TÍTULO

BRAZIL

A POSSIBLE SYMBIOTIC RELATIONSHIP BETWEEN THE EVOLUTION OF CARBON EMISSIONS, ENERGY CONSUMPTION AND ECONOMIC GROWTH

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BRAZIL: A POSSIBLE SYMBIOTIC RELATIONSHIP BETWEEN THE EVOLUTION OF CARBON EMISSIONS, ENERGY CONSUMPTION AND ECONOMIC GROWTH.

MASTER THESIS PRESENTED BY
ERIKA REESINK CERSKI
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“Scientific evidence for warming of the climate system is unequivocal, there is 95 percent confidence that humans are the main cause of the current global warming”.

- Intergovernmental Panel on Climate Change

"La evidencia científica para el calentamiento del sistema climático es inequívoca, hay 95 por ciento de confianza que los seres humanos son la principal causa del calentamiento global actual".

- Grupo Intergubernamental de Expertos sobre el Cambio Climático

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ABSTRACT

In December 2015, 195 countries adopted the first-ever legally binding global climate deal at Paris Climate Conference (COP21), known as Paris Agreement. Although, the agreement entered into force on November 4th in 2016, it sets out a global action plan to avoid risky climate change by limiting global warming less than to 2°C in the long term. In the Paris Agreement, Brazil plays a crucial role due to the fact that it has the ninth largest economy in the world, an important relationship with its neighbors in South America, a population exceeding 200 million people, and covers practically the entire Amazon Rainforest. These are some of the reasons that explain why Brazil has pledged to cut down greenhouse gases (GHG) emissions by 37 per cent by 2025, and 43 per cent by 2030, compared to 2005 levels.

The development of a country, especially Brazil, requires appropriate and realistic policies to current and changing demands. In this way, it is fundamental to achieve not only a secure but also a consistent environmental planning for the energy sector and GDP growth. Within this context, this study proposes a model of economic growth, carbon emissions and sustainable development for Brazil.

This work applies to the period 1971-2030, using the methodology proposed by Robalino-López (2014), based on a GDP formation approach, which includes the effect of renewable energies. A historical data, from 1971 to 2012, and a forecast period of 18 years have been considered for testing four different economic scenarios. Our predictions show that the scenario which corresponds to a heavy GDP increase can have the same value of CO_2 emissions as a scenario in which the GDP increases modestly if appropriate changes in the renewable energy and energy intensity are promoted. The final conclusion of this work suggests that Brazil goals at the COP21 are extremely ambitious, and it is likely the Brazilian targets will not be achieved. In any case, the Brazilian mitigation program for carbon emissions should be continued to benefit everyone.

RESUMEN

En diciembre de 2015, 195 países adoptaron un acuerdo climático universal y jurídicamente vinculante en Paris, conocido como Acuerdo de París sobre Cambio Climático y que nació en la Conferencia del Clima de París (COP21), aunque no ha entrado en vigor hasta el 4 de noviembre de 2016. El acuerdo establece un plan de acción global para evitar el peligroso Cambio Climático, y limita el calentamiento global por debajo de 2°C. Brasil tiene un papel crucial en el Acuerdo de París, pues es la novena economía del mundo, tiene una importante relación con sus países vecinos en América del Sur, tiene una población actual de 200,4 millones de personas y cubre casi toda la Amazonía. Estas son algunas de las razones que explican por qué Brasil se ha comprometido a reducir las emisiones de gases de efecto invernadero en un 37 por ciento en 2025, y en un 43 por ciento en 2030, en comparación con los niveles de 2005. El desarrollo de un país, especialmente del Brasil, requiere políticas adecuadas y realistas a las demandas actuales y futuras. De esta manera, es fundamental tener una planificación segura y consistente, pero también ecológica para el sector energético y el crecimiento del PIB.

Dentro de este contexto, el presente estudio propone un modelo que englobe el crecimiento económico, las emisiones de carbono y el desarrollo sostenible de Brasil. Este trabajo analiza el período 1971-2030, utilizando la metodología propuesta por Robalino-López (2014), para estudiar el efecto del uso de las energías renovables sobre la formación del PIB. Un período histórico de 1971 a 2012 y una previsión de 18 años han sido considerados en la prueba de cuatro diferentes escenarios económicos y energéticos. Nuestras predicciones muestran que el escenario que corresponde a un fuerte aumento del PIB puede tener el mismo valor de emisiones de CO_2 que un escenario en que el PIB crezca moderadamente si se promueven los cambios apropiados en el uso de energía renovable y en la intensidad energética. La conclusión final de este trabajo sugiere que las metas de reducción de carbono presentadas por Brasil en la COP21 son muy ambiciosas y probablemente no serán alcanzadas. En cualquier caso, el programa brasileño de mitigación de emisiones de carbono debe continuar en beneficio de todos.

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List of Acronyms

BERC	Brazilian Energy Research Company (*Empresa de Pesquisa Energética-EPE*)
BIGS	Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística-IBGE*)
CH_4	Methane
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
COP21	Paris Climate Conference
EKC	Environmental Kuznets Curve
FRB	Federative Republic of Brazil (*República Federativa do Brasil*)
GDP	Gross Domestic Product
GHG	Greenhouse Gas
Gt	Gigatonne
$GtCO_2eq$	Gigatonne Carbon Dioxide Equivalent
GWh	Gigawatt Hour
ICLFS	Integrated Cropland-livestock-forestry Systems
HDI	Human Development Index
iNDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt Hour
ME	Ministry of the Environment (*Ministério do Meio Ambiente- MMA*)
Mt	Million Tonnes
MW	Megawatt
NAEE	National Agency of Electric Energy
N_2O	Nitrous Oxide
PPP	Purchasing Power Parity
toe	Tonne of Oil Equivalent
ton	Tonne
TWh	Terawatt Hour
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WB	World Bank

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1. INTRODUCTION

According to Intergovernmental Panel on Climate Change (IPCC, 2014), despite a growing number of climate change mitigation policies, annual greenhouse gas (GHG) emissions grew on average by 1.0 gigatonne carbon dioxide equivalent ($GtCO_2eq$) (2.2%) per year from 2000 to 2010 compared to 0.4 $GtCO_2eq$ (1.3%) per year from 1970 to 2000. The highest anthropogenic GHG emissions in human history were from 2000 to 2010, which reached 49 (±4.5) $GtCO_2eq/yr$ in 2010. Besides, CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010. In addition, CO_2 remained the major anthropogenic GHG accounting for 76% of the total emissions in 2010, 16% coming from methane (CH_4), 6% from nitrous oxide (N_2O), and 2% from fluorinated gases.

Globally, economic and population growth are continued to be the important drivers in CO_2 emissions derived from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained similar to the previous three decades, whereas the contribution of economic growth rose sharply. Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy (IPCC, 2014).

Several international organizations have been warning about the need of stabilizing CO_2 and other anthropogenic GHG emissions in order to avoid catastrophic warming of the climatic system during this century. The adoption of environmentally sustainable technologies, energy efficiency improvement, energy saving, forest conservation, reforestation, or water conservation are the most effective ways to address the climate change issue. As a result of it, 195 countries adopted the first-ever legally binding global climate deal during the Paris Climate Conference (COP21), in December 2015. The international agreement sets out a global action plan to avoid dangerous climate changes by limiting global warming to well below 2°C. The agreement is due in 2020.

Unfortunately, the economic growth, according to the environmental Kuznets curve (EKC), in a first stage will also increase the CO_2 emissions of the country. The EKC reveals how a technically specified environmental quality measurement changes according to the income of a country (see Figure 1).

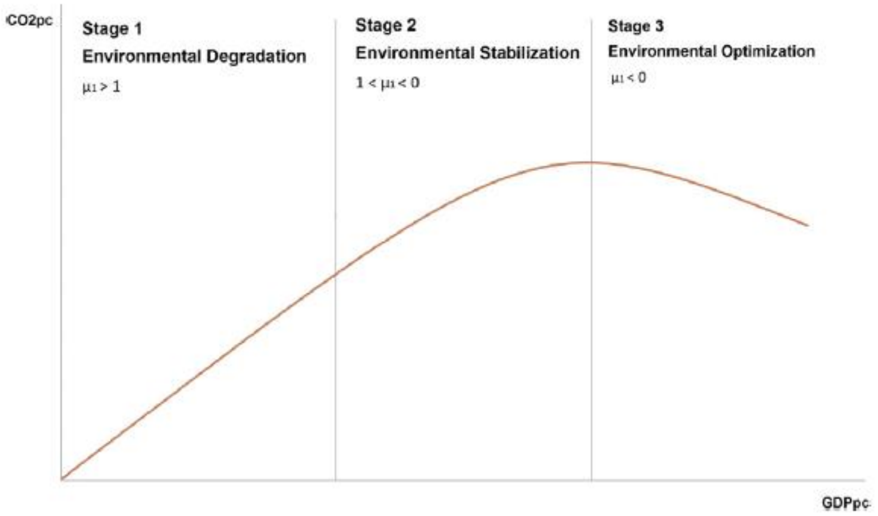

Figure 1. Schematic plot of the relationship between the GDP per capita (pc) and the CO_2 emission per capita: (1) linear growth of the emission, (2) stabilization, and (3) reduction of the CO_2 emission as the income increases. Source: Robalino-López et al., 2014.

The name EKC or the inverted-U relationship comes from the work of Kuznets who created an inverted-U relationship between income inequality and economic development. The logic of EKC hypothesis follows the general intuition. In the first stage of industrialization process, pollution grows rapidly because priority is given to increase material output, and the economy is more interested in providing jobs and income than keeping clean air and water (Dasgupta et al., 2002). The rapid growth due to the industrialization process inevitably results in greater use of natural resources and pollutant emission, which in turn put more pressure on the environment. Countries under this situation, are too poor to afford for abatement, so they disregard environmental growth consequences. In a later stage of industrialization, as income rises, the government and people value the environment more, regulatory institutions become more effective, green energy and energy efficiency are more frequent and pollution level declines. Thus, EKC hypothesis posits a well-defined relationship between level of economic activity and environmental pressure (defined as the level of concentration of pollution or flow of emissions, depletion of resources, etc.).

The decomposition of changes in an aggregate environmental impact and of its driving forces has become popular to unravel the relationship of society and economy with the environment. The specific application in energy consumption and CO_2 emissions is known as Kaya identity (Kaya, 1990 and Kaya et al., 1993). The Kaya identity is a linking expression of factors that determine the level of human impact on environment, in the form of CO_2 emissions. It states that total emission level can be expressed as the product of four inputs: population, GDP per capita, energy use per unit of GDP, carbon emissions per unit of energy consumed. The Kaya identity plays a core role in the development of future emissions scenarios in the IPCC Special Report on Emissions Scenarios (IPCC, 2000). The scenarios set out a range of assumed conditions for future development of each of the four inputs. Population growth projections are available independently from demographic research; GDP per capita trends are available from economic statistics and econometrics; similarly for energy intensity and emission levels. The projected carbon emissions can drive carbon cycle and climate models to predict future CO_2 concentration and climate change.

The identification of these kinds of sources of CO_2 emissions and of their magnitude is essential information for economic planning and decision makers. As Chien and Hu (2008) and Robalino-López et al. (2013, 2014) had shown the use of renewable energy improves the CO_2 efficient emission in relation to economic growth.

The proposal of the present work is to apply a model that links the GDP formation and the use of renewable energy. The methodology was created by Robalino-López et al. (2014) and was firstly applied to Ecuador (2013) and then to Venezuela (2015); the present work applies the proposed methodology to Brazil.

1.1. The goals of this research

The general objective of this research is to estimate the CO_2 emissions in Brazil using and improving the Robalino-López (2014) methodology; the research also aims to understand the driving forces that guide the emission process, such as economic growth, energy use, energy structure mix, and fuel use in the productive sectors.

A multi-scenario approach is used to analyze the evolution of energy consumption and energy-related emissions and its implications in the socio-economic and environmental development of the study area.

This study could help the development and implementation of proactive policies to the challenge of sustainable development. The application of scenario analysis-modelling in the short-to-medium term is intended to develop insights into plausible future changes with green goals in the driving forces of the national policies. The specific research objectives are:

- To study in details the way that changes in the energy matrix and in gross domestic product (GDP) will affect CO_2 emissions in the country.
- To develop a set of integrated qualitative and quantitative baseline scenarios at both macro and sectorial level to explore plausible alternative development of income, energy use and CO_2 emissions in a medium term (2030) in Brazil.
- To fill the gap in the literature of studies on the relationship between emissions, energy consumption and income growth in Brazil.

This research is organized as follows: Literature Review; Model and Methodology; Results and Discussion; and ends with Conclusions.

2. LITERATURE REVIEW

In this day and age, sustainable development it is a very popular topic. Many countries, regardless to their economic situation, have been studying the relationship between economic growth, energy consumption and CO_2 emission. In the literature it is possible to find many researches about this subject, as shown on Table 3, which summarizes the set of references, analyzed in detail below. Notice that there are different lines of research, some study the relationship between GDP and energy consumption or GDP, energy and CO_2 emissions, including the study of the causality relationships; others study the different aspects of the EKC hypothesis; and finally, there are also researches that use scenarios to be able to conduct forecast calculations of CO_2 emissions in forthcoming period.

Table 1. Summary of recent studies that analyzed the GDP growh-energy-CO_2 relationship.

Author	Relationship	Region	Methodology	Period	Outcomes
Padilla et al.	CO_2-GDP	Groups of countries	Non-parametric estimations	1971-1999	GDP inequality → CO_2 inequality
Kuntsi-Reunanen	CO_2-energy	Selected Latin America	CO_2 emission flows	1970-2001	No significant changes
Narayan and Narayan	CO_2-GDP	43 developing countries	EKC analysis	1980-2004	35% of the countries show EKC evidences
Jaunky	$C0_2$-energy-GDP	36 high-income countries	EKC analysis	1980-2005	GDP→CO_2 EKC evidence found
Robalino-López et al.	CO_2-energy-GDP	Ecuador	System dynamics modeling and scenario analysis	1980-2025	Strong connection GDP-$C0_2$
Robalino-López et al.	CO_2-energy-GDP	Ecuador	System dynamics modeling and scenario analysis	1980-2025	EKC not fulfilled
Cowan et al.	CO_2-energy-GDP	BRICS countries	Granger causality	1990-2010	Evidences of GDP → CO_2
Ibrahim et al.	CO_2-GDP	69 countries	GMM estimators	2000-2008	Mixed evidences
Al-mulali et al.	Energy-GDP	Latin America	Cointegration, Granger causality	1980-2010	Long run relationship between renewable energy and GDP growth
Robalino-López et al.	CO_2-energy-GDP	Venezuela	System dynamics modeling and scenario analysis	1980-2025	GDP→CO_2 CO_2→ renewable sources EKC not fulfilled
Robalino-López et al.	CO_2-energy-GDP	10 South America countries	Kaya I dentity	1980-2010	Relationship GDP→ $C0_2$
Zambrano-Monserrate et al.	CO_2- GDP-energy	Brazil	EKC analysis	1971-2011	EKC not fulfilled for short-run, but EKC fulfilled for long run.

Padilla et al. (2006) researched the inequality in $C0_2$ emissions across group of countries and the relationship with the income inequality from 1971 to 1999. The authors concluded that for an overwhelming majority of countries, higher per capita income should be expected to be followed by higher emissions.

In 2007 Kuntsi-Reunanen studied a comparison of Latin America energy with CO_2 emissions from 1970 to 2001. The author inferred that the increase in CO_2 emissions could be attributed partly to economic growth and to population growth. Also, the structural shifts from a rural, predominantly agricultural economic base, to a manufacturing one resulted in increasing energy demand. As Winkler et al. (2002) affirmed the nature of the energy economy will strongly influence emissions per capita of GDP. Kutsi as well concluded that since the developing countries will continue to emphasize their manufacturing sectors, CO_2 emissions can be expected to increase unless energy efficiency is increased commensurably. While energy efficiency has slightly improved in these countries, the improvement is considerably lower than countries of the Organisation for Economic Co-operation and Development (OECD). Most developing countries should be expected to increase their emissions to meet human development needs at least in the next few decades.

Narayan and Narayan (2010) explored the carbon dioxide emissions and economic growth from 43 developing countries in the period 1980 to 2004. A new approach was employed. They propose that if the long-run elasticity is lower than the short run elasticity, then this is also equivalent to lower carbon emissions as economic growth occurs over time. With this methodology, they found that in 35% of the sample the CO_2 diminished in the long run, which confirms that these countries approach the sloping down part of the EKC.

