The Brazilian Commitment to Combating Climate Change: Energy Production and Use

June/2016

Empresa de Pesquisa Energética

(This page has been intentionally left blank for the proper alignment of pages when printing with the double sided option)

Ministério de Minas e Energia

Empresa de Pesquisa Energética

Public company under the Ministry of Mines and Energy, established under Law No. 10,847, from March 15, 2004, EPE has the purpose of providing services in the area of studies and research to support the planning of the energy sector, such as electricity, oil and natural gas and derivatives, coal, renewable energy sources and energy efficiency, among others.

The Brazilian Commitment to Combating Climate Change: Energy Production and use

Coordinating Lead Authors:

Mauricio T. Tolmasquim
Ricardo Gorini

Lead Authors:

Emílio Matsumura
Jeferson Borghetti Soares
Luciano Basto Oliveira
Maria Luiza Viana Lisboa

Contributing Authors:

Glaucio Vinicius Ramalho Faria
Marcos Ribeiro Conde
Natália Gonçalves de Moraes
Renata de Azevedo Moreira da Silva

This summary should be cited as:

Tolmasquim, M.T., R. Gorini, E. Matsumura, J. B. Soares, L. B. Oliveira, M. L. V. Lisboa, G. V. R. Faria, M. R. Conde, N. G. Moraes, R. A. M. Silva (2016), ***The Brazilian Commitment to Combating Climate Change: Energy Production and Use***, Empresa de Pesquisa Energética-EPE, Rio de Janeiro, RJ, Brazil, 96 pp

We Thanks To

The preparation of the Brazilian commitment to the energy sector was based on long-term studies for energy demand and supply, and they have been developed from studies of several areas of EPE. Therefore, we offer special thanks to the staff of the superintendencies involved in these studies:

Superintendence of Energy and Economic (Coordination: Jeferson B. Soares)
Superintendence of Environmental Studies (Coordination: Isaura Maria Ferreira Frega)
Superintendence of Oil Studies (Coordination: Ricardo N. S. do Valle)
Superintendence of Natural Gas & Biofuels (Coordination: Giovani Vitória Machado)
Superintendence of Power Generation Planning (Coordination: Jorge Trinkenreich)
Superintendence of Power Generation Projects (Coordination: Paulo Roberto Amaro)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FOREWORD

In December, 2015, during COP21 (21st Conference of the Parties) of the United Nations Framework Convention on Climate Change (UNFCCC), the governments of around 190 countries gathered in Paris to seek an agreement on global climate change under the Convention.

Each country was asked to submit their ambition to reduce domestic emissions of greenhouse gases (GHG) called iNDC - Intended Nationally Determined Contribution - with the purpose of limiting temperature rise on the globe to a maximum of 2ºC by 2100. Brazil submitted its iNDC to the UNFCCC Secretariat in September 28th, 2015.

Brazil has committed to reducing, by 2025, their GHG emissions in 37% compared to 2005 levels and, as a subsequent indicative contribution, reducing, by 2030, GHG emissions in 43% under the same comparison basis.

It is worth mentioning that Brazil's iNDC comprises their whole economy and is based on flexible ways of achieving these objectives. In other words, the achievement of these objectives can occur in different manners, with different contributions from the economic sectors.

This document describes the scenario that subsidized the INDC concerning the activities related to energy production and use.

As will be evident, although ambitious and challenging, the proposal regarding energy production and use is fully feasible, and depicts the commitment and determination of the country to contributing to sustainable development and combating climate change.

Finally, it is worth remembering that the perspectives of economic and energy trend used to determine these contributions are built upon premises and information at the time of their preparation (September, 2015). Alterations in trajectories of some variables of interest may be required given the recent changes in economic perspectives, especially for the upcoming years. However, the challenges and feasibility of goals must not be changed in nature.

Mauricio T. Tolmasquim

(This page has been intentionally left blank for the proper alignment of pages when printing with the double sided option)

1. INTRODUCTION

In September, 2015, Brazil submitted its iNDC to the UNFCCC secretariat with the contribution that the country intends to commit to reduce greenhouse gas emissions by 37% below 2005 levels and an indicative contribution by 2030 43% below that same base year.

This commitment covers the whole economy, including the Energy, Agriculture, Forest, Waste and Industrial Processes sectors, and is based on flexible ways to achieve these objectives. In other words, the achievement of these objectives can occur in different paths, with different contributions from the economic sectors.

This document describes the scenario that subsidized the Brazilian INDC regarding energy production and use.

Brazil stands out for having an energy matrix with a large share of renewables, a reality observed in few countries in the world. This means that, currently, the GHG emissions per unit of energy consumed in Brazil are far below when compared to other countries.

On the other hand, if we compare socioeconomic indicators, we realize that Brazil still has a long way to go to achieve living standards comparable to those of developed nations. Thus, even with Brazil adopting a development path that is thriftless and less intensive in energy use than that of developed nations, disconnecting the increasing of energy consumption from their economic growth, it is hard to imagine that the country will be able to reduce the level of poverty on the horizon by 2030 without increasing the per capita energy consumption. As a result, GHG emissions will rise.

Indeed, the great challenge of Brazil's energy sector is precisely to maintain a high share of renewable sources in its matrix, which implies a significant expansion of the existing number of wind farms, solar plants, biomass-fueled thermal power plants and the construction of new hydroelectric plants, in addition to increasing production and consumption of liquid biofuels, ethanol and biodiesel, and investments in energy efficiency – various actions and policies to be taken with the ultimate goal of maintaining the GHG emission indicators among the world's best.

Brazil's iNDC shows the following commitments regarding energy production and use activities:

- Increase the share of sustainable bioenergy in the Brazilian energy matrix to approximately 18% by 2030, by expanding biofuel consumption, increasing ethanol supply, including by increasing the proportion of advanced biofuels (second generation), and increasing the share of biodiesel in the diesel mix;
- Achieve an estimated 45% share of renewables in the energy matrix by 2030;

- Obtain at least a 66% share of hydropower in electricity generation by 2030, not considering self-produced electricity;
- Expand the use of renewable energy sources other than hydropower in the total energy mix to between 28% to 33% by 2030;
- Expand the domestic use of non-fossil 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;
- Achieve 10% of efficiency gains in the electricity sector by 2030.

The commitments listed above reflect the country's choice in favor of a path that prioritizes the expansion of renewable sources in energy consumption and generation. The definition of this path, in turn, is tied to a series of long-term studies, generating elements for the quantification of these commitments. In summary, Figure 1 shows the analysis process for estimating future GHG emissions in the energy sector.

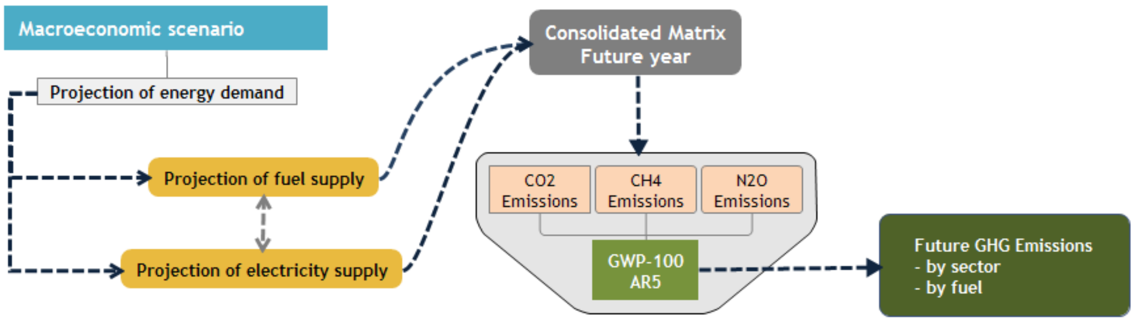


Figure 1- General Methodology for Estimating GHG in Energy Production and Use

The analysis of the proposal for all energy production and use activities shows that it can be considered ambitious and challenging, but fully feasible, and depicts the country's commitment and determination to contributing to sustainable development and combating climate change, as will be shown throughout this document divided into six sections, in addition to this introduction.

Chapter 2 briefly shows the main characteristics of the Brazilian energy sector and summarizes the main premises and the results that subsidized the Brazil's iNDC, demonstrating its feasibility. The technical details of the proposal are shown in the following chapters.

Chapter 3 details the results and methodology for projecting the final energy consumption, highlighting that it is a scenario that depends on actions outside the energy framework in order to be accomplished. The scenario also considers mitigating GHG emissions as one of the main premises.

Chapter 4, in turn, highlights the electricity supply, specifying the premises used in the challenging task of preparing a scenario that simultaneously ensures the power supply at a lower costs while minimizing environmental impacts.

Chapter 5 describes the main assumptions for oil and natural gas production, oil derivatives and biofuels.

Chapter 6 shows the consolidation of the Domestic Energy Supply and GHG emission indicators that served as reference to the preparation of the Brazil's INDC.

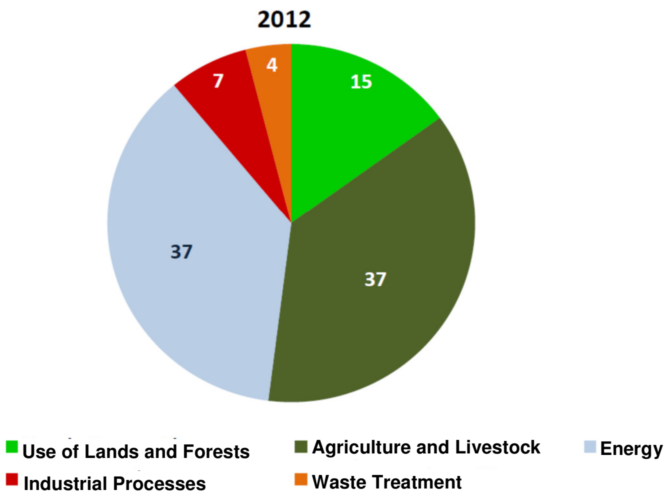
The procedure used for estimating GHG emissions is shown in the APPENDIX.

Finally, it is worth remembering that the perspectives of economic and energy trend used to determine these contributions are built upon premises and information at the time of their preparation (in September, 2015). Alterations in trajectories of some variables of interest may be required given the recent changes in economic perspectives, especially for the upcoming years. However, the challenges and feasibility of goals must not be changed in its nature.

2. CURRENT CONTEXT AND CHALLENGES UP TO 2030

2.1. CURRENT CONTEXT

In OECD countries, emissions related to transportation and energy production (electricity and heat) amount to 70% of the total GHG emitted. In Brazil, however, the same activities represent less than 40% of the total GHG emitted in 2012 (Figure 2).



Source: MCT

Figure 2 - Brazilian GHG Emissions per Sector in 2012 (%)

According to the International Energy Agency (IEA), Brazil is the world's sixth largest economy, but shows up only in 12th place in the ranking of nations regarding GHG emissions related to energy production and use (Table 1).

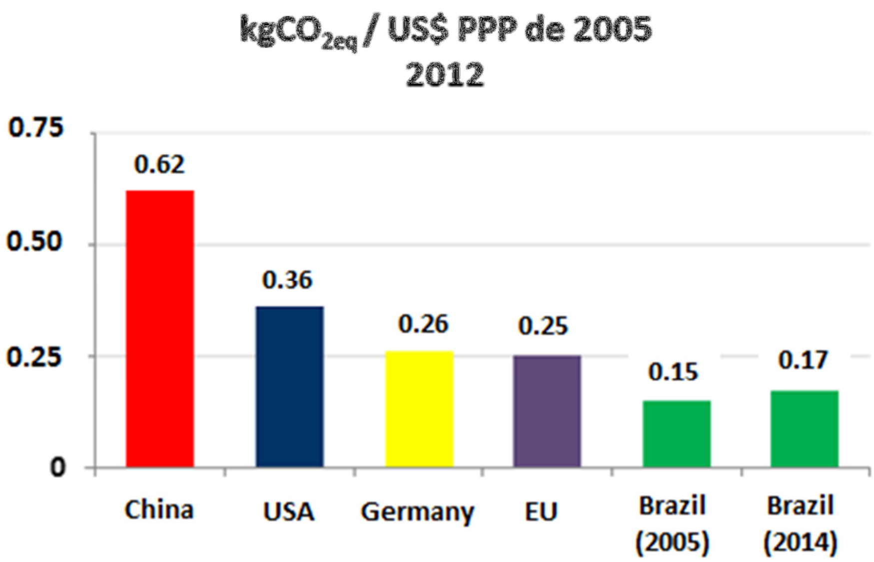
In 2012, these emissions reached 440 million tons of CO_2, less than 1.5% of the global total of 30 billion. Yet, if the Brazilian energy matrix were equivalent to the global matrix, it is estimated that the Brazilian GHG emissions would be 50% higher, reaching the rank of 7th largest emitter in the world and in line with the relative size of the country's economy in international terms.

Table 1 - GHG Emission and GDP, 2012

Country	Millions of tons of CO_{2eq}	GDP (US$ PPP billions of 2005)
China	8,251	12,969
United States	5,074	14,232
India	1,954	5,567
Russia	1,659	2,178
Japan	1,223	3,994
Germany	755	2,851
South Korea	593	1,400
Canada	534	1,291
Iran	532	1,053
Saudi Arabia	459	1,281
United Kingdom	458	2,069
Brazil	440	2,532
World Total	30,654	54,588

Source: IEA

As a result, carbon intensity in the Brazilian economy related to energy production and use is far below international standards: in 2012, this indicator was 0.17 kgCO_2/US$ PPP, 45% of the world average or 54% of the average of OECD countries (Figure 3). That is, in order to produce the equivalent of US$ 1 of value added in US$ PPP, Brazil emits only 45% of GHG emissions compared to the world average.

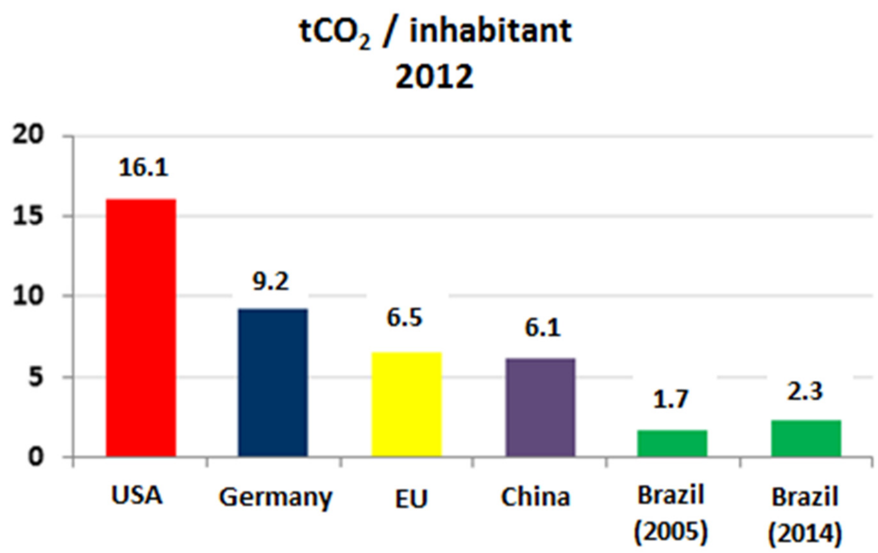


Source: IEA

Figure 3 - Emission intensity of GDP - Energy Production and Use - International Comparison

Another indicator that points to the same direction is the per capita emissions related to energy production and use that, in Brazil, were slightly greater than 2 tons of CO_2/inhab in 2012, while the world average exceeds 4.5 tons, and the average of OECD countries, 9.7 tons.

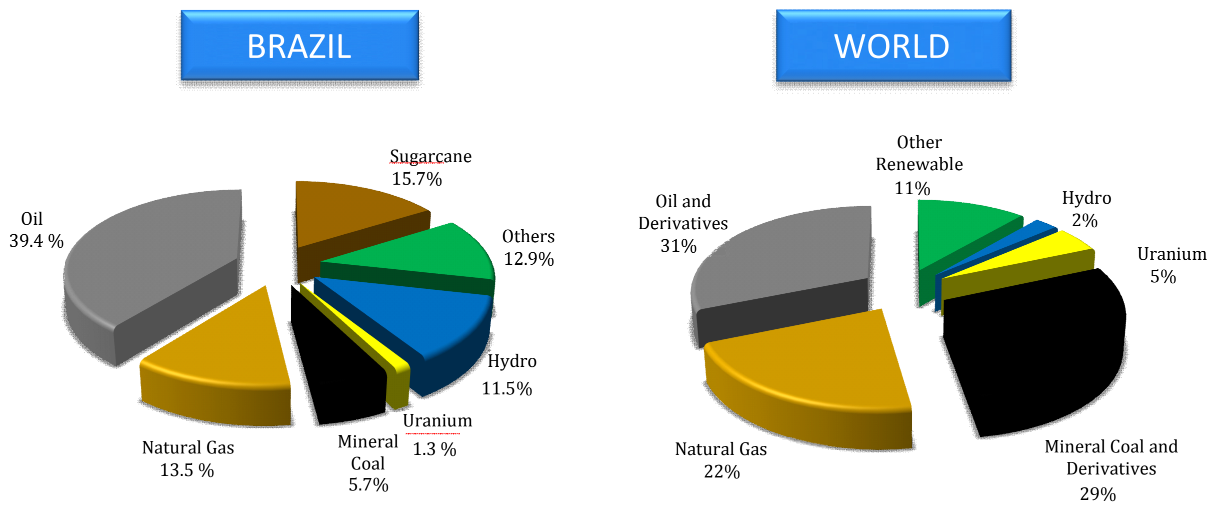
Thus, the average Brazilian have emitted about 20% of GHG of an inhabitant of OECD countries in activities related to energy production and use (Figure 4).



Source: IEA

Figure 4 - Per capita emissions related to energy production and use: International Comparison

These indicators are a result of the high relative share of renewable sources in Brazil's energy matrix, in particular thanks to hydropower and biomass (Figure 5).



Source: IEA (global data)

Figure 5 - Renewables in Brazil and the World

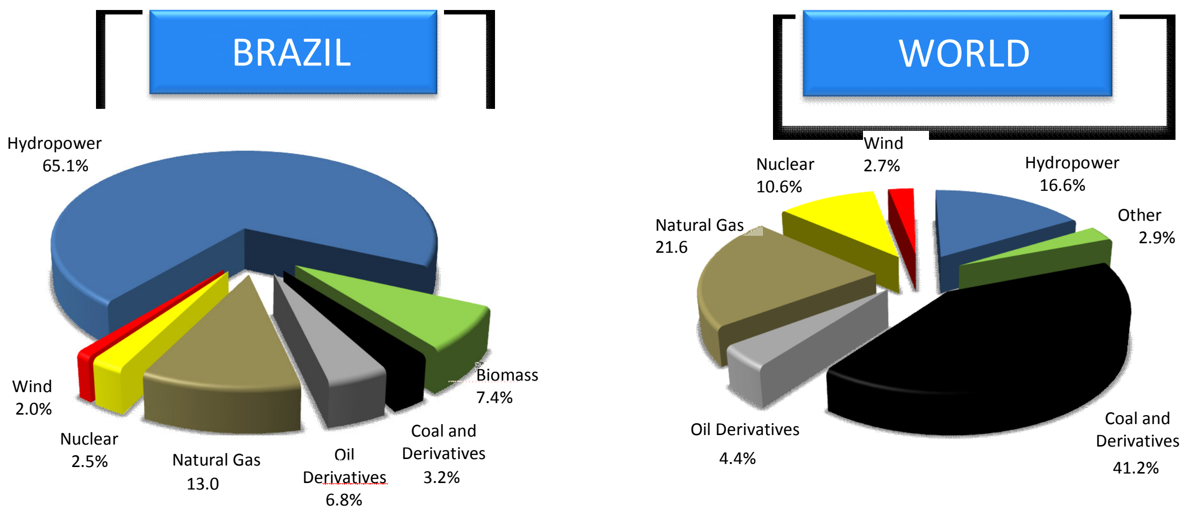
In fact, the high share of hydropower and biomass (more specifically sugarcane derivatives) in the Brazilian energy matrix reflects a long history of promoting renewable energies, as briefly shown below.

2.2. BRIEF HISTORY OF RENEWABLE ENERGY POLICIES

Brazil's energy matrix isn't just the result of the abundance of energy resources in the country. It can be said that renewability of Brazil's energy matrix has been widely conditioned by energy policies taken in the past, such as the preferential option for hydropower and promoting the use of sugarcane derivatives in the fuel matrix, in addition to energy efficiency programs, briely described below.

2.2.1. PREFERENTIAL OPTION FOR HYDROPOWER IN ELECTRICITY GENERATION

In Brazil, emissions related to electricity generation represent only 13% of the world average. This result is due to the strong predominance of renewable sources in the electricity matrix (more than 3/4 of the total), in particular the contribution of hydropower, which historically corresponds to about 2/3 of the total amount generated (Figure 6).



Source: IEA (global data)

Figure 6 - **Electricity Matrix in Brazil and the World**

Hydroelectricity has been the main source of generation of Brazil's electric system for many decades, due to its economic competitiveness and the fact that it is an abundant resource in the country. Other benefits can be added to those: it is a mature and reliable technology, its emissions are greatly reduced when compared to those associated with fossil thermoelectric generation, its operational flexibility and storage capacity allow for a greater penetration of intermittent renewable sources (as they are able to quickly respond to typical fluctuations of wind and solar photovoltaic generation, thus ensuring a reliable supply for the energy demand). In addition, the reservoirs of hydroelectric plants can provide a series of non-energy services, such as flood control, irrigation, industrial processing, water supply for human consumption, recreation and navigation services.

The exploration of this source in Brazil dates back to the late 19th century, but the more significant expansions occurred from the 50s, when there was a strategic decision by the Brazilian government to explore the country's vast hydroelectric potential.

In the 90s, with the increasing difficulty of financing state enterprises, institutional reforms were performed in the electricity sector in order to attract private investors. Also during this time, questions started emerging about the social and environmental impacts associated with the construction of large dams and financing difficulties for the construction of large hydroelectric projects, which resulted in a period of hydroelectric expansion at very modest rates, even though there was a significant hydroelectric potential to be explored.

Late hidro expansions and lower than necessary to meet the growing demand resulted in increased use of energy stored in existing hydroelectric reservoirs at the time. In 2001, due to the severity of the water crisis, insufficient energy stored in the reservoirs and reduced backup thermoelectric generation (related to the demand at the time), the federal government enacted an electricity rationing.

Currently, most of the inventoried potential is located in the Amazon and Tocantins-Araguaia river basins, where there are large extensions of protected areas (conservation units, indigenous lands and lands occupied by remaining *quilombo* communities). Due to these social and environmental conditions, hydroelectricity is expected to lose share in the following years (section 4.2), at the expense of an increased share of wind and biomass sources.

2.2.2. INSERTING SUGARCANE DERIVATIVES INTO THE FUEL MATRIX

The encouragement of ethanol expansion in Brazil's energy matrix began in the 1970s, after the first oil crisis. It was then aimed at reducing Brazil's dependence on importing energy and exposing the country to variations on international oil prices.

Since then, ethanol, replacing gasoline, has been increasing its share in the transportation matrix, also allowing for the reduction of the intensity of greenhouse gas emissions. Up to 2010, ethanol consumption represented a replacement of approximately 250 billion liters of gasoline, preventing emissions of 550 million tons of CO_2.

Today, the share of renewable fuels in the transportation matrix is about 20%. In 2011, the contribution of ethanol to reducing GHG was estimated to be 1/3 of the total emitted by light vehicles.

In addition to ethanol, there is also biodiesel contribution. Brazil works to maintain their policy of promoting the use of biofuels in their transportation matrix.

2.2.3. EFFICIENCY PROGRAMS

In addition to choosing to exploit renewable sources, Brazil has also undertaken actions and policies aimed at energy efficiency since the 1980s.

Among the national initiatives in this area, we highlight the Brazilian Labeling Program (PBE) and programs aimed at promoting an efficient use of energy (PROCEL) and gas and fuels (CONPET).

The PBE was created in 1984 with the purpose of "providing consumers with information that enables them to assess the energy consumption of household equipment and select, in their buying decision, those with a greater efficiency regarding consumption, allowing for a reduction of government investments in new power plants and of consumption for the general population."

The 2001 Energy Efficiency Act determined the establishment of maximum levels of consumption or minimum levels of energy efficiency of machines and energy consuming devices sold in the country, with the introduction of product labelling.

PROCEL was established in 1985 with the purpose of "promoting the rationalization of electricity production and consumption in order to eliminate losses and reduce costs and sectoral investments."

It is estimated that the program has generated a 32.9 TWh accumulated energy saving and reduced end-point demand in over 9,500 MW between 1986 and 2008, which means around 10,500 MW of equivalent plants.

In the period from 2006 to 2010, CONPET estimates that its programs and actions were responsible for saving over 1 billion liters of diesel oil and that this prevented about 2.8 million tons of CO_2.

2.3. CHALLENGES UP TO 2030

Even considering the recent and future path of the country's efforts in the rational and efficient energy use and production, as evidenced by the Brazilian energy matrix with a high proportion of renewables compared to international standards, the projected economic growth on the horizon until 2030 will lead to an increased energy use, as the national socioeconomic indicators are still relatively distant from those of developed nations.

Thus, Brazil's main challenge, unlike the iNDC of other countries, is not to increase the renewability of their energy matrix, but to maintain the high proportion of renewable energies, with a greater inclusion of the so-called "new renewables", in a context of growth of energy consumption by 2030.

On the consumption side (Chapter 3), we can identify the challenges related to Brazil's iNDC in three dimensions, illustrated in Figure 7 and described below:

1. Energy efficiency is one of the most important instruments of the Brazilian strategy to reduce energy consumption and anthropogenic GHG emissions (see section 3.1.4).
2. It is also expected that an increasing consumption is met by self-production and expansion of distributed generation (see section 4.1).
3. Disregarding the expansion of self-production and distributed generation and including the gains associated with a greater energy efficiency, it is expected that the growth of final energy consumption is approximately 160 million toe in the period between 2014 and 2030, with average growth rates of 3.0% per year.

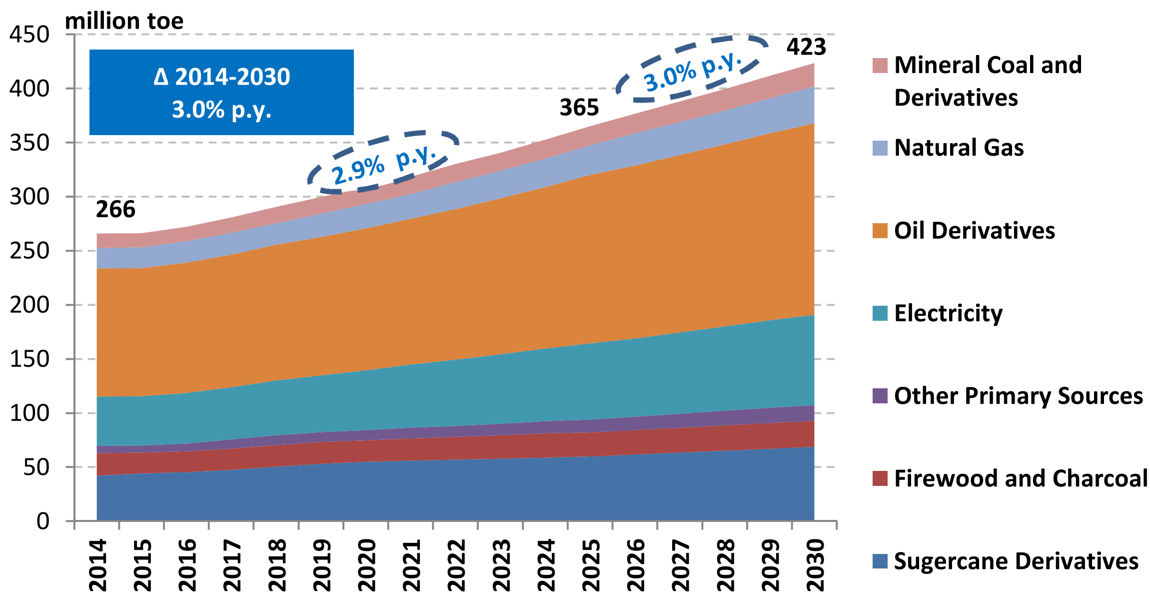


Figure 7 - Final energy consumption up to 2030

With emphasis on natural gas, electricity, oil derivatives and biofuels (section 3.3), the evolution of energy end-use is conditioned by the perspective of demographic trend (section 3.1.1), economic expansion (section 3.1.2) and its effects on the various consumption classes, in particular, of the industry and the transportation sector, which represent around 2/3 of the total consumption and whose relative shares change little in the period between 2014 and 2030 (Figure 8).

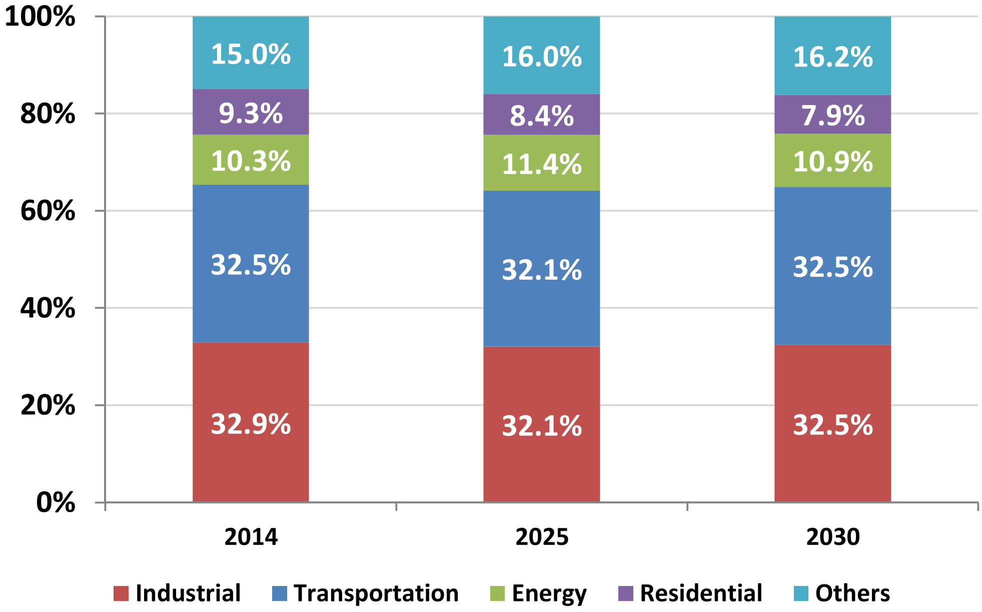


Figure 8 - Sectoral share in final energy consumption

The Transportation Sector energy matrix (Figure 9) is very concentrated on Diesel Oil and Automotive Gasoline (about 75% in 2014), but its aggregate share will be smaller thanks to the expansion prospective for ethanol, biodiesel and electric vehicles, whose aggregate share gain is 7 percentage points between 2014 and 2030.

