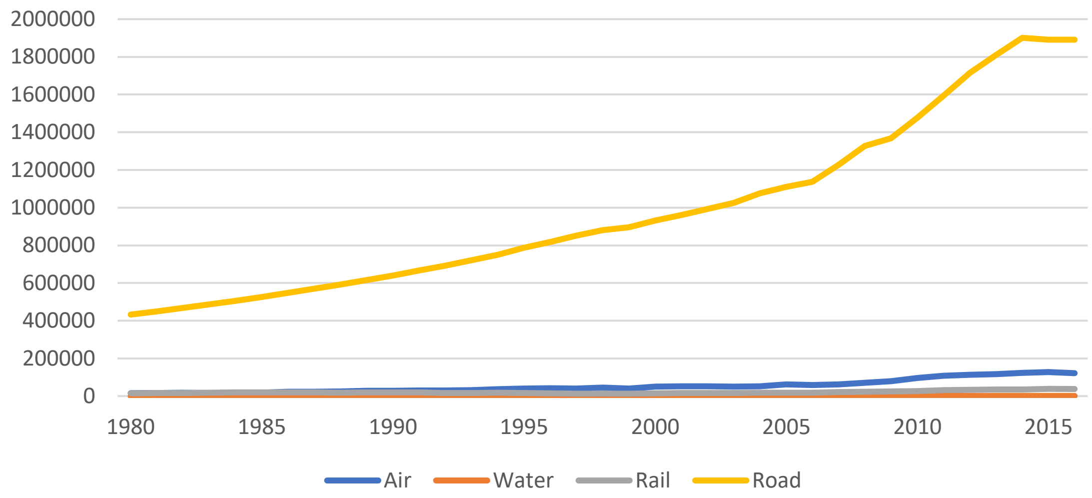

Figure 40. Transport activity of passenger transportation (pass.km).

In this case, the aggregate growth from 2005 to 2016 is 72%, the majority represented by the road transportation. Under these circumstances, total activity is 1,191 billion of passenger per kilometer in 2005, while it reaches 2,052 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.

Results

Scenario A

As illustrated in Figure 41, fleet grows 36% until 2030, in other words, from 58 million of 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 presents a slight increase in the market share up to 2030. BEV grows from almost 0% to 0.1%, while hybrids increases 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 supply of ethanol in the market (which is an assumption of this scenario). In relation to public transportation, BEV buses tend to increase the participation from 0% to 0.6% of the bus fleet. Considering other types of vehicles, growth is based on the historical trend.

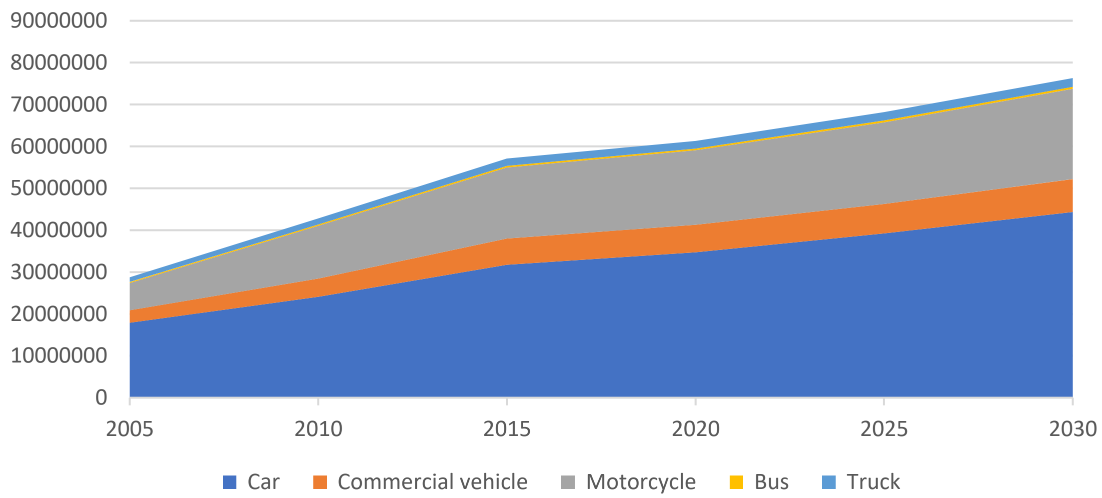

Figure 41. Fleet´s projection of road transportation in Scenario A.

With regards to the activity of freight transportation (all modes), Figure 42 presents the trajectory according to the assumptions of the Scenario A.