Jaunky (2011) attempted to examine the EKC hypothesis for 36 high income countries over the period 1980–2005. The author applied the methodology proposed by Narayan and Narayan (2010) and added several panel unit root and co-integration tests. He detected unidirectional causality, running from GDP to CO_2 emissions, in short-run and long-run. In the long-run, CO_2 emissions have fallen as income rises for various countries.

Robalino-López et al. (2013, 2014) presented a model approach of CO_2 emissions in Ecuador up to 2020 and also analyzed whether the EKC hypotheses holds within the period 1980-2025 under four different scenarios. The main goal was studied in detail the way the changes in the energy matrix and in the GDP would affect the CO_2 emissions of the country. In particular, the effect of a reduction of the share of fossil energy, as well as of an improvement in the efficiency of the fossil energy use. The results do not supported the fulfillment of the EKC, nevertheless, its showed that it is possible to control the CO_2 emissions even under a scenario of continuous increase of the GDP, if it is combined with an increase of the use of renewable energy, with an improvement of the productive sectoral structure and with the use of a more efficient fossil fuel technology.

Cowan et al., in 2014, studied the nexus of electricity consumption, economic growth and CO_2 emissions in the BRICS countries from 1990 to 2010. The results suggest that the existence and direction of Granger causality differ among the different BRICS countries. The main recommendation for these countries in general is to increase investment in electricity infrastructure. Because, this will expand electricity production capabilities in order to keep up with supply, while at the same time improving electricity efficiency. This will result in higher levels of electricity production and lower levels of CO_2 emissions.

However, in terms of Brazil, Cowan et al. (2014) concluded that no evidence of causality running in any direction between electricity consumption and economic growth is found, thus supporting the neutrality hypothesis. Similarly, no causality was found to exist between electricity consumption and CO_2 emissions. This result makes sense as electricity only accounts for a marginal amount of Brazil's total GHG emissions, the majority coming from land usage. This relatively small contribution made by the electricity sector may also be a result of increasing levels of infrastructure and the use of renewable energy sources, particularly hydroelectricity in Brazil. With respect to the CO_2 emissions—economic growth nexus, causality was found to run from CO_2 emissions to economic growth. This result may be due to the rapid and large-scale deforestation of the Amazon rain forest. This deforestation is being done in order to increase the area available for agriculture and human settlement. The increased in agriculture and the resulting employment have helped to increase economic growth but at the expense of raising CO_2 levels, not just in Brazil, but globally.

Ibrahim and Law (2014) examined the mitigating effect of social capital on the EKC for CO_2 emissions using a panel data of 69 developed and developing countries. Adopting generalized method of moments (GMM) estimators, they found evidence substantiating the presence of EKC. Moreover, the authors suggest that the pollution costs of economic development tend to be lower in countries with higher social capital reservoir. In addition to policy focus on investments in environmentally friendly technology and on the use of renewable energy, investments in social capital can also mitigate the pollution effects of economic progress.

Al-mulali et al. (2014) investigated the impact of electricity consumption from renewable and non-renewable sources on economic growth in 18 Latin American countries between 1980 and 2010. It was found that economic growth, renewable electricity consumption, non-renewable electricity consumption, gross fixed capital formation, total labor force and total trade were cointegrated. In addition, the results revealed that renewable electricity consumption, non-renewable electricity consumption, gross fixed capital formation, total labor force, and total trade have a long run positive effect on economic growth in the investigated countries. The most important conclusion is that electricity consumption from renewable sources is more effective in increasing the economic growth than the nonrenewable electricity consumption in the investigated countries.

Robalino-López et al., in 2015, tested the case of Venezuela for the period 1980-2025, through a methodology based on an extension of Kaya identity and on a GDP formation approach that includes the effect of renewable energies, the same that will be used in this work. Also the authors experimented the EKC hypothesis under different economic scenarios. The predictions showed that Venezuela does not fulfill the EKC hypothesis, however, the country could be on the way to achieve environmental stabilization in the medium term.

Later Robalino-López et al. (2016) analyzed the convergence process in CO_2 emissions per capita from 1980 to 2010 based on the Kaya identity and in its components, namely, GDP per capita, energy intensity, and CO_2 intensity among 10

South American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Paraguay, Uruguay and Venezuela). They concluded that over these countries Brazil has the highest GDP in the region reaching 1968 billion USD in 2010, and that Brazilian industry is the most energy demanding sector of these countries. Furthermore, the results show that energy intensity in South America is lower (136 kgoe/000 USD in 2010) than world average energy intensity (184 kgoe/000 USD). However, the CO_2 intensity (CO_2 over energy) in the region has remained relatively constant (2.2 kg CO_2/kgoe) during the analyzed period and always below the world average (2.5 kg CO_2/kgoe). In addition, the use of renewable energy is very heterogeneous in the region. Indeed, the share of renewable and alternative energy in the total energy use is (for the year 2010): 6.0% for Argentina, 2.5% for Bolivia, 14.7% for Brazil, 6.1% for Chile, 11.1% for Colombia, 5.6% for Ecuador, 9.0% for Peru, 98.7% for Paraguay, 18.4% for Uruguay and 8.8% for Venezuela. Finally, CO_2 emission per capita in the region (2.3 tonnes) is much lower than the world average (4.3 tonnes). Venezuela is the country with the highest CO_2 emission per capita (6.2 tonnes), followed by Argentina (3.8 tonnes), Chile (3.0 tonnes), Ecuador (1.9 tonnes), Brazil, Colombia and Uruguay (1.6 tonnes each), Peru (1.2 tonnes), Bolivia (1.1 tonnes) and Paraguay (0.6 tonnes).

Zambrano-Monserrate et al. (2016) investigated the relationship between CO_2 emissions, economic growth, energy use and electricity production by hydroelectric sources in Brazil. They verified the EKC hypothesis using a time-series data for the period 1971-2011. Empirical results find out that there is a quadratic long run relationship between CO_2 emissions and economic growth, confirming the existence of an EKC for Brazil in the long run. Furthermore, energy use shows increasing effects on emissions, while electricity production by hydropower sources has an inverse relationship with environmental degradation. The short run model does not provide evidence for the EKC theory. The difference between the results in the long and short run could be related to the establishment of environmental policies.

3. MODEL AND METHODOLOGY

The methodology which was chosen to analyze the relationship between carbon emissions, energy consumption and sustainable development in Brazil was proposed by Robalino-López (2014) and will be explained in the next pages.

3.1 Formulation of the model

The authors projected a model which uses a variation of the Kaya identity, where the amount of CO_2 emissions can be studied quantifying the contributions of five different factors:

- Global industrial activity;
- Industry activity mix;
- Sectoral energy intensity;
- Sectoral energy mix;
- CO_2 emission factors.

The CO_2 emissions can be calculated as

$$C = \sum_{ij} Cij = Q \sum_{ij} \frac{Qi}{Q} \frac{Ei}{Qi} \frac{Eij}{Ei} \frac{Cij}{Eij} = Q \sum_{ij} Si.EIi.Mij.Uij \tag{1}$$

Where:

C - is the total CO_2 emissions (in a given year)

Cij - is the CO_2 emission arising from fuel type j in the productive sector i

Q - is the total GDP of the country

Qi - is the GDP generated by the productive sector i

Ei - is the energy consumption in the productive sector i

Eij - is the consumption of fuel j in the productive sector i

Si - is the share of sector i to the total GDP (Qi/Q)

EIi - is the energy intensity of sector i (Ei/Qi)

Mij - is the energy matrix (Eij/Ei)

Uij - is the CO_2 emission factor (Cij/Eij)

i - index runs over the considered industrial sectors

j - index runs over the considered types of energy

It is also of interest to write up how to calculate the total energy in terms of the GDP,

$$E = \sum_{ij} Eij = Q \sum_{ij} Si.EIi.Mij \qquad (2)$$

And the expended energy of every kind of fuel,

$$Ej = Q \sum_{i} Si.EIi.Mij \qquad (3)$$

The equation 1 is an extension of the Kaya identity because Robalino-López et al. (2014) disaggregated in type of productive sector and kind of fuel used, while in the original formulation only aggregated terms are considered: C, Q, and E.

Like Robalino-López et al. (2015) suggests the subsequent data analysis and the preprocessing of the time series was performed using the Hodrick-Prescott (HP) filter (1997), which allows isolation of outliers of the time series under study. After that, it is possible to get the trend component of a time series and to perform more adequate estimations.

The raw data to perform the model correspond to the official available data based on Brazil, provided by the Word Bank and the Brazilian Energy Research Company.

The simulation period extends from 1971 to 2030. The period of 1971-2012 (which corresponds to 31 years) was used to fix the parameters of the model and 2013-2030 (18 years) corresponds to the forecast period, under the assumption of different scenarios concerning the evolution of the income, the evolution of the energy mix, and the efficiency of the used technology.

As a convention for this work, the productive sector will be refer as i index and the type of energy source like j index. It is important to highlight that the index I runs over four sectors (1) Agriculture sector, (2) Industrial sector, (3) Energy sector and (4)

Services, residential and transportation sector. While the index j runs over seven type of fuels, which are (1) natural gas, (2) liquefied petroleum gases, (3) motor gasoline, (4) gas/diesel oil, (5) fuel oil, (6) petroleum coke and (7) renewable, alternative and nuclear energy.

3.2 Economic submodel

This methodology presents a key point the explicit inclusion of the effect of renewable energy on the GDP, allowing to establish a link between economic indicators and CO_2 emissions. Also this method considers that renewable energy can increase GDP through substitution of the energy import which has direct and indirect effects on increasing GDP and trade balance (Chien and Hu, 2008). The expenditure approach to form the GDP is

$$Q = Ca + I + G + TB \tag{4}$$

Where:

Ca - is the final household consumption expenditure

I - is the gross domestic capital formation

G - is the general government final consumption expenditure

TB - is the trade balance

However, there is a particular concern which it is important to highlight, the variable G should be removed of the model estimation in order to avoid multicollinearity. The system of the theoretical GDP formation model is composed of the equation below

$$Q = a_1.I + a_2.TB + a_3.Ca + a_4.E_{imp} + a_5.RN + \in_1 \tag{5}$$

Where:

E_{imp} - is the energy import

RN - is the renewable energy

$\in$ - are residuals

$a_1 \ldots a_5$ - are the coefficients

The data used to calibrate the model corresponds to the period of 1971-2012 and was extracted from the official dataset of the country. In equation 5 the GDP is positively influenced by consumption (a_3 = +7.882 10^{-1}), energy import (a_4= +1.728 10^{-2} \$2005/koe) and renewable energies (a_5 = +6.698 10 \$2005/koe), however, capital formation (a_1= -5.309 10^{-1}) and trade balance (a_2= -4.253 10^{-1}) had a negatively influenced.

3.3 Energy consumption and productive sectoral structure submodel

Energy consumption refers to the use of primary energy before transformation into any other end-use energy, which is equal to the local production of energy plus imports and stock changes, minus the exports and the amount of fuel supplied to ships and aircrafts engaged in international transport. Energy intensity is defined as the ratio of energy consumption and GDP.

3.4 CO_2 intensity and energy matrix submodel

CO_2 intensity of a given country corresponds to the ratio of CO_2 emissions and the total consumed energy written in terms of mass of oil equivalent.

$$CO_{2int} = \frac{\sum_{ij} C_{ij}}{\sum_{ij} E_{ij}} \qquad (6)$$

The value of the $\mathrm{CO}_{2\mathrm{int}}$ in a given year depend on the particular energy mix during that year. M_{ij} gives the energy matrix, but is more convenient to sum over the different sectors and aggregate the fossil fuel contributions, therefore, it was defined for each type of fuel (j=1 to 7).

$$Mj = \frac{\sum_{i} E_{ij}}{\sum_{ij} E_{ij}} \qquad (7)$$

Hence, the share of expended fossil energy is given by $6\sum_{\mathrm{i}=1} = \mathrm{Mj}$, while M_7 is the share of used renewable energy in the country. It was assumed that M_7 does not contribute to the CO_2 emissions.

The emission factors, Uij, were taken from the IPCC Guidelines for National Greenhouse Gas Inventories (2006) to estimate $C0_2$ emission of each fuel. The used values are highlighted in gray (Table 2). According to IPCC combustion processes are optimized to derive the maximum amount of energy per unit of fuel consumed, hence delivering the maximum amount of CO_2. Efficient fuel combustion ensures oxidation of the maximum amount of carbon available in the fuel. CO_2 emission factors for fuel combustion are therefore relatively insensitive to the combustion process itself and hence are primarily dependent only on the carbon content of the fuel.

Table 2. Default CO_2 emission factors for combustion.

DEFAULT CO_2 EMISSION FACTORS FOR COMBUSTION [1]

	Fuel type English description	**Default Carbon Content (kg/GJ)**	**Default Carbon Oxidation Factor**	**Effective CO_2 emission factor (kg/TJ) [2]**		
		A	**B**	**Default Value[3]**	**95% Confidence Interval**	
				C=A*B*44/ 12*1000	**Lower**	**Upper**
	Crude Oil	20.0	1	73 300	71 100	75 500
	Orimulsion	21.0	1	77 000	69 300	85 400
	Natural Gas Liquids	17.5	1	64 200	58 300	70 400
Gasoline	Motor Gasoline	18.9	1	69 300	67 500	73 000
	Aviation Gasoline	19.1	1	70 000	67 500	73 000
	Jet Gasoline	19.1	1	70 000	67 500	73 000
	Jet Kerosene	19.5	1	71 500	69 700	74 400
	Other Kerosene	19.6	1	71 900	70 800	73 700
	Shale Oil	20.0	1	73 300	67 800	79 200
	Gas/Diesel Oil	20.2	1	74 100	72 600	74 800
	Residual Fuel Oil	21.1	1	77 400	75 500	78 800
	Liquefied Petroleum Gases	17.2	1	63 100	61 600	65 600
	Ethane	16.8	1	61 600	56 500	68 600
	Naphtha	20.0	1	73 300	69 300	76 300
	Bitumen	22.0	1	80 700	73 000	89 900
	Lubricants	20.0	1	73 300	71 900	75 200
	Petroleum Coke	26.6	1	97 500	82 900	115 000
	Refinery Feedstocks	20.0	1	73 300	68 900	76 600
Other Oil	Refinery Gas	15.7	1	57 600	48 200	69 000
	Paraffin Waxes	20.0	1	73 300	72 200	74 400
	White Spirit & SBP	20.0	1	73 300	72 200	74 400

	Other Petroleum Products	20.0	1	73 300	72 200	74 400
	Anthracite	26.8	1	98 300	94 600	101 000
	Coking Coal	25.8	1	94 600	87 300	101 000
	Other Bituminous Coal	25.8	1	94 600	89 500	99 700
	Sub-Bituminous Coal	26.2	1	96 100	92 800	100 000
	Lignite	27.6	1	101 000	90 900	115 000
	Oil Shale and Tar Sands	29.1	1	107 000	90 200	125 000
	Brown Coal Briquettes	26.6	1	97 500	87 300	109 000
	Patent Fuel	26.6	1	97 500	87 300	109 000
Coke	Coke oven coke and lignite Coke	29.2	1	107 000	95 700	119 000
	Gas Coke	29.2	1	107 000	95 700	119 000
	Coal Tar	22.0	1	80 700	68 200	95 300
Derived Gases	Gas Works Gas	12.1	1	44 400	37 300	54 100
	Coke Oven Gas	12.1	1	44 400	37 300	54 100
	Blast Furnace Gas[4]	70.8	1	260 000	219 000	308 000
	Oxygen Steel Furnace Gas[5]	49.6	1	182 000	145 000	202 000
	Natural Gas	15.3	1	56 100	54 300	58 300
	Municipal Wastes (non-biomass fraction)	25.0	1	91 700	73 300	121 000
	Industrial Wastes	39.0	1	143 000	110 000	183 000
	Waste Oil	20.0	1	73 300	72 200	74 400
	Peat	28.9	1	106 000	100 000	108 000
Solid Biofuels	Wood/Wood Waste	30.5	1	112 000	95 000	132 000
	Sulphite lyes (black liquor)	26.0	1	95 300	80 700	110 000
	Other Primary Solid Biomass	27.3	1	100 000	84 700	117 000
	Charcoal	30.5	1	112 000	95 000	132 000
Liquid Biofuels	Biogasoline	19.3	1	70 800	59 800	84 300
	Biodiesels	19.3	1	70 800	59 800	84 300
	Other Liquid Biofuels	21.7	1	79 600	67 100	95 300
Gas biomas	Landfill Gas	14.9	1	54 600	46 200	66 000
	Sludge Gas	14.9	1	54 600	46 200	66 000
	Other Biogas	14.9	1	54 600	46 200	66 000
	Municipal Wastes (biomass fraction)	27.3	1	100 000	84 700	117 000

Notes:

[1] The lower and upper limits of the 95 percent confidence intervals, assuming lognormal distributions, fitted to a dataset, based on national inventory reports, IEA data and available national data. A more detailed description is given in section 1.5

[2] TJ = 1000GJ

[3] The emission factor values for BFG includes carbon dioxide originally contained in this gas as well as that formed due to combustion of this gas.