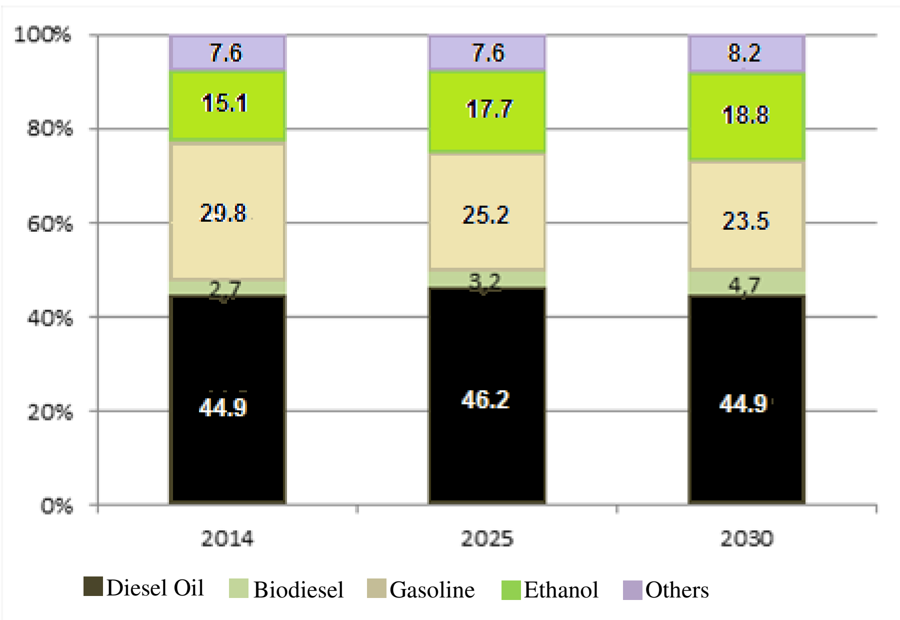


Figure 9 - Fuel share in final energy consumption - Transportation Sector

In the industry, end consumption is more diverse, when compared to the transportation sector: electricity, sugarcane bagasse and natural gas currently make up about 50% of the sector's energy requirements.

We highlight the small gain in relative share for electricity and the increased end consumption for renewable sources by 2030, as there is also a small gain in share in the sum of percentages of Sugarcane Products and Other Renewables, as shown in Figure 10.

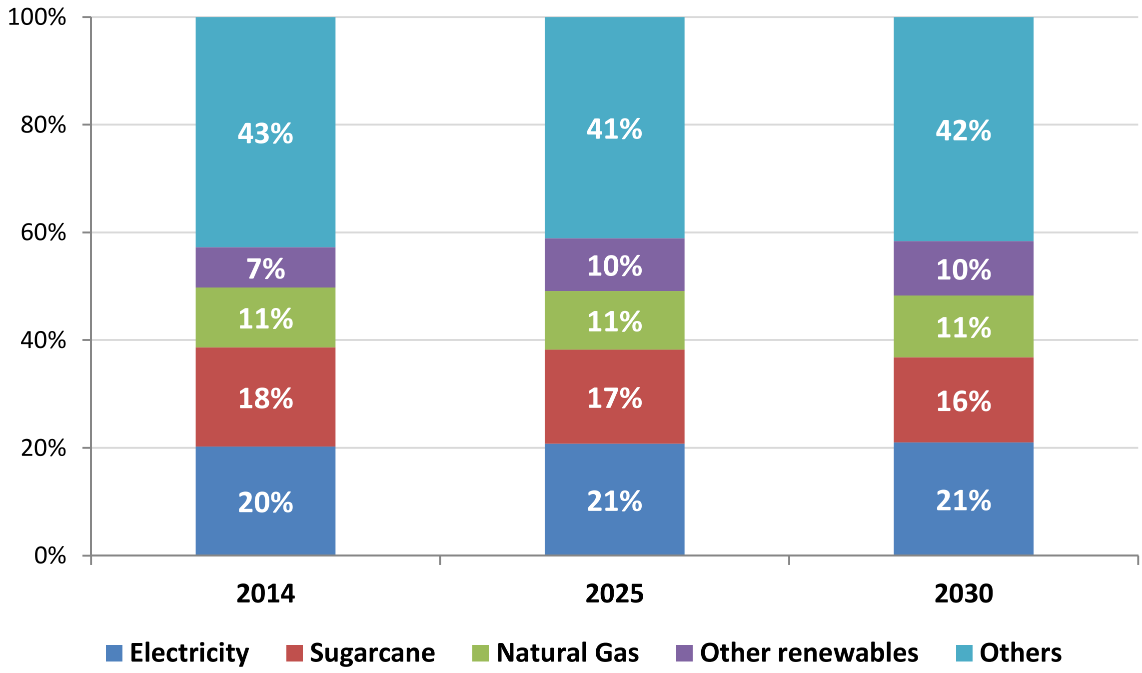


Figure 10 - Final energy consumption in the Industry

Consequently, in order to tackle increasing emissions associated with energy production and use in a manner consistent with the requirements for economic growth and mitigation of climate change, policies and actions are required both on the energy use side and the production side, embodied in the following commitments.

2.3.1. MAINTAIN A HIGH SHARE OF RENEWABLES IN THE ENERGY MATRIX BY DIVERSIFYING RENEWABLE SOURCES

In terms of energy matrix, Brazil's goal is to achieve a 45% share of renewable energies by 2030, according to the trend shown in Figure 11.

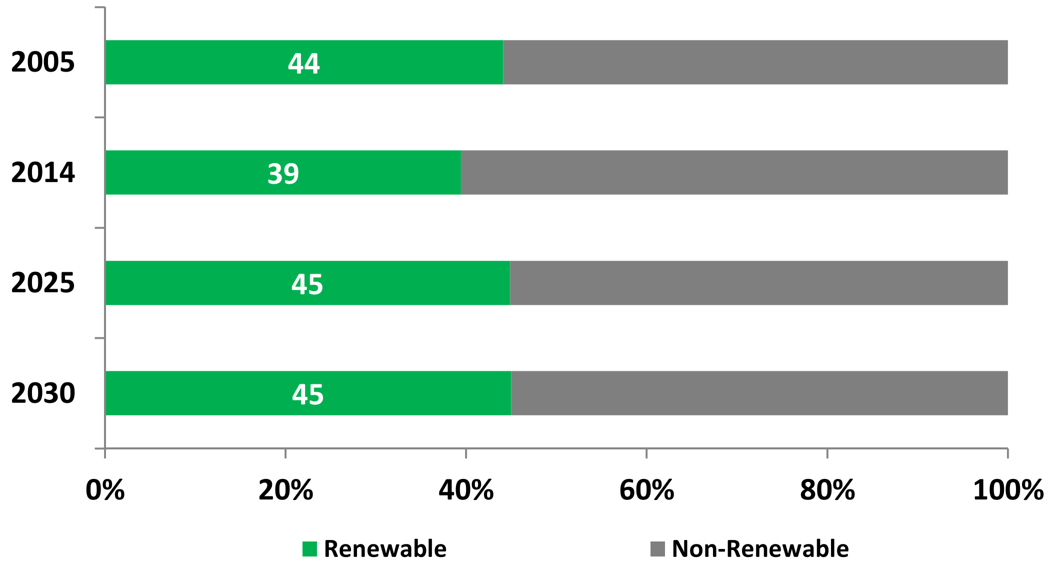


Figure 11 - The share of renewables up to 2030

After the decline in 2014, caused by unfavorable hydrological conditions, Brazil is expected to recover the proportion of renewables and reach 45% by 2025. Although this number may initially seem hardly challenging, recovering the 45% proportion of renewables in the energy matrix contains a great challenge both in obtaining a greater diversification of sources (with the contribution of "new renewables") and in the absolute values of the associated expansion (Table 2):

- The increase in domestic energy supply is estimated at 105 million toe between 2014 and 2025 and 176 million toe between 2014 and 2030, which represents respectively 34% and 58% increases in the corresponding periods.
- The portion of this increase corresponding to the expansion of renewables is significant: 64 million toe between 2014 and 2025 (which represents 61% of the total increase) and 96 million toe (54% of the total increase) between 2014 and 2030.
- About 1/3 of the increase corresponding to renewables comes from the contribution of sugarcane derivatives and vegetable oil, raw materials for biodiesel. Altogether, it is estimated that these sources will increase in 23 million toe between 2014 and 2025 and 38 million toe between 2014 and 2030. In particular, it is expected that the growth in sugarcane derivatives is 21 million toe between 2014 and 2025 and 33 million toe between 2014 and 2030.

- The share of sustainable bioenergy (products derived from sugarcane and vegetable oil, notably biodiesel) will make up 18% of the energy matrix in 2030, reiterating its importance to energy renewability in the country.

- Wind, solar and other sources (black liquor for the most part) rise in all approximately 20 million toe between 2014 and 2025 and 29 million toe between 2014 and 2030. Especially in the period from 2025 to 2030, their growth exceeds the expected expansion of hydropower, estimated at 24 million toe.

- It is estimated that, not considering hydropower, other renewable sources will represent 33% of Brazil's energy matrix in 2030, which evidences both the abundant availability of renewable sources in the country and their economic viability along the horizon.

Table 2 - Domestic Energy Supply

Source	2005	2014	2025	2030	2014-2025 Increase	2014-2030 Increase
	million toe					
Renewable Energy	96,117	120,489	184,097	216,820	63,608	96,331
Hydropower	32,379	35,019	53,209	59,949	18,190	24,930
Other Renewables	63,738	85,470	130,888	156,871	45,418	71,401
Sustainable Bioenergy	30,150	50,321	73,545	88,421	23,224	38,100
Sugarcane Derivatives	30,150	48,128	69,087	80,940	20,959	32,812
Vegetable Oil (Biodiesel)	0	2,193	4,458	7,481	2,265	5,288
Wind	8	1,050	7,898	8,989	6,848	7,939
Solar	0	0	1,075	3,056	1,075	3,056
Other	5,112	9,370	21,037	27,383	11,667	18,013
Non-Renewable Energy	121,819	185,100	226,153	265,152	41,053	80,052
Total	217,936	305,589	410,240	481,972	104,651	176,383

Based on these projections, two specific commitments in biomass sources and in the use of renewable sources, excluding hydropower, have been established:

- Increase the share of sustainable bioenergy in the energy matrix to approximately 18% by 2030.

- Expand the use of renewable sources, other than hydropower, in the total energy matrix to a 28% to 33% share by 2030.

2.3.2. MAINTAIN A HIGH SHARE OF RENEWABLES IN THE ELECTRICITY MATRIX BY DIVERSIFYING SOURCES

In electricity generation, the established commitment is to obtain at least a 66% share of hydropower in electricity generation, by 2030, without considering the self-produced portion. Currently, this number is about 70% of electricity generation in the country, a level that should continue on the horizon until 2025, dropping to 66% only in the period from 2025 to 2030 (Table 3).

Table 3 – Evolution of Centralized Power Generation

Sources	2005	2014	2025	2030	2005	2014	2025	2030
	TWh				relative share (%)			
Hydropower	373	404	612	690	90	71	71	67
Biomass (*)	1	18	55	76	0	3	6	7
Solar	0	0	13	26	0	0	2	3
Wind	0	12	92	105	0	2	11	10
Non-Renewable Energy	39	137	85	136	9	24	10	13
Total	413	572	858	1,033	100	100	100	100

Note: (*) Includes biogas, bagasse, black liquor and firewood.

In absolute terms, the expected increase in centralized electricity generation is 286 TWh in the period between 2014 and 2025 and 461 TWh between 2014 and 2030, which represents in both cases more than 85% of expansion in total generation.

Part of the expansion of the electricity generating facilities will also occur through self-production, which should represent 10% of the total electricity generation (Table 4). In particular, self-produced electricity in the industrial sector is an important portion of the supply that should be considered, especially when it comes to mostly renewable resources.

Table 4 - Relative Share of Energy Sources in Electricity Generation

Sources	2005	2014	2025	2030	2005	2014	2025	2030
	TWh				relative share (%)			
Hydropower	**375**	**407**	**618**	**697**	**86**	**66**	**65**	**61**
Centralized	373	404	612	690	86	65	64	60
Self-Production & DG	2	3	6	7	0	1	1	1
Biomass (*)	**9**	**41**	**102**	**134**	**2**	**7**	**11**	**12**
Centralized	1	18	55	76	0	3	6	7
Self-Production & DG	8	23	47	58	2	4	5	5
Solar	**0**	**0**	**16**	**35**	**0**	**0**	**1**	**3**
Centralized	0	0	13	26	0	0	1	2
Self-Production & DG	0	0	3	9	0	0	0	1
Wind	**0**	**12**	**92**	**105**	**0**	**2**	**10**	**9**
Non-Renewable Energy	**52**	**163**	**124**	**180**	**11**	**25**	**14**	**15**
Centralized	39	137	85	136	8	21	10	11
Self-Production & DG	13	26	39	44	3	4	4	4
Total	**436**	**624**	**953**	**1,151**	**100**	**100**	**100**	**100**
Centralized	413	572	858	1,033	95	92	90	90
Self-Production & DG	23	52	95	119	5	8	10	10

Note: (*) Includes biogas, bagasse, lixivium and firewood.

Also considering self-production, the share of renewable sources in electricity generation, other than hydroelectric energy, jumps from 9% in 2014 to 24% in 2030, as established in the following commitment:

- Expand the domestic use of non-fossil energy sources, increasing the share of renewables (other than hydropower) in the electricity supply to at least 23% by 2030, including by increasing the share of wind, biomass and solar energy.

2.3.3. OBTAIN 10% OF ELECTRICAL EFFICIENCY BY 2030

The efficiency goal in the electricity sector is to reach the 10% level of electricity consumption by 2030, which will correspond to 105 TWh in 2030. This amount is equivalent to 1/6 of the expansion in electricity consumption in the period from 2014 to 2030 (Figure 12).

Due to the expected efficiency gains (section 3.1.4), it is estimated that the prevented electricity consumption is 105 TWh, which represents about 20% of the estimated increase in consumption in the period between 2013 and 2030, redounding in the commitment to obtain 10% of electrical efficiency in 2030.

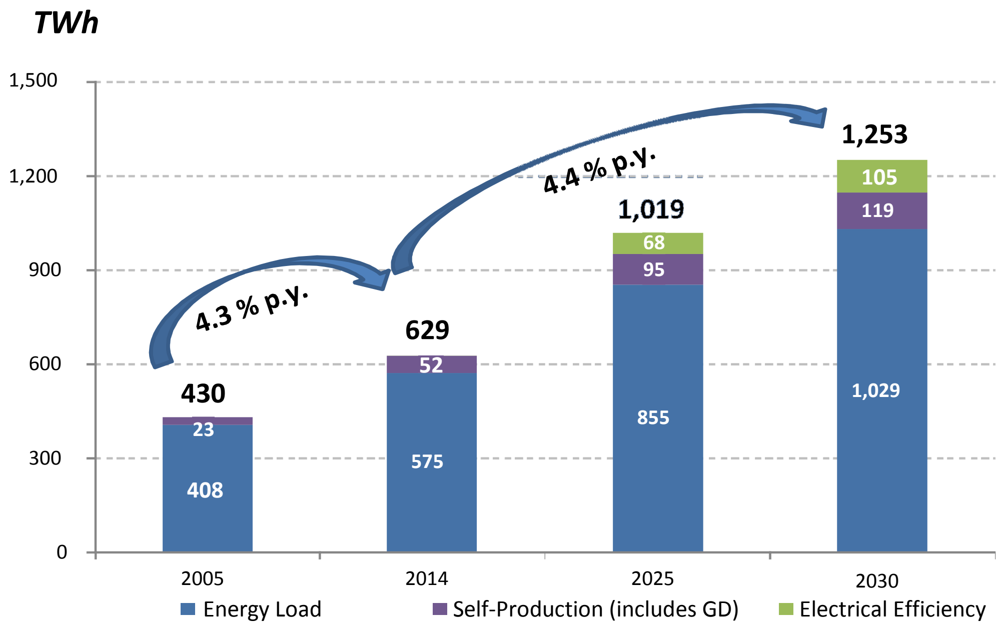


Figure 12 - Projected Electricity Consumption

This significant increase in the efficiency rate will require additional efforts related to public policies to encourage the acceleration of energy efficiency actions in the country, with the use of more efficient equipment and consumption patterns.

The penetration of more efficient equipment is conditioned, both from a part of the supply of these equipment and the consumer's power of choice. Under the supply point of view, the production of new equipment with different levels of end service and energy efficiency indexes is highlighted.

2.3.4. MAINTAIN A HIGH PROPORTION OF RENEWABLES IN THE FUEL MATRIX

The commitment regarding renewables is also based on the increase in sustainable bioenergy share in Brazil's energy matrix on the horizon analyzed in at least three fronts:

- Increase in ethanol supply in 25 billion liters: it is considered that the anhydrous content in Gasoline C will be maintained at 27% throughout the study period. As a result, the consumption of fuels in the Otto cycle shows an increase in total ethanol share, which in 2014 was 40%, reaching 45% in 2030, as seen in Figure 13 which, for proper comparison, is shown in liters of gasoline equivalent.

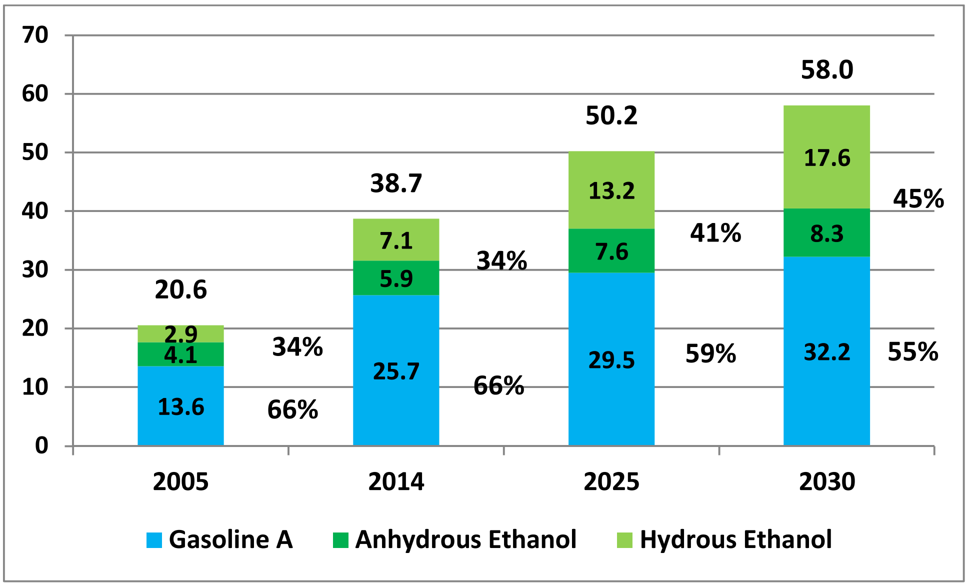


Figure 13 - Fuel Consumption in the Otto Cycle

- Increase in the proportion of advanced biofuels (second generation). It is estimated that the production of first-generation ethanol will grow from 29 billion liters in 2014 to 51 billion liters in 2030, while second-generation ethanol will begin showing up in considerable volumes starting from 2023, reaching 2.5 billion liters at the end of the period. Thus, the total ethanol available will be 54 billion liters in 2030 (Figure 14).

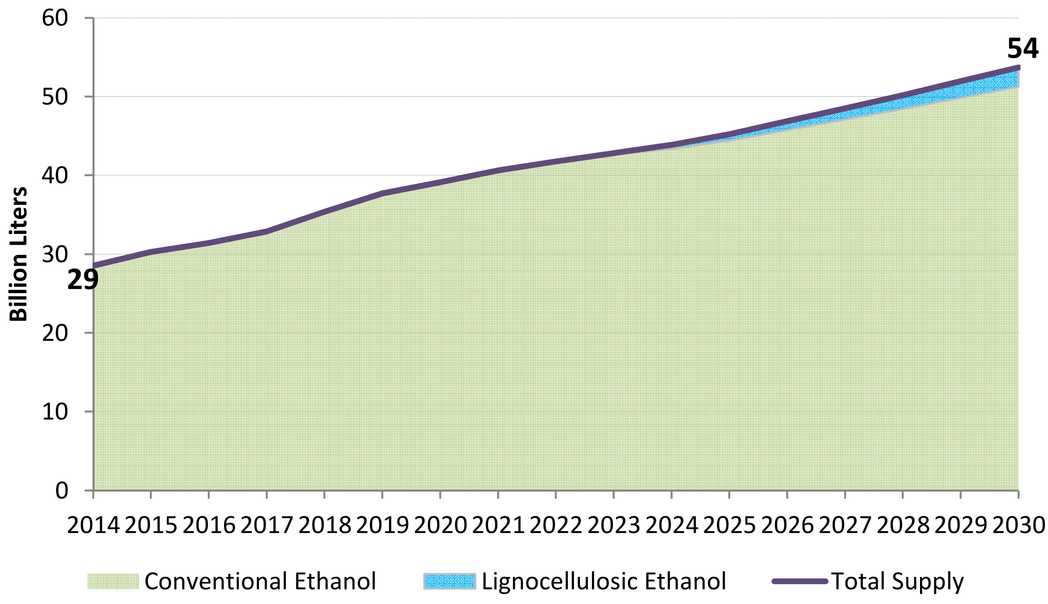
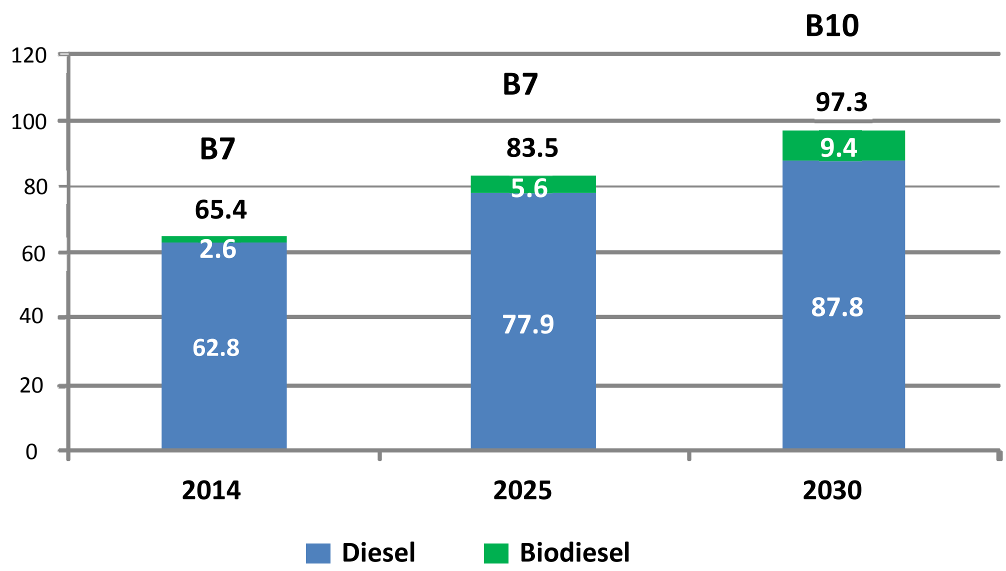


Figure 14 - Projected Ethanol Supply

- Increase in the portion of biodiesel in diesel blend. The total energy demand in the Diesel cycle will grow, in average, 2.5% per year until 2030, while the biodiesel demand grows faster (8.4% per year) given the increase in the share of vegetable diesel in mineral diesel from 7% to 10% in the analyzed period (Figure 15). The lowest growth rate of energy demand in relation to that of cargo transportation activity is explained by the technological advances in transportation modes, reflected in efficiency gains, and the improved logistics infrastructure, which allows for an increasing share of less energy-intensive modes.



Source: EPE

Figure 15 - Diesel Cycle: Consumption

From these estimates, the following goal for renewables in biofuels has been established:

- [Expand] the consumption of biofuels, increasing ethanol supply, including by increasing the proportion of advanced biofuels (second generation), and increasing the proportion of biodiesel in the diesel blend. This is equivalent to reaching about a 24% share of biofuels (ethanol and biodiesel) in the total consumption in transportation in 2030.

Therefore, one of the main reasons for the decline in the share of oil derivatives in the matrix on the horizon is due to the greater penetration of biofuels in the transportation sector, particularly ethanol in individual transport vehicles.

2.4. PROJECTION OF GHG EMISSIONS

The resulting GHG emissions projected for 2025 and 2030 are shown in Table 5 per fuel.

Table 5 - GHG Emissions per Fuel

Fuel	2005	2025	2030
	million tons of CO_2 eq		
Diesel Oil	106	203	229
Natural Gas	44	86	116
Gasoline	40	86	94
Steam Coal	17	40	40
Petroleum Coke	16	30	35
LPG	19	27	29
Kerosene	5	16	20
Fuel Oil	23	16	19
Refinery Gas	10	16	16
Other Secondary Oil Sources	7	8	9
Other Primary Sources	4	8	9
Naphtha	6	7	7
Coke Oven Gas	2	5	6
Sugarcane Products	2	4	4
Non-Energy Petroleum Products	1	3	4
Mineral Coal Coke	2	3	3
Firewood	8	2	2
Charcoal	2	2	2
Tar	0.4	1	1
Anhydrous & Hydrous Alcohol	0.1	1	1
Fugitive	19	36	43
TOTAL	332	598	688

Note: The 2005 data come from the II National Inventory

Brazil's GHG emissions broken down by fuel show the preponderance of diesel oil, natural gas and gasoline which make up more than 60% of emissions in 2025 and 2030, in addition to jointly making up 70% of the increase in total emissions between 2005 and 2030.

The consumption of diesel oil and gasoline are preponderant in the transportation sector. In fact, Brazil's GHG emissions broken down by sector (Table 6) indicate that the transportation sector, which made up 40% of emissions in the base year of 2005, will reach 45% of emissions in 2025 and 2030. Indeed, the transportation sector will make up almost 55% of the increase in total emissions between 2005 and 2025 and half of the increase in total emissions between 2005 and 2030.

In turn, natural gas is mainly consumed in the industry and energy sector and is used in electricity generation. Almost 40% of total emissions in 2030 are concentrated in the energy, industrial and electricity sectors, whose additional emissions will jointly make up for a little over 35% of the increase in total emissions between 2005 and 2025, rising to approximately 38% in the period between 2005 and 2030.

Table 6 - Results of GHG Emission Projections per Sector

Sector	2005	2025	2030
	million tons of CO_2 eq		
Energy Sector	28	46	49
Residential	18	22	24
Commercial	2	3	3
Public	2	1	1
Agriculture and Livestock	15	22	24
Transportation	135	278	315
Industrial	87	130	156
Energy Consumption	79	114	136
Non-Energy Consumption	8	16	20
Electricity Sector	26	60	73
Electricity Sector - SIN	17	40	50
Electricity Sector - Self-Production	9	20	23
Fugitive Emissions	19	36	43
TOTAL	332	598	688

Note: The 2005 data come from the II National Inventory

The following chapters detail the projected scenario in final energy consumption utilized to establish the Brazilian commitment assumed in COP 21.

3. FINAL ENERGY CONSUMPTION

Initially, it is important to highlight that the energy demand path represented herein cannot be characterized as a trend, as they are considered complementary measures to those that would occur in a "business-as-usual" (BAU) path. In other words, the projection of energy consumption used to support the Brazilian commitment in COP-21 embeds actions that allow for mitigating emissions of greenhouse gases and that would not occur in a BAU path.

In particular, the viability of the path of energy efficiency penetration in the economy will require promoting additional legislative efforts for preparing/creating policies and mechanisms to encourage energy efficiency in the country. Specific actions include, for instance: maintaining a strong labelling agenda and establishing minimum energy efficiency indexes on equipment, promoting the modal transformation of cargo transportation, encouraging the improvement of the urban mobility structure (e.g. with partial discouragement of individual motorized transport), establishing mandatory percentages of biodiesel, encouraging less energy-intensive buildings, etc. In this context, actions that will be required for encouraging the increasing penetration of distributed energy and biogas are also highlighted, with the potential for applying in specific niches such as the use of biomethane for vehicular use.

It is also necessary to warn that the numbers shown herein refer to the consumption of energy in the so-called end consumption sectors, comprising only energy use for own consumption. In plants that produce energy (electricity generating stations, refineries, ethanol distilleries, oil production platforms, etc.), the projections take into account only those destined for the consumption of their facilities.

3.1. MAIN CONDITIONS

In the face of the numerous uncertainties that condition the final energy consumption, the study identified the following key aspects on the horizon by 2030:

- **The demographic trend** with an increase of approximately 27 million inhabitants in the period from 2010 to 2030.
- **The economic growth of 3.3%** per year in average in the period of 2014 to 2030, making the per capita GDP increase in almost 50%.
- **The future pattern of urban mobility**, an aspect that will deeply influence the energy consumption pattern and environmental aspects of the cities and the quality of life standard of the general population, depending on the transport conFiguretions that are adopted, involving, for example, discouraging the use of motorized individual transport, encouraging quality public transport, among others;

* **The light vehicle fleet profile trend,** with the predominance of flex fuel vehicles, but with the prospect of an increasing competitiveness of vehicles with electric propulsion along the horizon.
* The dynamics of the **pattern of use** of machines, equipment of Brazilian consumers and the penetration of new technologies, influenced by the increase in average per capita income of the population concomitant with the expected social mobility movement, which drives an increasing demand for new equipment in Brazilian households, for higher quality services, among others. In all sectors, these aspects impact the level of energy consumption, the way in which this consumption occurs and which sources are in higher demand;

Each key aspect described is shown in the following items. Further details are available on Technical Note "Economic Scenarios 2050"[1].