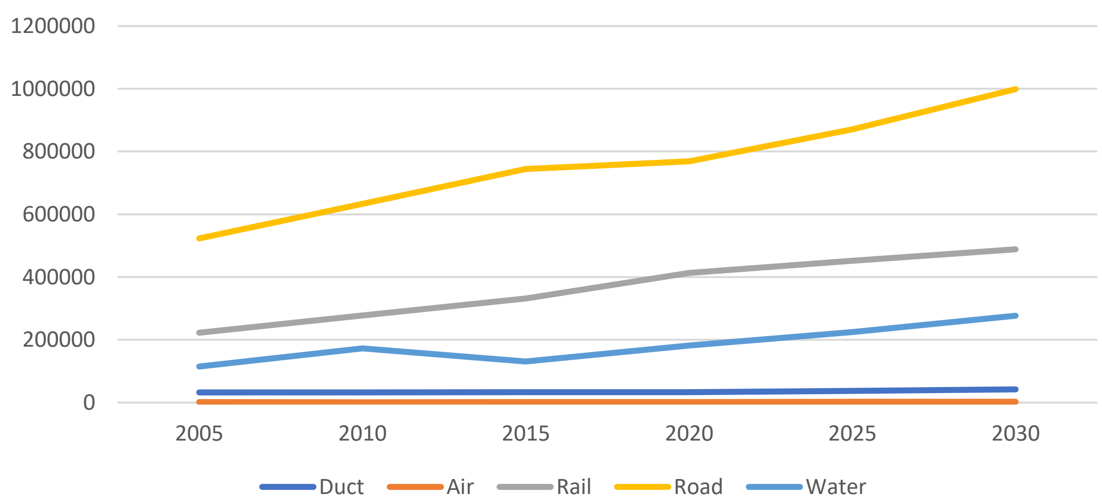

Figure 42. Transport activity of freight transportation (t.km), in Scenario A.

From the baseline (2017), where the activity considering all modes is around 1,210 billion of tons per kilometer, the transport activity grows 36% until 2030, reaching the amount of 1,809 billion of tons per kilometer. Figure 36 shows the activity of passenger transportation.

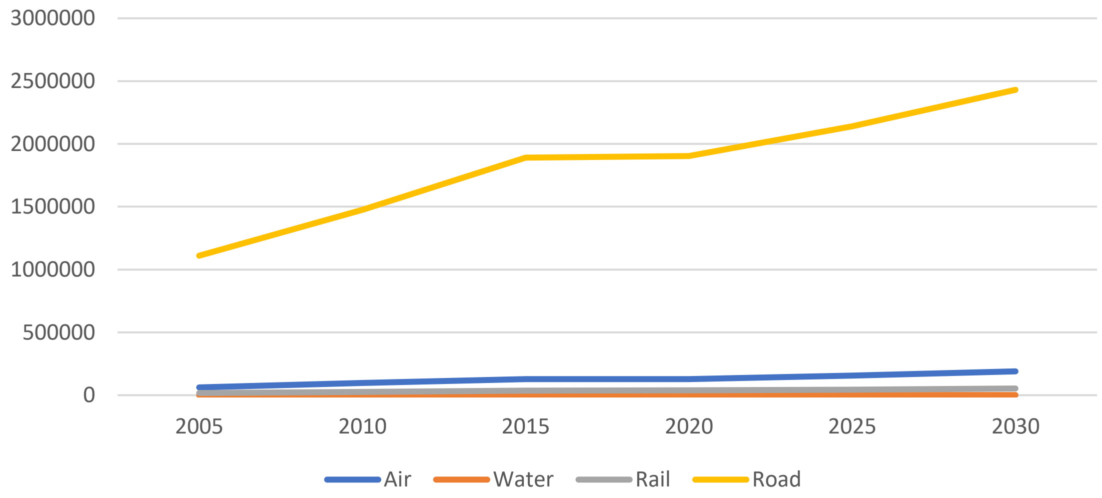

Figure 43. Transport activity of passenger transportation (pass.km), in Scenario A

In this case, the transport activity increases 30% during the period, from 2,065 billion of passenger per kilometer to 2,675 billion. Here, road mode represents 90,8% of the transport activity (1,39% lower than in 2017). Resuming, Figure 44 illustrates the modal share of freight and passenger transportation according to the activity of the sector.