[4] The emission factor values for OSF includes carbon dioxide originally contained in this gas as well as that formed due to combustion of this gas

[5] Includes the biomass-derived CO_2 emitted from the black liquor combustion unit and the biomass-derived CO_2 emitted from the kraft mill lime kiln.

Source: IPCC Guidelines for National Greenhouse Gas Inventories, 2006.

3.5 Model equations and causal diagram

In the equation presents along this chapter it is possible to see how the model is split in two different parts: energy and productive sectoral submodels, equations (2) and (3) , and economic submodel, equation 5.

In the first case, the energy and, in particular, the amount of renewable energy, $E_{j=7}$, are calculated. In the second one, the value of GDP is calculated in terms of its components, one of which is renewable energy. These two parts are coupled throught the renewable energy terms which generates a feedback mechanism positive in the case of Brazil.

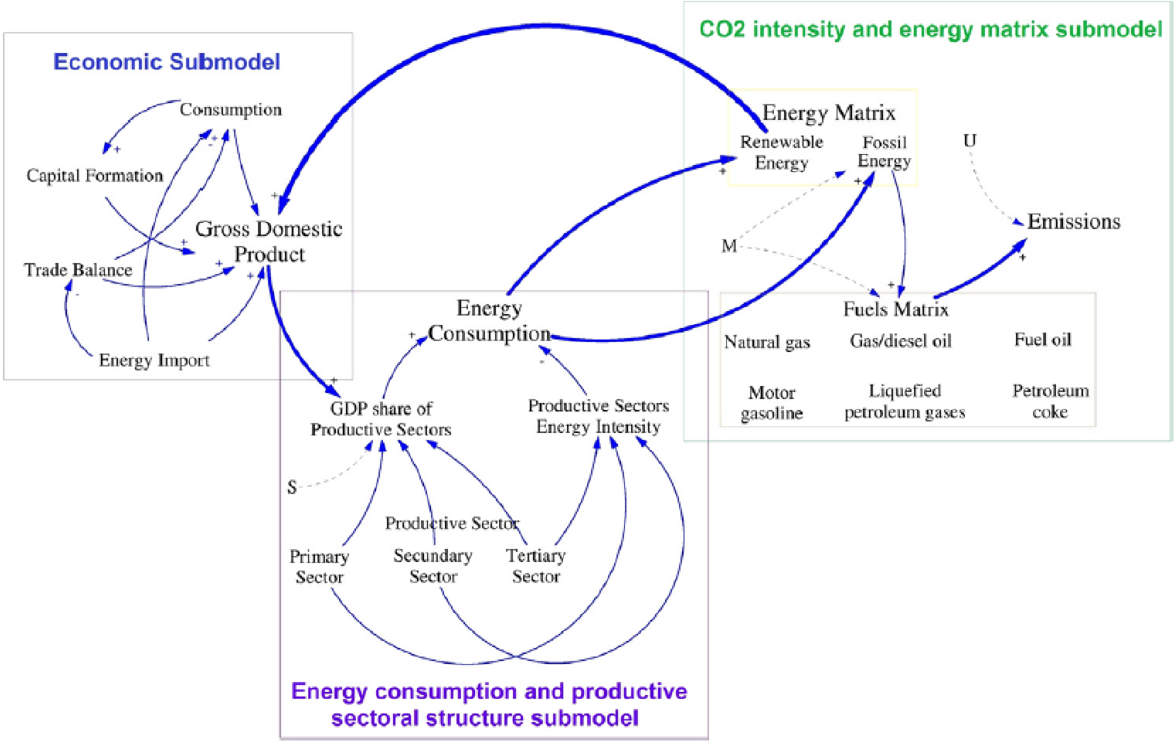

Figure 2. Causal diagram of the model. Continuous lines stand for the relationship between variables, while dashed ones correspond to control terms(S: productive sectoral structure, M: energy matrix, U: emission factors). Bold line represents a feedback mechanism. Source: Robalino-López et al., 2014.

Figure 2 presents the schematic view of the model. Where the feedback mechanism is highlighted. This way of presenting the model is extremely useful because it allows us to see the driving forces of CO_2 emissions in a hierarchical way, showing the causality relationship between the different variables. It can be observed that the CO_2 emitted into the atmosphere has several connections with the variables of the model: economic growth, productive sectoral structure, energy consumption, and energy matrix.

A more quantitative way of presenting how the different variables are extrapolated is through the difference equations that should be solved:

$$Q(t) = a_1 I(t) + a_2 TB(t) + a_3 Ca(t) + a_4 E_{imp}(t) + a_5 RN(t-1) \quad (8)$$

$$Ej(t) = \sum_i Si(t). EIi\ (t).\ Mij(t). GDP(t) \quad (9)$$

$$RN(t) = E_7(t) \quad (10)$$

$$y(t) = y(t-1).(1 + r_y) \quad (11)$$

Where Si(t), EI(t), Mij (t), I(t), TB(t), Ca (t) and $\mathrm{E_{imp}(t)}$ evolve following Eq. (11) while the parameters $\mathrm{a_i}$ have constant values. Note that index j runs over the type of energy sources, while i on the industrial sectors; j=7 corresponds to renewable and alternative energy. t=o corresponds to the reference year 2012 and t is given in number of years since 2012. The value of $\mathrm{r_y}$ is fixed through the definition of the used scenario. In the case of the BS scenario one should use a value of $\mathrm{r_y}$ that depends on the time. In this case $\mathrm{r_y}$ roughly corresponds to the yearly average increase over the period 1971-2012.

3.6 Model validation and verification

The official dataset from 1971 to 2012 and the output of the model can be compared to test its robustness and reliability. This analysis can be carried out calculating the mean absolute percentage error (MAPE), which is defined as equation 12. MAPE is commonly used to evaluate cross-sectional forecasts.

$$MAPE(\%) = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{Data_i - Model_i}{Data_i} \right| x\ 100 \qquad (12)$$

Where:

N - Number of data

$\mathrm{Data_i}$ - is the real data

$\mathrm{Model_i}$ - is the calculated values

4. RESULTS AND DISCUSSION

4.1 Brazil in numbers

4.1.1 Overview

Brazil is the fifth largest country in the world in terms of area and population, occupying approximately half of the entire South America. Brazil extends through 8,515,692 km² divided into 99.3 % of land and 0.7% of water. The coastline stretches for 7,491 km (Brazilian Institute of Geography and Statistics-BIGS, 2016).

First country to sign the Convention on Biological Diversity, Brazil is the most biologically diverse nation in the world with six terrestrial biomes and three large marine ecosystems, and with at least 103,870 animal species and 43,020 plant species currently known in Brazil. There are two biodiversity hotspots currently acknowledged in Brazil – the Atlantic Forest and the Cerrado, and 6 biosphere reserves are globally recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in the country (ME, 2011). This diversity makes Brazil one of the 17 mega-diverse countries in the world (United Nations Environment Programme-UNEP, 2002).

Brazil's Human Development Index (HDI) was 0.755 in 2014 (UN Development Program, 2015), placing it in 75th position of 188 countries and territories. Between 1980 and 2014, Brazil's HDI soared from 0.547 to 0.755, an increase of 38.1% which represents an annual growth of 0.95%.

The Brazilian Institute of Geography and Statistics (BIGS, 2013) provides population projection, which is a calculated demographic component based on the 2000 Demographic Census and the latest information from records of births and deaths. The projection starts in 2000 and the time horizon adopted for the projection of Brazil's population is 2060. The results are shown in Table 3.

Table 3. Brazilian total population from 2000 to 2060.

Years	Population	Years	Population	Years	Population
2000	173,448,346	**2020**	212,077,375	**2040**	228,153,204
2001	175,885,229	**2021**	213,440,458	**2041**	228,287,681
2002	178,276,128	**2022**	214,747,509	**2042**	228,359,924
2003	180,619,108	**2023**	215,998,724	**2043**	228,343,224
2004	182,911,487	**2024**	217,193,093	**2044**	228,264,820
2005	185,150,806	**2025**	218,330,014	**2045**	228,116,279
2006	187,335,137	**2026**	219,408,552	**2046**	227,898,165
2007	189,462,755	**2027**	220,428,030	**2047**	227,611,124
2008	191,532,439	**2028**	221,388185	**2048**	227,256,259
2009	193,543,969	**2029**	222,288,169	**2049**	226,834,687
2010	195,497,797	**2030**	223,126,917	**2050**	226,347,688
2011	197,397,018	**2031**	223,904,308	**2051**	225,796,508
2012	199,242,462	**2032**	224,626,629	**2052**	225,182,233
2013	201,032,714	**2033**	225,291,340	**2053**	224,506,312
2014	202,768,562	**2034**	225,896,169	**2054**	223,770,235
2015	204,450,649	**2035**	226,438,916	**2055**	222,975,532
2016	206,081,432	**2036**	226,917,266	**2056**	222,123,791
2017	207,660,929	**2037**	227,329,138	**2057**	221,216,414
2018	209,186,802	**2038**	227,673,003	**2058**	220,254,812
2019	210,659,013	**2039**	227,947,957	**2059**	219,240,240
				2060	218,173,888

Source: BIGS, 2013.

4.1.2. Economy

According to the World Bank (2016), in 2015 Brazil was the ninth largest economy in the world, with a GDP 1,774,725 USD (2011 purchasing power parity-PPP). Moreover, the GDP per capita in 2015 was 8,538 USD (2011 PPP).

In addition, the World Bank (2016) affirms that Brazil's economic and social progress between 2003 and 2014 took 29 million people away from poverty, as well as the social inequality dropped significantly. The income level of 40% of the poorest population rose, at the average of 7.1% (in real terms) between 2003 and 2014, compared to a 4.4% income growth for the population as a whole. However, the rate of poverty and inequality reduction has been showing signs of stagnation since 2015.

Besides, Brazil is currently going through a strong recession. The country's growth rate has decelerated steadily since the beginning of this decade, from an average annual growth of 4.5% between 2006 and 2010 to 2.1% between 2011 and

2014. The GDP contracted by 3.8% in 2015. The realignment of regulated prices combined with the pass-through of exchange rate depreciation caused an inflation peak in 2015 (with 12-month accumulated inflation rate of 10.7% in December of 2015), exceeding the upper limit of the target band (6.5%).

The economic crisis - coupled with the ethical-political crisis faced by the country - has contributed to those numbers. On August 31st, with public opinions divided, the Resolution N°35 of 2016 was published in the Official Newspaper of the Union, which established the impeachment of Mrs. Dilma Vana Rousseff, who had been the democratically elected President of the Brazilian Republic (FRB,2016).

The fiscal adjustment is undermined by budget rigidities and by a difficult political environment. Less than 15% of expenditures in Brazil are expected to be discretionary. Most public spending is mandatory (mandated by the Constitution or other legislation) and increases in line with revenues, nominal GDP growth, or other pre-established rules. Additionally, a large portion of revenues for education and health care are earmarked. Attempts to pass legislation to increase revenue collection in the short term and address issues of a more structural nature - such as pensions - have so far fallen short of the government's intentions (Word Bank, 2015).

4.1.3 Energy analysis

The information summarized below was obtained from the 2015 Brazilian Energy Balance report published by the Brazilian Ministry of Mines and elaborated by the Energy Research Company (BERC, 2015).

Electricity: The electricity generation in the Brazilian public service and self-producer power plants reached 590.5 TWh in 2014. The public service plants remain as the main contributors, with 84.1% of total generation, which the main source is hydropower. The electricity generation from fossil fuels accounted for 26.9% of the national total in 2014, also the self-producer generation participated with 15.9% of total production, considering the aggregation of all sources used, reaching 94 TWh. Of this total, 52.2 TWh are produced and consumed *in situ*, in other words not injected in the electricity network. Net imports of 33.8 TWh, added to internal generation, allowed a domestic electricity supply of 624.3 TWh and the final consumption was 531.1 TWh.

Figure 3 illustrates the structure of the domestic supply of electricity in Brazil in 2014. It can be observed that Brazil presents an electricity matrix predominantly renewable, and the domestic hydraulic generation accounts for 65.2% of the supply. Adding imports, which are also mainly from renewable sources, it can be stated that 74.6% of electricity in Brazil comes from renewable sources.

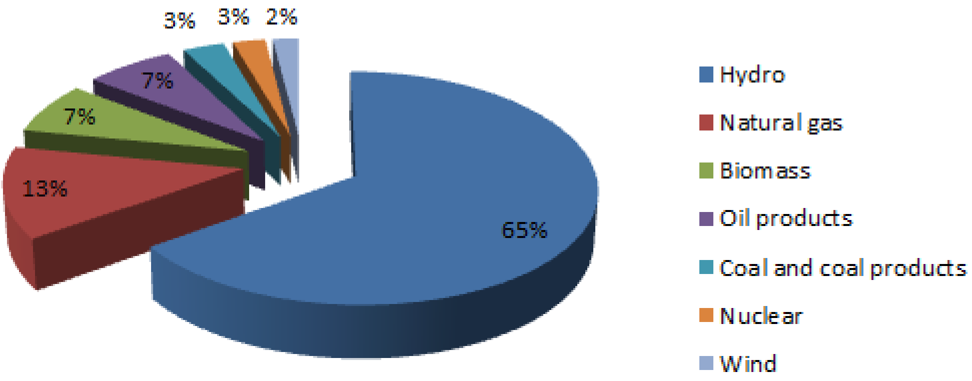

Figure 3. Domestic electricity supply by source. Source:BERC, 2015.

On the consumption side, the residential sector grew by 5.7%. The industrial sector recorded a decrease of 2.0% in electricity consumption over the previous year (2013). The other sectors - public, agriculture and livestock, commercial and transportation - when analyzed collectively showed a positive growth of 7.0% over 2013. The energy sector increased 4.8%. Figure 4 shows the domestic electricity supply by sector.

In 2014, due to an increase of 7,171 MW, Brazil’ installed electricity generation capacity reached 133,914 MW, which is the sum of the public service and self-producer power plants. Out of this total, the increase in hydro power plants accounted for 44.3%, while thermal power plants accounted for 18.1% of the added capacity.

Finally, wind and solar farms were responsible for 37.6% of the remaining growth in the national grid installed capacity.

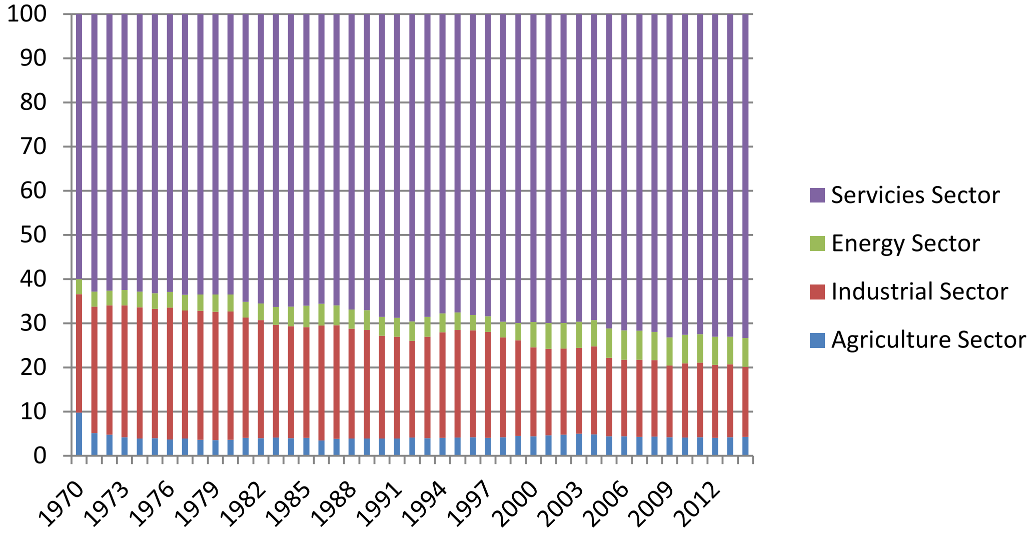

Figure 4. Domestic electricity supply by sector. Source: BERC, 2015.