3.1.1. DEMOGRAPHIC TREND

Brazil has undergone a major change in their demographic profile. In recent years, the population growth rate has been significantly reduced, particularly due to the decline in their fertility rate (IBGE, 2010).

The expected trend of the Brazilian population until 2030 is shown in Figure 16. An increase of approximately 27 million inhabitants in the period from 2010 to 2030 is expected.

[1] Available on the EPE website at: http://www.epe.gov.br/mercado/Paginas/Estudos_27.aspx.

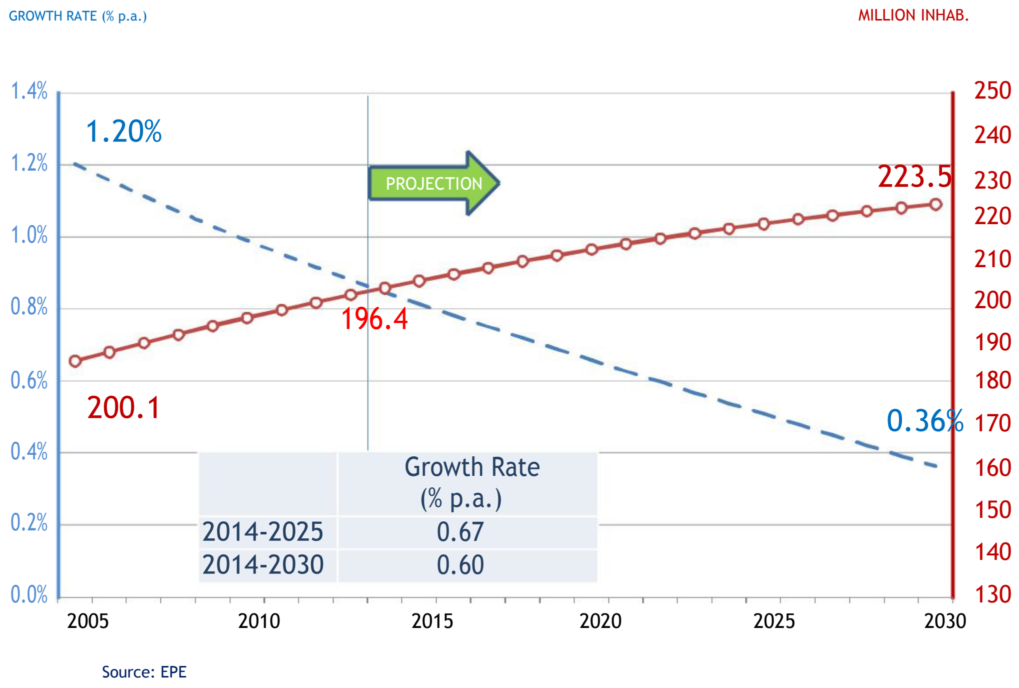


Figure 16 - Population Trend and Growth Rate

3.1.2. MACROECONOMIC DEVELOPMENT

On the 2030 horizon, we consider a context in which the country is relatively successful in managing their strengths and weaknesses, i.e. facing their main obstacles (although a few aspects are not fully resolved in the studied horizon) allows them to unlock the growth potential of the Brazilian economy. It is important to stress that this exercise is characterized as a non-trend, as it considers complementary measures to those that would be adopted in the natural evolution of the economy sectors.

For this, efforts are needed both in the production environment and in the regulatory, tax and infrastructure sectors. Among the measures of the first case, the significantly improved energy efficiency rate considered is worth mentioning, as well as the productivity gain – partly due to the universalization of quality education.

In order to endure competitiveness in the entire production chain, especially in the industry, the great recognized effort to reduce logistics and tax costs has been considered.

Finally, by virtue of the international negotiations on global environmental issues, this exercise considers the mitigation of the emissions of gases responsible for global warming high above what would happen in the trend path.

The ten-year projection of average economy growth rates is shown in Figure 17, as well as the historical average growth, for comparison purposes. Premises related to the demographic and economic prospects can be found in Technical Note "Economic Scenarios 2050"[2].

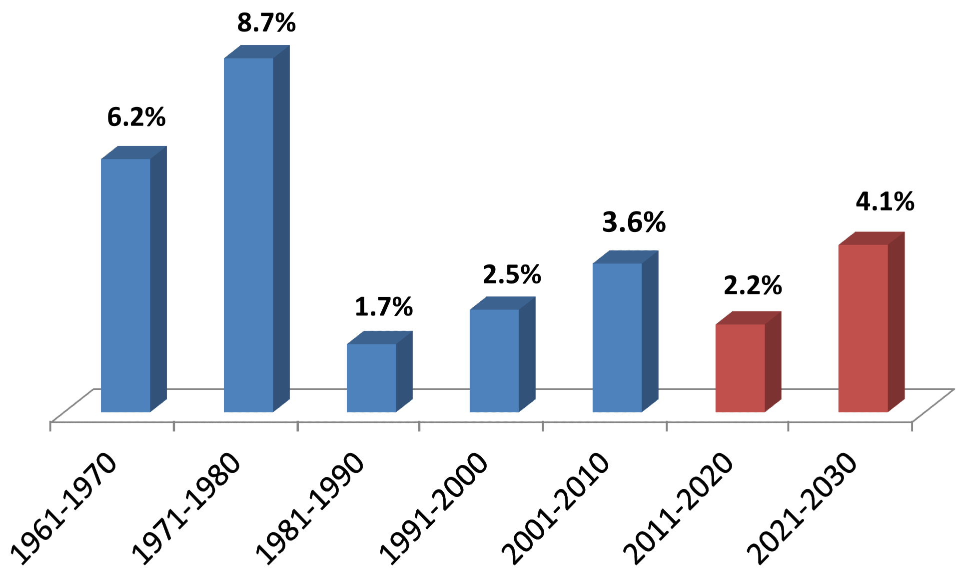


Figure 17 - Average Rates of Economic Growth

[2] Available on the EPE website at: http://www.epe.gov.br/mercado/Paginas/Estudos_27.aspx.

From the projection for the population and the path for Brazil's GDP, Figure 18 gives us the trend for the growth rate of per capita GDP, where Brazil will reach the value of per capita income that will place the Brazilian population near the levels between Argentina and Italy nowadays.

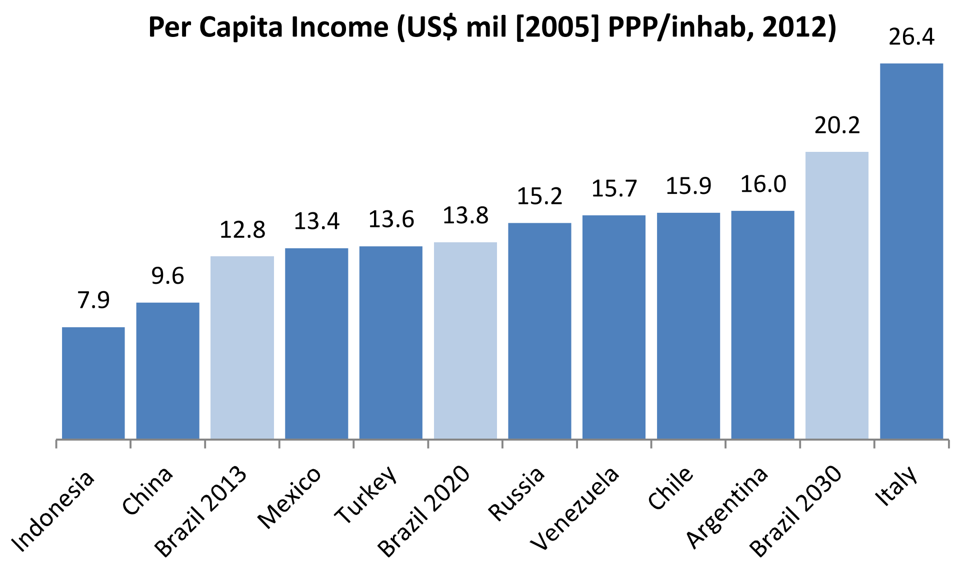


Figure 18 - Projected Brazilian Per Capita Income and International Comparison

Source: IEA, 2014: Key World Energy Statistics 2014 and EPE (2015).

As a result, the economy's demand for goods and services should also have a significant development along the horizon, which, combined with an expected process of better income distribution, will drive the inclusion of a substantial number of consumers, i.e. various families will have access to certain goods that they did not own before.

3.1.3. CHANGES IN CONSUMER OWNERSHIP AND HABITS

Even considering that Brazilians have a thriftless consumption pattern than some developed nations, the still low per capita consumption of much of the population should grow on the horizon due to the increase in (and better distribution of) available income. Thereby, an increase in ownership of equipment such as air conditioners, light bulbs, television sets, washing machines, among others is expected.

Table 7 shows the evolution of ownership indicators for selected equipment in the period.

Table 7 - Evolution of Average Ownership for Selected Equipment

Equipment	2014	2030
Air Conditioner	0.41	0.88
Refrigerator	1.04	1.03
Light Bulb	8.20	9.12
Shower	0.66	0.57
TV	1.70	2.25
Washing Machine	0.69	0.82
Freezer	0.18	0.14

Besides these, it is estimated that there will be a significant increase in ownership of other electronic equipment, which currently represent 24.5% of consumed electricity and are estimated to make up 37% in 2030. At the comparison level, in the USA, in 2009 these equipment already represented 55% of residential consumption.

The premise of an increase in the intensity of equipment use is also considered, both for the already mentioned increasing income availability and the increasing use of technologies for entertainment, interconnectivity of people and equipment and new habits that will expand on the horizon, such as distance work.

On the horizon of the study, the introduction and expansion of the "smart grid" in the sector is expected, enabling the use of smart household equipment that consume energy in off-peak hours, with different rates. This equipment may be pre-programmed to operate at alternative times, according to the rate value. This technology also enables the expansion of electric vehicles; however, in this case, even when the vehicle refueling occurs at home, for the purpose of our study, the amount of electricity consumed in this case will be accounted for in the transportation sector, as the methodology used herein follows the classification adopted in the National Energy Balance.

3.1.4. ROLE OF ENERGY EFFICIENCY ACTIONS

The role of the end consumer as an active agent in the energy market includes both demand response actions such as energy efficiency and load management actions, and on the supply side, generating their own energy. In both situations, the result is a reduced need for the expansion of centralized power plants in the country.

Figure 19 illustrates schematically this impact on power generation, where it can be observed that, without the contribution of the portion of energy efficiency and own energy generation (distributed generation and self-production), the portion to be met by centralized power generation would be much larger.

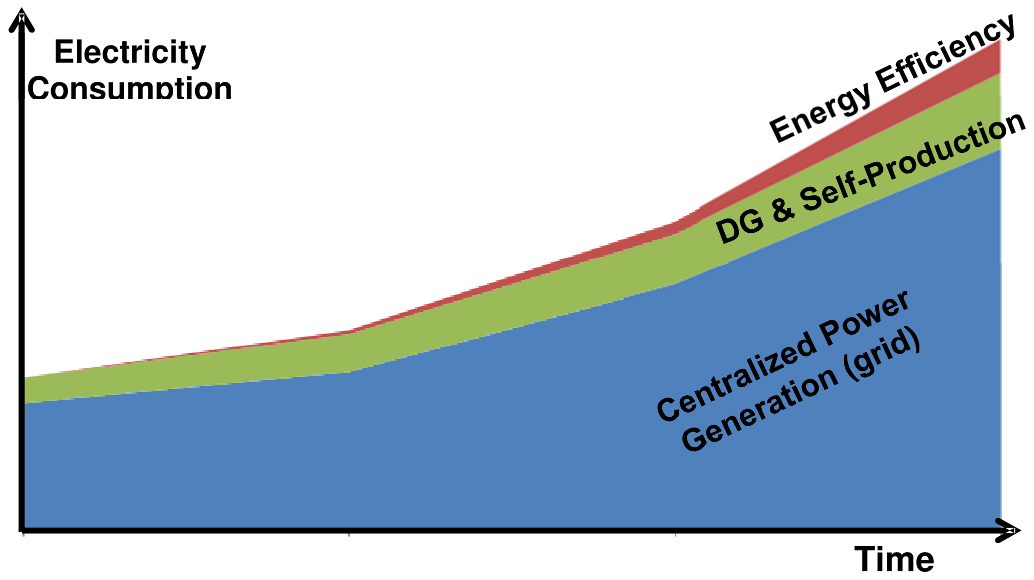


Figure 19 - Options to Fulfill the Electricity Demand

Another portion with a relevant contribution until the 2030 horizon refers to the gains in energy efficiency, which comprises one of Brazil's iNDC measures, assuming they can reach 10% of efficiency gains in the use of electricity by 2030 (Figure 20), which is equal to preventing the expansion equivalent to two hydroelectric plants the size of Itaipu. Enabling the contribution of these gains in this horizon will surely require public policies and encouragements for this energy efficiency market to be realized.

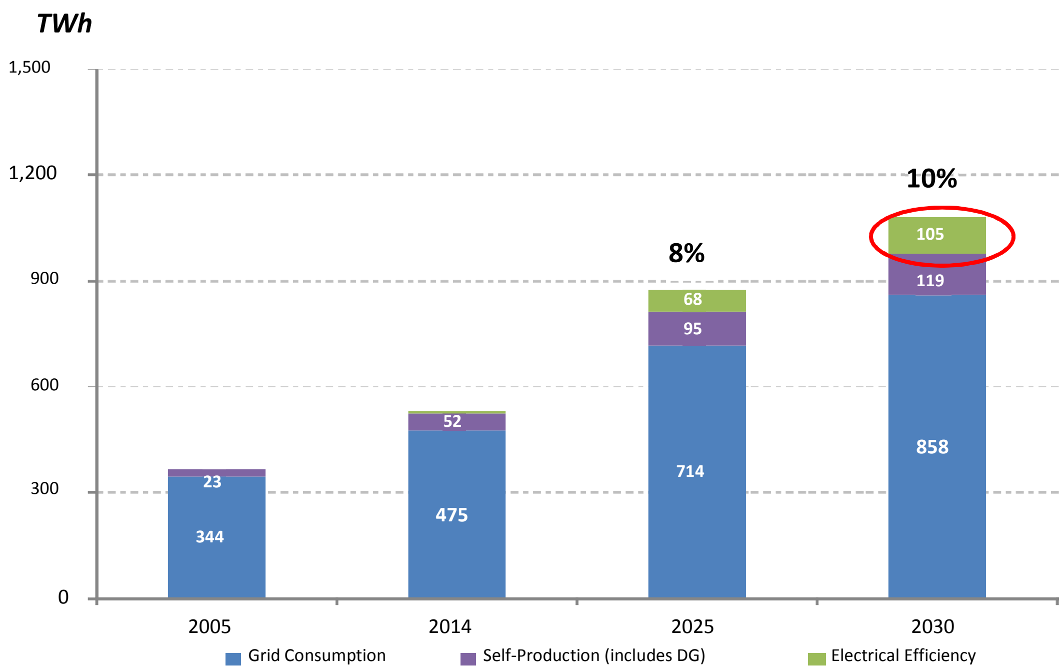


Figure 20 - Electrical Efficiency Gains

Note: Considers the electricity consumption of SIN, isolated systems and self-production. Losses are not considered in the efficiency calculation

The contribution of energy efficiency to reducing energy demand in this study is achieved through the penetration of more efficient technologies in all sectors, through the change, even if gradually, in patterns of consumption and also through structural changes resulting in less energy-intensive conFiguretions (in this case, we can mention the transformation of the cargo transportation modal structure).

It is acknowledged that achieving this contribution is the result of the action of two distinct dynamics for the penetration of these energy efficiency gains:

- The first one involves the trend movement of the energy end-consumer, motivated both by the existing regulatory environment and individual decisions not directly related to this environment. In this case, we include equipment change decisions at the end of its service life, effects of conservation policies, programs and actions in force in the country, and it is correct to associate this movement with a "business-as-usual" path.
- The second dynamic for enabling these energy efficiency gains requires establishing additional programs and actions (i.e. not yet in force) geared towards the promotion of energy efficiency. This portion then mainly relates to the action of public policies related to the subject. Along the horizon of this study, typologies of mechanisms for encouraging energy efficiency to be developed are shown in Table 8.

Table 8 - Mechanisms Considered for Enabling Energy Efficiency Gains

Mechanism	Main Target Sectors
Equipment labelling	All Sectors
Sectoral Energy Conservation Programs	Industry & Commerce/Services
Minimum Energy Consumption Rates	All Sectors
Efficient Building labelling	Commercial, Public and Residential
Programs for Energy Efficiency in Sustainable Public Sector	Public Sector
Encouragement of Penetration of Smart Grids (SG)	All Sectors

As a result of the simultaneous effect of both dynamics of energy efficiency gain, in 2030, energy efficiency contributes to reducing the total energy demand (considering all energy sources) in about 9% and, specifically for electricity, in approximately 10%.

Specifically with respect to energy efficiency gains in electricity consumption, translated in Brazil's commitment in the form of an iNDC, the total gains are approximately 105 TWh in 2030, which is equivalent to preventing the installation of about 25,500 hydroelectric MW. Sectors such as industry, residence and commerce are the ones that contribute the most to these gains, as can be seen in Figure 21.

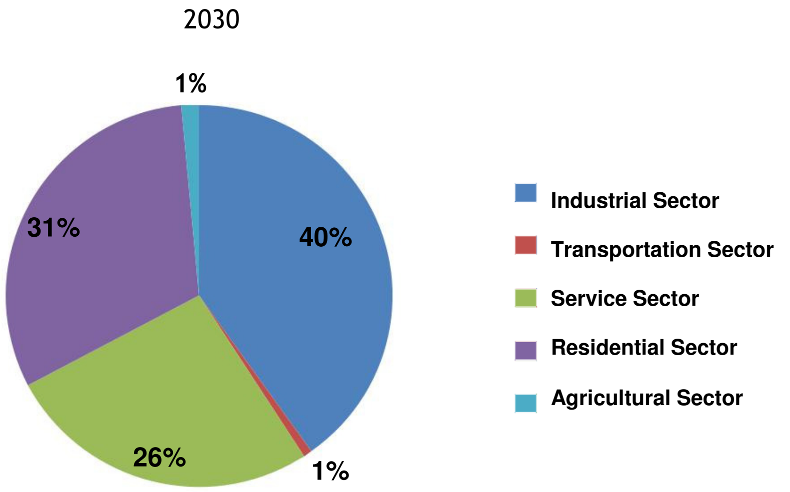


Figure 21 - Electrical Efficiency Gains per Sector

In the case of Brazilian industry, the specific electricity consumption shows a progressive decline (Table 9), with the exception of the ferroalloy industry, whose specific consumption results from two mutually antagonistic effects: efficiency gains in the production of specific alloys and the growth in the production of alloys with higher specific consumption compared to the rest; the latter prevails, resulting in a sectoral development of 0.2% of specific consumption growth by 2030.

Table 9 - Major Industrial Consumers: Specific Electricity Consumption

Segment	2013	2030
	kWh per ton produced	
Primary Aluminum	14,826	13,326
Alumina	299	268
Bauxite	13	12
Crude Steel	507	443
Pelletizing	49	47
Soda-Chlorine	2,727	2,657
Petrochemical (Ethylene)	1,573	1,486
Cellulose	980	902
PAR	2,189	2,060
Paper	791	791
Ferroalloys	8,471	9,180
Copper	1,545	1,427
Cement	112	101

In Brazilian residences, it is accepted that the progressive increase in the average efficiency equipment stock is due to the movement for replacement of these devices at the end of their service life with more efficient ones. Because of possible technological changes on this horizon, this study addressed equipment groups in typologies of energy service provided to residential consumers, whose premises of development of the energy efficiency gains are shown in Table 10, resulting in total gains presented in Table 11.

Table 10 - Efficiency Gains per Energy Services

Energy Service	Annual Increase in Efficiency (%)	Specific Reasoning
Air Conditioning	0.90	Significant increase in ownership and use, with a reduction in average power per consumption class.
Entertainment	1.10	Increase in ownership and use.
Cooking	0.01	Increase in average power due to the introduction of electric stoves, increase in ownership and use.
Water Heating	0.15	Decline in the number of inhabitants per household.
Refrigeration	0.08	Decline in the number of freezers and significant increase in ownership of duplex and side-by-side refrigerators.
Lighting	0.16	Replacement of incandescent bulbs with fluorescent ones and LEDs, increase in the average number of bulbs per household.
Other Household Services	0.30	Significant increase in ownership and use.

*Except for light bulbs and air conditioners

Table 11 - Estimated Efficiency Gains in the Residential Sector

Energy Service	2030
Air Conditioning	15.7%
Entertainment	18.2%
Cooking	0.2%
Water Heating	2.6%
Refrigeration	1.4%
Other Household Services	5.1%
Lighting	2.7%

Notes: (1) Computed from the base year of 2013 and expressed as a percentage of consumption reduction in each year;
(2) The values shown take into account the increased quality of the service provided in the segments.

Despite having less contribution to electrical efficiency gains in absolute terms, the transportation sector has an important role in reducing demand for fuels, primarily responsible for the emission of greenhouse gases in Brazil's energy sector.

Among the main premises adopted in estimating energy efficiency gains in the transportation sector, the following stand out:

- Increase of 1% p.a. in average performance of diesel engines used in trucks and buses;
- Average growth of 1% p.a. in average efficiency for new light vehicles;
- Penetration of electric vehicles (hybrid and purely electric) starting more strongly from the second half of the 2020s;
- Increases of 1% p.a. in air and water transportation.

At last, it is worth highlighting the expansion considered for the exploitation of thermal solar energy for water heating, particularly in Brazil's residential sector, which contributes to reducing GHG emissions.

Figure 22 shows the estimated penetration of solar heating systems (SHS) in Brazilian households, contributing to the shifting of electricity use for this use in these consumers.

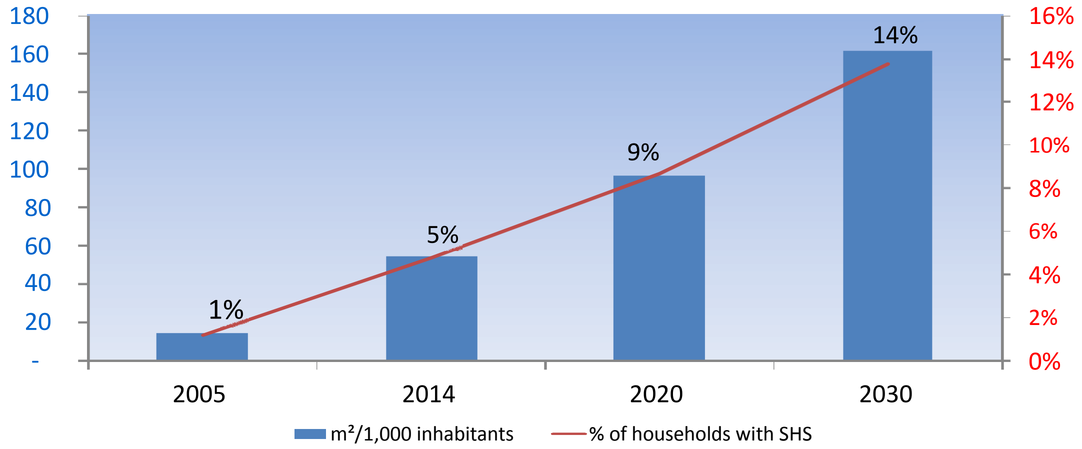


Figure 22 - Solar Water Heating System Indicators

Thus, the share of solar energy in heating bath water in the residential sector rises from 6% to 17% between 2014 and 2030 (Figure 23).

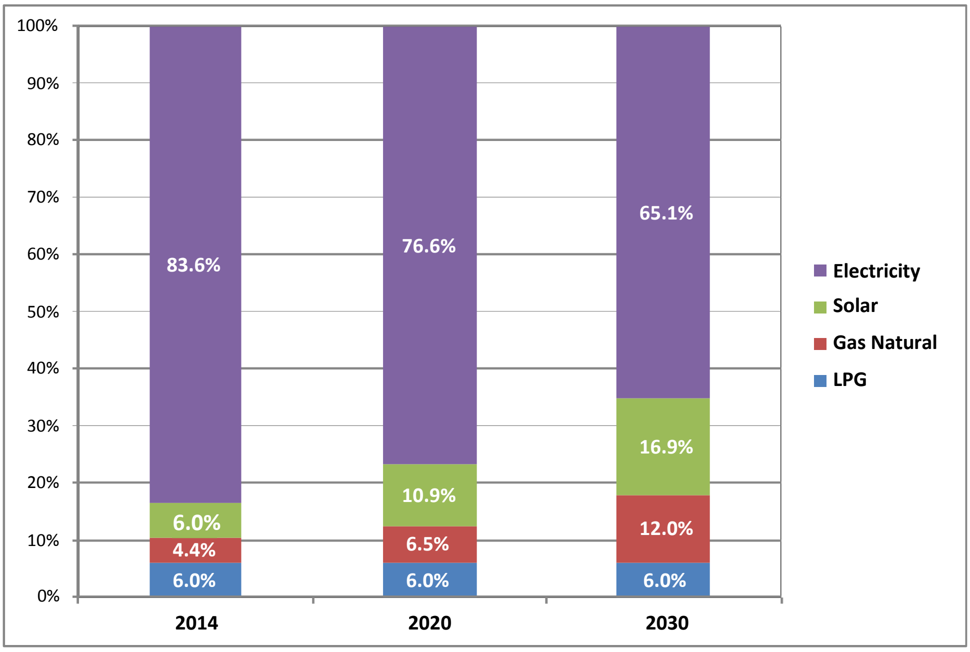


Figure 23 - Share of Sources in Heating Bath Water

3.1.5. EVOLUTION OF THE LIGHT VEHICLE FLEET

In Brazil, as well as other emerging countries, there is the challenge of avoiding the increase in passenger mobility too focused on car use, considering an expected population increase of about 20 million inhabitants between 2014 and 2030 and per capita income growth of around US$ 24,000/inhabitant in the same period.

It is noted that in the first decade of the millennium, there was a sharp increase in sales of light vehicles (cars and light commercial vehicles) in Brazil, as the result of an improved income level of the population, favorable credit conditions and tax breaks, among others.

In the long term, the projected development of sales of light vehicles considers as a premise the population motorization rate and the projections of per capita income. The fact that Brazil's motorization rate (inhabitants per vehicle), which amounted to 5.3% in 2012, is well below those observed in developed countries (ANFAVEA, 2014) combined with a per capita income growth prospect suggests the existence of a space for increasing this indicator in the long term in Brazil, even considering an important investment in public transport. Therefore, light vehicle sales, which in 2005 amounted to 1.6 million units, reach 6.3 million units in 2030.

As a result, the light vehicle fleet reaches 70 million units, which means a motorization rate of 3.2 by 2030. The light vehicle fleet projection can be seen in Figure 24.

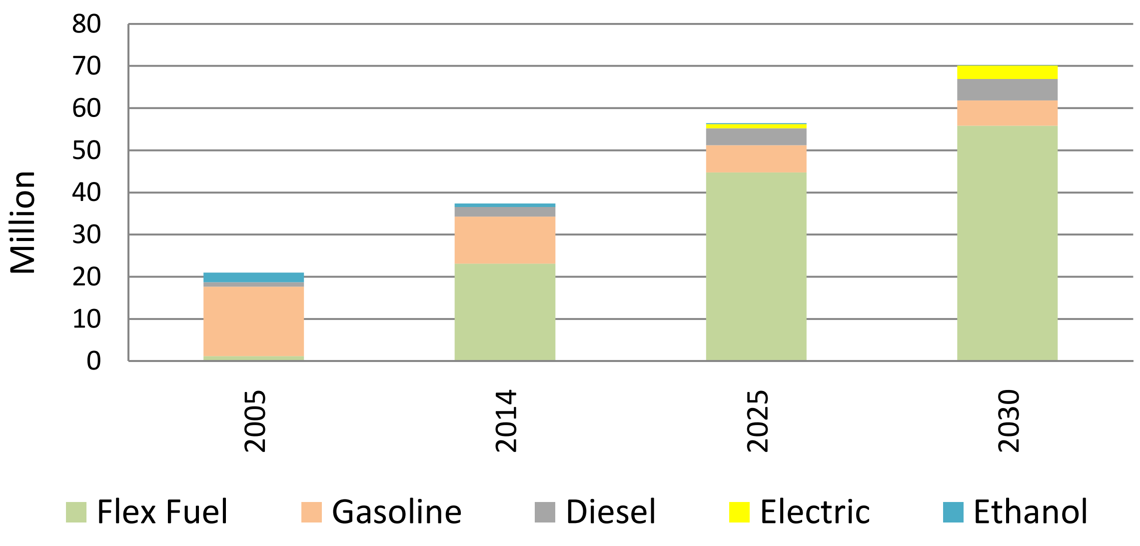


Figure 24 - Brazil: Light Vehicle Fleet per Technology

Note: Gasoline vehicles include those exclusively powered by ethanol (E100); Electric vehicles encompass hybrids, plug-in hybrids and purely electric vehicles

The *flex fuel* vehicle technology, currently present in the majority of the new vehicles sold in Brazil, increases its share from 5.6% to 79.5% between 2005 and 2030, especially due to the market loss of dedicated gasoline vehicles. This last technology, which made up 78.5% of the fleet in 2005, only has a 8.6% share of the fleet in 2030.

Vehicles with electric propulsion (hybrids, plug-in and purely electric) may have a larger share in the fleet as they gain competitiveness in relation to internal combustion models, mostly due to the technological development and scale gains that enable the reduction of prices for batteries used in these vehicles.

Among the electric propulsion technologies, hybrid vehicles without external recharging prevail over the considered period because they do not need a charging infrastructure and represent a transition in relation to purely electric vehicles. Purely electric vehicles represent paradigmatic industrial and economic transformations in the transportation sector and require significant changes in industrial chains, market niches, corporate strategies, and legislative and behavioral changes that vary by country.