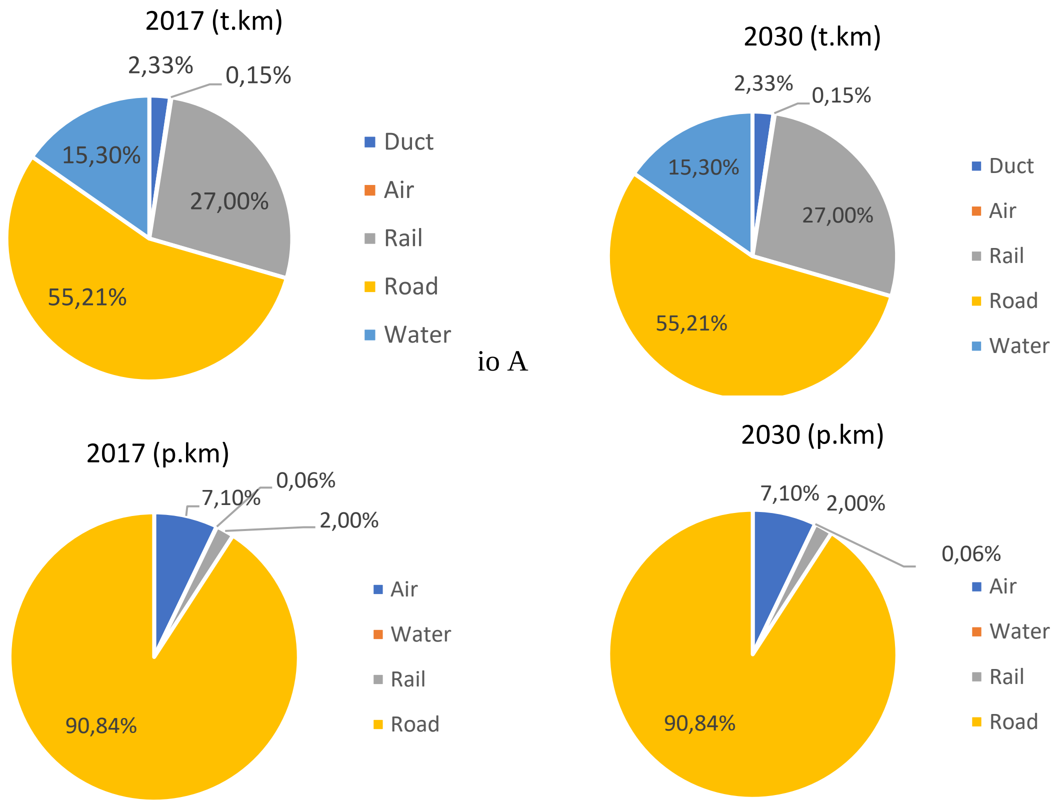

Figure 44. Modal split of freight and passenger transportation in Scenario A.

Table 64. Energy consumption (toe) in Scenario A

Year	Scenario A		
	Fossil fuels	Renewable	Total
2005	44,243	7,296	**51,539**
2010	53,516	13,734	**67,250**
2015	64,151	18,197	**82,348**
2016	64,410	16,745	**81,156**
2017	65,212	17,069	**82,281**
2020	66,437	17,879	**84,315**
2025	72,449	20,538	**92,987**
2030	79,733	23,216	**102,949**

Table 65. Gg CO_2-eq emissions between 2005 and 2030 in Scenario A.

Year	Scenario A
2005	144,371
2010	177,702
2015	203,349
2016	204,105
2017	206,970
2020	207,748
2025	223,852
2030	246,592

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, taking into account 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^-kt

where DDOCm(0) is the mass of decomposable degradable organic carbon (DOC) at the start of the reaction, when t=0 and e^-kt=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) • (1 – e^(-k • ((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) • e^-k)

The total amount of DDOCm decomposed in year T

(8) DDOCmdecomp(T) = DDOCmdec(T) + (DDOCma(T-1) • (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 = (ΣxCH_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 Emissions = Σ (M i • EF i) • 10-3 – 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 Emissions = Σ i (Mi • EFi) • 10-3

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, emissions of CO_2 from waste incineration are more significant than CH4 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 on the basis of waste types/material (such as paper, wood, plastics) in the waste incinerated or open-burned as shown in Equation 13

(13) $$CO_2 \text{ Emissions} = MSW \cdot \Sigma_j (WF_j \cdot dm_j \cdot CF_j \cdot FCF \cdot OF_j) \cdot 44/12$$

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 openburned)

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: Σj WFj = 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) $$CH_4 \text{ Emissions} = \Sigma i\ (IWi\ .\ EFi\ )\ .\ 10^{-6}$$

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) $$N_2O \text{ Emissions} = \Sigma i\ (IWi\ .\ EFi\ )\ .\ 10^{-6}$$

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 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 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 utilisation 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 realised 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 66. 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, ground water table lower than latrine, small family)	0,10	0,06
Latrine (Dry climate, ground water table lower than latrine, communal)	0,50	0,30
Latrine (Wet climate/flush water use, ground water table higher than latrine)	0,70	0,42
Latrine (Regular sediment removal for fertilizer)	0,10	0,06

Source: IPCC (2006)

ICAT Brazil Project

Report 1

GHG Emissions in Brazil up to 2030 under Current Mitigation Policies – Scenario A

PPE-21314

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