Petroleum and Oil Products: The domestic production of oil in 2014 reached an average of 2.25 million barrels per day, of which 93% are offshore. In addition, the shale oil production reached 0.3 million m³. The production of oil products in domestic refineries amounted to 110.4 million toe, highlight for diesel and gasoline, which accounted for 39% and 20%, respectively, of the total.

Natural Gas: The average daily production for the year was 87.4 million m³/day and the volume of imported natural gas was an average of 52.9 million m³/day. Thus, the natural gas share in the national energy matrix reached the level of 13.5%. The thermal power generation with natural gas (including self-producer and public service power plants) increased by 17.5% reaching a level of 81.1 TWh. In 2014 the average consumption in the electricity sector reached 51.7 million m³/day. It represents an increase of 20.9% compared to 2013. The share of natural gas intended for transformation centers overcomes the sector consumption reaching 51% of the total, which 8% is intended for oil items production and 43% for electricity generation.

Steam and Metallurgical Coal: National steam coal, produced in the southern states of Brazil, is used for electric generation. The demand of steam coal for this final use increased 9.4% in 2014 when compared to the previous year. In 2014, the steel industry showed a 7.5% increase in consumption of metallurgical coal due to the increase of crude steel production via reducing coke in this period (2.1%).

Wind Energy: The production of electricity from wind power reached 12,210 GWh in 2014. This represents an 85.6% increase over the previous year, when it had reached 6,578 GWh. In 2014, the installed capacity for wind generation in the country increased by 122%. According to the Power Generation Database from National Agency of Electric Energy (NAEE), the national wind farm grew 2.686 MW, reaching 4,888 MW by the end of 2014.

Biodiesel: In 2014 the amount of biodiesel produced in Brazil reached 3,419,838 m³, against 2,917,488 m³ in the previous year. Thus, there was an increase of 17.2% in available biodiesel in the national market. The percentage of biodiesel compulsorily added to mineral diesel was increased to 6% in July and 7% in November 2014. The main raw material was the soybean oil (69.2%), followed by tallow (17%).

Sugarcane, Sugar and Ethanol: According to the Ministry of Agriculture, Livestock and Food Supply, the sugar cane production in the calendar year 2014 was 631.8 million tons. This amount was 2.5% lower than in the previous calendar year, when the milling was 648.1 million tons. In 2014 the national sugar production was 35.4 million tons, 5% lower than the previous year, while the production of ethanol increased by 3.3%, yielding the amount of 28,526 m³. About 57.1% of this total refers to hydrous ethanol: 16,296 m³. In comparative terms, the production of this fuel increased by 4.4% compared to 2013. Regarding the production of anhydrous ethanol, which is blended with gasoline A to form gasoline C, there was an increase of 1.9%, totaling 12,230 m³. The Total Recoverable Sugar (ATR) in sugarcane, which is the amount of sugar available in raw material minus the losses in the manufacturing process, kept stable and recorded averages of 136.3 and 132.6 ATR/ton of cane for the 2012-2013 and 2013-2014 harvests, respectively.

Table 4 and Figure 5 below demonstrate consolidated data of the evolution of domestic energy supply for the period 2005-2014.

Table 4. Domestic energy supply from 2005 to 2014

Sources (%)	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Non-renewable energy	**55.9**	**55.4**	**54.5**	**54.4**	**53.2**	**55.3**	**56.5**	**58.2**	**59.6**	**60.6**
Petroleum and oil products	38.8	37.9	37.5	36.7	37.9	37.8	38.6	39.3	39.3	39.4
Natural gas	9.4	9.6	9.3	10.3	8.8	10.2	10.2	11.5	12.8	13.5
Coal and coke	6.0	5.7	5.7	5.5	4.6	5.4	5.7	5.4	5.6	5.7
Uranium	1.2	1.6	1.4	1.5	1.4	1.4	1.5	1.5	1.4	1.3
Other none-renewable	1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	1.0
Renewable energy	**44.1**	**44.6**	**45.5**	**45.6**	**46.8**	**44.7**	**43.5**	**41.8**	**40.4**	**39.4**
Hydraulic	14.9	14.9	14.9	14.1	15.2	14.0	14.7	13.8	12.5	11.5
Firewood and charcoal	13.1	12.7	12.0	11.6	10.1	9.7	9.6	9.1	8.3	8.1
Sugar cane products	13.8	14.6	15.9	17.0	18.1	17.5	15.7	15.4	16.1	15.7
Other renewable source	2.3	2.5	2.7	2.9	3.4	3.5	3.5	3.5	3.6	4.1

Source: BERC, 2015.

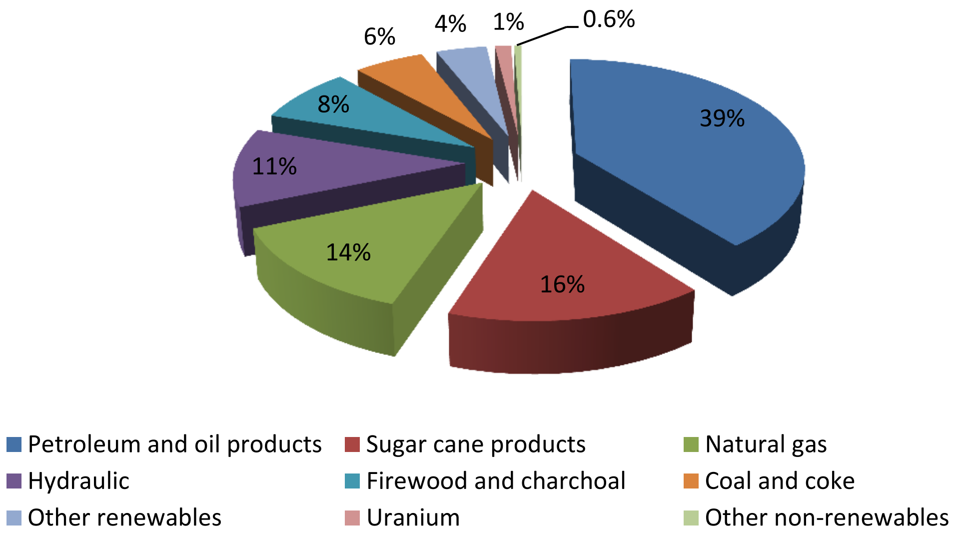

Figure 5. Domestic energy supply in 2014. Source: BERC, 2015.

4.1.4 Forecasts for 2030

The Brazilian National Energy Plan 2030 (BERC, 2007) establishes different economic and energy demand scenarios considering four different GDP trajectories, the scenarios have been based on different annual GDP growth rates for the period between 2005 and 2030, as follows: Scenario A 5.1%, B1 scenario 4.1%, B2 scenario

3.2% and scenario C 2.2%. The plan, however, prioritizes the scenario B1 and Figure 6 shows the evolution of the domestic energy supply structure.

The evolution of the energy matrix in the period 2005-2030 shows an expansion in its diversification. Thus, within this period, it is expected a significant reduction from 13% to 5.5% in the use of wood and charcoal; an increased share of natural gas from 9.4% to 15.5%; a reduction of oil and derivatives share from 38.7% to 28%; an increase in the share of derived products from sugarcane and other renewables (ethanol, biodiesel and others) from 16.7% to 27.6%.

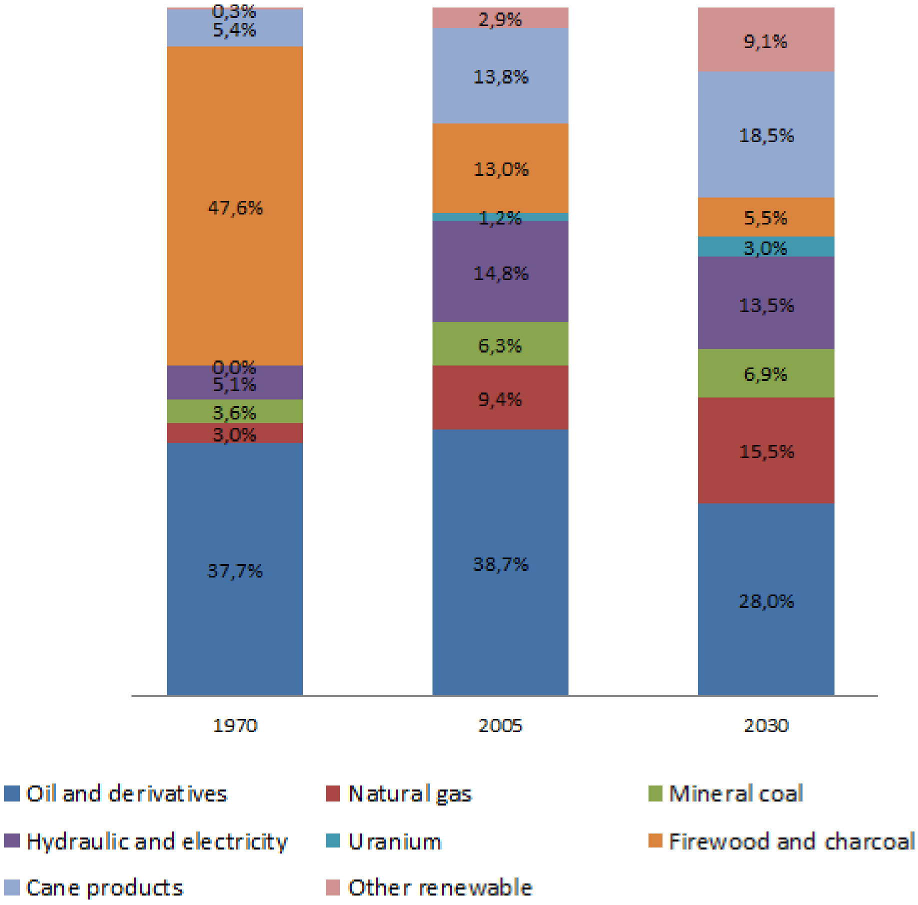

Figure 6. Evolution of the domestic energy supply structure Source: MME, 2007.

The demographic scenario considered a population growth of 185,4 million people in 2005 to 238,5 million inhabitants in 2030. The domestic supply of energy per capita of 1.19 toe/capita recorded in 2005 evolve to 2.33 toe/capita in 2030. In relation to GDP, this domestic energy supply would imply 5% reduction in energy intensity. The value expressed in toe/ (US$ 1,000) is 0.275 in 2005 and 0.261 in 2030.

The import of energy focuses on coal for steel, natural gas and electricity, the latter coming mainly from the Paraguayan side of Itaipu. It can be stated that, according to the same assumptions, Brazil would find a situation in this period 2005-2030, which was close to energy self-sufficiency.

4.1.5. Brazil and the United Nations Framework Convention on Climate Change

Despite the fact that Brazil was responsible for only 1.45% of global emissions in 2013 (Word Bank, 2016), in September 2015, the Brazilian Government communicated to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) their intended Nationally Determined Contribution (iNDC) to the new agreement under the Convention that was adopted at the 21st Conference of the Parties (COP-21) to the UNFCCC in Paris (FRB, 2015).

In this document, the Brazilian contribution intends to be committed to reduce greenhouse gas emissions by 37% below 2005 levels (reference point) by 2025. In addition, Brazil proposed, for reference purpose only, a subsequent indicative contribution, which was to reduce greenhouse gas emissions by 43% below 2005 levels by 2030. These goals cover 100% of the territory, the Brazilian economy, and include CO_2, CH_4, N_2O, perfluorocarbons, hydrofluorocarbons and SF_6 emissions.

Brazil hopes to achieve these cuts by implementing measures that are in line with a transition to a low-carbon economy, mainly:

- increasing the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030, by expanding biofuel consumption, by increasing ethanol supply, by increasing the share of advanced biofuels (second generation), and also by increasing the share of biodiesel in the diesel mix;
- in land use change and forestry: by strengthening and enforcing the implementation of the Forest Code, at federal, state and municipal levels; also, strengthening policies and measures with a view to achieve,

in the Brazilian Amazonia, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030; and restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes; finally, enhancing sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management, with a view to curbing illegal and unsustainable practices;

- in the energy sector: by achieving 45% of renewables in the energy mix by 2030. Including: the expanding the use of renewable energy sources other than hydropower in the total energy mix to between 28% and 33% by 2030; the expanding the use of non-fossil fuel energy sources domestically, increasing the share of renewables (other than hydropower) in the power supply to at least 23% by 2030, by raising the share of wind, biomass and solar; and, achieving 10% efficiency gains in the electricity sector by 2030.

Furthermore, Brazil also intends to:

- in the agriculture sector: strengthen the Low Carbon Emission Agriculture Program as the main strategy for sustainable agriculture development. This includes: restoring an additional 15 million hectares of degraded pasturelands by 2030 and enhancing 5 million hectares of integrated cropland-livestock-forestry systems (ICLFS) by 2030;
- in the industry sector: promote new standards of clean technology and further enhance energy efficiency measures and low carbon infrastructure;
- in the transportation sector: promote efficiency measures and improve infrastructure for transport and public transportation in urban areas.

Finally, in September 2016, the president Michel Temer ratifies the Paris Agreement against the climatic changes in Brasilia (UNFCCC, 2016).

4.1.6. Data

According to the previously information presented about Brazil, this subchapter shows in table format all the compiled data, which was necessary to fill up the model.

Table 5. Brazilian general data.

Years	External balance on goods and services ($2005)	Household final consumption expenditure ($2005)	General government final consumption expenditure ($2005)	Energy imports (koe)	Renewable Energy (koe)	Gross domestic product ($2005)
1971	-1.72	1.67E+11	4.99E+10	2.07E+10	3.93E+10	2.50E+11
1972	-1.58	1.90E+11	5.41E+10	2.44E+10	4.09E+10	2.80E+11
1973	-1.23	2.13E+11	6.08E+10	3.07E+10	4.16E+10	3.20E+11
1974	-5.87	2.38E+11	6.09E+10	3.37E+10	4.29E+10	3.48E+11
1975	-3.97	2.36E+11	7.01E+10	3.72E+10	4.36E+10	3.67E+11
1976	-2.40	2.70E+11	7.55E+10	4.15E+10	4.38E+10	4.02E+11
1977	-0.67	2.90E+11	7.14E+10	4.30E+10	4.53E+10	4.21E+11
1978	-1.19	2.94E+11	7.53E+10	4.80E+10	4.59E+10	4.35E+11
1979	-2.05	3.14E+11	8.14E+10	5.12E+10	4.88E+10	4.64E+11
1980	-2.25	3.42E+11	8.16E+10	4.95E+10	5.15E+10	5.06E+11
1981	-0.38	3.19E+11	7.90E+10	4.27E+10	5.14E+10	4.84E+11
1982	-0.66	3.24E+11	8.52E+10	4.00E+10	5.27E+10	4.87E+11
1983	2.41	3.25E+11	7.82E+10	3.37E+10	5.73E+10	4.70E+11
1984	5.62	3.52E+11	6.98E+10	2.71E+10	6.37E+10	4.95E+11
1985	5.15	3.51E+11	8.87E+10	2.70E+10	6.70E+10	5.34E+11
1986	2.46	3.80E+11	1.06E+11	3.34E+10	6.77E+10	5.77E+11
1987	3.27	3.55E+11	1.29E+11	3.52E+10	7.10E+10	5.98E+11
1988	5.20	3.49E+11	1.27E+11	3.78E+10	7.13E+10	5.97E+11
1989	3.47	3.33E+11	1.50E+11	3.77E+10	7.30E+10	6.17E+11
1990	1.24	3.52E+11	1.36E+11	3.61E+10	6.84E+10	5.98E+11
1991	0.76	3.60E+11	1.32E+11	3.81E+10	6.86E+10	6.07E+11
1992	2.48	3.55E+11	1.36E+11	3.96E+10	6.83E+10	6.04E+11
1993	1.41	3.78E+11	1.39E+11	4.23E+10	6.92E+10	6.32E+11
1994	0.00	4.04E+11	1.39E+11	4.51E+10	7.28E+10	6.66E+11
1995	-1.89	4.42E+11	1.41E+11	4.90E+10	7.31E+10	6.95E+11
1996	-2.18	4.62E+11	1.38E+11	5.11E+10	7.42E+10	7.11E+11
1997	-2.61	4.79E+11	1.40E+11	5.20E+10	7.72E+10	7.35E+11
1998	-2.38	4.72E+11	1.45E+11	4.91E+10	7.79E+10	7.37E+11
1999	-1.85	4.65E+11	1.47E+11	4.53E+10	7.97E+10	7.41E+11
2000	-2.26	4.79E+11	1.48E+11	3.98E+10	7.83E+10	7.71E+11
2001	-2.19	4.93E+11	1.51E+11	3.91E+10	7.83E+10	7.84E+11

2002	0.84	5.00E+11	1.57E+11	2.84E+10	8.39E+10	8.08E+11
2003	2.22	4.97E+11	1.59E+11	2.07E+10	9.03E+10	8.17E+11
2004	3.41	5.17E+11	1.65E+11	2.76E+10	9.52E+10	8.64E+11
2005	3.40	5.40E+11	1.68E+11	2.06E+10	9.85E+10	8.92E+11
2006	2.71	5.68E+11	1.74E+11	1.65E+10	1.04E+11	9.27E+11
2007	1.36	6.04E+11	1.82E+11	1.90E+10	1.12E+11	9.83E+11
2008	-0.19	6.43E+11	1.85E+11	2.04E+10	1.18E+11	1.03E+12
2009	-0.40	6.72E+11	1.91E+11	9.86E+09	1.17E+11	1.03E+12
2010	-1.04	7.14E+11	1.98E+11	1.93E+10	1.24E+11	1.11E+12
2011	-0.77	7.48E+11	2.03E+11	2.08E+10	1.23E+11	1.15E+12
2012	-1.36	7.74E+11	2.07E+11	2.98E+10	1.22E+11	1.18E+12

Table 6. Brazilian general data. Part II.