It is estimated that the penetration of hybrid vehicles should start occurring in the five-year period from 2015-2020, accelerating sales from the first half of the 2020s and reaching a share in sales of about 3.7% in 2030. With regard to vehicles with predominantly electric propulsion (plug-in hybrid vehicles and exclusively battery vehicles), their penetration begins from the second half of the 2020s, reaching a 0.8% share in total light vehicle sales or the equivalent to about 500 thousand units.

As a result, the share of vehicles with electric propulsion in the light vehicle fleet amounts to 1.7% in 2025 and 4.5% in 2030, as can be seen in Figure 25.

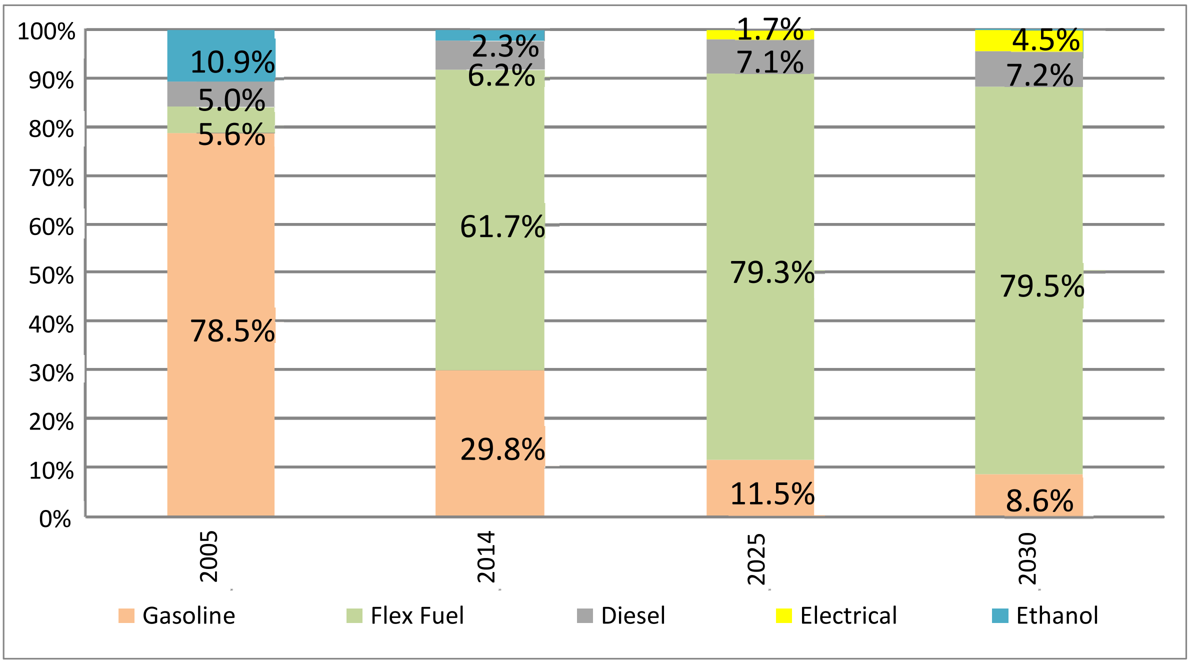


Figure 25 - Brazil: Evolution of Light Vehicle Fleet per Technology

It is noteworthy that, in Brazil's case, the penetration of purely electric vehicles in light vehicle sales for the justification of fossil dependence and mitigation of greenhouse gases (GHG) is less relevant than in developed countries, for instance, due to the wide share of renewable sources in Brazil's energy matrix, the significant share in total sales of national flex-fuel vehicles which use (in any proportion) ethanol and gasoline, and the lower global cost of producing ethanol from sugarcane.

3.1.6. CARGO TRANSPORTATION MODAL STRUCTURE

In cargo transportation, the increase of income and population in Brazil and the world affects the flow of goods and, consequently, in the activity of the sector, which grows from 1.3 trillion t-km in 2014 to 2.7 trillion t-km in 2030, an annual average growth of 4.7%.

The reduction in infrastructure bottlenecks and the realization of investments that favor more efficient transport modes, such as water and rail transportation, are challenges that will have an impact on both productivity and competitiveness of the economy, and energy consumption of the sector.

In this context, it is assumed that programs aimed at the logistics sector and concession policies will be successful in improving the efficiency of the transportation sector, allowing for an expansion in the share of less energy-intensive transport modes, especially with regard to cargo transportation. In Figure 26 we can see the trend of cargo activity per mode.

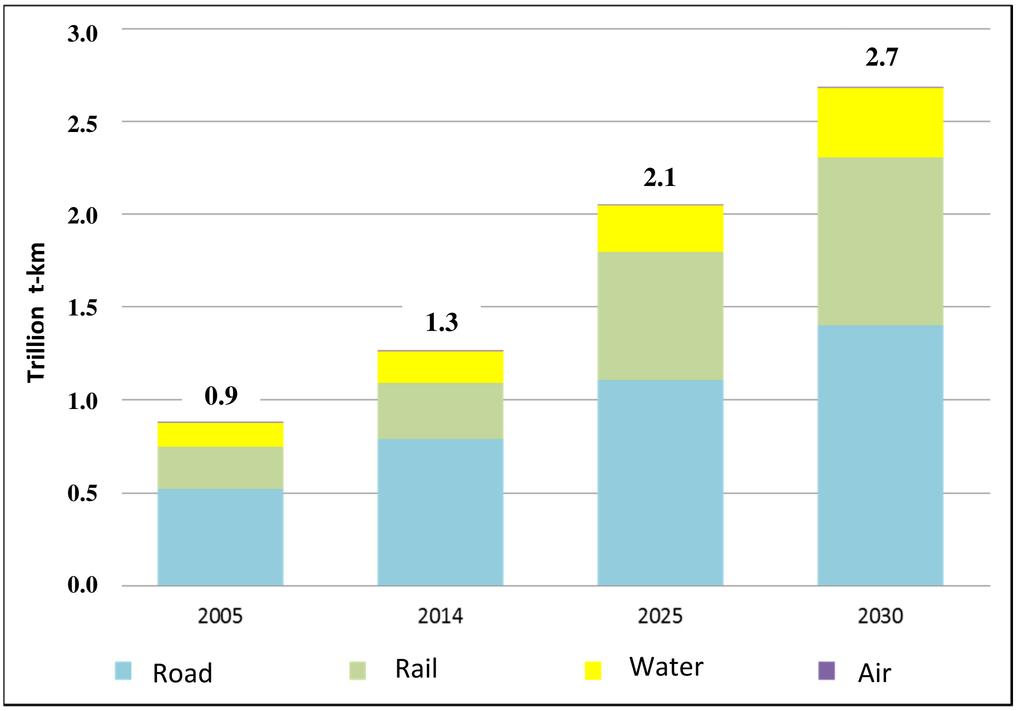


Figure 26 - Evolution of Cargo Activity per Mode

Among the currently implemented government programs, the Logistics Investment Program (PIL) stands out for cargo transportation, which provides a series of actions to develop and integrate transport modes and totals more than R$ 200 billion in investments throughout 35 years, most of which is concentrated in the first five years.

Despite recent advances in logistics investments, there is still a lack of a few projects and, especially, certain failures remain in the ability to execute scheduled works. Thus, it is considered that the entry of projects planned by the federal government will occur with adjustments to their implementation speed.

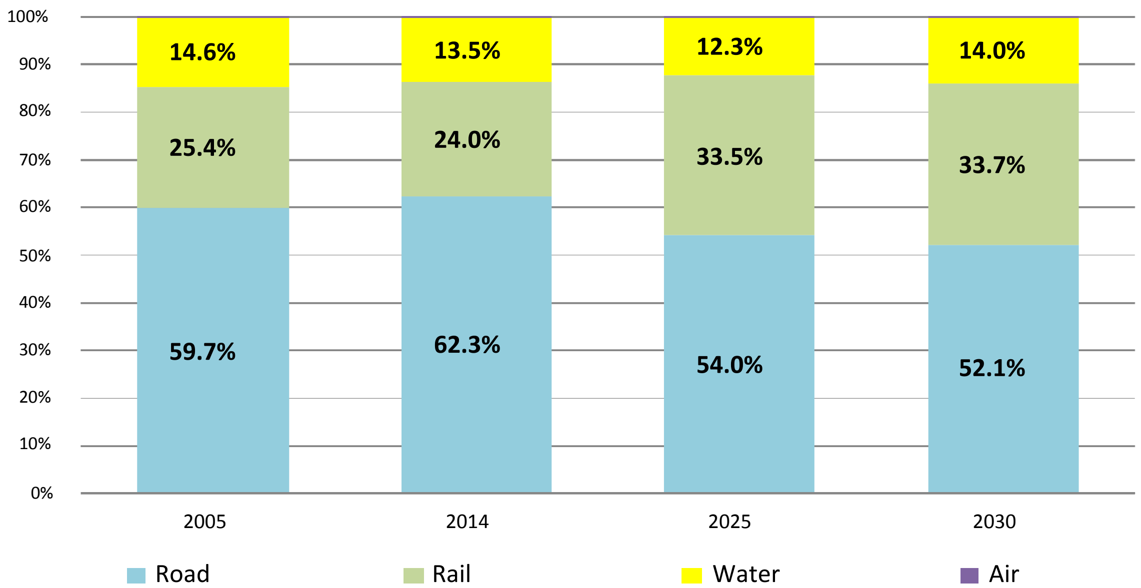
In road transport, truck sales should grow at an annual average rate of 4.1% between 2014 and 2030. Higher growth rates are expected until 2025 due to delays in implementing a few railway works and the need to meet the increase in cargo handling.

As the rail and water projects become operational, the need to increase truck sales tends to decrease. Therefore, after 2025, it is expected that truck sales grow at an average rate of about 1.5% per year until 2030. With these expected sales, the circulating truck fleet will grow from 1.9 million vehicles in 2013 to 3.8 million in 2030.

Water mode, which includes cabotage and inland navigation, rises in importance in the following decades. Cabotage in Brazilian ports expands mainly due to the location of new refineries (cabotage of oil from production fields to refineries and produced derivatives to major markets) and the logistics associated with oil exploration and production activities. Thus, the cabotage and inland navigation activity increases by 5.1% per year, from 2014 to 2030.

Even with the strong growth of air cargo transportation (3.4% p.a. between 2014 and 2030), its share in the transportation matrix, measured in ton-kilometers, remains extremely low, as air cargo transportation is more expensive and is primarily used for transporting low weight and volume products with higher added value.

At the prospect of improving the diversification of cargo transport modes, it is estimated that the share of road transport will decrease from 62.3% to 52.1% between 2014 and 2030 mainly due to the great increase in cargo handling by rail transport, whose share rises from 24% to 33.7% in the same period (Figure 27).



Nota: Due to the small share of air cargo transport mode, it is not visible in the chart above

Figure 27 - Relative Distribution of Cargo Activity by transportation modal

The energy demand of rail and water modes is established from the projections of activity and energy intensity (ratio of demanded energy to activity). It is considered that rail cargo transportation will keep using exclusively diesel oil and have efficiency gains around 1% per year.

Water cargo transportation consumes bunker fuel, which is comprised of marine diesel and fuel oil. Despite the growing environmental bias, also translated in stricter specifications for bunker, it is considered that the percentage of diesel in bunker fuel composition will remain constant, In water transport, an efficiency gain of about 1% per year is also considered.

For road transport, which concentrates the highest demand for diesel in transportation, a bottom-up methodological approach has been established. In general, key variables are projected, such as the truck fleet, specific consumption (l/km), annual average mileage and average load factor.

In the case of fleet projection, a scrapping curve was used, which had as basic premise an average service life of 30 years for trucks. The sales projections were established in accordance with the expectations for road cargo transport, considering historical growth rates and the prospect of other transport modes meeting the demand. Trucks will remain with predominant diesel use in internal combustion motorization, because of the difficulty of a technological change due to its usage profile (i.e. greater distances and bigger loads). An increment of 1.0% per year was considered in the average efficiency of new vehicles.

Table 12 - Projections for the Parameters of Transportation Sector

Parameter	2005	2014	2025	2030
Truck fleet (units)	1,263,832	1,980,739	2,999,464	3,765,868
Specific consumption (l/km)	0.236	0.240	0.189	0.177
Annual average mileage per vehicle (km)	80,811	79,039	72,719	72,455
Usage (months per year)	8.00	7.95	7.35	7.35
Distance covered without cargo	25%	25%	25%	25%
Average tons transported	6.7	6.71	6.78	6.85

3.2. CONSOLIDATED RESULTS

The process for estimating final energy consumption has long-term economic scenarios as one of its main information inputs. From the preparation of sectoral scenarios of agricultural activity, services and industry, in addition to infrastructure and mobility demands, specific sectoral models allow for the estimation of the trend of demand per source and per sector, at a national level. The electricity self-production prospects are also an important part of the process, which will point to the energy demand requirements that Brazil's energy system must meet in the long run.

In this sense, the results will be shown in two projections: (i) per consumption sector; (ii) per source/group of selected sources, depending on the case. In order to allow for the handling of uncertainties and specific parameters of each sector, the methodology uses a specific modeling for each sector of the economy. The employed sectoral analysis, in turn, generates results per energy source that are consolidated to form the total energy consumption, including energy and non-energy use. The methodology overview can be seen in Figure 28.

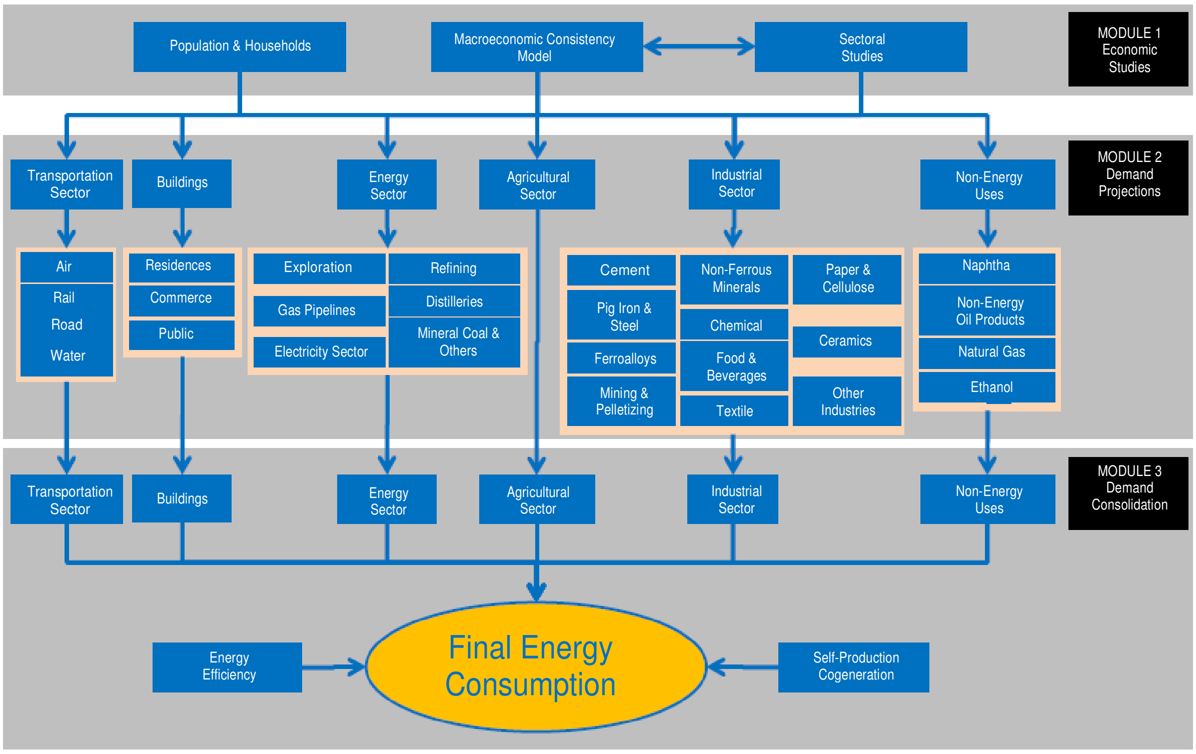


Figure 28 - Methodology for the Projection of Final energy consumption

In the 2013-2030 period, it is estimated that Brazil's total energy demand will increase at about 60% (Figure 29) when compared to the base year, with emphasis on the growth of natural gas and electricity, as well as the decline in oil derivatives (Figure 30). As a result of the improvement of these sources, GHG emissions due to energy consumption at the end use grow at a slower rate than the observed due to the consumption of fuels.

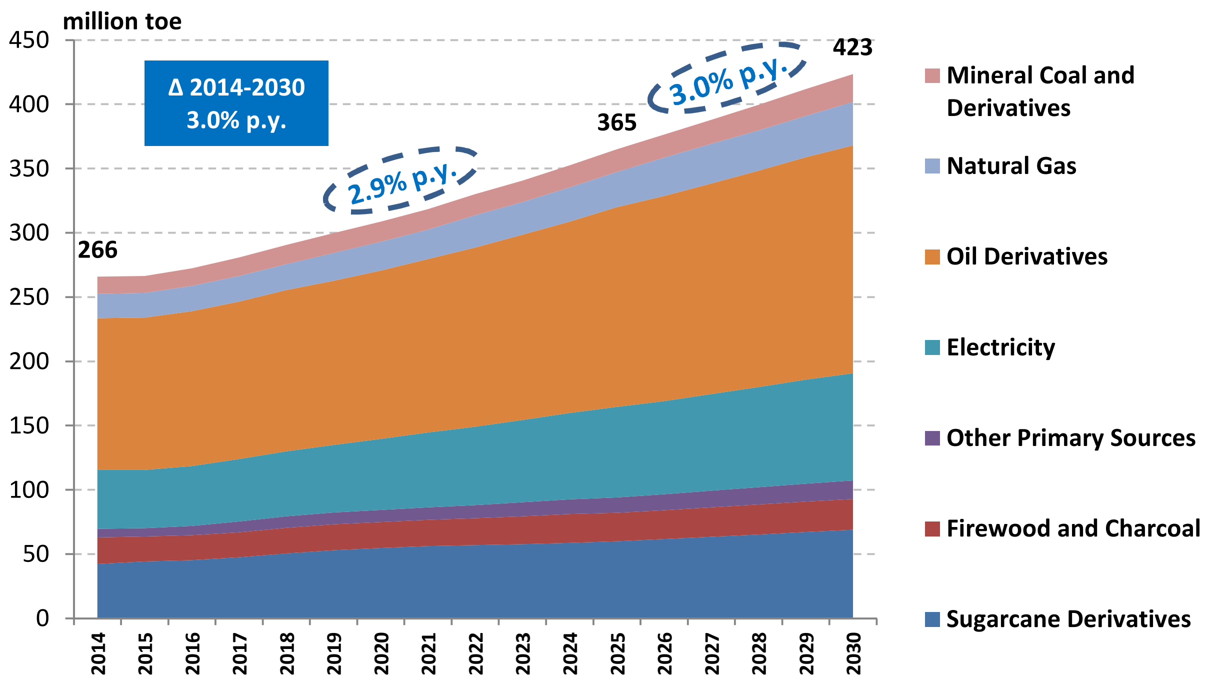


Figure 29 - Final energy consumption by Source

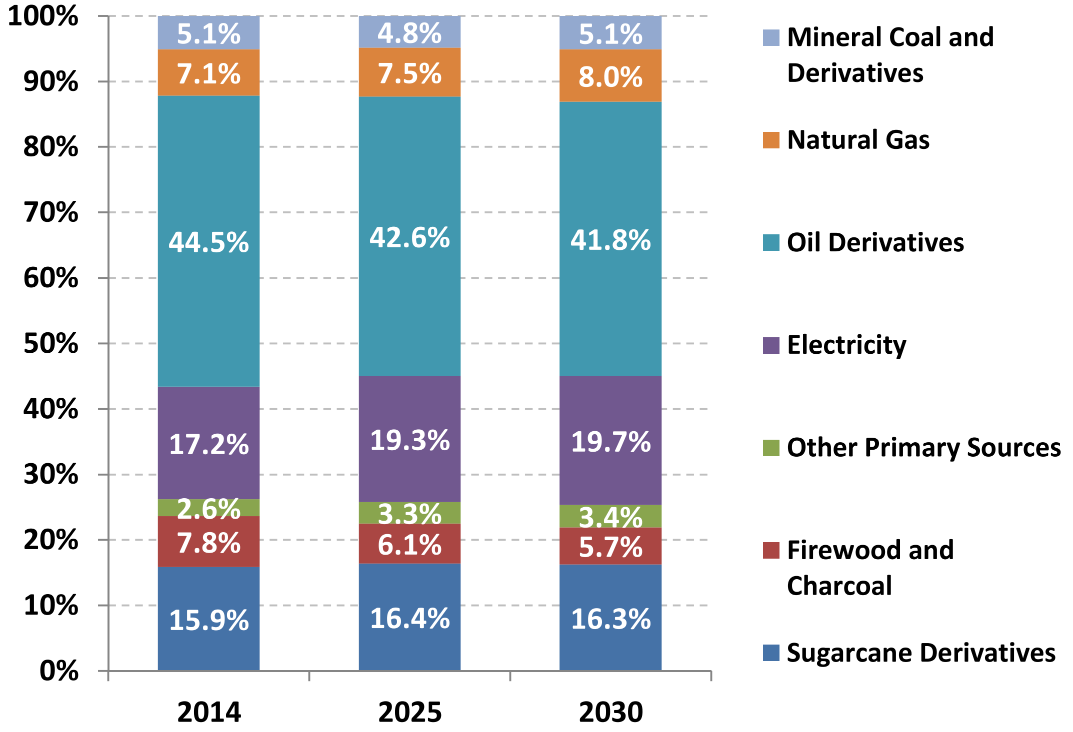


Figure 30 - Source Share in Final energy consumption

These results stem from the increasing penetration of natural gas in Brazil's energy matrix, shifting the consumption of oil derivatives in the industry and households (mainly fuel oil and LPG). The decline in the share of oil derivatives in the matrix is also due to the penetration of biofuels in the transportation sector, particularly ethanol in individual transport vehicles.

Firewood also shows a decline, whether due to the smaller expansion rate of charcoal-based steel industry compared to production based on mineral coal coke, or the smaller share in Brazil's residential sector, where there is a greater replacement with LPG and natural gas.

In terms of energy sectoral usage, the trend until 2030 is shown in Figure 31 and Figure 32, in turn, and we can highlight the following movements that contribute for GHG emissions to grow at lower rates that those for energy consumption:

- Increased share of commercial sector, typically less energy-intensive, and consequently responsible for lower GHG emissions compared to other sectors such as industry and transportation, for instance;
- Stabilization of the transportation sector share, in terms of participation, combined with the penetration of ethanol in flex fuel vehicles and the introduction of hybrid and battery electric vehicles as a solution for individual transport. Furthermore, the transformation of the modal structure of cargo transport, favoring the rail and water modes (more energy-efficient), also contributes to reducing GHG emissions due to the transportation sector;

- In the residential sector, in addition to losing a share in the total consumption, drivers such as the introduction of thermal solar heating and the replacement of natural gas for LGP help reduce the contribution of this sector in terms of GHG emissions;
- In the industry, the share loss in pair with the shift in fuel oil at the expense of natural gas and the slight increase in electricity share (Figure 34).