Years	Etotal (koe)	Efossil (koe)	CO_2 (kg)
1971	69782239000	30462959000	102635663000
1972	74795465000	33940037000	114362729000
1973	81979056000	40410700000	132463041000
1974	87240887000	44327931000	143456707000
1975	91088153000	47466218000	151164741000
1976	95613021000	51771859000	155154437000
1977	98812027000	53479117000	162961480000
1978	105143010000	59270804000	176925416000
1979	111795554000	62993257000	188322452000
1980	113851143000	62391966000	187090340000
1981	109221017000	57785378000	171806284000
1982	111048266000	58356502000	172176651000
1983	113818111000	56514565000	166632147000
1984	121142064000	57424648000	168806678000
1985	129353459000	62365653000	181248809000
1986	135404315000	67713126000	198883412000
1987	140665921000	69633442000	207530198000
1988	142563758000	71252283000	209363698000
1989	145436473000	72475374000	214024455000
1990	140206947000	71808152000	208886988000
1991	142858191000	74221609000	219330604000
1992	144347671000	76048684000	220705729000
1993	147959977000	78809772000	230738641000
1994	155760142000	82967033000	242154012000
1995	161094731000	87971017000	258347484000
1996	169663097000	95465071000	284782887000
1997	178276103000	101049006000	300547320000
1998	182552948000	104676788000	312289054000
1999	186690738000	106952649000	320173104000

2000	187441584000	109151103000	327983814000
2001	190711767000	112423995000	337433673000
2002	195758711000	111883929000	332266870000
2003	198976524000	108723416000	321621569000
2004	210041760000	114889113000	337826042000
2005	215331854000	116822529000	347308904000
2006	222817428000	119035502000	347668270000
2007	235459748000	123994607000	363212683000
2008	248579623000	130676967000	387675240000
2009	240453393000	123396972000	367147374000
2010	265862911000	142197735000	419754156000
2011	270026935000	147344496000	439412943000
2012	281724649000	159305890000	470029000000

Table 7. Information about Brazilian agriculture sector.

Years	E1 (toe)	QiS1 ($2005)	EIS1 (koe/$2005)
1971	5317393	12747328362	0.417137857
1972	5338469	13266383781	0.40240576
1973	5441909	13277561656	0.409857561
1974	5376379	13560571269	0.396471439
1975	5348720	14467230432	0.369712806
1976	5426899	14757370032	0.367741584
1977	5500892	16493196402	0.333524938
1978	5372788	15785603000	0.340360003
1979	5565328	16529093581	0.336698939
1980	5752243	18092857362	0.317928926
1981	5724525	19505610406	0.293480959
1982	5772134	19414489329	0.297310631
1983	5906319	19229663086	0.307146235
1984	5736611	19710901245	0.291037471
1985	6058588	21618403812	0.280251384
1986	5949630	19976787839	0.297827183
1987	6386838	22982759541	0.277896917
1988	6461362	23165919194	0.278916719
1989	6532165	23853738504	0.273842387
1990	6026929	23265949662	0.25904505
1991	6147780	23696849617	0.259434477
1992	6073669	24985314289	0.243089563
1993	6432895	25231832312	0.254951562
1994	6652211	27109399276	0.245383944
1995	7050618	28664417688	0.245971078
1996	7287707	29527880535	0.246807648

1997	7528143	29773497162	0.252847133
1998	7308493	30881986380	0.236658778
1999	7536184	32967958777	0.228591154
2000	7322063	33765662219	0.216849368
2001	7728679	35958389316	0.214933961
2002	7809259	38477327408	0.202957417
2003	8149978	40723243107	0.200130868
2004	8274035	41659945213	0.198608879
2005	8357612	38958191676	0.214527723
2006	8550542	40817363327	0.20948295
2007	9054700	42167678540	0.214730806
2008	9908631	44514949276	0.22259109
2009	9551669	42877973582	0.222764005
2010	10026747	45772592734	0.219055697
2011	9998667	48351978361	0.206789203
2012	10361298	47208027453	0.219481702

Table 8. Information about Brazilian manufacturing sector.

Years	E2 (toe)	QiS2 ($2005)	EIS2 (koe /$2005)
1971	18294772	71700000000	0.255173942
1972	19949620	82100000000	0.243001041
1973	22332696	95540000000	0.233758892
1974	23966850	103400000000	0.231704499
1975	25140543	107500000000	0.233912068
1976	27933382	120300000000	0.232161297
1977	30623874	121900000000	0.251213633
1978	31985725	126600000000	0.252564194
1979	34151271	134800000000	0.253306144
1980	36237490	147200000000	0.246247695
1981	33067304	131800000000	0.250796009
1982	33840772	129900000000	0.260470777
1983	34738063	120100000000	0.289178805
1984	37749169	125400000000	0.301143515
1985	39702697	134000000000	0.296207019
1986	42166445	150000000000	0.281175377
1987	44469317	153600000000	0.289485024
1988	45454856	148300000000	0.306487431
1989	45341751	151700000000	0.298820683
1990	42233981	138900000000	0.303952896
1991	43182926	139800000000	0.308876689
1992	44116935	132000000000	0.334255495
1993	46138230	144900000000	0.318369933

1994	48714651	158800000000	0.306673849
1995	49836986	169400000000	0.294229327
1996	51777402	171900000000	0.301161269
1997	54020557	176100000000	0.30675709
1998	55451871	166400000000	0.333270908
1999	57394330	160800000000	0.356888827
2000	58425520	155300000000	0.376267513
2001	58798037	153800000000	0.382307459
2002	62519161	157500000000	0.397042378
2003	65284855	158400000000	0.412273752
2004	68958858	172200000000	0.400554261
2005	70041303	158800000000	0.441056515
2006	73155403	160400000000	0.456010775
2007	77938001	171400000000	0.454696143
2008	78371741	178900000000	0.438120444
2009	73934426	167800000000	0.440511751
2010	82384369	186400000000	0.441974475
2011	85380217	194400000000	0.439118129
2012	85457509	194300000000	0.439797946

Table 9. Information about Brazilian energetic sector.

Years	E2 (toe)	QiS2 ($2005)	EIS2 (koe /$2005)
1971	2248954	8476700000	0.265309325
1972	2391536	9350900000	0.255753346
1973	2956545	11118000000	0.265913668
1974	3558248	12428000000	0.286304424
1975	3832458	12850000000	0.298252273
1976	4148742	14022000000	0.295870052
1977	4777789	15057000000	0.317304954
1978	5900753	16279000000	0.362476365
1979	7078769	17915000000	0.395131772
1980	7126379	19357000000	0.368158191
1981	7084486	17136000000	0.41343645
1982	8097160	18437000000	0.43917108
1983	9653381	18873000000	0.511493128
1984	11148817	22040000000	0.505840995
1985	12786809	25817000000	0.495279385
1986	12299589	28748000000	0.427843865
1987	14039770	26934000000	0.521264483
1988	13671540	25968000000	0.526478918
1989	13878542	27767000000	0.49981599
1990	13330803	25684000000	0.519026782

1991	13810942	25857000000	0.534135866
1992	13699348	26702000000	0.513051329
1993	13857328	28491000000	0.486380046
1994	14855638	28671000000	0.518133036
1995	14342093	27392000000	0.523596349
1996	15443295	25116000000	0.614881676
1997	17063396	25892000000	0.659024426
1998	16107878	26411000000	0.609899361
1999	15346391	28792000000	0.533002513
2000	15067330	44530000000	0.338366005
2001	15742729	45588000000	0.345327611
2002	16645791	46882000000	0.355057098
2003	18235151	48657000000	0.374767723
2004	18945485	51151000000	0.370386043
2005	20417013	59446000000	0.343456124
2006	21684932	62106000000	0.349157688
2007	24244030	64631000000	0.375113316
2008	27877201	66467000000	0.419416311
2009	26170480	65993000000	0.396564398
2010	27440718	71629000000	0.383096402
2011	25506337	74156000000	0.343956441
2012	26107941	74951000000	0.348335075

Table 10. Information about Brazilian tertiary sector.

Years	E2 (toe)	QiS2 (2005)	EIS2 (koe / $2005)
1971	38192238	157300000000	0.242867678
1972	40479927	175600000000	0.230505698
1973	43314530	199600000000	0.217027774
1974	45143382	219000000000	0.206154097
1975	46336611	231800000000	0.199935464
1976	48071992	253300000000	0.189751318
1977	47491375	267500000000	0.177522018
1978	49553289	275900000000	0.179622636
1979	51781247	294700000000	0.175695276
1980	50993561	321700000000	0.158535717
1981	50703707	315500000000	0.160694117
1982	50911727	319100000000	0.159570364
1983	50202550	312000000000	0.160905909
1984	51681017	327900000000	0.157611254
1985	53588468	352900000000	0.151866624
1986	58287337	378300000000	0.154063565
1987	59169621	394300000000	0.150077213

1988	60098346	399700000000	0.150344842
1989	62043994	413400000000	0.150079664
1990	61448787	409700000000	0.149973753
1991	63538728	417300000000	0.152259497
1992	63933204	420200000000	0.152163931
1993	65077987	433400000000	0.1501708
1994	67884840	451100000000	0.150491418
1995	72385412	469700000000	0.154115583
1996	76821906	483900000000	0.158757251
1997	79751378	502800000000	0.158608825
1998	82736622	513400000000	0.161156963
1999	82824877	517900000000	0.159909155
2000	82103480	537400000000	0.152775902
2001	81195599	548400000000	0.148053516
2002	84303846	564900000000	0.149243988
2003	83196304	569200000000	0.146171058
2004	87952728	599000000000	0.146833539
2005	90412680	634400000000	0.14251177
2006	91197620	663600000000	0.137429742
2007	98393767	705000000000	0.13956089
2008	106391617	743400000000	0.143105335
2009	107945393	755300000000	0.142917061
2010	115681669	805900000000	0.1435425
2011	118872472	836200000000	0.14216534
2012	124143966	858700000000	0.144569048

Table 11. Energy by type of fuels in agriculture sector.

Years	ktoe						
	E11	E12	E13	E14	E15	E16	E17
1971	0	0	0.00	531.54	23.01	0	4762.84
1972	0	0	0.00	711.58	46.02	0	4580.87
1973	0	0	0.00	936.20	73.64	0	4432.08
1974	0	0	0.00	1035.64	85.60	0	4255.13
1975	0	0	0.00	1150.53	91.13	0	4107.07
1976	0	0	0.82	1329.71	104.32	0	3992.06
1977	0	0	0.82	1511.46	106.20	0	3882.42
1978	0	0	1.64	1534.61	115.59	0	3720.95
1979	0	0	1.64	1886.11	120.29	0	3557.29
1980	0	0	1.63	2217.86	115.52	0	3417.23
1981	0	0	1.65	2155.23	100.37	0	3467.27
1982	0	0	0.83	2257.23	67.21	0	3446.87
1983	0	0	0.00	2443.99	25.63	0	3436.69
1984	0	0	0.83	2571.79	25.63	0	3138.36

1985	0	0	0.84	3005.97	23.93	0	3027.85
1986	0	0	0.82	2975.75	25.15	0	2947.92
1987	0	0	0.83	3230.57	34.53	0	3120.92
1988	0	0.62	0.00	3383.78	35.88	0	3041.09
1989	0	0.62	0.00	3588.39	28.70	0	2914.46
1990	0	0.62	0.00	3246.26	26.25	0	2753.80
1991	0	0.62	0.00	3376.52	21.39	0	2749.25
1992	0	1.23	0.83	3461.85	32.09	0	2577.66
1993	0	0.62	0.83	3825.80	34.99	0	2570.65
1994	0	0.62	0.00	4013.87	63.18	0	2574.54
1995	0	1.23	0	4275.07	94.29	0	2680.02
1996	0	1.23	0	4479.68	82.63	0	2724.16
1997	0	3.70	0	4659.05	79.71	0	2785.69
1998	0	7.97	0	4475.08	45.35	0	2780.10
1999	0	13.49	0	4617.46	87.27	0	2817.97
2000	0	15.90	0	4452.01	106.45	0	2747.70
2001	0	21.37	0	4855.39	143.85	0	2708.07
2002	0	19.55	0	4772.54	106.45	0	2910.71
2003	0	17.72	0	4825.12	83.43	0	3223.71
2004	0	20.16	0	4766.61	70.97	0	3416.30
2005	0	22.91	0.11	4734.22	63.87	0	3536.50
2006	0	19.00	0	4799.30	66.17	0	3666.07
2007	0	19.28	0	5098.85	61.00	0	3875.57
2008	0	22.28	0	5685.25	68.09	0	4133.01
2009	0	22.96	0	5514.69	68.09	0	3945.93
2010	0	8.09	0	5772.22	78.85	0	4167.58
2011	0	12.06	0.02	5662.47	16.52	0	4307.60
2012	0	11.35	0.01	5889.07	21.14	0	4439.73

Table 12. Energy by type of fuels in imanufacturing sector.

Years	ktoe						
	E21	E22	E23	E24	E25	E26	E27
1970	2.64	288.03	27.86	292.35	5015.61	1237.02	10072.12
1971	10.56	305.47	45.07	297.49	6003.27	1235.35	10397.57
1972	19.35	326.26	114.43	288.92	6526.09	1347.09	11327.47
1973	20.23	363.07	121.96	295.78	8005.28	1388.90	12137.48
1974	143.38	383.39	130.97	296.63	8683.66	1432.56	12896.25
1975	152.18	467.54	135.11	312.07	9112.59	1743.05	13218.01
1976	160.98	527.41	121.43	350.64	10636.53	2166.60	13969.79
1977	274.45	670.49	158.56	354.93	11090.45	2963.05	15111.94
1978	258.62	716.78	175.33	365.22	11921.22	3293.60	15254.96
1979	273.57	856.07	179.16	348.93	12314.99	4065.41	16113.14
1980	319.31	952.49	146.67	323.08	12093.91	4412.00	17990.02

1981	335.15	952.58	155.80	382.77	8979.53	3958.99	18302.49
1982	363.29	1030.63	140.65	260.42	8198.55	4614.14	19233.08
1983	394.96	1298.83	93.44	223.51	6083.10	5151.25	21492.97
1984	404.64	1448.29	82.14	199.51	4940.58	6294.79	24379.22
1985	540.10	1556.08	69.46	187.38	4932.40	6990.58	25426.68
1986	703.72	1642.57	70.13	202.18	5359.53	7232.06	26956.25
1987	951.78	2067.50	64.37	204.31	6081.27	7826.71	27273.37
1988	1005.52	2032.96	70.64	209.69	6145.32	8501.85	27488.87
1989	1023.50	1913.80	62.66	231.88	6460.26	8013.82	27635.83
1990	1288.31	1560.76	49.11	241.50	6298.00	6867.21	25929.08
1991	1357.37	1668.62	47.45	226.38	6332.03	8080.66	25470.42
1992	1523.55	1684.38	33.30	242.92	6809.30	7748.16	26075.31
1993	1639.66	1697.91	25.81	278.62	6930.82	8276.96	27288.45
1994	1704.76	1785.03	30.80	336.96	6715.02	8828.70	29313.39
1995	1989.76	1911.37	24.14	334.34	7283.68	9245.91	29047.78
1996	2405.84	1975.05	18.31	305.61	8258.66	9550.32	29263.61
1997	2659.61	2062.05	26.64	356.98	8629.01	9915.51	30370.75
1998	2649.50	2010.04	20.66	362.08	8322.36	10296.90	31790.34
1999	2952.10	2047.10	12.32	353.01	7136.88	11408.31	33484.61
2000	3725.68	2249.46	13.97	365.90	6253.64	13225.27	32591.61
2001	4285.45	2028.79	10.68	324.94	5398.21	13340.83	33409.14
2002	5399.77	1806.60	10.93	412.98	5104.76	13734.76	36049.37
2003	5668.08	1943.23	9.29	447.74	4298.24	13841.65	39076.62
2004	6434.56	1997.88	7.64	490.14	3855.18	13974.79	42198.66
2005	6954.01	2070.76	6.39	455.02	3773.91	13707.28	43073.92
2006	7303.23	2091.78	3.95	445.50	3324.85	13658.36	46327.73
2007	7859.79	2253.13	2.75	482.79	3418.88	15217.33	48703.33
2008	8026.90	2393.03	1.48	500.14	3412.12	15025.47	49012.60
2009	7083.34	2363.32	1.64	482.80	3309.42	13516.07	47177.84
2010	8645.48	2507.23	1.22	464.99	2835.71	16695.18	51234.56
2011	9317.37	2725.78	1.25	610.37	2660.82	18307.82	51756.80
2012	9175.36	2755.59	1.03	653.05	2395.67	17918.88	52557.92

Table 13. Energy by type of fuels in energetic sector.