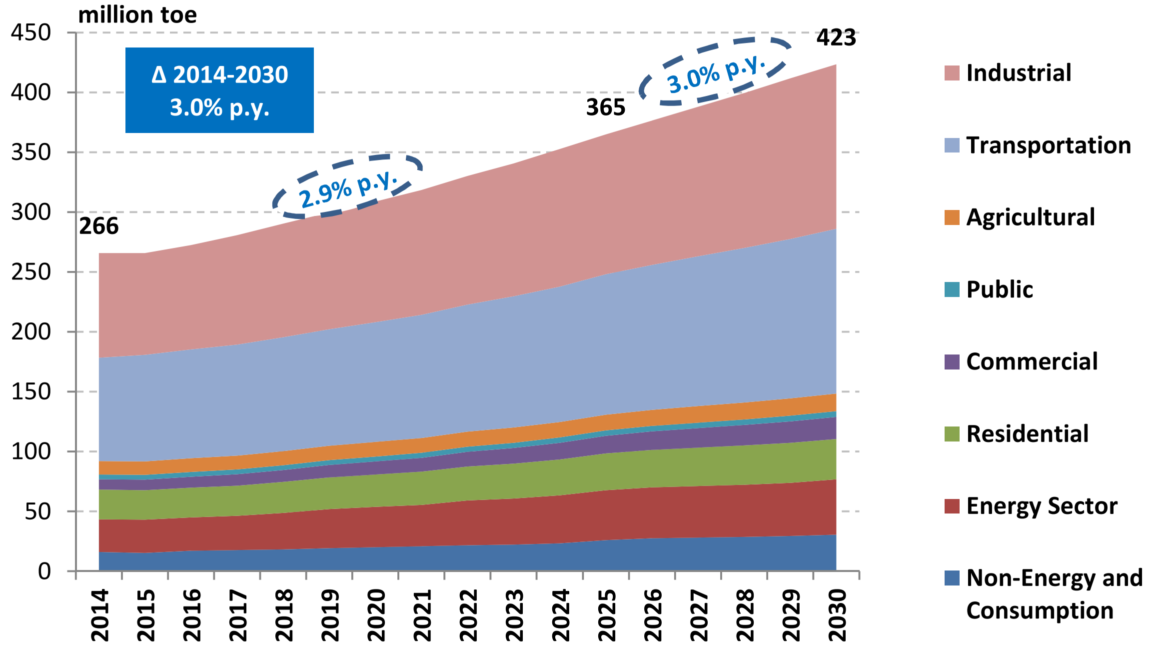


Figure 31 - Evolution of Final Energy Consumption by Sector

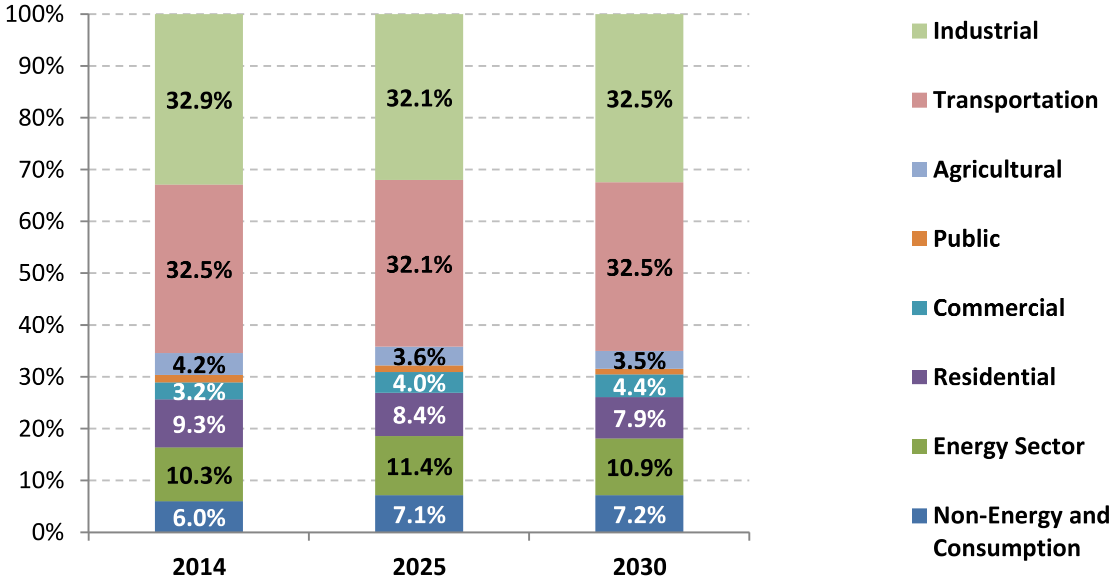


Figure 32 - Sectoral Share in Final Energy Consumption up to 2030

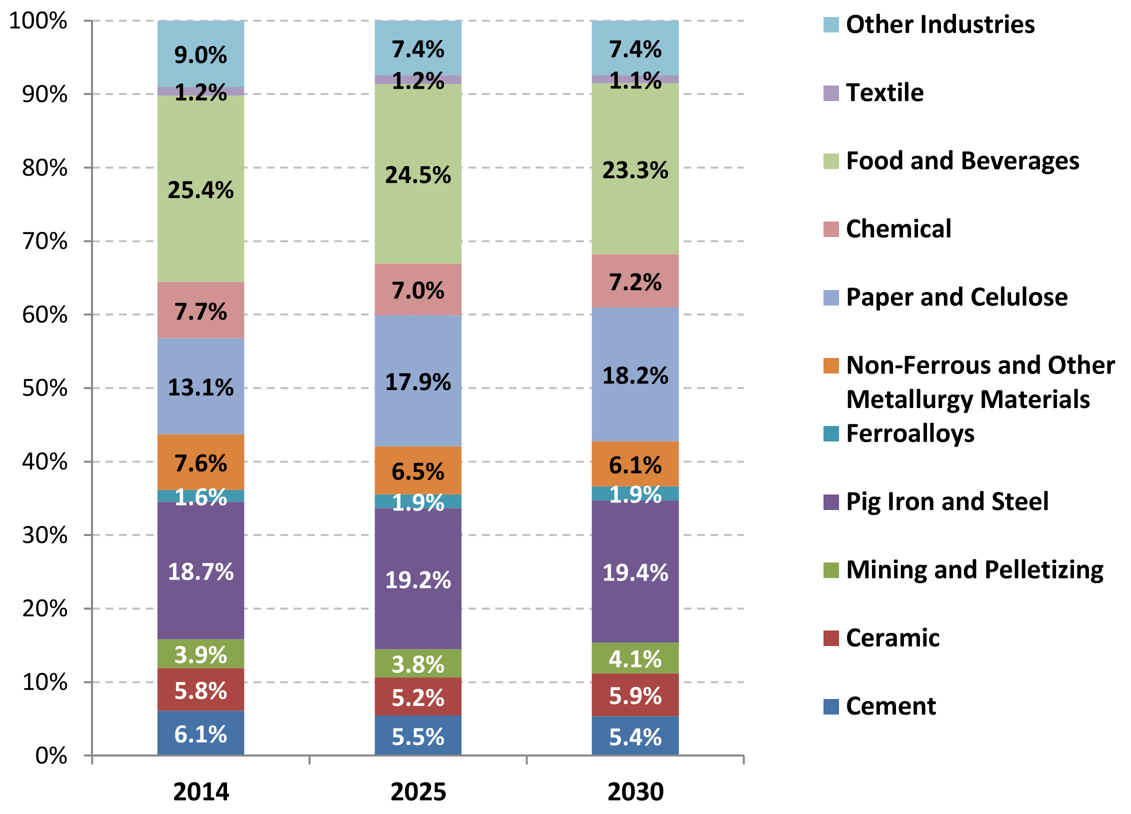


Figure 33 - Industry: Final Energy Consumption by Segment

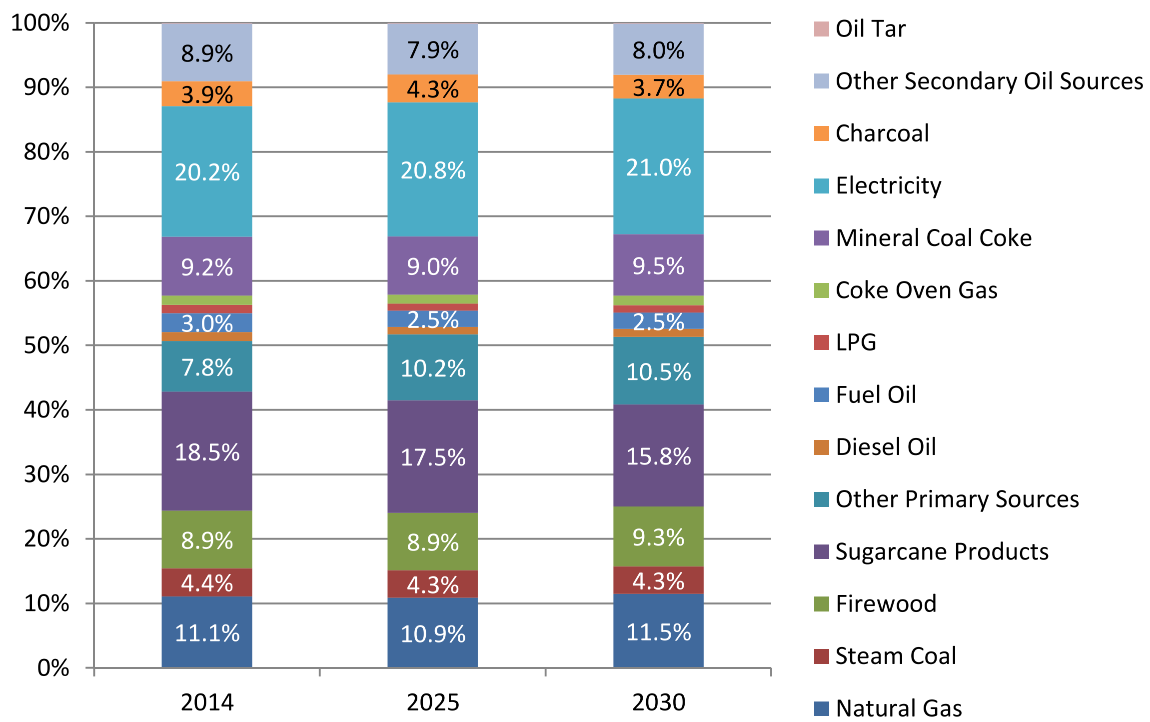
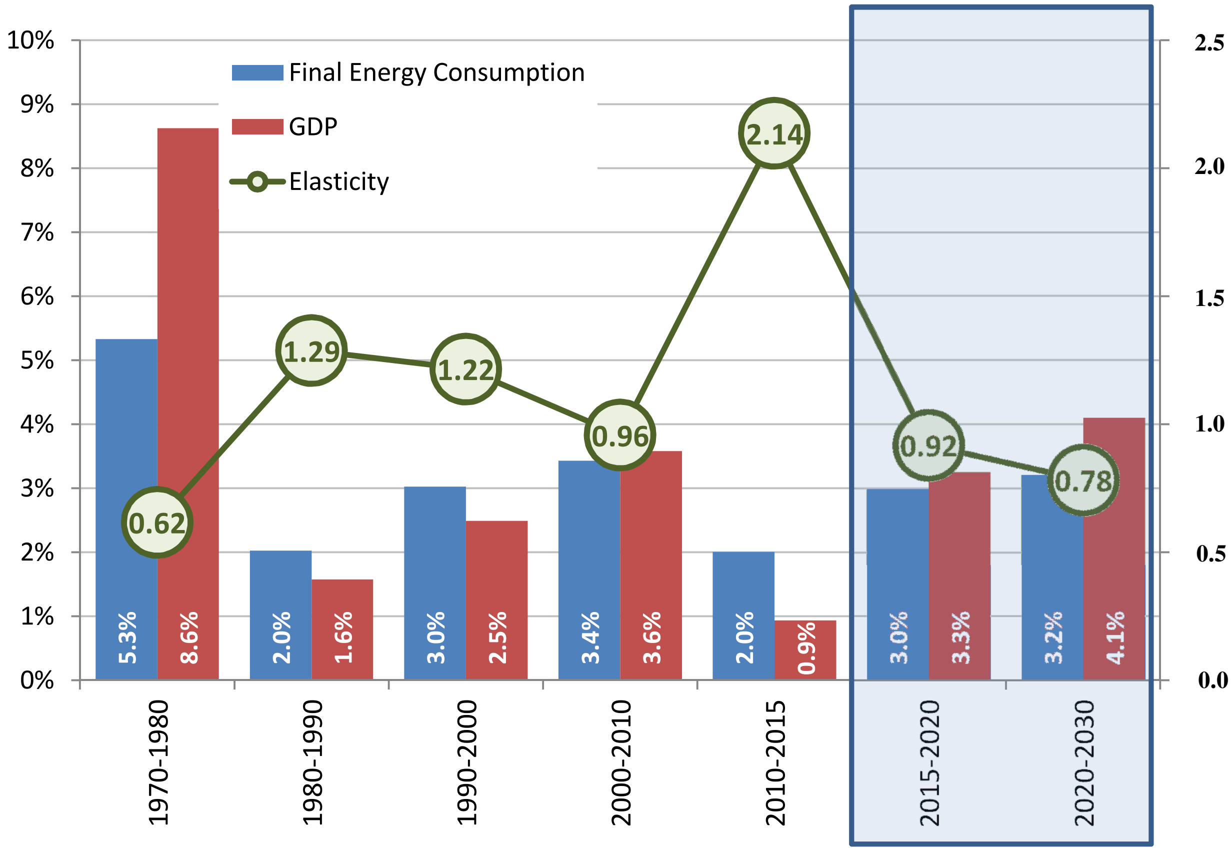


Figure 34 - Industry: Final energy consumption by Source



In terms of grouped indicators related to energy demand, the obtained results lead to a downward trend in elasticity-GDP of final energy consumption over time (Figure 35).

Figure 35 - Evolution of GDP elasticity of Final energy consumption

In the ten-year period, we observe the highest peak for this indicator, as it is in this period that a significant part of expansions of industrial, oil refinery, and oil and natural gas production activities is concentrated, compared to other decades ahead. After this ten-year period, the effects of investments and policies, which allow for increasing the energy efficiency of the economy, begin to have an effectiveness due to the maturity of Plano Nacional de Logística e Transporte (PNLT) projects, energy efficiency politics, and the penetration of new automotive technologies, such as electric and hybrid vehicles.

3.3. ENERGY CONSUMPTION BY SOURCE

3.3.1. ELECTRICITY

The expected growth for the electricity market in the long run results in an increased share in final energy consumption from 17.2% in 2014 to 19.7% in 2030. This development is explained by factors such as: penetration of electric vehicles in the individual transport fleet, increased ownership and use of electronic equipment in Brazil's residential sector, expansion of sectors with higher aggregated value in the economy (industry and commerce), among others. Thus, until 2030, it is estimated that the electricity demand will be approximately twice that observed in 2014 (Figure 36).

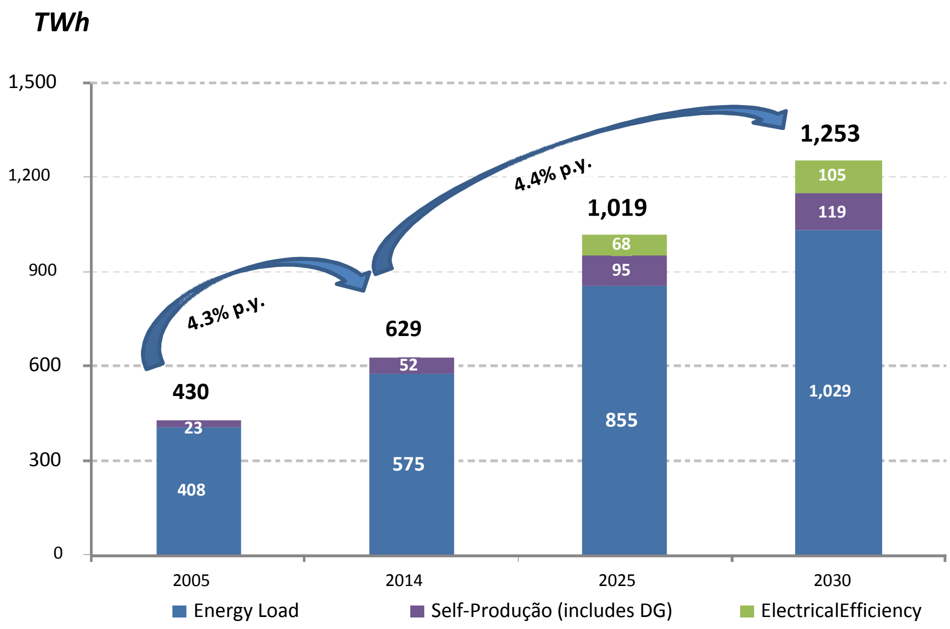


Figure 36 - Evolution of Electricity Demand

The trend of electrical intensity and per capita electricity consumption indicators is growing (Figure 37 and Figure 38). This progress places the country around indicators currently seen in Portugal. That is, despite the growth in per capita consumption, this Brazilian indicator is far from the consumption level of most developed nations.

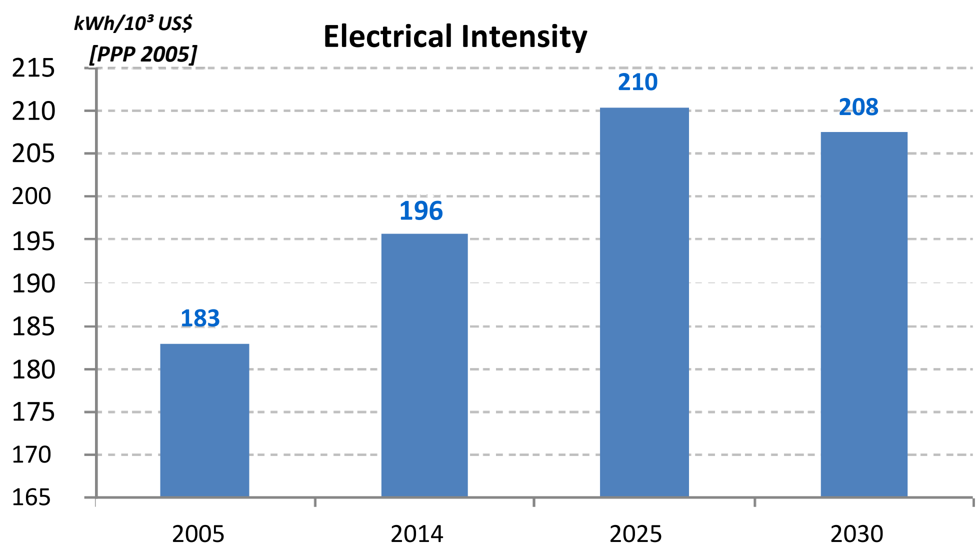


Figure 37 - Electrical Intensity Trend

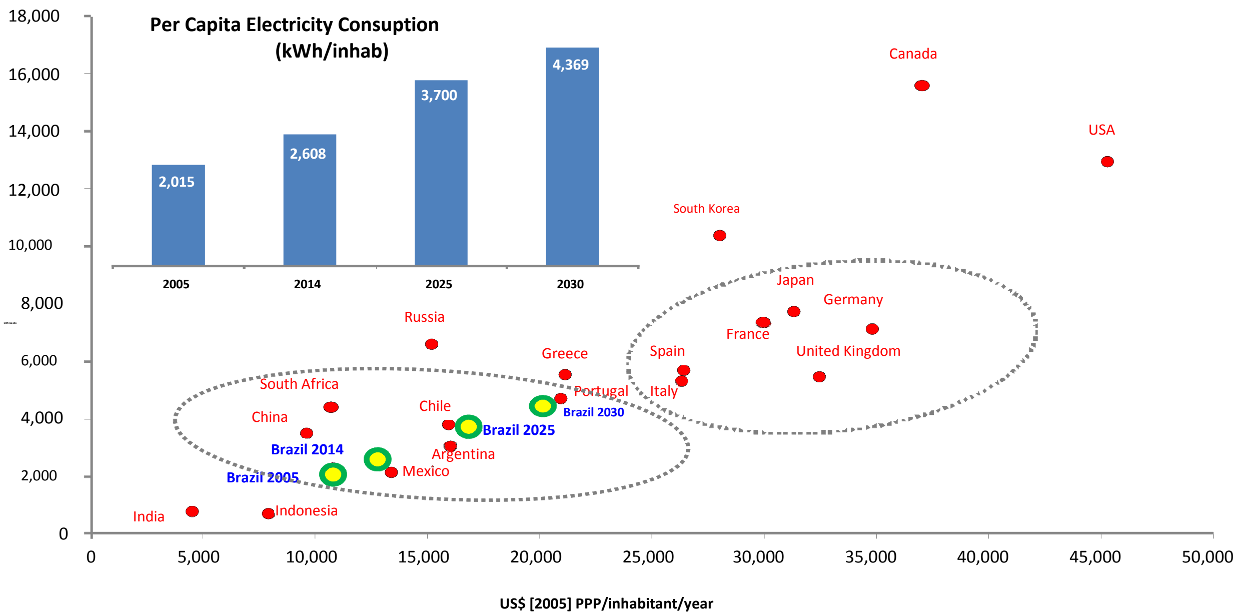


Figure 38 - Evolution of Per Capita Electricity Consumption

3.3.2. NATURAL GAS

Natural gas consumption is the one that grows more rapidly among all energy sources in the long term, highlighting the strong growth in non-energy consumption of natural gas (used as raw material), directly related to the expansion of the production of nitrogenous fertilizers in the country, so as to minimize external dependence of these inputs.

Furthermore, the hydrogen production in refineries also contributes to the significant expansion of the demand of gas as a raw material. Another sector that stands out is the industrial sector, whose future access to natural gas will depend on adequate conditions of competitiveness for its use in this sector. The basic premise of this study considers that until 2030 natural gas will be more competitive than its replacements in the industry. The realization of this premise will certainly require public policies to enable this competitiveness scenario.

Table 13 shows the trend in natural gas consumption up to 2030, including electricity generation.

Table 13 - Projections for Total Natural Gas Demand

Natural Gas	2014	2025	2030	Average Annual Growth
	million m³/day			
End Consumption	**51.3**	**79.7**	**100.5**	**4.3%**
Non-Energy (1)	2.1	11.7	17.3	14.0%
Energy Sector (2)	12.4	19.1	22.5	3.8%
Residential	1.0	2.1	2.8	7.0%
Commercial/Public/Agri.	0.7	1.2	1.5	5.1%
Transportation	5.0	6.0	7.3	2.4%
Industrial (3)	30.2	39.6	49.1	3.1%
Electricity Generation	**46.7**	**23.3**	**43.0**	**-0.5%**
Power Stations	44.3	20.5	40.1	-0.6%
Self-Prod./Cogeneration (4)	2.4	2.8	2.9	1.3%
Total Demand	**98.0**	**103.0**	**143.5**	**2.4%**

Notes: (1) Natural gas used as input in refineries (hydrogen production), fertilizer units and industry.
(2) Consumption in refineries, not including hydrogen production, and movement on the grid. Does not consider consumption in E&P and NG absorbed in processing units.
(3) Includes energy portion of fertilizers.
(4) Industrial and commercial cogeneration. Does not include generation in E&P.

The residential sector expands its natural gas consumption about 3 times the current consumption by 2030, due to the expansion of its distribution grid in most part of the major urban centers in the country.

Figure 39 shows the projection for the natural gas final consumption structure, where we can see the strong expansion of the share of consumption as raw material (non-energy consumption) until 2030.

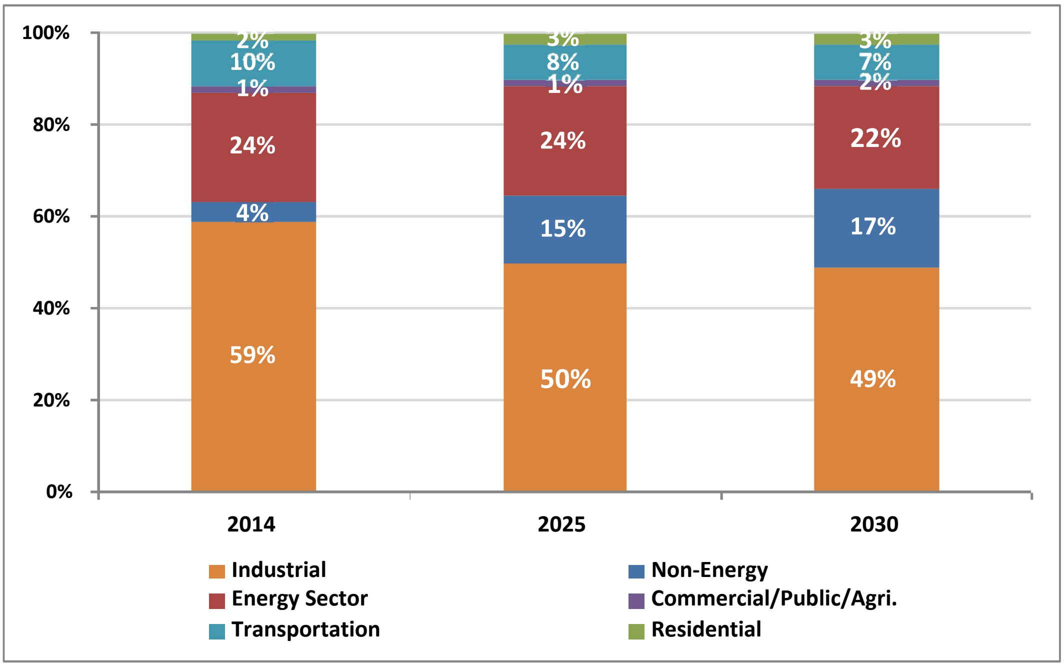


Figure 39 - Evolution of Natural Gas Final Consumption by Sector

3.3.3. OIL DERIVATIVES

On the analyzed time horizon, the consumption of oil derivatives maintains its downward trend in the share of total energy consumption, reducing its share to 42% in 2030 (Figure 40).

Fundamentally, this movement is due to the penetration of energy substitutes (natural gas in the industrial and residential sectors, in addition to ethanol in the transportation sector) and the change in the cargo transport modal structure.

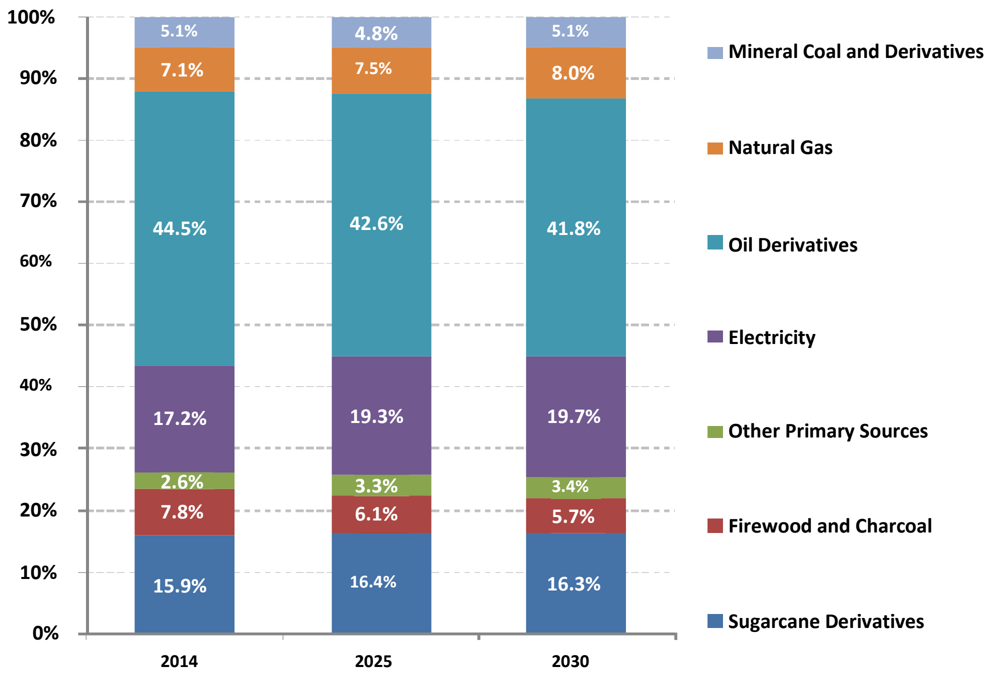


Figure 40 - Oil Derivative Share in Final energy consumption

Among the oil derivatives, in turn, the following movements warrant comments:

- Maintenance of the diesel oil share due to the expansion of the cargo transport activity to counterbalance the efficiency of engines and the migration of the transportation matrix to more efficient modes (rail and water);
- Decline in the gasoline share due to the greater penetration of ethanol in the light vehicle fleet;
- Slight gain in naphtha share to meet part of the national petrochemical production, so as to contribute to maintaining a manageable level of resin importation;
- Gain in aviation kerosene share, motivated by the expansion of air passenger transport;
- Expansion of the consumption of non-energy petroleum products, driven by demands from infrastructure (asphalt for expansion/maintenance of roads), industrial expansion in general and automotive (lubricants), and also chemical and petrochemical activity (solvents for paints and varnishes, adhesives, leathers, resins, detergents and cosmetics).

Gasoline and diesel oil are the two main oil derivatives consumed in Brazil up to 2030.

Gasoline has a consumption linked to the use of light vehicles, and its share decline in total consumption is due to efficiency gains in internal combustion engines, gain in ethanol share in relation to gasoline, penetration of hybrid and electric vehicles, and also the reduction of average expected use of the vehicle, due to policies for improving urban mobility to be implemented on the horizon.

The consequence of these movements generates a higher growth rate of ethanol consumption in relation to gasoline, contributing to the reduction of GHG emissions due to the use of light vehicles when compared with a trend path.

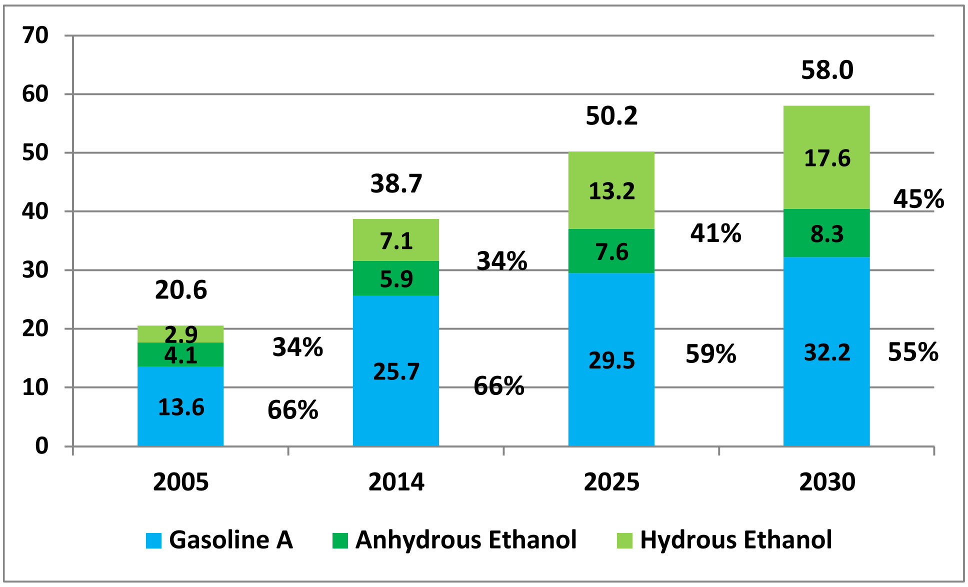


Figure 41 - Fuel Consumption in the Otto Cycle

With regard to diesel oil consumption, it is preponderant for cargo transportation (although a reduced portion of the total is used in light diesel-powered vehicles), and most of it is destined to road transport. As highlighted in the previous chapter, the change in the modal structure of cargo for configuration with a larger share of water and rail transport will contribute to the reduction in the growth rate of GHG emissions in the transportation sector.

The total energy demand in the diesel cycle will grow, in average, 2.5% per year until 2030, while the biodiesel demand grows faster (8.4% per year) given the increase in the share of vegetable diesel in mineral diesel from 7% to 10% in the analyzed period. The lowest growth rate of energy demand in relation to that of cargo transportation activity is explained by the technological advances of modes, reflected in efficiency gains, and the improved logistics infrastructure, which allows for an increasing share of less energy-intensive modes.

3.3.4. BIOFUELS

Regarding the consumption of biofuels, it is worth mentioning that Brazil's commitment assumed in COP 21 considers reaching a percentage of 10% biodiesel in the blend in 2030 (Figure 42).

It is emphasized that, as explained in the item about demand, Law 13,263/2016 anticipates to 2020 the 10% content and allows for higher blends. However, given that the production of biodiesel in Brazil is based on soy, witch production is aimed at the foreign market, and that other oilseeds have a high value in the chemical industry, the authors decided to be conservative on growth assumptions of this fuel.

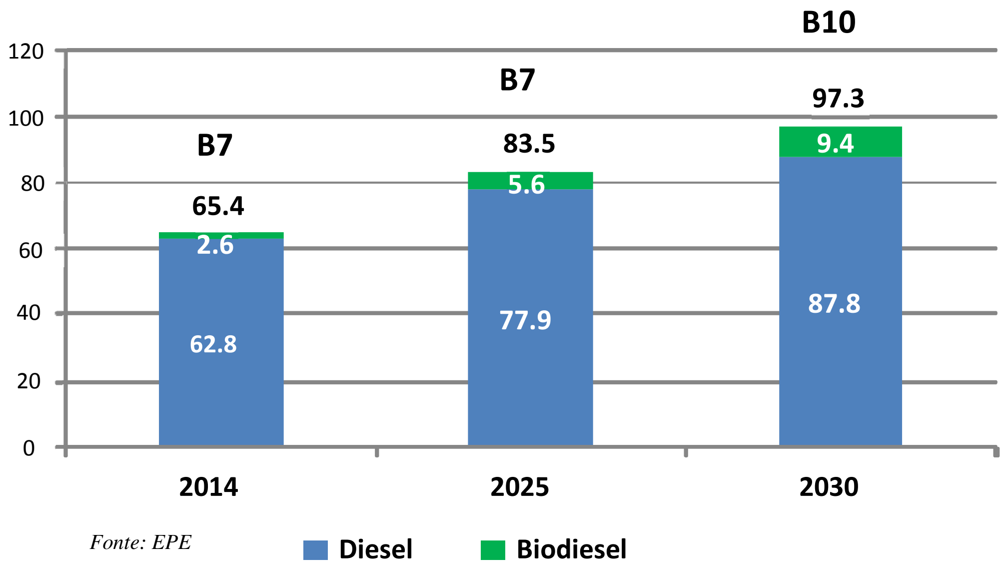


Figure 42 - Diesel Cycle: Consumption

In addition to ethanol and biodiesel, other biofuels show an increase in final energy consumption, as can be seen in Table 14. This behavior, however, differs according to the type of biofuel.

- Firewood consumption shows low growth due to its replacement with LPG in the residential sector (currently the primary consumer sector) and due to the penetration of natural gas in the industry;
- Sugarcane bagasse consumption in the industry is for the production of sugar;
- The considerable expansion of black liquor consumption is due to the expected growth of the paper and cellulose segment;
- Charcoal penetrates the steel segment as an energy replacement.

Table 14 - Evolution of Biofuel consumption (mil toe)

Biofuel	2014	2025	2030	Average Annual Growth
Firewood	16,672	16,813	18,521	0.7%
Sugarcane Bagasse	28,612	38,301	42,018	2.4%
Lixivium	6,338	11,288	13,600	4.9%
Charcoal	3,963	5,444	5,431	2.0%
Total	55,584	71,847	79,570	2.3%

4. ELECTRICITY SUPPLY

The expansion of total electricity generation can occur through distributed generation (and self-production) and centralized generation, with different determinants.

Until 2030, it is estimated that self-production will meet approximately 10% of the total electricity demand. Industry segments with a profile based in the use of large amounts of steam and electricity in its processes will strongly contribute to the expansion of self-production.

In addition, the amount of electricity self-production through natural gas thermoelectric generation on offshore platforms is significant, and this portion should gain importance with the exploration of pre-salt oil. Therefore, the determinants for self-production expansion are more linked to decisions of each agent.