Years	ktoe						
	E31	E32	E33	E34	E35	E36	E37
1970	65.09	85.97	0.00	90.02	1075.10	191.15	306.95
1971	81.81	88.11	0.00	90.02	1170.83	477.40	340.78
1972	87.96	90.26	0.00	100.31	1338.35	438.02	336.63
1973	86.21	103.16	2.46	156.03	1656.84	537.92	413.94
1974	120.51	99.29	4.10	168.04	1851.05	887.14	428.12
1975	131.07	122.93	5.74	185.18	2045.27	874.69	467.58
1976	128.43	158.61	8.19	197.18	2263.95	908.76	483.62

1977	140.74	162.90	9.01	202.33	2398.34	896.31	968.14
1978	137.23	174.08	12.29	210.04	2528.97	1140.05	1698.09
1979	141.62	166.77	16.39	280.34	2694.37	1223.91	2555.35
1980	165.37	165.91	15.48	305.08	2693.95	1138.08	2642.49
1981	173.29	157.56	16.54	296.56	2247.96	1189.19	3003.39
1982	343.94	178.67	12.44	376.35	2087.32	1206.82	3891.63
1983	430.15	223.65	10.77	427.18	1810.31	1426.06	5325.26
1984	604.32	299.23	37.16	367.65	1988.32	1509.69	6342.46
1985	859.42	377.37	7.53	421.62	1977.55	1349.00	7794.33
1986	986.09	376.42	8.16	453.36	2085.39	1405.42	6984.75
1987	977.29	367.98	6.60	433.07	2218.26	1598.34	8438.23
1988	934.25	380.09	4.11	517.70	2211.66	1657.39	7966.34
1989	928.98	383.36	4.95	465.50	2128.55	1800.48	8166.72
1990	901.72	361.76	7.49	506.63	2128.82	1583.95	7840.44
1991	798.65	399.41	7.49	523.28	1558.22	1803.65	8720.24
1992	850.65	419.61	18.31	579.88	1636.68	1871.26	8322.95
1993	1029.53	432.32	15.82	435.34	1957.74	1939.39	8047.19
1994	984.95	402.01	11.24	379.62	2271.71	2053.82	8752.29
1995	978.37	373.68	32.26	282.10	2289.21	1960.51	8425.95
1996	1223.28	384.19	14.85	290.81	2116.18	2506.41	8907.58
1997	1343.08	379.28	6.34	331.73	2302.82	2753.98	9946.17
1998	1400.40	367.43	7.98	375.01	2275.96	2760.43	8920.67
1999	1681.06	324.05	8.76	395.86	1964.03	2748.72	8223.92
2000	2207.36	384.49	7.93	410.99	1892.11	3102.29	7062.16
2001	2481.60	359.09	8.76	424.20	1660.99	3420.60	7387.49
2002	2727.92	342.66	8.76	247.62	1736.75	3525.39	8056.69
2003	2930.65	351.83	4.11	350.22	1868.13	3538.14	9192.07
2004	3176.65	378.98	2.47	362.94	1568.92	4060.50	9395.03
2005	3521.27	371.21	1.40	368.76	1698.08	4399.97	10056.32
2006	3760.58	385.48	0.82	314.03	1773.48	4385.52	11065.02
2007	4054.72	422.63	1.34	373.41	1820.76	4564.07	13007.10
2008	5352.18	174.07	1.32	400.76	1481.94	4610.41	15856.51
2009	5164.41	228.35	1.64	386.49	1336.09	4526.93	14526.57
2010	4503.18	217.84	0.61	1168.01	1002.30	4492.12	16056.66
2011	5366.18	237.52	0.56	1311.75	719.29	4349.31	13521.73
2012	5931.30	224.85	0.71	1573.55	540.59	4052.25	13784.69

Table 14. Energy by type of fuels in tertiary sector.

Years	ktoe						
	E41	E42	E43	E44	E45	E46	E47
1970	0	1422.11	8544.68	4617.54	497.97	16.16	21510.77
1971	0	1528.06	9276.18	5048.77	542.15	16.16	21780.91
1972	0	1679.56	10358.56	5726.91	629.60	10.78	22074.53

1973	0	1839.34	12117.68	6751.41	779.63	1.96	21824.51
1974	0	1948.80	12597.73	7524.71	1329.15	7.84	21735.15
1975	0	2009.31	12903.55	8433.47	1439.61	9.80	21540.88
1976	0	2197.96	13123.71	9786.33	1574.15	12.73	21377.12
1977	0	2276.19	12121.18	10473.04	1196.35	15.67	21408.94
1978	0	2506.08	12359.24	11560.98	1449.15	19.10	21658.73
1979	0	2766.51	12529.11	12283.71	1662.49	18.61	22520.82
1980	0	2959.96	10820.75	12854.70	1306.73	21.55	23029.86
1981	0	3195.40	10627.25	12614.11	1708.22	20.08	22538.64
1982	0	3607.62	10241.94	13024.26	1743.60	19.59	22274.71
1983	0	3754.54	9042.95	12494.40	1627.10	24.49	23259.09
1984	0	3731.97	8098.24	12987.86	1550.74	23.51	25288.69
1985	0	4067.88	8090.88	13469.16	1885.66	12.73	26062.15
1986	0	4346.13	8996.41	15388.13	1533.09	6.86	28016.73
1987	1.76	4604.64	8128.30	15882.16	1494.18	6.37	29052.21
1988	2.75	4971.38	7938.21	16214.13	1558.15	7.35	29406.37
1989	4.51	5270.77	8754.84	16926.95	988.22	6.86	30091.84
1990	8.80	5463.28	9531.98	16949.70	1108.15	8.95	28377.93
1991	10.56	5569.88	10242.88	17577.43	1029.42	2.55	29106.02
1992	7.92	5818.04	10062.19	17874.33	1090.15	0	29080.58
1993	51.02	5843.49	10572.31	18337.54	1348.25	0	28925.37
1994	82.69	5889.96	11410.09	19075.01	1473.65	18.33	29935.11
1995	120.51	6170.55	13563.85	20293.10	1461.98	16.59	30758.83
1996	138.10	6440.05	15599.88	21102.84	1589.33	17.46	31934.25
1997	193.52	6535.41	17113.35	22221.67	1288.96	0	32398.46
1998	255.10	6654.52	18008.46	23328.84	1343.00	0	33146.70
1999	259.50	6915.82	16796.44	23717.91	1345.48	0	33789.74
2000	451.26	6991.99	16479.20	24275.90	1236.15	20.94	32648.05
2001	784.65	7022.73	16319.50	25014.23	1253.41	20.94	30780.15
2002	1217.92	6809.76	15620.18	26311.07	1279.31	0	33065.61
2003	1583.12	6372.73	15369.84	25392.77	944.62	0	33533.23
2004	1834.80	6571.92	15965.33	27259.04	976.26	0	35345.37
2005	2184.17	6463.01	16207.96	27084.04	981.86	0	37491.64
2006	2557.46	6427.66	16889.88	27558.00	897.62	0	36867.00
2007	2804.24	6620.19	16969.85	28936.08	1131.72	0	41931.70
2008	2616.19	6760.10	17404.97	30497.91	1246.70	0	47865.74
2009	2339.81	6622.99	17556.33	29837.61	1194.82	0	50393.84
2010	2283.65	6976.18	20770.06	32512.56	993.49	0	52145.73
2011	2247.32	7136.90	24465.69	34162.39	1008.36	0	49851.80
2012	2241.69	7087.20	28278.15	36171.15	966.02	0	49399.76

4.2 Estimates

4.2.1 MAPE

MAPE values for the main variables of the model are show in the Table 15, and Figures 7, 8, 9, 10 and 11. The main difference between official data and the predicted one due to the application of Hodrick-Prescott filter (1997).

Table 15. MAPE values for the main variables of the model.

Variable	**MAPE (%)**
GDP	2.4%
E_{fossil}	6.8%
RN	2.8%
E_{total}	2.4%
CO_2	4.4%

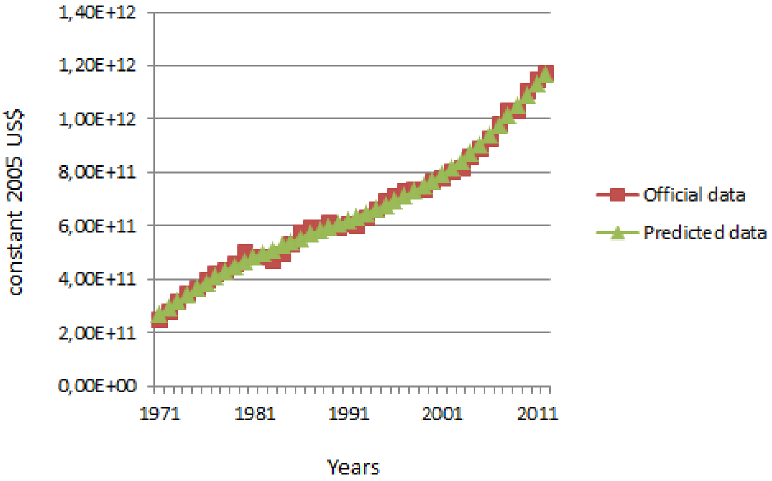

Figure 7. GDP official and predicted data.

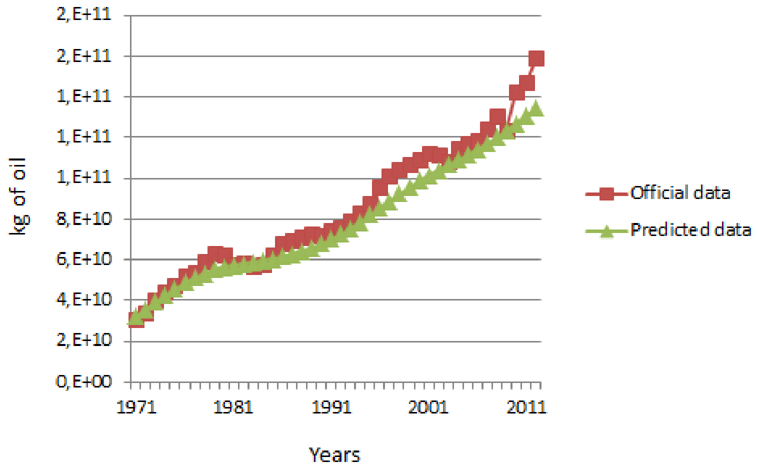

Figure 8. Fossil energy official and predicted data.

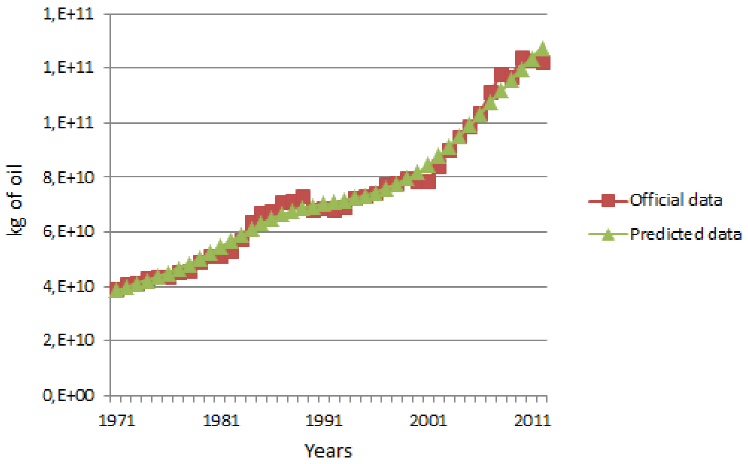

Figure 9. Renewable energy official and predicted data.

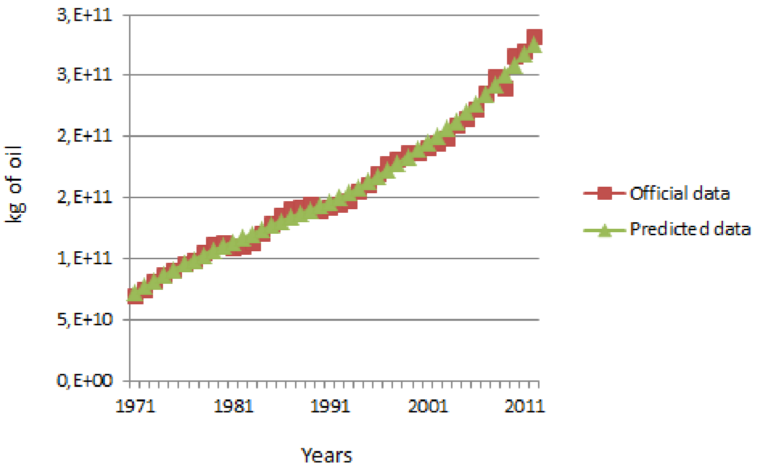

Figure 10.Total energy official and predicted data.

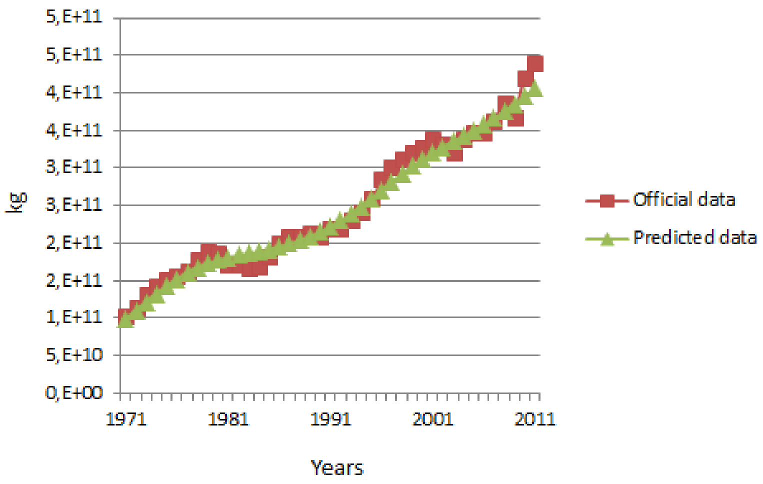

Figure 11.CO_2 emissions official and predicted data.

4.2.2 Scenarios

In this research we calculate the value of CO_2 emissions in the medium term. As it was said before, CO_2 emissions depend on several variables, therefore we have defined four scenarios concerning the growth of GDP, the evolution of the energy matrix, of the productive sectoral structure, and the improvement of energy efficiency for the period 2013-2030.

1. Baseline scenario (BS): GDP, energy matrix and productive sectoral structure will evolve through the smooth trend of the period 1971-2012, extrapolated to 2013-2030 using the geometric growth rate method.