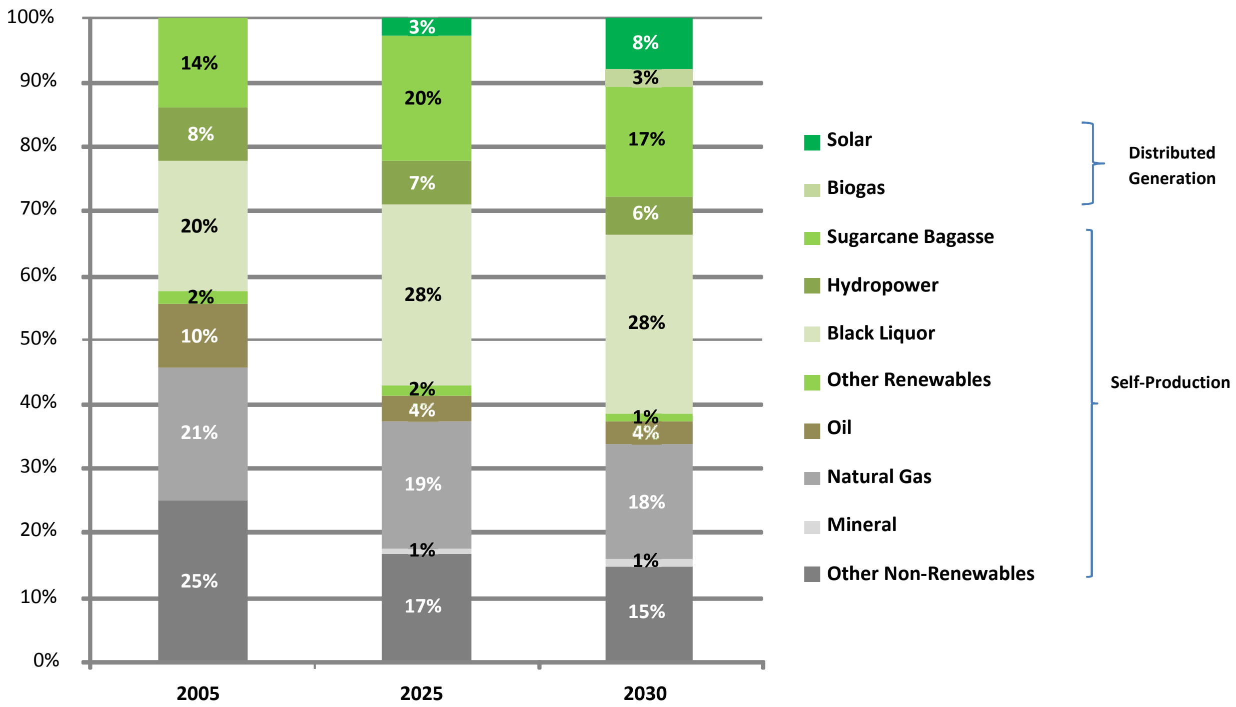
The expansion of centralized generation, on the other hand, despite also depending on the investment decisions of agents, can be driven by guidelines and strategies set by policy makers, notably in the case of the challenge to build an electricity generation matrix on a sustainable basis in the economic, social, technical and environmental dimensions.

From the perspective of power supply simulation, the portion of self-production is considered a deduction from the total to be met by the centralized system. The portion of distributed generation, in turn, given that it originates mainly from intermittent renewable sources, is considered in the portfolio of generation alternatives, so as to quantify peak requirements for the expansion of Brazil's electric system.

Therefore, first we analyze the main conditions of self-production, and then of centralized generation.

4.1. EXPANSION OF DISTRIBUTED GENERATION AND SELF-PRODUCTION

It is worth highlighting that an increasing contribution of renewable sources to decentralized generation in the long run is projected to meet the expansion of self-production. In fact, it is estimated that the contribution seen in 2014 (44%) will jump to approximately 63% in 2030, with a strong contribution of sources such as solar photovoltaic, biogas and biomass (Figure 43).



43 - Energy Sources share in Distributed Generation

The prospects of decentralized power generation were assessed in two separate categories: (i) large, corresponding to that installed in general industries; (ii) small, where projects in mini and micro-scale prevail.

In addition to large distributed generation already representing about 10% of the current electricity demand met, the expansion prospects for the activity of traditionally self-producing industries (sugar & alcohol, cellulose & paper, E&P, oil & natural gas, steel) are promising in the long term, so that self-produced energy share in total energy consumption is expected to increase.

The results of the expansion of large distributed generation are shown in Figure 44.

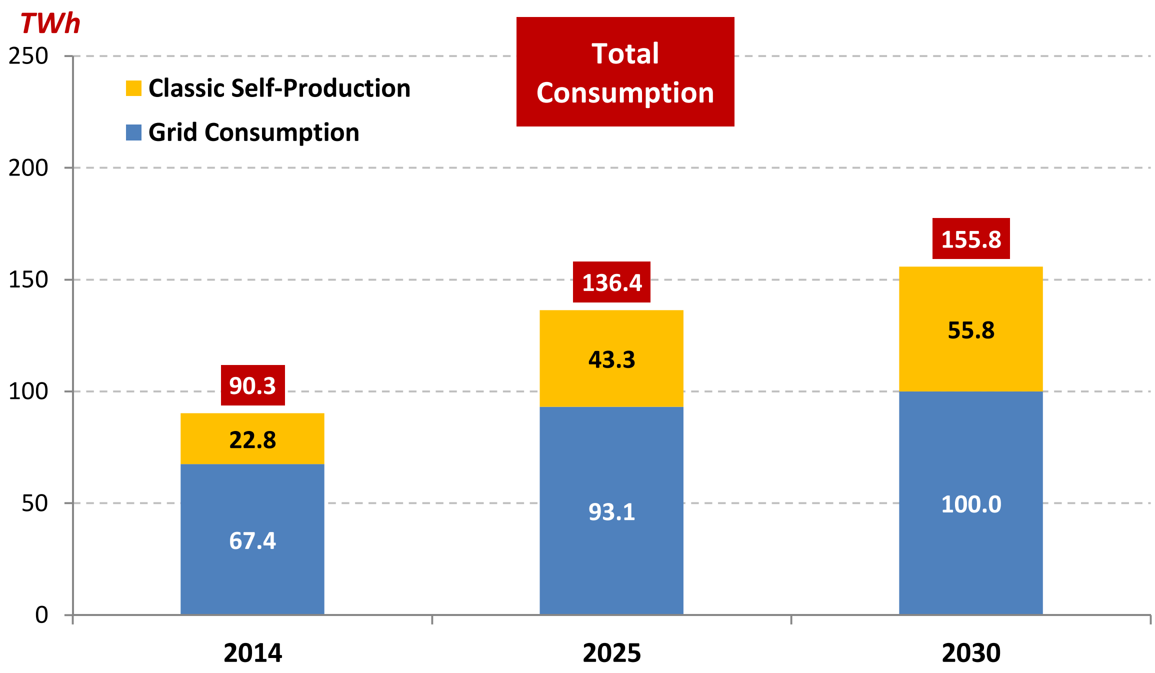


Figure 44 - Electricity Consumption of Major Industrial Consumers

The penetration of small distributed generation is assessed from the economic viability between the levelized cost of photovoltaic generation and the price of the electricity from local electricity distributor (including taxes), assuming as hypothesis the maintenance of the price in real terms along the horizon. It is assumed that the costs of photovoltaic systems show a reduction over time, as seen in Table 15.

Table 15 - Cost Reduction Perspective of Photovoltaic Systems

Industrial	2013	2020	2030
		(R$/Wp)	
Residential	7.0	4.4	3.2
Commercial	6.5	4.2	3.0
Industrial	6.0	3.4	2.7

Source: EPE based on IEA (2012).

In the residential sector, it is assumed that, in addition to the price reduction of the systems, a greater financing accessibility and the appearance of different business models (leasing[3], group purchases[4], the purchase of solar generation quotas[5], among other possibilities) will be present.

[3] The leasing system consists in renting a photovoltaic system, paying a monthly fee for it. In general, renting the system provides savings so that the monthly fee value plus the new energy bill is lower than the old bill paid entirely to the distributor. This system has zero initial cost to the consumer and, therefore, its adoption is hugely attractive.

In this study, it is admitted that units with a consumption over 100 kWh/month, except for low-income ones, are potential adopters of photovoltaic systems. In the industry and commerce, in addition to the abovementioned factors, aspects such as adaptation of the company's image to the profile of its audience also act as drivers to encourage the installation of these systems in the long run. In this environment, it is also estimated that the public sector contributes with the efficiency of its installations and energy self-production, leading by example.

As a result, the projection for power generation from distributed photovoltaic systems is shown in Figure 45.

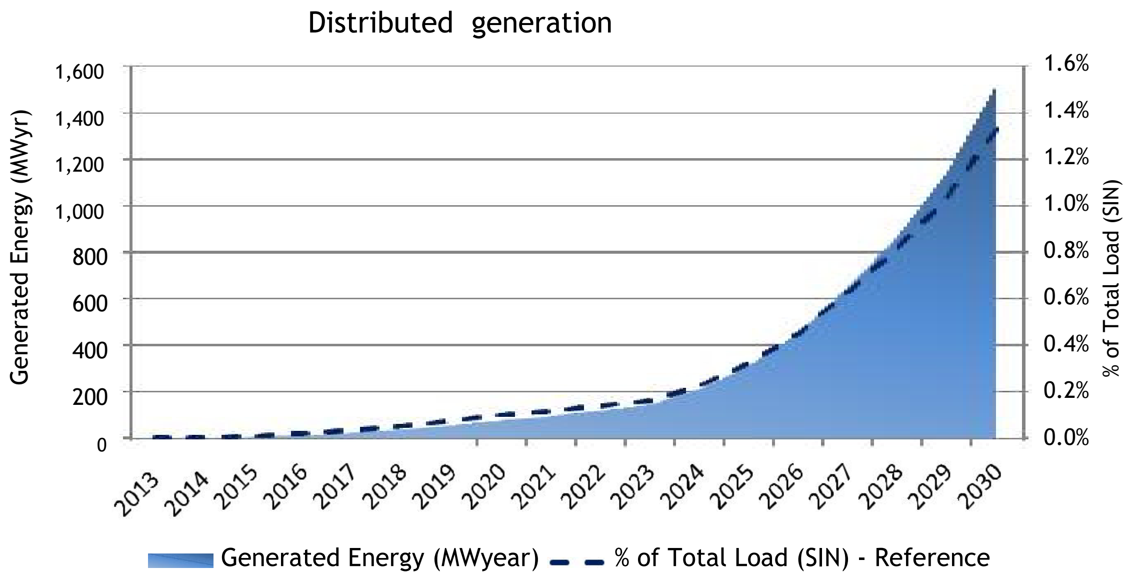


Figure 45 - Projection for Photovoltaic Distributed Generation

4.2. EXPANSION OF CENTRALIZED GENERATION

4.2.1. GUIDELINES

As a whole, the challenge to form Brazil's future electricity generation matrix includes meeting the electricity demand safely, at the lowest possible cost and taking into consideration the environmental and social protection policies and commitments (Figure 46).

[4] By organizing residents, a joint purchase is made of systems that reduce individual cost. During these programs, the adoption is encouraged by the community spirit, in addition to the feeling that, if you do not adhere, you will be missing an opportunity that may not exist in the future.

[5] Many users do not have technical conditions for installation (rented residence with the prospect of moving, living in an apartment, unsuitable roofs, shading, etc.). For these consumers, it would be appropriate to be able

to purchase quotas of a photovoltaic system installed elsewhere, with a right to the portion of energy generated by this system regardless of where they live. It is important to highlight that, in order for this model to be possible, some regulatory changes are needed, such as the permission of virtual net metering.

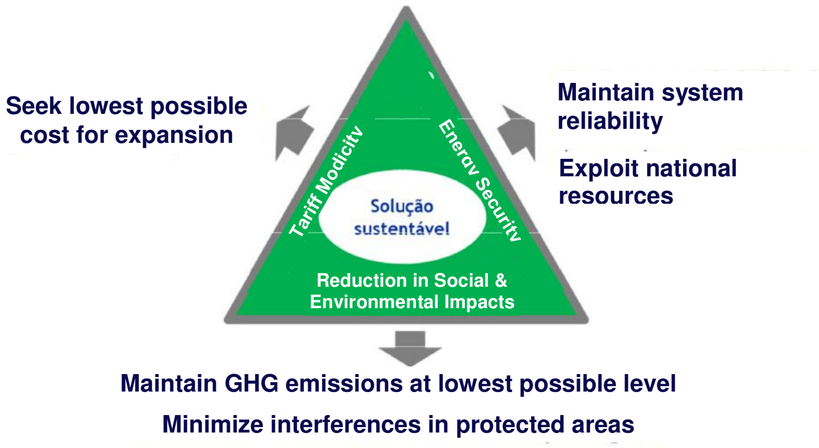


Figure 46 - Trilemma Considered in the Brazilian Electricity Sector Expansion Strategy

Balancing the trillema of energy security, tariff modicity and reduced social and environmental impacts is even more challenging in the point of view of an expansion of total installed capacity of the electric sector capable of meeting virtually double the current consumption until 2030.

In fact, various paths can be followed so that the establishment of strategic guidelines becomes necessary in order to guide how this expansion may occur.

The following conditions have steered the strategy adopted for the expansion of electricity generation until 2030 that comprises the context of Brazil's commitment assumed in COP-21:

- Limiting GHG emissions from power generation at a maximum ad hoc trajectory .
- Prioritizing the renewable sources for the power system expansion.
- Prioritizing hydropower projects that do not interfere with protected areas.

4.2.1.1. LIMITING EMISSIONS IN ELECTRICITY GENERATION

In case of GHG emissions, a maximum trend related to the electric sector was defined ad hoc, based on the intensity of emissions of this sector.

It was established as an objective to reach, by 2050, a 40% reduction in relation to the value of the emission intensity verified in 2014 (14.1 tCO2/thousand R$), which is much lower than that of developed countries (Brazil's emission intensity in 2014 makes up 45% of the emission intensity of the United States, 65% of Germany's intensity and 70% of the average intensity of European Union countries). For this, a gradual reduction path of 5% per five-year period was chosen, resulting in an emission intensity value in relation to the GDP limited to 11.3 tCO_2/thousand R$ in 2030.

The considered path is illustrated in Figure 47.

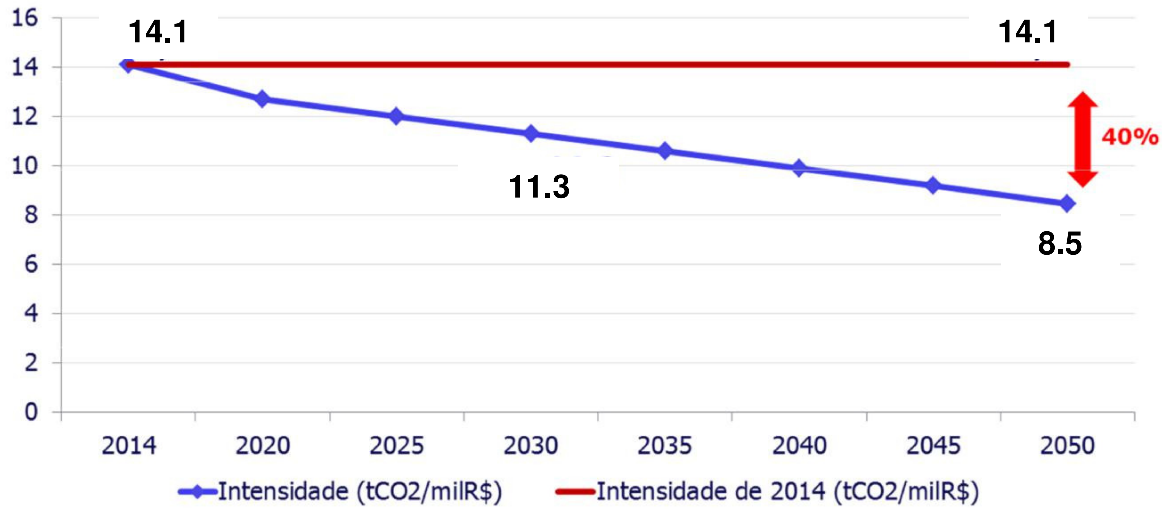


Figure 47 - GHG Emission Restriction Adopted for the Electricity Sector Expansion

Thus, the resulting expansion of the electric sector was conditioned to result an electricity matrix in witch annual average operation did not exceed the cap amount of GHG emissions for a given year, while meeting the other expansion strategy criteria, such as tariff modicity and energy security.

4.2.1.2. PRIORITIZING RENEWABLE SOURCES

It is noteworthy that prioritizing renewable sources does not mean excluding non-renewable sources, as it must be acknowledged that there are complementarities to be explored in all sources which have distinctive characteristics, as shown in Table 16.

Table 16 - Comparison of Available Sources for Electricity Generation

Sources	Cost	Social & Environmental Aspects	Energy Security
Hydroelectric	Capital-intensive: high Low operating cost	Negligible emissions Location alternative: no flexibility Part of the potential interferes with protected areas	With seasonality No intermittence
Biomass	Capital-intensive: medium Low operating cost	Negligible emissions Has location alternative	With seasonality No intermittence
Wind	Capital-intensive: medium Low operating cost	No emissions Has location alternative	With seasonality With intermittence
Solar Photovoltaic	Capital-intensive: medium Low operating cost	No emissions Has location alternative	Seasonality (negligible) With intermittence
Coal	Capital-intensive: low High operating cost	With high emissions Has location alternative	No seasonality No intermittence
Natural Gas	Capital-intensive: low High operating cost	With emissions Has location alternative	No seasonality No intermittence
Nuclear	Capital-intensive: high Medium operating cost	No emissions Has location alternative	No seasonality No intermittence

Among the technologies currently in the commercial stage, thermoelectric ones, with the exception of nuclear technologies, have GHG emissions, particularly CO_2, in their energy conversion process for electricity generation.

On the other hand, the bigger share of sources such as wind, solar and biomass energy requires a greater expansion of thermal generation for the base of the system, case in which coal power plants start having a relevant role, as, from the electric operation point of view, in order to exploit the synergies and ensure system reliability, both nuclear and thermoelectric (natural gas, mineral coal or oil) plants are capable of generating electricity in a continuous and reliable manner.

In the case of hydroelectric technology, there is seasonal variability, i.e. the river flows are not the same during all months of the year. The construction of plants with reservoirs allows for accumulating water and operating the plant more consistently throughout the year, in addition to providing energy for the system to compensate supply reduction situations. For the case of biomass, there is dependence on the harvest, which is when the fuel is available if there is no storage.

The pros and cons of each source, their potential complementarities, in addition to technological advances (e.g. storage and backup technologies such as reversible hydroelectric plants and battery), have all been considered in the result of the electric sector expansion.

4.2.1.3. PRIORITIZING HYDROELECTRIC POTENTIAL EXPLOITATION

The expansion of hydroelectricity faces challenges related to the negative social and environmental impacts caused. In particular, one of the most relevant issues to exploiting the potential is the harmonization between planning the electric sector and respecting indigenous peoples, *quilombolas*, and traditional peoples and communities, in addition to the environmental licensing process of hydroelectric projects with interference in conservation units.

From the portfolio of 69 GW inventoried available in the country, 37 GW do not have interference in protected areas (conservation units, indigenous lands and lands occupied by remaining *quilombo* communities), while 32 GW have some kind of interference.

Much of this portfolio is in the Amazon, which has about half of its extension covered by protected areas.

It is presumed that exploring the hydroelectric potential in protected areas will require special studies, technological advances and a more complex environmental licensing process, since various negotiations will be needed for the installation of projects in these areas. This complexity can be reflected in longer terms for properly addressing the issues for the exploitation of this resource.

In selecting projects to comprise the hydroelectric expansion alternative, it was decided to completely exclude from the portfolio those projects that had a direct or indirect interference in indigenous lands[6] or *quilombolas*[7], which represented the disregard of almost 21 GW on the analysis horizon.

For the case simulations, those that do not interfere with protected areas were prioritized, which amounts to 37 GW of power. For exploitations with interferences in conservation units (CU), a classification was done according to the category of affected CU: Sustainable Use (less resctritive) or Full Protection (more restrictive), prioritizing in the simulations exploitations with interference in Sustainable Use CU.

4.3. EXPANSION STRATEGY

The construction of the electric sector expansion configuration considers as a starting point the expansion assessment based on the total minimization of expansion costs, which results in lower absolute levels of GHG emission, but also requires the use of a substantial portion of Brazil's hydroelectric potential. The expansion guidelines, however, require including in the end case considerations on protected areas and the effects on GHG of the expansion. The process of simulating cases of the electricity generation expansion is outlined in Figure 48.

---

[6] In order to reach these numbers, interferences in Indigenous Lands (IL) were considered in different phases of the demarcation procedure, including those delimited, declared, approved and regularized. According to FUNAI, the delimited condition corresponds to the second phase of the process, when the identification and delimitation studies have already been approved by this Foundation and published on the Federal Official Gazette.

[7] For lands occupied by remaining *quilombo* communities, interference in *quilombola* territories mapped by INCRA was considered. The remaining *quilombo* communities certified by Fundação Cultural Palmares, which do not yet have georeferenced mapping, were not considered.

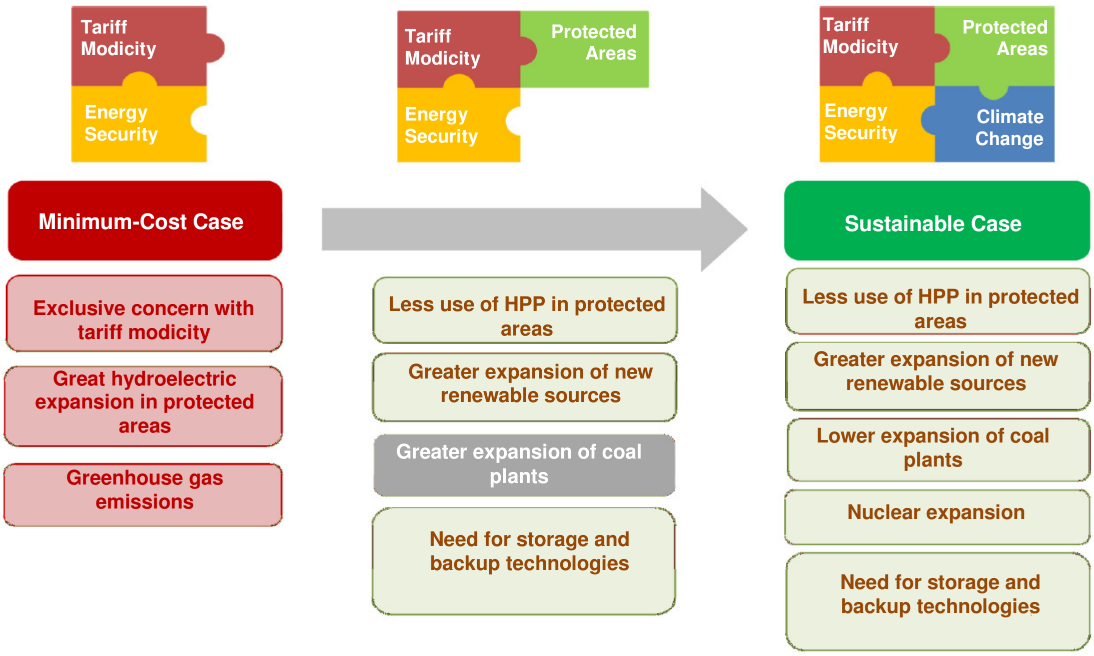


Figure 48 - Setting Specific Guidelines for the Long-Term Electricity Generation Expansion

The expansion path is determined through the use of a minimum-cost optimization model, considering restrictions applicable to each source.

The minimum-cost case is simulated from the entire portfolio of 69 GW inventoried available. Since hydroelectric power plants are more competitive than the other sources, the result was an expansion of the electricity supply using virtually the entire hydroelectric potential until 2030, including exploitations in protected areas. Additionally, GHG emissions related to the generation of electricity were relatively low, as hydroelectricity greatly contributes to keeping emissions under control, without a high expansion and operation of the thermoelectric facilities.

In turn, the final simulation, called "Sustainable Case", uses 45 GW of the hydroelectric potential by 2030, of which 37 GW do not have any interference in protected areas and 8 GW have interference in CU, with 4.7 GW in sustainable use CU and 3.3 GW in Full protection CU. That is, the exploitation of 24 GW is discarded (with 21 GW with interferences in indigenous lands or *quilombolas* and about 3 GW with interference in full protection CUs).

Figure 49 illustrates the hydroelectric exploitation in the case developed for Brazil's iNDC, comparing it to the minimum-cost case.

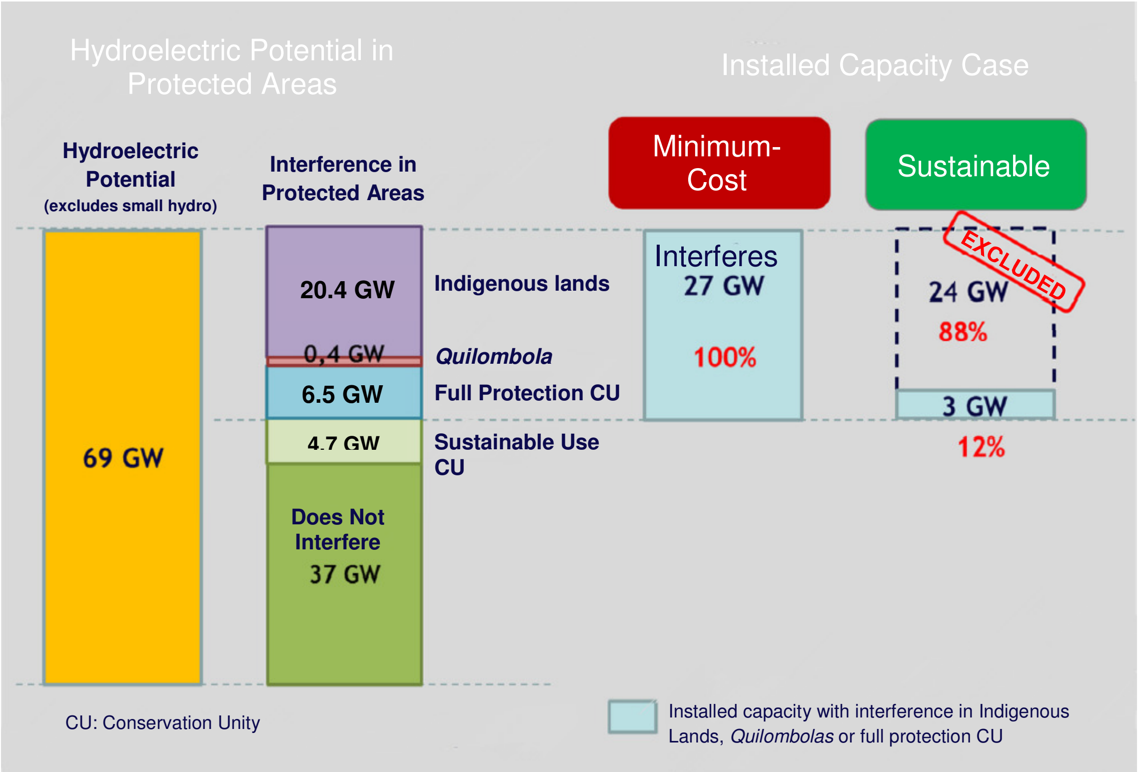


Figure 49 - Hydroelectric Potential Exploitation in the Case Built for Brazil's iNDC and Comparison to the Minimum-Cost Case

It is worth mentioning again that the results above refer to the studies carried out until September/2015, when Brazil's commitments were established in the iNDC. The recent review of the economic scenario in the early years of the projection results in a lower total electricity demand on the long-term horizon, indicating no need to exploit 3 GW located in Full Protection Conservation Units, as shown in Figure 49.

4.4. EXPANDING THE TOTAL ELECTRICITY GENERATION

The total expansion of the power generation system (centralized generation, in addition to self-production and distributed generation) evolves from 133 GW in 2014 to 257 GW in 2030, a 93% increase in the period. In particular, the expansion of renewable sources (biomass, wind and solar) from 12% in 2014 to 34% in 2030 stands out.

It is important to highlight that, without prejudice against the commitments agreed to in Brazil's iNDC for 2030, it was decided to show estimated ranges of installed capacity for 2025. This is because, as projections were made in September, 2015, and since then revisions have been made on relevant parameters related to the economic and energy prospects which resulted in a reduction in the increment projected for installed capacity in 2025.

Therefore, Table 17 shows possible increment ranges in power for each source, highlighting in bold the installed capacity in the Sustainable Case (as the INDC), in which an average GDP growth of 3.7% p.a. was considered between 2016 and 2025. In addition, the expected lower GDP growth in relation to the projection made in September, 2015, given the reversal of the economic context in the following years, makes it so that the projection of renewable sources share in the energy matrix, shown in the iNDC, can be achieved with a lower expansion than the one considered in this study and Brazil remains within the proposed GHG emission goals (see not bold 2025 numbers).

Table 17 - Capacity Installed in the National Integrated System (SIN) and Distributed Generation

Installed Capacity	2005		2014		2025		2030	
	GW	%	GW	%	GW	%	GW	%
Hydro	71	76.5	96	71.8	120 - **127**	58.7 - 61.1	139	54.2
Natural Gas	10	10.4	11	8.3	**21**	10.0 - 10.4	21	8.2
Coal	1	1.5	3	2.4	3 - **4**	1.6 - 1.7	4	1.4
Nuclear	2	2.2	2	1.5	**3**	1.6 - 1.7	5	2.1
Biomass	3	3.6	11	8.3	20 - **21**	9.7 - 9.9	28	11.0
Wind	0	0.0	5	3.7	**24** - 25	11.4 - 12.1	33	12.9
Solar (Centralized)	0	0.0	0	0.0	**7** - 8	3.3 - 3.7	17	6.8
Others	5	5.8	5	4.0	**0** - 2	0.0 - 1.1	0	0.0
Total SIN	**93**	**100**	**133**	**100**	197 - **207**	**99.1**	**248**	**96.5**
Distributed Generation								
Biogas	0	0.0	0	0.0	**0**	0.0	1	0.3
Solar	0	0.0	0	0.0	**2**	0.9 - 1.0	8	3.2
Total (SIN + DG)	**93**	**100**	**133**	**100**	199 - **209**	**100**	**257**	**100**

The results of total electricity generation are shown in Table 18.

Table 18 - Total Electricity Generation

Centralized Generation	2005		2014		2025		2030	
	TWh	%	TWh	%	TWh	%	TWh	%
Hydropower	373	86	404	65	612	64	690	60
Natural Gas	14	3	72	11	39	4	76	7
Coal	6	1	11	2	15	2	17	1
Nuclear	10	2	15	2	26	3	39	3
Biomass	1	0	18	3	55	6	76	7
Wind	0	0	12	2	92	10	105	9
Solar (Centralized)	0	0	0	0	13	1	26	2
Others	9	2	39	6	5	1	4	0
Subtotal (Load Met)	**413**	**95**	**572**	**92**	**858**	**90**	**1,033**	**90**
Self-Production & Distributed Generation	**2005**		**2014**		**2025**		**2030**	
	TWh	**%**	**TWh**	**%**	**TWh**	**%**	**TWh**	**%**
Biomass*	8	2	23	4	47	5	58	5
Solar	0	0	0	0	3	0	9	1
Hydropower	2	0	3	1	6	1	7	1
Non-Renewables	13	3	26	4	39	4	44	4
Subtotal (Self-Prod. & DG)	**23**	**5**	**52**	**8**	**95**	**10**	**119**	**10**
Total	**436**	**100**	**624**	**100**	**953**	**100**	**1,151**	**100**

Note: (*) Includes biogas, bagasse, black liquor and firewood.

Based on the result obtained from centralized electricity generation (1,033 TWh), the share of hydroelectric generation in the year 2030 was used as reference for establishing the commitment to obtain at least a 66% share of hydroelectric source in electricity generation, by 2030, not considering self-production.

The share of hydro in the total electricity generation drops to 61% at the expense of other renewable sources, which grow from 9% in 2014 to 24% in 2030. This occurs because self-produced electricity in the industry is a relevant part of the total self-production and has, as main inputs, bagasse in the sugar and alcohol segment and black liquor in the paper and cellulose segment.

Based on the projections for total electricity generation, which includes industrial self-production, the commitment to increase "the share of renewable energies (other than hydropower) in the electricity supply to at least 23% by 2030, including by increasing the share of wind, biomass and solar energy" has been defined.

5. FUEL SUPPLY

5.1. OIL AND NATURAL GAS

The considered oil resources, for the purpose of preparing Brazil's commitment in COP-21, include those referred to as conventional (representing almost the entire national oil production to date) and the so-called unconventional.

The exploitation of said conventional resources does not typically face technological and operational challenges and includes both discovered (with exploratory commerciality, whether declared or under evaluation) and undiscovered (estimated based on the geological knowledge of Brazil's sedimentary basins) resources.

The production projection indicates the possibility of the country maintaining itself as a major oil producer. There is a growing trend sustained primarily by the expected production of accumulations already discovered in the pre-salt layer. The start of production of undiscovered resources is expected, in contracted areas and governmental areas to be contracted, in the upcoming years, by concession or production sharing.

In the case of natural gas, it is projected that the contribution of possible unconventional gas production, with which the dependence on imported gas is reduced, begins starting from 2022, but associated with a higher degree of technical, economic, social and environmental uncertainties and risks. This resource category includes: tight gas, shale gas, gas hydrates, oil shale and tight oil.

The levels of oil and natural gas production are relevant to estimate the fugitive emissions and fuel consumption for driving the facilities required for their production.

5.1.1. SUPPLY OF OIL DERIVATIVES

On the whole, the country will go from a situation of net importer of derivatives in 2015 to a slight surplus position in 2030, maintaining however a certain degree of dependence in relation to gasoline and naphtha.

The highlight of the profile change on this horizon refers to diesel oil, whose production will allow for sharply exceeding the demand, so that the country becomes a net exporter in 2030. An important implication in the increased production of this derivative includes the increase in specific energy consumption in Brazilian refineries, so as to allow for obtaining the specification of lower sulfur content in diesel oil.

5.2. ENERGY USE OF BIOMASS

The large-scale use of bioenergy has been rapidly growing, moving the local and international biomass markets. For this reason, understanding what are the biomass resources in Brazil not only serves to maintain the renewability of Brazil's energy matrix but can also develop an international market for bioenergy and bioproducts. The expansion of bioenergy, however, must consider multiple land use, which includes food production, reason why special attention is dedicated to the prospects of using Brazilian territory in the long term.

5.2.1. TOTAL POTENTIAL AREA

In order to delimit and quantify potential areas for biomass expansion, legal restrictions and environmental guidelines that guide the occupation and use of the national territory were considered.

The first restriction applied was the exclusion of Conservation Units, Indigenous Lands and *Quilombolas*, and also urban areas. Then, the Pantanal and Amazon biomes were excluded, on the assumption that they are regions whose occupation model should be differentiated, in addition to the fragments of native vegetation in the Atlantic Forest protected by Federal Law no. 11,428/2006.

In other areas, those whose agricultural soil capacity is classified as unsuitable and those that are currently occupied by agriculture or reforesting were disregarded, as no changes are expected in land use in these areas.

Finally, from remaining areas, those with use restrictions on rural property provided for in the new Forest Code (Permanent Preservation and Legal Reservation Areas) were also discounted.

The study result indicates a potential area for a 144 Mha expansion of the agricultural frontier with no legal impediments, much of which already has anthropic use, classified as livestock or agriculture and livestock, or is covered by native vegetation[8]. Although the Amazon and Pantanal biomes have been excluded from the spatial analysis shown in Figure 50, today a relevant area of these biomes is already occupied with extensive livestock with low rates of density gain. In the case of intensifying livestock in these areas, more lands would be cleared for agricultural use and reforesting.

Thereby, it can be seen that there are no conflicts between environmental preservation and agricultural and livestock production as well as competition for land for food and bioenergy on the horizon until 2030, so that the projection of biomass product expansion is not restricted by the potential area.

[8] Although there are still areas covered with native vegetation free of legal impediments, enough to meet the agricultural and livestock expansion, the trend shows that environmental restrictions are increasing and there will possibly be resistance for the conversion of land use in these areas.

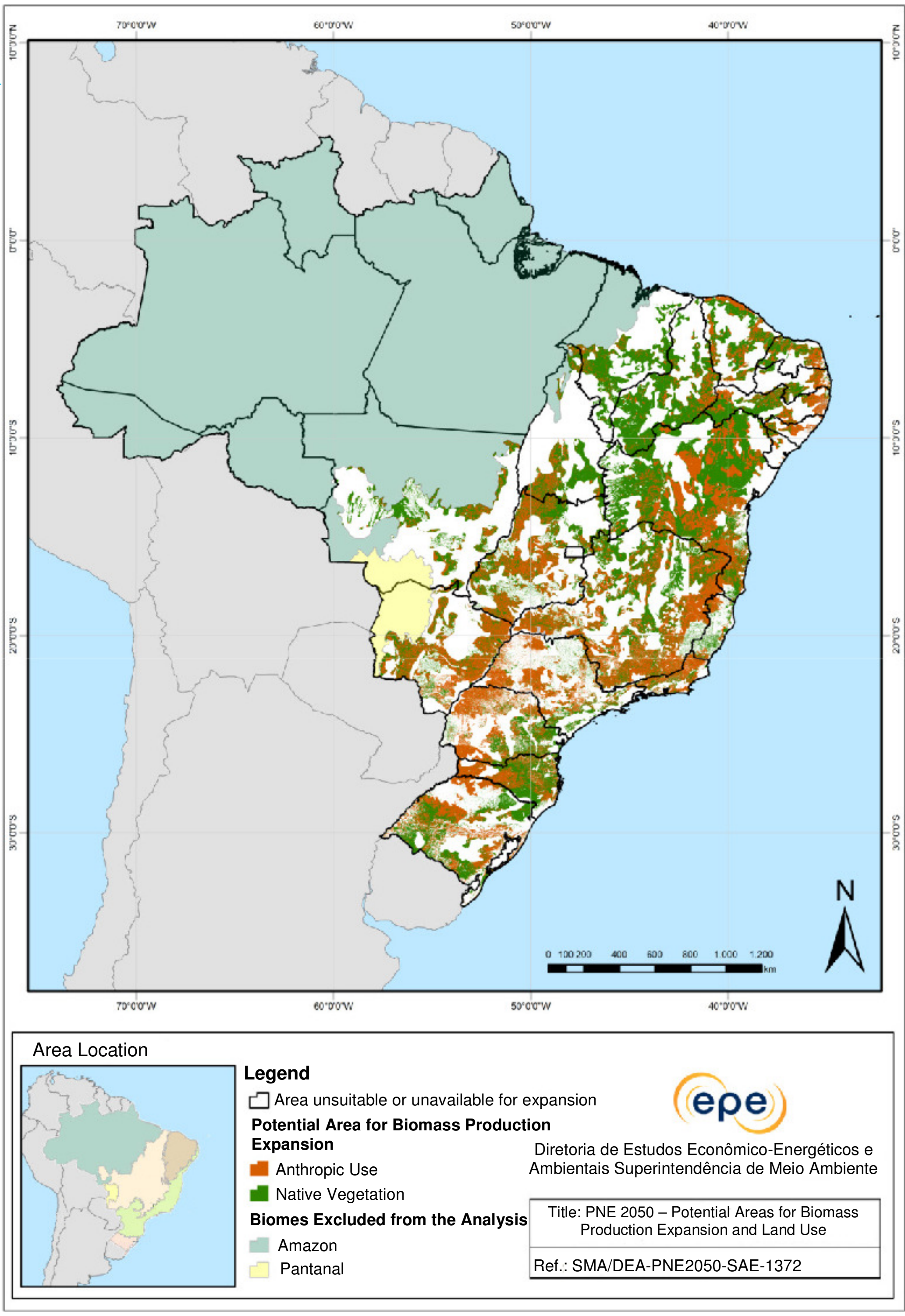


Figure 50 - Suitable Areas for Biomass Production

5.2.2. SUGARCANE RESOURCES AND ETHANOL SUPPLY

In Brazil, sugarcane juice is used to produce sugar and first-generation ethanol, and the bagasse is mostly used as fuel in the boilers for cogeneration, which feeds the plant with heat and electricity and allows export of electricity to the grid.

The projections for bagasse, juice for sugar and ethanol, and straw is made so as to meet the demand for sugar and ethanol in the domestic and foreign markets. For this, sugarcane production must grow by approximately 47% until 2030, reaching 1.1 billion tons.

The productions of juice, bagasse and straw must grow proportionally, as a fixed proportion of 27% and 73% is considered, respectively, for bagasse and juice in the cane composition and a production of 0.155 kg of straw per ton of cane.

The estimated evolution of disaggregated production until 2030 is shown in Figure 51.

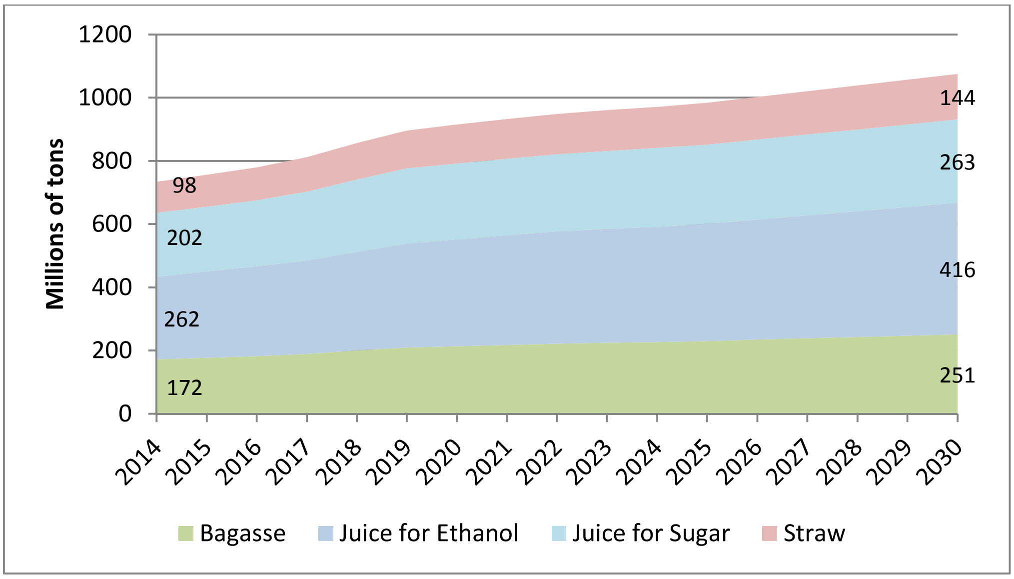


Figure 51 - Projection of Bagasse, Juices for Ethanol and Sugar, and Straw

It is estimated that the production of first-generation ethanol will grow from 28 billion liters in 2013 to 51 billion liters in 2030, while second-generation ethanol will begin showing up in considerable volumes starting from 2023, reaching 2.5 billion liters at the end of the period.

It is considered that the economic viability of second-generation ethanol in Brazil will be accomplished, among other reasons, for its integration with the production of first-generation ethanol, due to sharing equipment.

It is assumed that the typical second-generation unit, which has an average capacity of 80 liters of ethanol per ton of cane, rises to 100 liters from 2028 onwards. Thus, the existing units only reach full capacity (245 million liters) and competitive costs for commercial production starting from 2023.

Mills that have already implemented high-efficiency cogeneration show difficulties in manufacturing second-generation ethanol in commercial plants, on a ten-year horizon, as almost all bagasse is already committed. To do this, they would need to use the available straw or energy cane to be planted in a nearby area and, in this case, a new economic viability study will be required, due to additional costs with equipment for harvesting and processing. These conFiguretions have not been considered in this study.

Thus, it is expected that the total ethanol available grows from 28 billion liters in 2014 to 54 billion liters in 2030 (Figure 52).

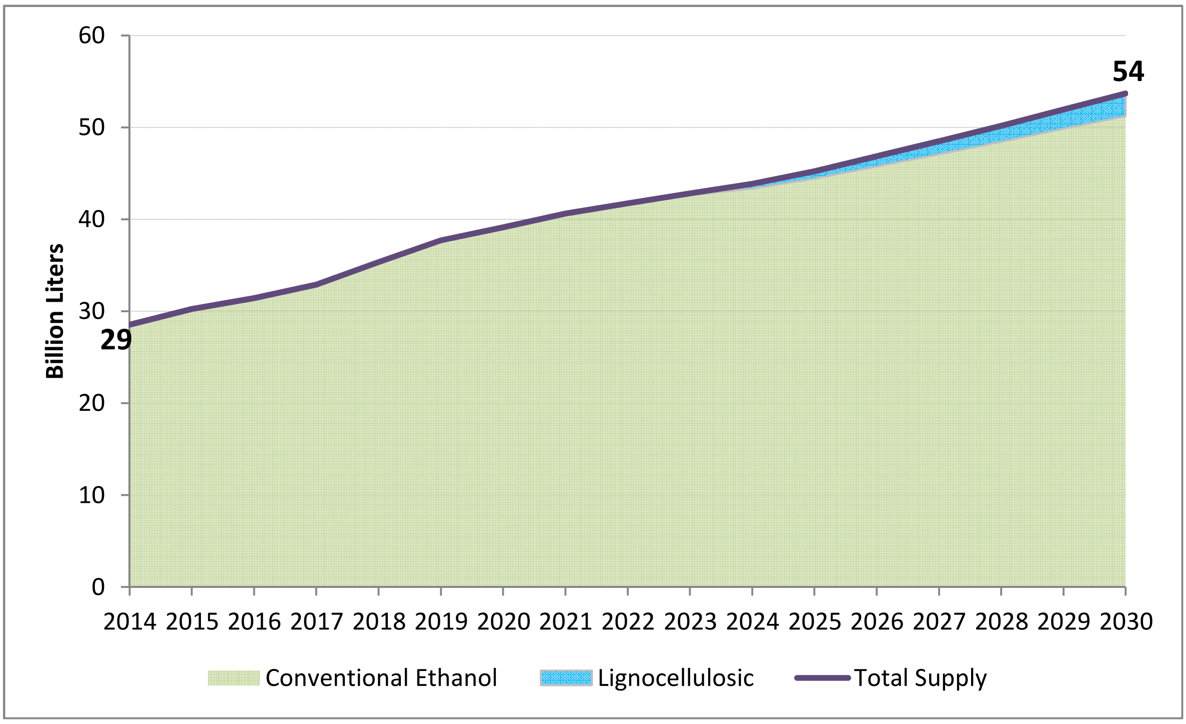


Figure 52 - Projection for Ethanol Supply

5.2.3. BIOMASS RESOURCES AND SUPPLY FOR BIODIESEL

In 2014, the recorded biodiesel production was slightly over 2 million toe, which corresponds to 13% of the theoretical potential for that year. In 2030, this value may reach 25 million toe in the available area considered, or exceed 30 million toe, assuming that part of the Amazon area can provide inputs from palm.

Considering the projections for diesel oil demand, the 7% percentage of biodiesel between 2015 and 2029 and 10% from 2030 on, we obtain the projection for biodiesel consumption (Figure 53), which defines the estimated biodiesel production path until 2030.

It is emphasized that, as explained in the item about demand, Law 13,263/2016 anticipates to 2020 the 10% content and allows for higher blends, showing the conservative nature of Brazil's position on this international commitment.

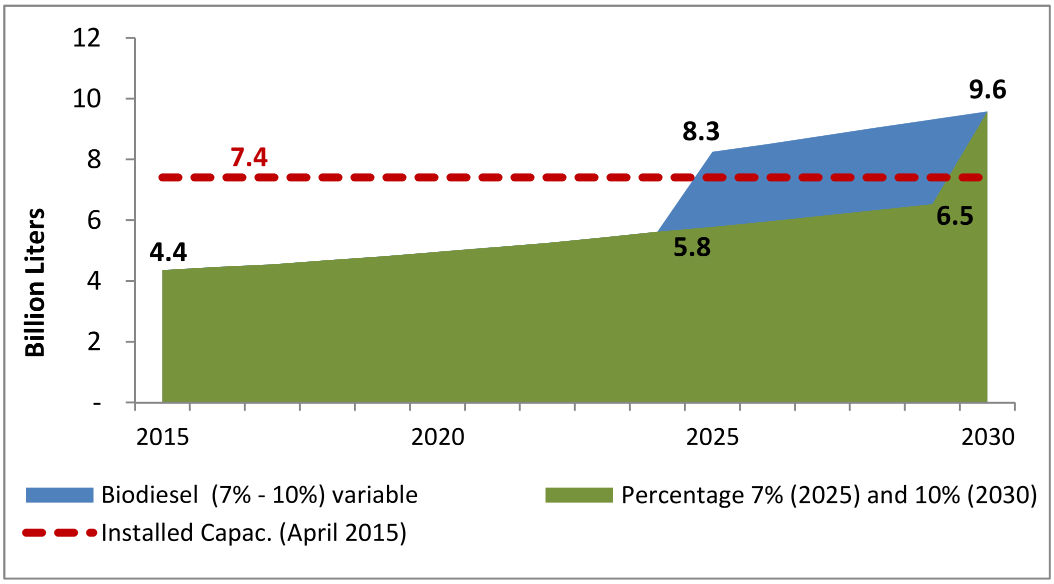


Figure 53 - Projection for Biodiesel Production

The installed capacity in 2015 for biodiesel manufacturing will be enough to meet the estimated demand in 7% until 2025, when considering the maximum limit of the variable 7% to 10% range. Consequently, it is assumed that it increases along the period, so as to meet the resulting consumption from changes in the regulatory framework that should happen from 2025.

Currently, the crop that fuels most of the national biodiesel consumption is soy, which should prevail, but with the prospect of introducing palm. Figure 54 shows the projection of resource availability for producing biodiesel on the horizon in vogue, with explicit values for the years 2015, 2025 and 2030.

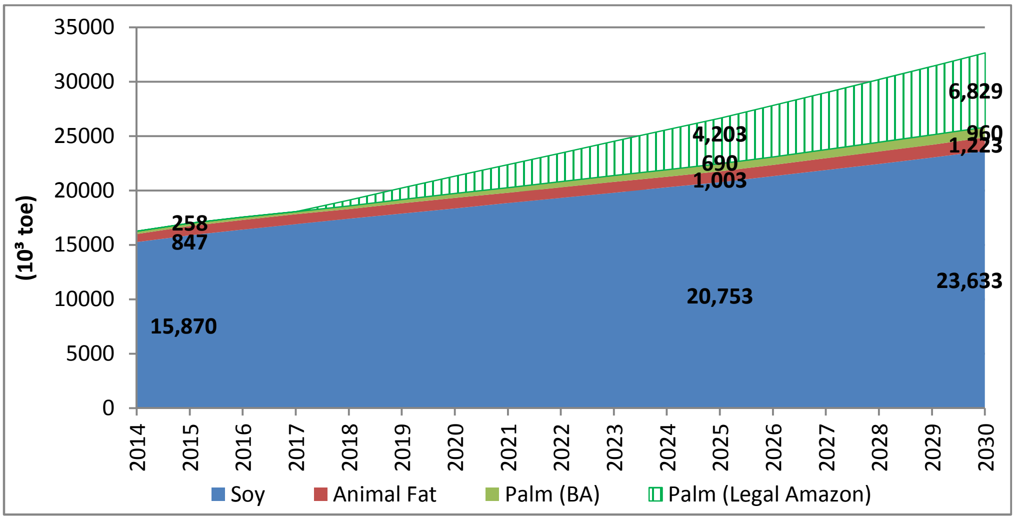


Figure 54 - Projection for Vegetable Oil, input for Biodiesel Production

6. ENERGY MATRIX, EMISSIONS AND INDICATORS

Accounting for results of the projections for domestic energy supply and electricity supply follows the same methodology as the National Energy Balance – BEN, as well as energy matrices used as reference for the calculation of greenhouse gas (GHG) emissions. The results shown in this chapter were the basis for establishing the goals of Brazil's iNDC in the energy field.

6.1. DOMESTIC ENERGY SUPPLY

Based on the premises shown in the previous chapters, it is estimated that, in 2030, the domestic energy supply will reach approximately 482 million toe, which represents an average growth of 2.9% per year in the period. The domestic electricity supply evolves at an average rate of 4.2% p.a., reaching 1,147 TWh. The final energy consumption will reach 393 million toe in 2030 with an average growth rate of 2.9% per year. The Domestic Energy Supply per GDP and Final Energy Consumption per GDP have downward trends and, in 2030, reach levels below that of 2005, which shows a reduction in the energy intensity of Brazil's economy. Table 19 gives a summary with the main economic premises, energy consumption and supply expansion until 2030.

Table 19 - Economy & Energy

Breakdown		2005	2014	2025	2030	Annual Average Growth 2014 - 2030
Resident Population	(10^6 inhab)	186.2	203.2	218.9	223.5	0.6%
GDP	(10^9 R$ [2009])	2,802	3,709	5,259	6,429	3.5%
	per capita (10^3 R$/inhab)	15.0	18.3	24.0	28.8	2.9%
Domestic Energy Supply	(10^6 toe)	217.9	305.6	410.2	482.0	2.9%
	per PIB (toe/10^3 R$)	0.078	0.082	0.078	0.075	-0.6%
	per capita (toe/inhab)	1.170	1.504	1.874	2.156	2.3%
Domestic Electricity Supply	(TWh)	403	591	938	1,147	4.2%
	per PIB (kWh/10^3 R$)	143.8	159.2	178.4	178.4	0.7%
	per capita (kWh/inhab)	2,164	2,906	4,286	5,133	3.6%
Final energy consumption	(10^6 toe)	182.3	249.9	339.0	393.0	2.9%
	per PIB (toe/10^3 R$)	0.065	0.067	0.064	0.061	-0.6%
	per capita (toe/inhab)	0.979	1.230	1.549	1.758	2.3%

Table 20 shows the consolidation of the domestic energy supply, highlighting the evolution of renewables share to 45.0% in 2030. In particular, Other Renewables, which include wind, solar and biodiesel energy, increase their share to about 10%. Products derived from sugarcane, which include bagasse, juice and molasses, also increase their share in domestic energy supply to approximately 17%.

Table 20 - Domestic Energy Supply

	2005		2014		2025		2030	
	10^3 toe	%	10^3 toe	%	10^3 toe	%	10^3 toe	%
Non-Renewable Energy	121,819	55.9	185,1	60.6	226,143	55.1	265,152	55.0
Oil & Derivatives	84,553	38.8	120,327	39.4	146,515	35.7	164,43	34.1
Natural Gas	20,526	9.4	41,373	13.5	46,679	11.4	61,207	12.7
Mineral Coal & Derivatives	12,991	6.0	17,551	5.7	23,303	5.7	26,421	5.5
Uranium (U3O8) & Derivatives	2,549	1.2	4,036	1.3	6,996	1.7	10,232	2.1
Other Non-Renewables	1,2	0.6	1,814	0.6	2,65	0.6	2,862	0.6
Renewable Energy	96,117	44.1	120,489	39.4	184,097	44.9	216,82	45.0
Hydraulic & Electricity	32,379	14.9	35,019	11.5	53,209	13.0	59,949	12.4
Firewood & Charcoal	28,468	13.1	24,728	8.1	27,333	6.7	29,022	6.0
Sugarcane Derivatives	30,15	13.8	48,128	15.7	69,087	16.8	80,94	16.8
Other Renewables	5,12	2.3	12,613	4.1	34,468	8.4	46,91	9.7
Wind	8	0.0	1,05	0.3	7,898	1.9	8,989	1.9
Solar	0	0.0	0	0.0	1,075	0.3	3,056	0.6
Vegetable Oil (Biodiesel)	0	0.0	2,193	0.7	4,458	1.1	7,481	1.6
Others	5,112	2.3	9,37	3.1	21,037	5.1	27,383	5.7
Total	**217,936**	**100.0**	**305,589**	**100.0**	**410,24**	**100.0**	**481,972**	**100.0**

The growth of shares of renewable sources in the projections for Domestic Energy Supply was the reference used to establish three of Brazil's iNDC goals in the energy area:

- Achieve an estimated 45% share of renewables in the energy matrix composition by 2030;
- Increase the share of sustainable bioenergy in the energy matrix to approximately 18% by 2030, expanding the consumption of biofuels, increasing ethanol supply, including by increasing the proportion of advanced biofuels (second generation), and increasing the proportion of biodiesel in the diesel blend;
- Expand the use of renewable sources, other than hydropower, in the total energy matrix to a 28% to 33% share by 2030.

Figure 55 compares the percentage of renewables of Brazil's energy matrix to the global and OECD average percentages.

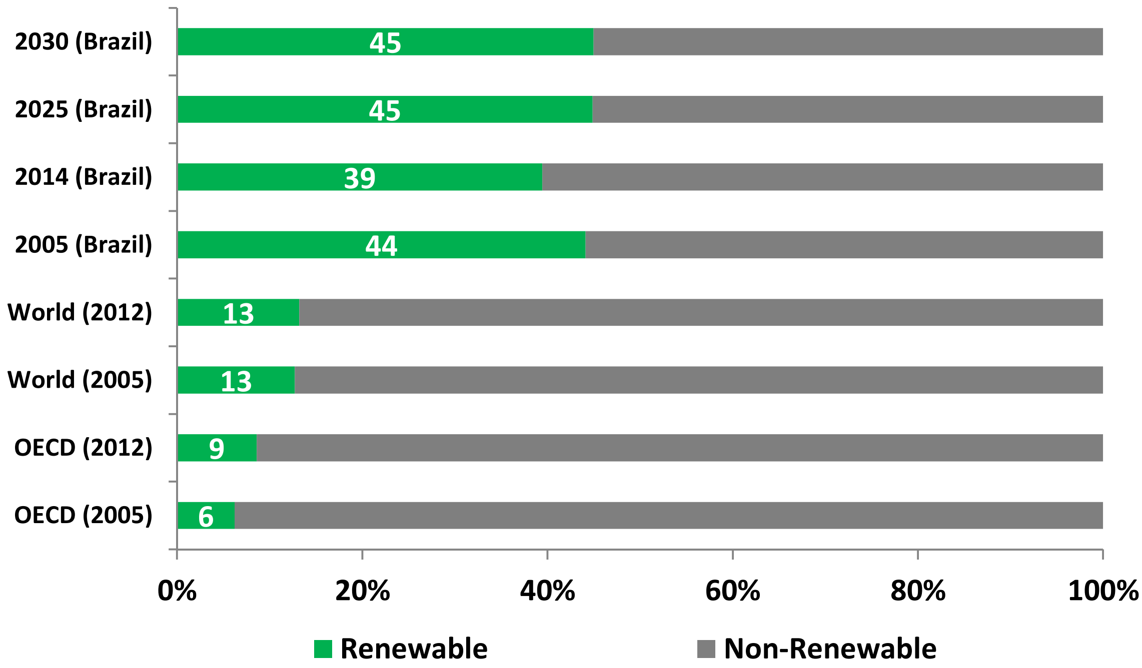


Figure 55 - Renewables in Brazil and the World

6.2. ESTIMATED GHG EMISSIONS

The greenhouse gas emissions projected for 2025 and 2030, according to the premises given in this Technical Note, are displayed in Table 21, per fuel, and Table 22, showing the sectoral distribution of emissions. It is worth reminding that all results are expressed in million tons of CO_2 equivalents using GWP-100 (AR5). The details of the methodology used are found in the Appendix of this document.

Table 21 - GHG Emissions by Fuel

Fuel	2005	2025	2030
	million tons of CO_2 eq		
Diesel Oil	106	203	229
Natural Gas	44	86	116
Gasoline	40	86	94
Steam Coal	17	40	40
Petroleum Coke	16	30	35
LPG	19	27	29
Kerosene	5	16	20
Fuel Oil	23	16	19
Refinery Gas	10	16	16
Other Secondary Oil Sources	7	8	9
Other Primary Sources	4	8	9
Naphtha	6	7	7
Coke Oven Gas	2	5	6
Sugarcane Products	2	4	4
Non-Energy Petroleum Products	1	3	4
Mineral Coal Coke	2	3	3
Firewood	8	2	2
Charcoal	2	2	2
Oil Tar	0.4	1	1
Anhydrous & Hydrous Alcohol	0.1	1	1
Fugitive	19	36	43
TOTAL	332	598	688

Note: The 2005 data come from the II National Inventory

Table 22 - GHG Emissions by Sector

Industrial	2005	2025	2030
	million tons of CO_2 eq		
Energy Sector	28	46	49
Residential	18	22	24
Commercial	2	3	3
Public	2	1	1
Agricultural	15	22	24
Transportation	135	278	315
Industrial	87	130	156
Energy Consumption	79	114	136
Non-Energy Consumption	8	16	20
Electricity Sector	26	60	73
Electricity Sector - SIN	17	40	50
Electricity Sector - Self-Production	9	20	23
Fugitive Emissions	19	36	43
TOTAL	332	598	688

Note: The 2005 data come from the II National Inventory

6.3. INDICATORS

Figure 56 illustrates the expected emissions for the energy sector. In relation to the 2005 emissions, those projected for 2030 are 107% higher.