2. Doubling of the GDP (SC-2 scenario): GDP in 2030 will be more than double that of 2012. To generate this scenario a constant annual growth of the GDP formation components (I, TB, C, $\mathrm{E}_{\mathrm{imp}}$) of 4.1% per year between 2012 and 2030 is assumed. This value was extracted of the Brazilian national plan on energy (2007). Also, it was assumed a structural change in the productive sectorial, that will be implemented through a stabilization of the primary sector, a reduction of 4.5% on the industrial and energetic sector and an increase on the service sector of 9%. The rest of the variables will evolve as in the BS scenario.

3. Doubling of the GDP and changed the energetic matrix (SC-3 scenario): The doubling of the GDP and the change of the productive sectoral structure as in the SC-2 scenario are considered, however, the consumption of renewable and nuclear fuel will increase 9% while the natural gas growth 2%. At the same time the consumption of oil and its derivatives will decrease 10% in the whole period.

4. 3. Doubling of the GDP, changed the energetic matrix and improved the efficiency of energy use (SC-4 scenario): The doubling of the GDP, the change of the productive sectoral structure and the reordering of fuel use are the same as in the SC-3 scenario. Moreover an improvement in the efficiency of energy use is implemented with a reduction in the sectoral energy intensity of 5% in the whole period.

4.2.3 Economic estimates

The estimate values of GDP for the pre-established scenarios are presented in Figure 12, Figure 13 and Appendix 1. The first projection refers to 2013 and for the BS scenario corresponds nearly to 1,2 trillion short scale 2005$*. For the year 2030, the BS scenario reaches 2,5 trillion short scale 2005$, which corresponds to more than double that of 2013.

As Figure 13 shows the estimated GDP for the SC-2 scenario is around 3,6 trillion short-scale (2005$) in 2030 (44% higher than for BS scenario) and its average growth rate is 6.5% while in BS scenario it is 4.4%. Furthermore, for SC-3 and SC-4 the results are 3,4 trillion short scale USD 2005 (36% higher than for BS scenario) and 2,9 trillion short scale 2005$ (16% higher than for BS scenario), with an average growth rate of 6.0% and 5.2%, respectively.

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*Trillion short scale means 10^{12} 2005$

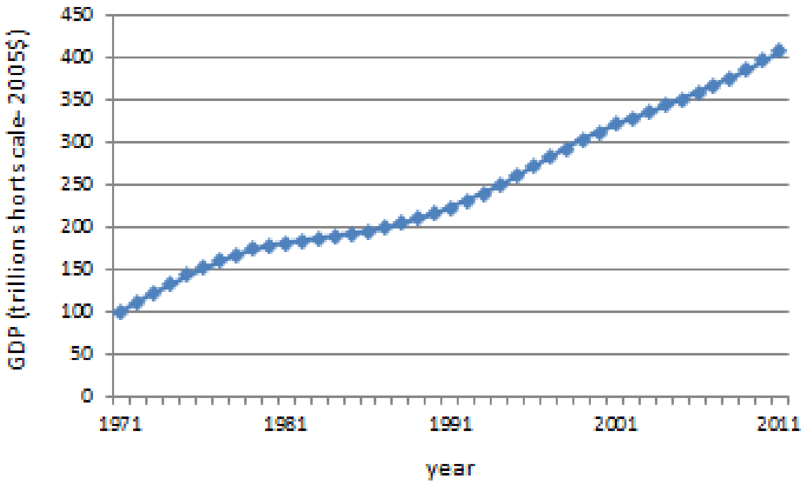

Figure 12. GDP of Brazil for the period 1971-2011.

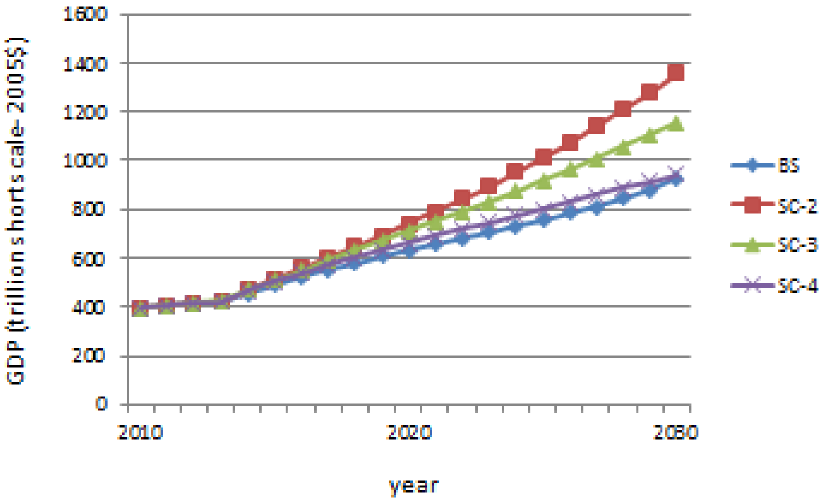

Figure 13. GDP of Brazil for the period 2010-2030.

Note that the difference in the values found between SC-2, SC-3 and SC-4 scenarios are due to the feedback mechanism between GDP and renewable energy. Besides, it is important to highlight that these values do not intend to be a meticulous projection of the GDP, but rather the repercussion of the considered scenarios.

4.2.4 Energy estimates

4.2.4.1 Total energy

Figure 14, Figure 15 and Appendix 2 illustrate the progress of the total energy consumption. In 2013 the projections demonstrated 277130556 toe; 279586116 toe; 279586116 toe; and 278778771 toe for BS scenario, SC-2, SC-3 and SC-4, respectively. However, for 2030, the numbers are superior, being 550593722 toe; 829104077 toe; 774498261 toe; and, 629445279 toe for the same order above.

Further, in 2030 the total energy consumption of the SC-2 corresponds to 50.6% higher than the BS scenario. Likewise, the SC-3 is 40.6% higher than BS scenario. These two last scenarios show the growth of the energy consumption due to the increase of GDP and to the changes of the productive sectoral structure. Lastly, SC-4 generates a consumption of only 14.3% higher than the BS scenario. It distinctly reveals the benefits of the reduction of energy intensity.

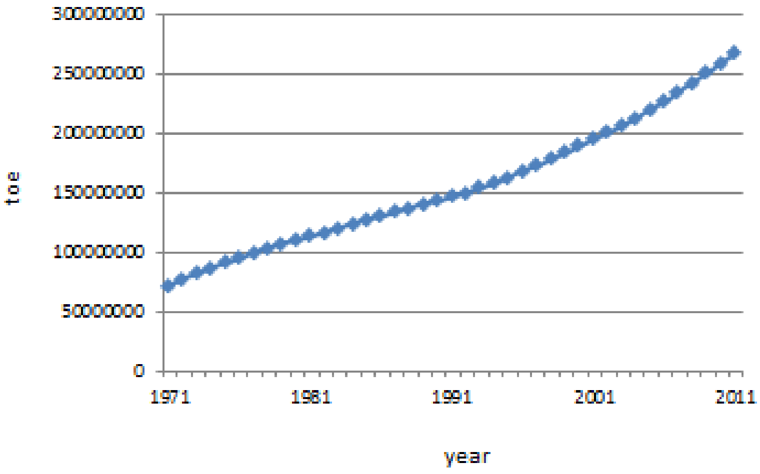

Figure 14. Total energy consumption of Brazil for the period 1971-2011.

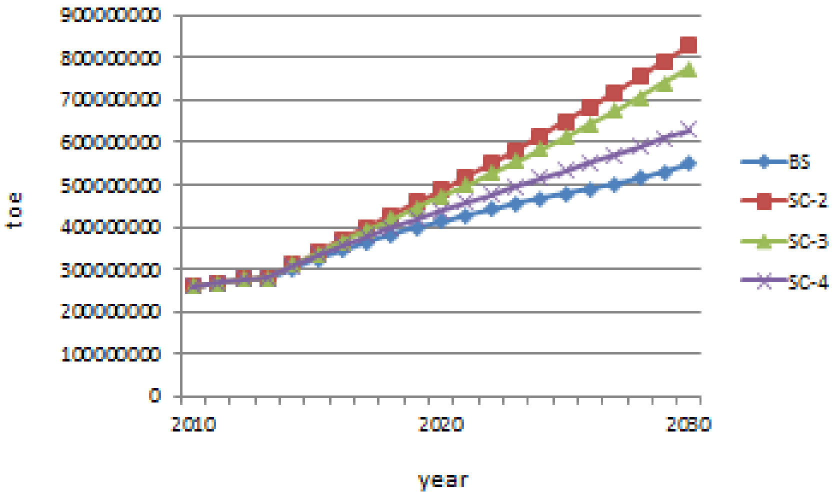

Figure 15. Total energy consumption of Brazil for the period 2010-2030.

The previsions of the consumption of fossil energy (Figure 16 and Appendix 3) in 2030 in the BS scenario is 306448946 toe, while in SC-2 is 444402429 toe (45% higher than the BS scenario), in SC-3 is 371067222 toe (21% higher than the BS scenario) and in SC-4 is 305332983 toe (0.66% lower than the BS scenario). Moreover, the estimations of the consumption of renewable energy are elucidated in Figure 17 and Appendix 4. As we can see, in 2030 the results correspond nearly to 290212188 toe, 443429030 toe, 405460499 toe and 325638742 toe in the BS, SC-2, SC-3 and SC-4 scenarios, representing increases about of 53%, 40% and 12% compared to the BS scenario, respectively.

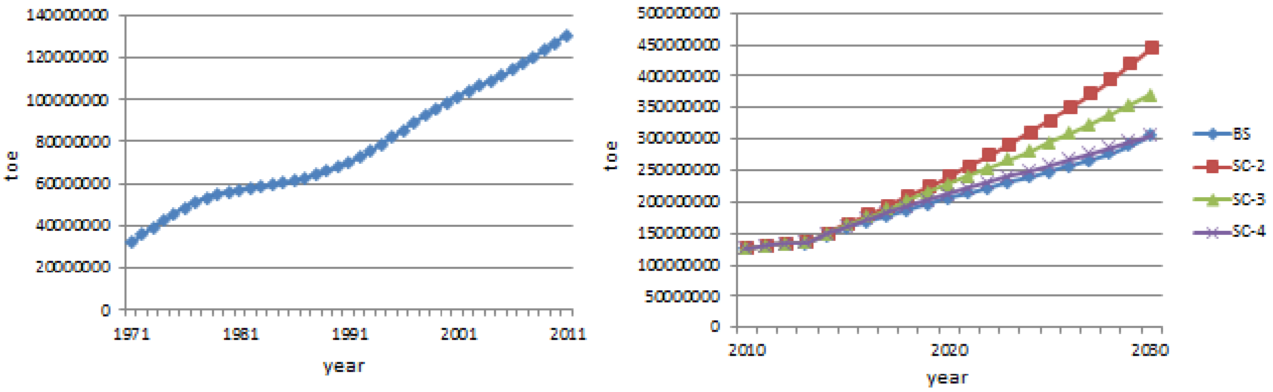

Figure 16. Fossil energy consumption of Brazil for the period 1971-2030.

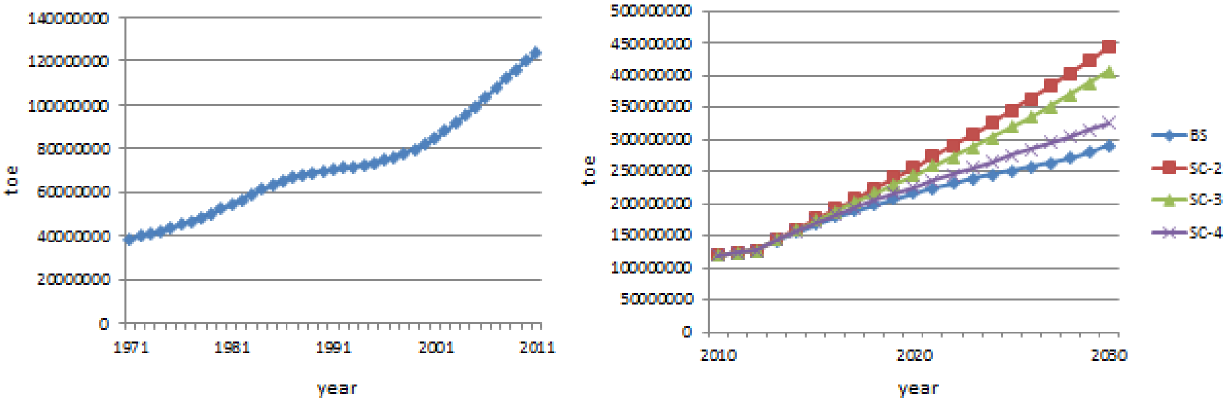

Figure 17. Renewable energy consumption of Brazil for the period 1971-2030.

4.2.4.2 Energy by sector

The change in the behavioral pattern of energy consumption in the primary sector can be seen in Figure 18 and 19, the first makes reference to BS scenario and SC-2, while the second refers to the SC-3 and SC-4.

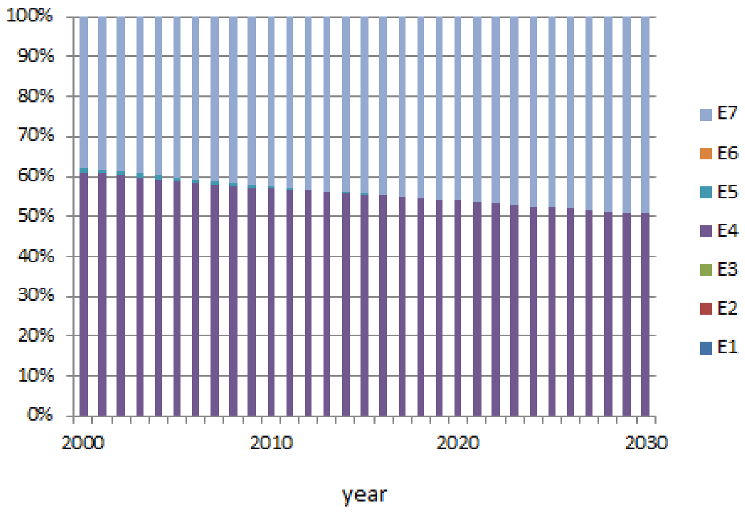

Figure 18. Energy consumption of Brazilian primary sector for the BS and SC-2 scenarios during the period 2000-2030.

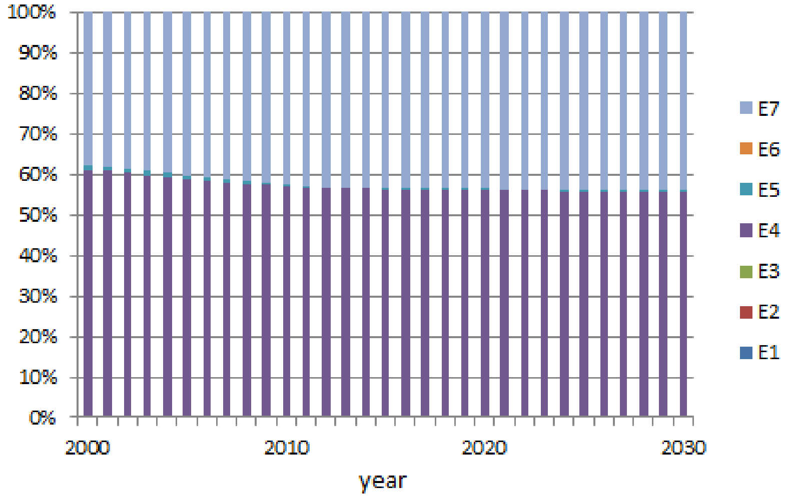

Figure 19. Energy consumption of Brazilian primary sector for the SC-3 and SC-4 scenarios during the period 2000-2030.

In the BS scenario and SC-2, for the next years the fuel oil tends to have an insignificant consumption, while gas/diesel oil will decline 10% and renewable, alternative and nuclear energy will rise 12% (Appendix 5). For the same period, in 2030, the SC-3 and SC-4 shows the same disappearance of fuel oil in the agricultural sector, but the reduction in gas/diesel oil will be 5% and the accretion in the renewable, alternative and nuclear energy will be 7% (Appendix 6).

In the manufacturing sector, the BS scenario and SC-2 result in a nearly rise from 6 to 16% of natural gas and from 58 to 63% of renewable, alternative and nuclear energy. At the same time, the liquefied petroleum gases, gas/diesel oil, fuel oil and petroleum coke practically keep the same values (Figure 20 and Appendix 7).