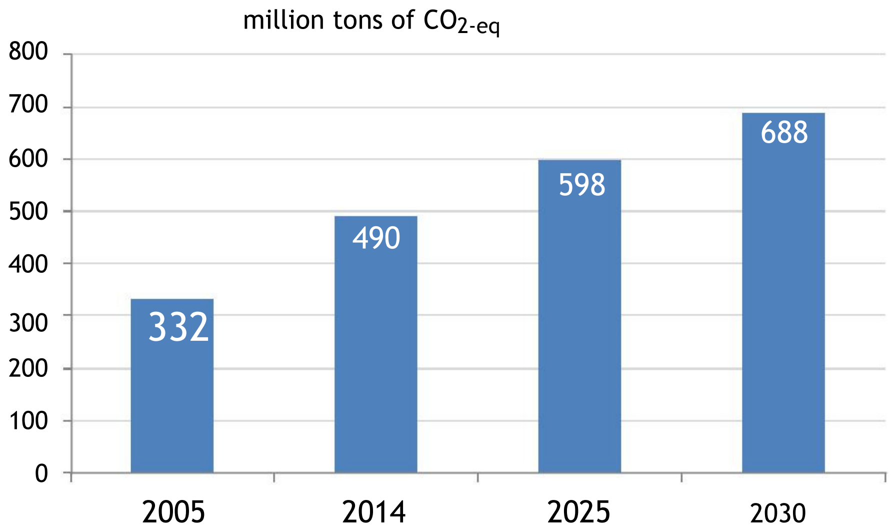


Figure 56 - Total Emissions in the Energy Sector

Yet, the intensity of emissions shows a downward trend on the projected horizon, i.e. the Brazilian economy is becoming less carbon-intensive, getting to 2030 with an emission intensity 10% lower than in 2005 (Figure 57).

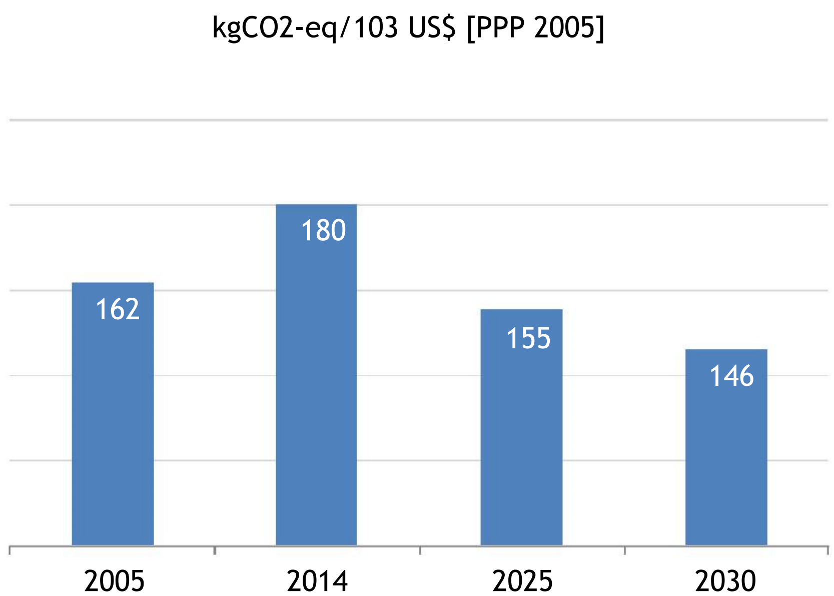


Figure 57 - Emission Intensity in the Energy Sector

The comparison of Brazil's emission intensity with that of some of the world's major countries shows that in 2030 Brazil will be far below the level verified currently in USA, China, Germany and European Union (Figure 58).

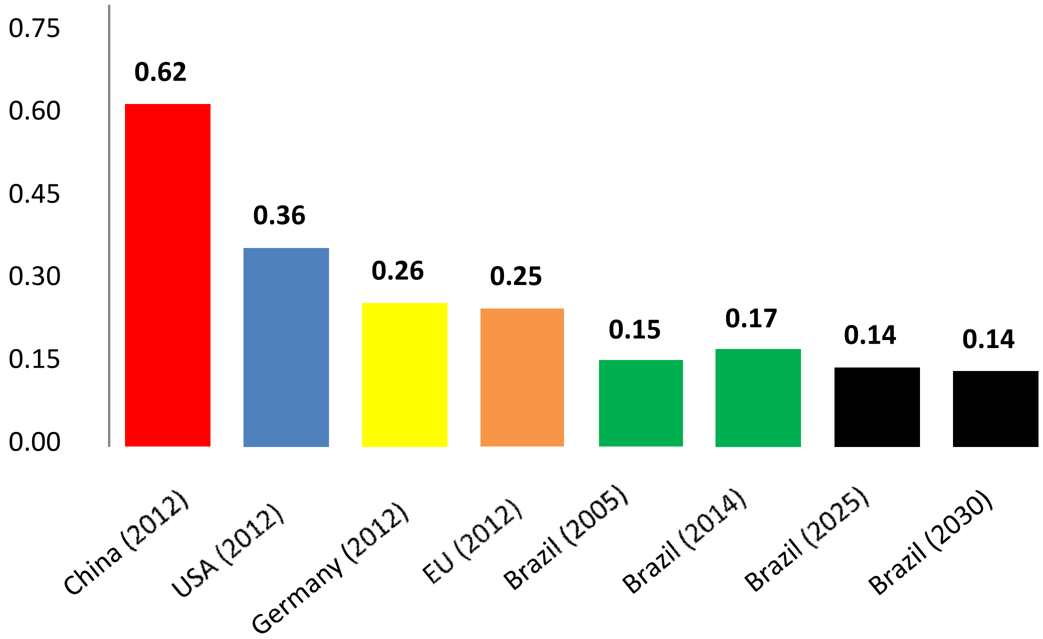


Figure 58 - Emission Intensity in the Energy Sector: International Comparison

Figure 59 shows the increase in per capita emissions by 73% in relation to 2005. Despite this increasing projection, the emission levels in Brazil's energy area will be much lower than the current levels of the USA, China, Germany and European Union (Figure 60).

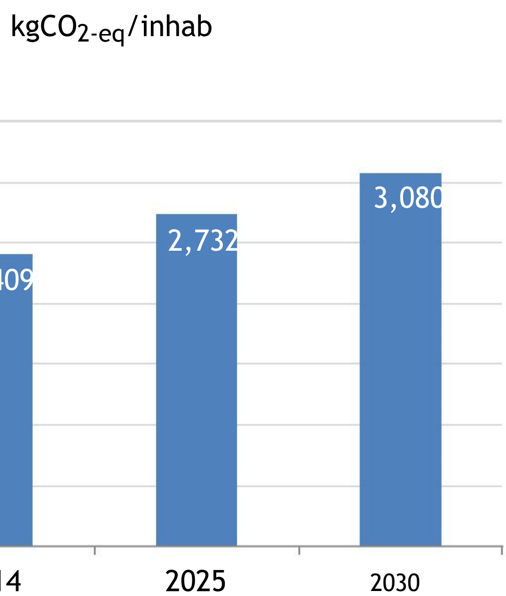


Figure 59 - Per Capita Emissions

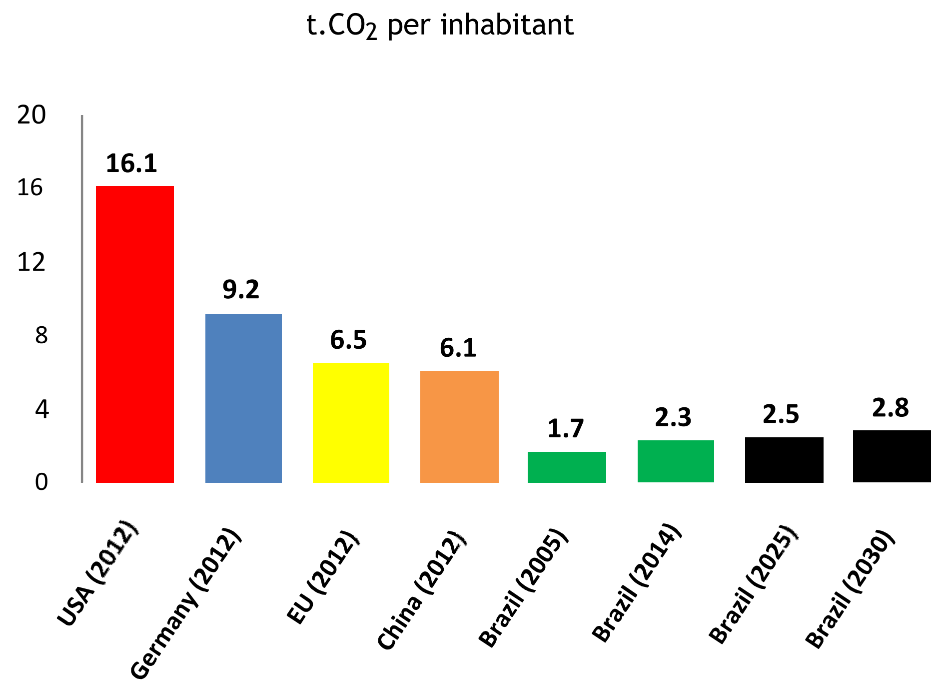


Figure 60 - Per Capita Emissions: International Comparison

7. CONCLUSION

The commitment assumed by Brazil in the Paris Agreement for reducing greenhouse gas emissions in 2025 and 2030 by, respectively, 37% and 45% in relation to 2005 levels was an example for the world regarding the mitigation of climatic change, as the country already has a low-carbon economy and has been reducing the Amazon deforestation rate since 2004.

In the energy field, Brazil already has one of the most renewable matrices in the world, with approximately 75% of renewable sources in the electricity supply, in addition to one of the most successful biofuel program, which results in about 40% of its renewable energy matrix (three times higher than the world average).

Achieving the goals agreed to in the energy area is fully possible, but it remains a challenge and will require efforts in measures and public policies that favor even more the expansion of renewable energy sources and energy efficiency measures.

Brazil's iNDC applies to the entire economy and, therefore, is based on flexible paths to achieve the 2025 and 2030 objectives. In other words, the objective to reduce the emissions to lower levels than those of the year 2005 can occur in many ways.

Thus, it is necessary to monitor the path in order to do the required adjustments, not only with the purpose of seeking the goal on the horizon of the agreement, but so that Brazil maintains itself as a low-carbon economy and is one of the world references in actions to combat climate change.

8. REFERENCES

ABIOVE [Associação Brasileira da Indústria de Óleo Vegetal]. (Economist Daniel Furlan Amaral) Conjuntura e Perspectivas – Panorama do Mercado de Extração de Óleos. I Simpósio Tecnológico PBIO de Extração de Óleos Vegetais. Rio de Janeiro/RJ. 2009.

ABRAF [Associação Brasileira de Produtores de Florestas Plantadas]. Anuário Estatístico Ano-Base 2012. Brasília. 2013.

ANFAVEA [Associação Nacional dos Fabricantes de Veículos Automotores]. Anuário da Indústria Automobilística Brasileira 2013. São Paulo/SP. 2013a.

ANP [Agência Nacional do Petróleo, Gás Natural e Biocombustíveis]. Produção por Campo para a Incidência dos Royalties. 2014. Available at: http://www.anp.gov.br/?id=532.

___________. Anuário Estatístico Brasileiro do Petróleo, Gás Natural e Biocombustíveis. 2015.

WORLD BANK. Becoming Old in an Older Brazil: Implications of Population Aging on Growth, Poverty, Public Finance and Service Delivery. [s.l.]: World Bank, 2011.

BETTINI, C.; SILVA, R.R. Forecasting Petroleum Production with a Model Based from Discharge Process. AAPG 2009 (American Association of Petroleum Geologists), International Conference & Exhibition; Nov. 15-18; Rio de Janeiro-RJ. 2009.

BURGI, A. S. Avaliação do potencial técnico de geração elétrica termossolar no Brasil a partir de modelagem em SIG e simulação de plantas virtuais. Dissertation (Masters in Energy Planning Program) – UFRJ/COPPE. 2013

CAMARGO-SCHUBERT Engenheiros Associados, Atlas eólico: Bahia, 2013.

DENHOLM, P. and MARGOLIS, R. M. Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States. Energy Policy, Volume 36, Issue 9, September 2008, Pages 3531-3543.

ELETROBRÁS-CONSULPUC, Atlas do Levantamento Preliminar do Potencial Eólico Nacional, 1979.

ELETROBRÁS, Fundação Padre Leonel Franca, Atlas do Potencial Eólico Nacional. 1988.

EPE [Empresa de Pesquisa Energética]. Plano Nacional de Energia 2030. Available at http://www.epe.gov.br. Rio de Janeiro/RJ. 2007.

____________ Nota Técnica: "Consolidação de Bases de Dados do Setor Transporte: 1970-2010". Available at http://www.epe.gov.br. Rio de Janeiro/RJ. 2012.

____________ Zoneamento Nacional de Recursos de Óleo e Gás. 2012 Available at: http://www.epe.gov.br/Petroleo/Documents/Zoneamento/Zoneamento_Nacional_Oleo_Gas.pdf.

____________ Balanço Energético Nacional 2015 (Ano base 2014). 2015.

____________ Plano Decenal de Expansão de Energia 2024. Available at http://www.epe.gov.br. Rio de Janeiro/RJ. 2015.

____________ Nota Técnica: "Demanda de Energia 2050". Available at http://www.epe.gov.br/mercado/Paginas/Estudos_27.aspx. Rio de Janeiro/RJ. 2016.

FAPESP – Fundação de Amparo à Pesquisa do Estado de São Paulo. Eucalipto transgênico pode aumentar a produtividade da madeira – Available at www.painelflorestal.com.br. 2013.

Government of the State of São Paulo. Atlas Eólico do Estado de São Paulo. Secretaria de Energia, 2012.

IBGE [INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA]. Censo Demográfico 2010. Rio de Janeiro: IBGE, 2010.

___________ Projeção da População do Brasil por sexo e idade: 2000-2060. Rio de Janeiro: IBGE, 2012.

___________ Sinopse do Censo Demográfico 2010. Rio de Janeiro: IBGE, 2012.

___________ Sistema IBGE de Recuperação Automática – SIDRA. Accessed on August 14, 2013.

IEA [International Energy Agency]. Large Industrial Uses of Energy Biomass. 2013 Available at: http://www.bioenergytrade.org/downloads/t40-large-industrial-biomass-users.pdf.

MMA [Ministry of the Environment]. Ordinance no. 422/2011.

MINISTRY OF TRANSPORT. Projeto de Reavaliação de Estimativas e Metas do PNLT. Relatório final. Available at http://www.transportes.gov.br. Brasília/DF. September/2012.

OECD/ITF [Organization for Economic Co-operation and Development/International Transport Forum].Transport Outlook. Meeting the Needs of 9 Billion People. Available at:<http://www.internationaltransportforum.org>. Accessed in November, 2013.

PEREIRA, E. B. et al. Atlas brasileiro de energia solar, 2006

SANTOS, I. Desenvolvimento de ferramenta de apoio à decisão em projetos de integração solar fotovoltaica à arquitetura. Thesis (PhD in the Graduate Program in Civil Engineering) - Universidade Federal de Santa Catarina. 2013.

SANTOS JUNIOR, A. Possibilidades e Impactos da Ampliação da Siderurgia a Carvão Vegetal Oriundo de Florestas Plantas no Brasil., Rio de Janeiro - COPPE/UFRJ. 2011

APPENDIX

PROCEDURE FOR ESTIMATING GHG EMISSIONS

The future emissions of greenhouse gases (GHG) have been estimated using as a reference the IPCC Guidelines for National Greenhouse Gas Inventories[9] (IPCC, 2006). Only emissions related to the Energy category of said methodology were estimated, which includes the burning of fossil fuels in the following activities:

- Exploration and Production (E&P) of oil and natural gas;
- Energy consumption for the production of other primary energy products;
- Oil refining;
- Energy consumption in the production of secondary energy products (includes the biofuel industry);
- Electricity generation, cogeneration and heat production;
- Energy consumption in the industrial sector;
- Energy consumption in the transportation sector;
- Energy consumption in the agriculture and livestock, residential, and commercial sectors.

The methodology also encompasses fugitive emissions[10], which occur in oil and gas E&P activities and the transportation and storage of fuels, especially natural gas. The mineral coal extraction activities also generate fugitive emissions, which are accounted for.

For emissions due to the burning of fuels, the methodology's Bottom-Up approach has been used. To apply it, the main input is the consolidated matrix (model from the National Energy Balance - BEN). The difference for the official National Inventory usually done in National Communications is that the consolidated matrix used here refers to future years, based on the results of energy demand and supply projections, already shown throughout this technical note. The matrix consolidates these results and is used to calculate GHG emissions. Figure 61 schematically illustrates the consolidated matrix.

[9] IPCC: Intergovernmental Panel on Climate Change.

[10] Fugitive emissions are intentional or unintentional GHG releases into the atmosphere that may occur in the extraction, processing and distribution of fossil fuels. In the oil & gas chain, they include: equipment leakages, evaporation, venting, flaring, incineration and accidental releases. In the coal chain, they include the release of CO_2 and CH_4 (associated with the ore) during its mining, processing, transportation and storage (IPCC, 2006)

Unit: 10^3 toe		Primary Energy Sources					Secondary Energy Sources				
		Oil	Natural Gas	Coal	Firewood	(...)	Diesel	Gasoline	Electricity	Ethanol	(...)
Domestic Supply Balance	Production										
	Importation										
	Stock variation										
	Exportation										
	Not used										
	Reinjection										
Transformation Sectors	Oil Refineries										
	Natural gas plants										
	Gasification Plants										
	Coke ovens										
	Nuclear fuel cycle										
	Public Service power stations										
	Self-producing power stations										
	Coal Pits										
	Distilleries										
	Other transformations										
	Losses in distribution and storage										
Sectoral consumption	Non-final energy consumption										
	Energy Sector										
	Residencial										
	Commercial										
	Public										
	Agricultural										
	Transportation										
	Industries										

Figure 61 - Schematic Representation of the Consolidated Matrix

The cells highlighted in gray in Figure 61 indicate where there are emission calculations due to having the burning of fossil fuels. We can note the following: 1) the entire sectoral consumption of primary and secondary fuels is accounted for; 2) in the transformation sectors, the rows referring to electricity generation in public service power stations and self-producing power stations are accounted for; and 3) the cells referring to the production of oil, natural gas and coal are used to calculate fugitive emissions, as we shall see.

It is important to emphasize that, in the BEN logic, energy consumption in the fuel transformation and production processes, such as refineries, natural gas plants, distilleries, etc., as well as consumption in the operations of primary fuel production is fully accounted for in the sectoral consumption, in the Energy Sector row.

The algebra involved in the calculation of GHG emissions is relatively simple, just by multiplying the fuel consumption by the respective emission factors (EF), as shown in the formula below.

$$Emission_{GHG,fuel} = \text{Consumption}_{Fuel} \times EF_{\ GHG,Fuel}$$

In addition to CO_2, the methane (CH_4) and nitrous oxide (N_2O) gases were contemplated[11]. The emission factors used are those indicated by IPCC in Tier 1[12] of the methodology. Table 23 shows the default emission factors of IPCC already converted to the t.GHG/thousand toe unit[13].

Table 23 - Greenhouse Gas Emission Factors for Different Fuels

	Emission Factors (t.GHG/thousand toe)		
Fuel	CO_2	CH_4	N_2O
Tar	3,921	0.126	0.025
Anhydrous & Hydrous Ethanol	-	0.754	0.025
Metallurgical Coal	3,882	0.042	0.063
Steam Coal	3,882	0.042	0.063
Charcoal	-	8.374	0.167
Mineral Coal Coke	4,438	0.042	0.063
Petroleum Coke	4,180	0.126	0.025
Hydraulic Energy	-	-	-
Coke Oven Gas	1,986	0.042	0.004
Refinery Gas	2,780	0.042	0.004
Natural Gas	2,337	0.042	0.004
Gasoline	2,873	1.382	0.025
LPG	2,614	0.042	0.004
Firewood	-	1.256	0.167
Naphtha	3,040	0.126	0.025
Fuel Oil	3,207	0.126	0.025
Diesel Oil	3,070	0.126	0.025
Other Primary Sources	3,040	0.126	0.167
Other Secondary Oil Sources	3,040	0.126	0.025
Oil	3,040	0.126	0.025
Sugarcane Products	-	1.256	0.167
Non-Energy Petroleum Products	3,040	-	-
Kerosene	2,964	0.126	0.025
Uranium Contained in UO_2	-	-	-
Uranium U_3O_8	-	-	-

Source: Adapted from IPCC (2006)

[11] Other greenhouse gases such as Hydrofluorocarbons (HFCs), Chlorofluorocarbons (CFCs), Perfluorocarbons (PFCs), and Sulfur Hexafluoride (SF_6) are considered not relevant to the Energy Sector. The non-metallic volatile organic compounds (NMVOC), carbon monoxide (CO) and nitrogen oxides (NO_x), considered tropospheric ozone (O_3) precursors were also not accounted for. The latter, in addition to causing damage to human health, vegetation and ecosystems, is also considered a greenhouse gas.

[12] The IPCC methodology calls for three levels of details of the calculations that must be applied according to the availability of information on the activities and specificities of the fuels. Tier 1 is the less detailed level.

[13] The IPCC default emission factors are originally shown in kgGHG/TJ.

It is important to note that fuels based on biomass: firewood, sugarcane products, anhydrous and hydrous alcohol, and charcoal have null CO_2 emission factors following the premise that the carbon emitted in the burning of these fuels is the one that was absorbed in the photosynthesis process, as recommended by the IPCC. The same does not occur for CH_4 and N_2O, as these gases have a global warming potential that is much higher than that of CO_2. Therefore, for fuels derived from biomass, the CH_4 e N_2O emissions are calculated normally by the same procedure already shown.

Hydraulic energy and uranium consumption have been considered free of emissions for all gases[14].

It is also worth noting the consumption of mineral coal coke in the Pig-Iron and Steel industrial sector. The fuel is consumed in blast furnaces in the steel industries, and it is understood that its main function is the reduction of iron ore. In this case, it is recommended that the allocation of these emissions is done in the Industrial Processes category of the Inventory methodology.

In view of the comparability of Brazilian goals with other countries and considering that most countries have set GHG emission goals in CO_2 equivalents in the GWP (Global Warming Potential) metric, we chose to follow this trend in this work. Thus, the final results are shown in million tons of CO_2 equivalents ($MtCO_2eq$). The reference for conversion of gas emissions using GWP was the IPCC Fifth Assessment Report (AR5), whose values are shown in Table 24.

Table 24 - GWP-100 Conversion Factors

	CO_2	CH_4	N_2O
GWP 100 years	1	28	265

Source: IPCC, 2014

The calculation is done multiplying the sum of emissions of each gas by the respective conversion factor.

$$Emissions_{CO2eq} = \sum Emissions_{GHG} \times GWP_{GHG}$$

FUGITIVE EMISSIONS

The estimated fugitive emissions followed the methodology that has been used by the MCT (2014) for estimating national emissions for years after 2005, last year inventoried in the 2nd National Communication.

[14] Emissions from the creation of hydroelectric reservoirs have been studied by various authors. The results of the latest BALCAR project (CEPEL, 2015) studies indicate that, for most hydroelectric plants, the trend is for low net emissions of greenhouse gases, with a strong correlation to the indicator of wetland per power (km^2/MW), so that the lower this indicator, the less CO_2 and CH_4 emissions of the plant per energy unit generated. In this work, we opted to disregard emissions of existing and planned hydroelectric reservoirs.

That method is based on historical data for fugitive emissions of the inventoried years and their correlation to indicators of coal, oil and natural gas production activities.

Fugitive CO_2 e CH_4 Emissions in E&P Activities

According to the MCT (2013), there is a good correlation between fugitive CO_2 emissions in E&P activities and the actual oil production variable, as shown in the chart of Figure 62.

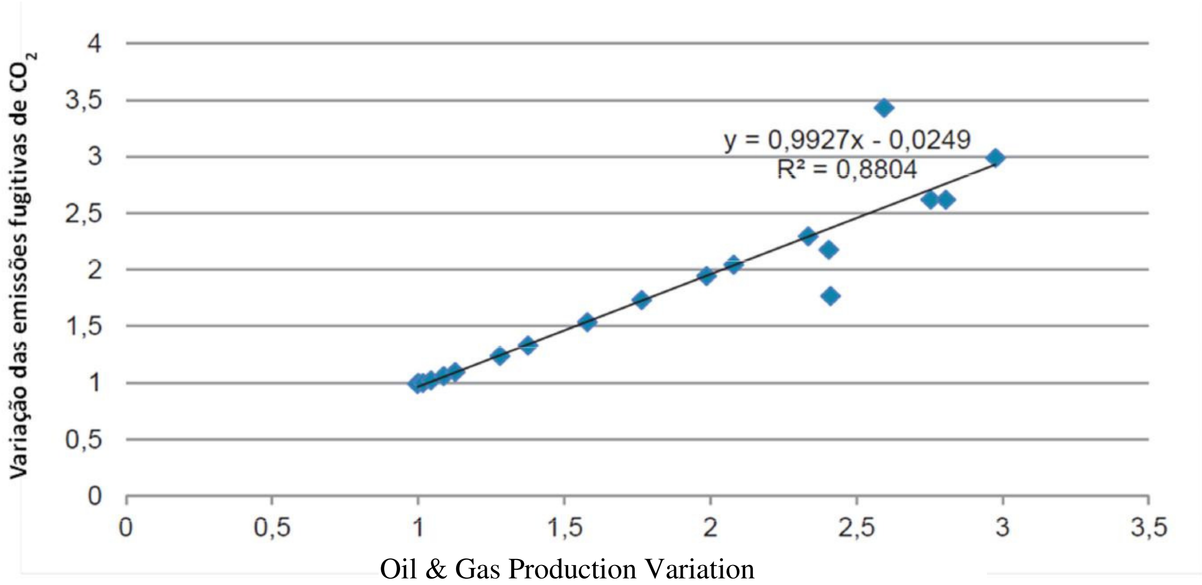


Figure 62 - Correlation of Oil & Gas Production and Fugitive CO_2 Emissions

Source: MCT (2013)

Therefore, it is possible to estimate emissions in a future year using the linear equation contained in the chart.

$$\frac{Fugitives\ E\&P_{GHG,future}}{Fugitives\ E\&P_{GHG,reference}} = 0{,}9927 \times \left(\frac{Production_{oil,future}}{Production_{oil,reference}}\right) - 0{,}0249$$

The reference year used for calculating variations was the year 2010. Thus, considering that the fugitive CO_2 emission in oil and gas E&P activities in 2010 was 5,573 Gg CO_2, emissions in 2025 can be calculated as the example:

$$\frac{\boldsymbol{Fugitives\ E\&P_{CO2,2025}}}{Fugitives\ E\&P_{CO2,2010}} = 0{,}9927 \times \left(\frac{Production_{oil,2025}}{Production_{oil,2010}}\right) - 0{,}0249$$

$$\frac{\boldsymbol{Fugitives\ E\&P_{CO2,2025}}}{5.573\ Gg\ CO2} = 0{,}9927 \times \left(\frac{272.104\ mil\ tep}{106.559\ mil\ tep}\right) - 0{,}0249$$

$$\boldsymbol{Fugitives\ E\&P_{CO2,2025}} = \left(0{,}9927 \times \left(\frac{272.104\ mil\ tep}{106.559\ mil\ tep}\right) - 0{,}0249\right) \times 5.573\ Gg\ CO2$$

$$\boldsymbol{Fugitives\ E\&P_{CO2,2025}} = 2{,}51 \times 5.573\ Gg\ cO2 = \boldsymbol{13{,}98\ Gg\ CO_2}$$

The same is applied for fugitive emissions of methane gas (CH_4).

Fugitive CO_2 e CH_4 Emissions in Oil Refining Activities

The same logic shown for fugitive emissions in E&P is applied to fugitive emissions in refining, as there is a good correlation with the volume of oil processed in refineries, as per the equation below.

$$\frac{Fugitives\ Oil\ Refining_{GHG,future}}{Fugitives\ Oil\ Refino_{GHG,reference}} = 1{,}3121 \times \left(\frac{Processed\ Oil_{future}}{Processed\ Oil_{reference}}\right) - 0{,}3341$$

Fugitive CO_2 e CH_4 Emissions in Oil & Gas Transportation

Fugitive emissions in the transportation stoe are less than 1% of oil and gas fugitive emissions, and the MCT could not find a good correlation, reason why these emissions have been estimated with a simple linear trend of the inventoried data.

Fugitive Emissions in the Mineral Coal Chain

The calculation of CH_4 emissions in coal mining has been done with differentiated emission factors for opencast and underground mining. Emissions are estimated by multiplying the projection of mineral coal production by the emission factors of the respective types of mine. The share of both types of mining has been kept constant as verified in the year 2012, with 46% opencast and 54% underground. The emission factors used were 0.23 kgCH_4/t.coal for opencast mining and 7.3 kgCH_4/t.coal for underground mining.

$$Fug.Coal_{CH4} = (Prod._{coal,year} \times 0{,}46\ \times EF_{opencast})\ \times (Prod._{coal,year} \times 0{,}54\ \times EF_{underground})$$

The calculation of fugitive CO_2 emissions derived from the spontaneous burning on waste piles was done with the extrapolation of the linear trend of inventoried data and estimated by the MCT until 2012 (MCT, 2014).