The SC-3 and SC-4 scenarios, show that the liquefied petroleum gases, gas/diesel oil and petroleum coke maintained the same proportions, which are approximately 3%, 0.6% and 20%, respectively. Whereas, the natural gas increase to 11% and the renewable, alternative and nuclear energy to 63%. In addition, the consumption of fuel oil decreases from 10.8% to 2.2% (Figure 21 and Appendix 8).

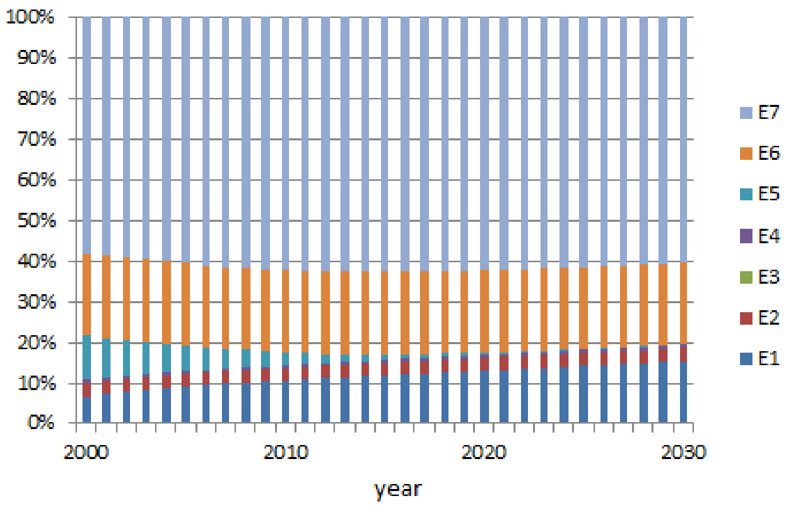

Figure 20. Energy consumption of Brazilian manufacturing sector for the BS and SC-2 scenarios during the period 2000-2030.

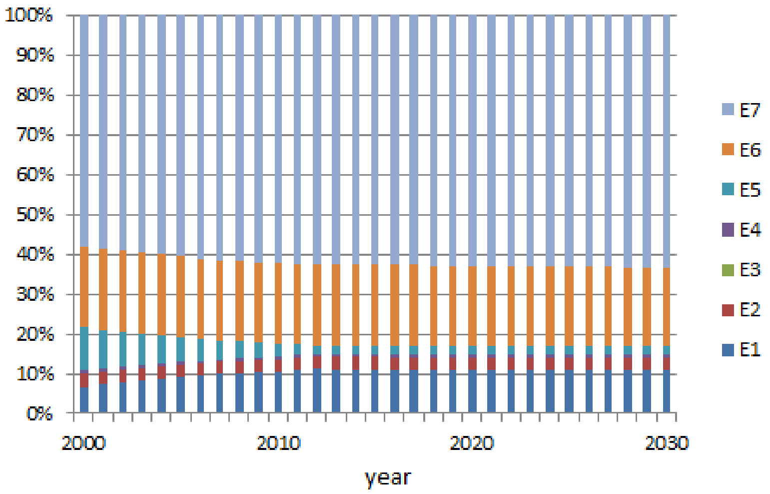

Figure 21. Energy consumption of Brazilian manufacturing sector for the SC-3 and SC-4 scenarios during the period 2000-2030.

In the energetic sector, the forecast for the BS scenario and SC-2 shows devaluation for liquefied petroleum gases, motor gasoline and fuel oil. Although, presents a significativly rise of gas/diesel oil until to 50%, the renewable, alternative and nuclear energy also increase to 63%. Besides, petroleum coke decreases to 8.5% (Figure 22 and Appendix 9). In addition, the SC-3 and SC-4 predicted a developing until

21% of natural gas, up 4.5% of gas/diesel oil and up 56% of renewable, alternative and nuclear energy (Figure 23 and Appendix 10).

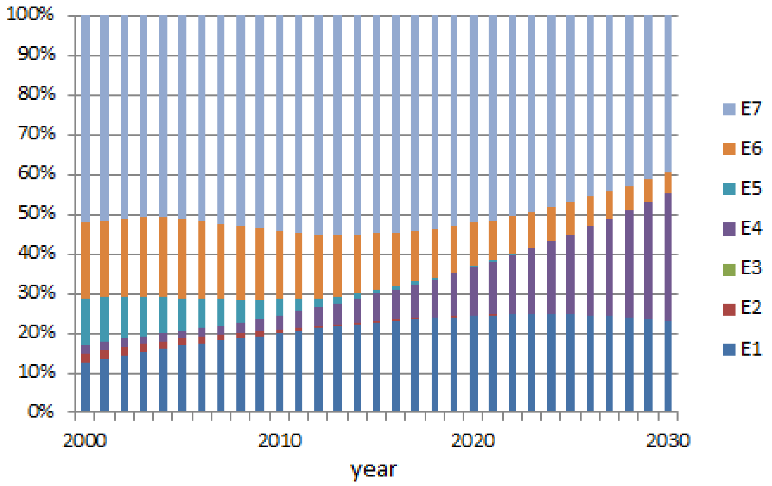

Figure 22. Energy consumption of Brazilian energetic sector for the BS and SC-2 scenarios during the period 2000-2030.

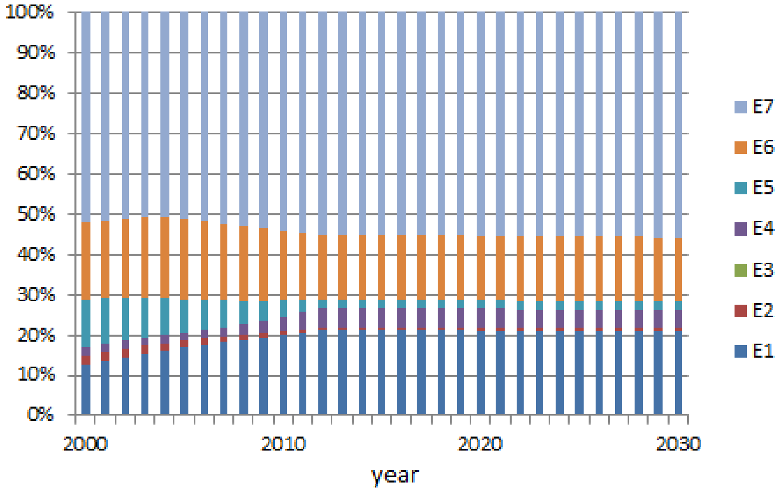

Figure 23. Energy consumption of Brazilian energetic sector for the SC-3 and SC-4 scenarios during the period 2000-2030.

Finally, the tertiary sector presents a reduction on liquefied petroleum gases from 8.2 to 2.7%, and gas/diesel oil from 29.5 to 24.3%. At the same time, the increase on natural gas is only 1%, the motor gasoline growth up to 26% and the renewable, alternative and nuclear energy up to 44.7%, as it is possible to see in Figure 24 and Appendix 11.

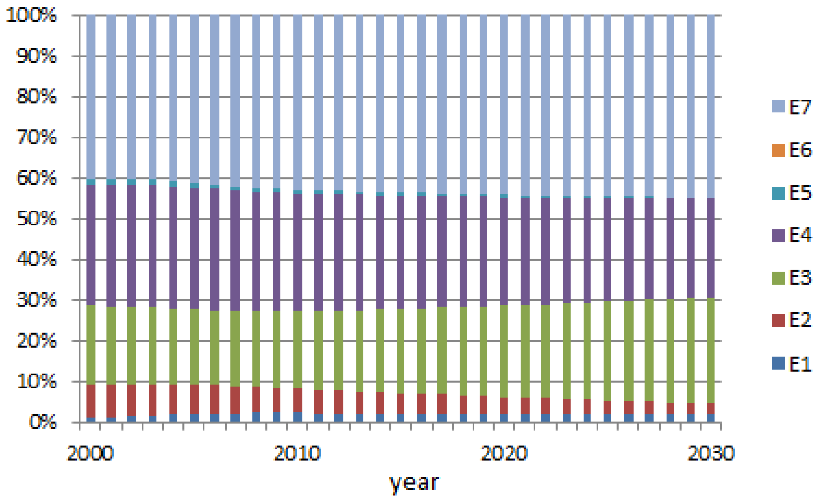

Figure 24. Energy consumption of Brazilian tertiary sector for the BS and SC-2 scenarios during the period 2000-2030.

Furthermore, SC-3 and SC-4 show an add to 2.2% of natural gas and to 44% of renewable, alternative and nuclear energy. However, the decline of liquefied petroleum gases is only 5.5% and the consumption of motor gasoline and gas/oil diesel are almost the same (Figure 25 and Appendix 12).

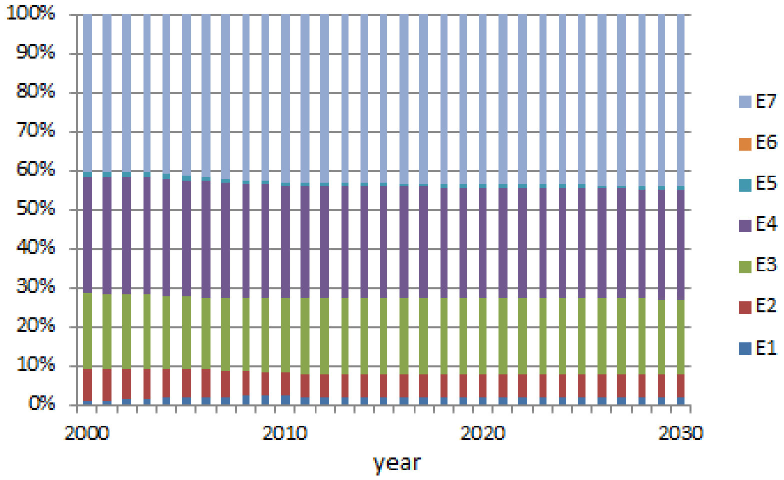

Figure 25. Energy consumption of Brazilian tertiary sector for the SC-3 and SC-4 scenarios during the period 2000-2030.

4.2.4.3 Energy by type of fuels

The energy consumption in accordance with seven types of fuels for each scenario is present on the Figure 26.

Such as Figure 27 and Appendix 13 illustrate, the natural gas in 2010 represents 7.1% of all energy consumption, later in 2030 for BS scenario and SC-2 it reaches 10.2%, however SC-3 and SC-4 remain the same value (7%). Posteriorly, Figure 28 and Appendix 14 show that in 2010, the liquefied petroleum gases was 4.2% of all energy consumption, 30 years later the forecast shows 2.5% for BS scenario and SC-2 while it shows 4% for SC-3 and SC-4.

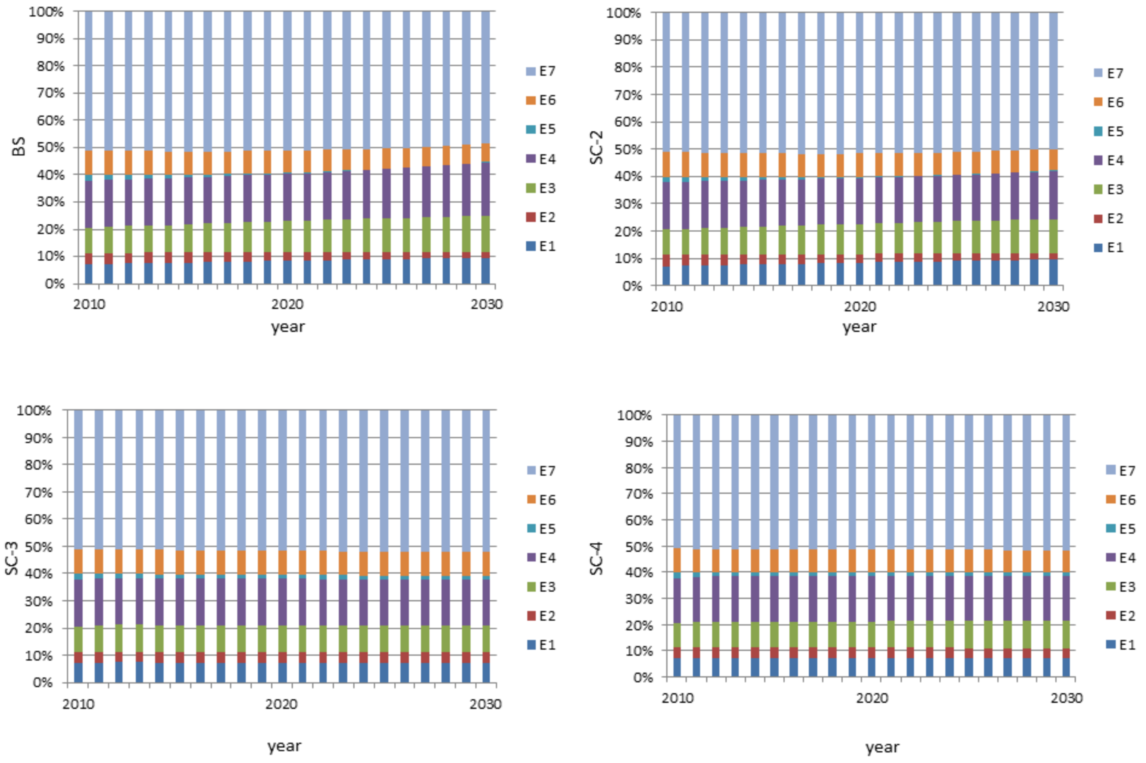

Figure 26. The Brazilian energy consumption by seven types of fuels according to the four scenarios during the period 2010-2030. The types of energy are: natural gas (E1), liquefied petroleum gases (E2), motor gasoline (E3), gas/diesel oil (E4), fuel oil (E5), petroleum coke (E6) and renewable, alternative and nuclear (E7).

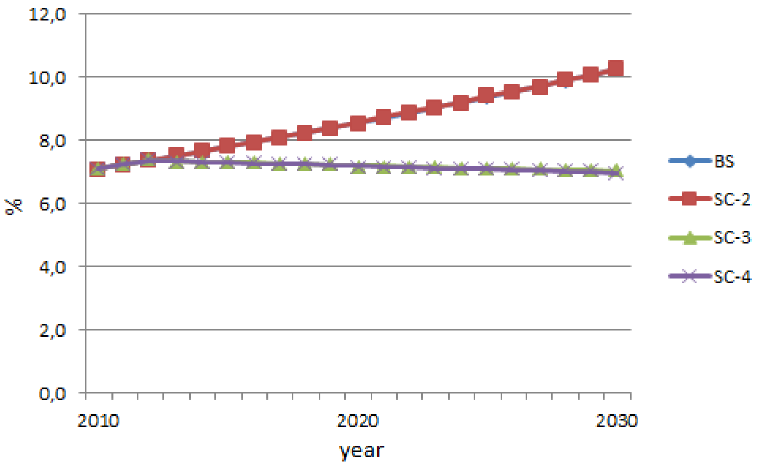

Figure 27. Brazilian energy consumption of natural gas for the four scenarios for the period 2010-2030.

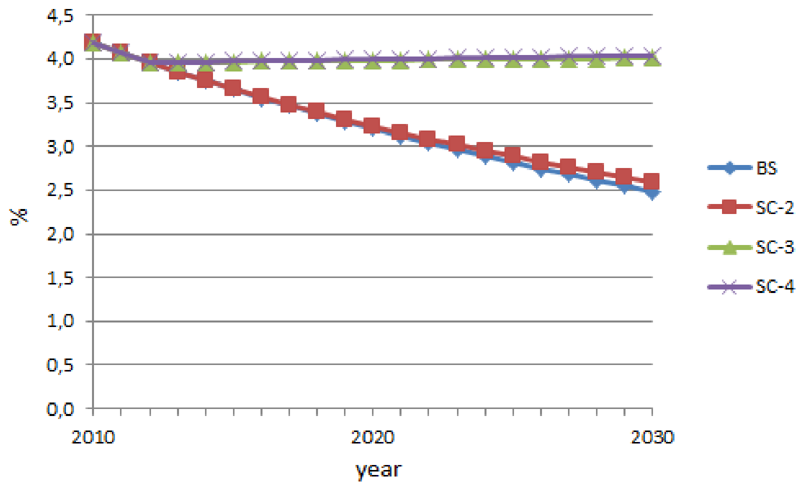

Figure 28. Brazilian energy consumption of liquefied petroleum gases for the four scenarios for the period 2010-2030.

The motor gasoline was 10.3% of all energy consumption in 2010, this number go up to 14.2%, 13.2%, 9.9% and 10.4% for the BS scenario, SC-2, SC-3 and SC-4, respectively (Figure 29 Appendix 15).

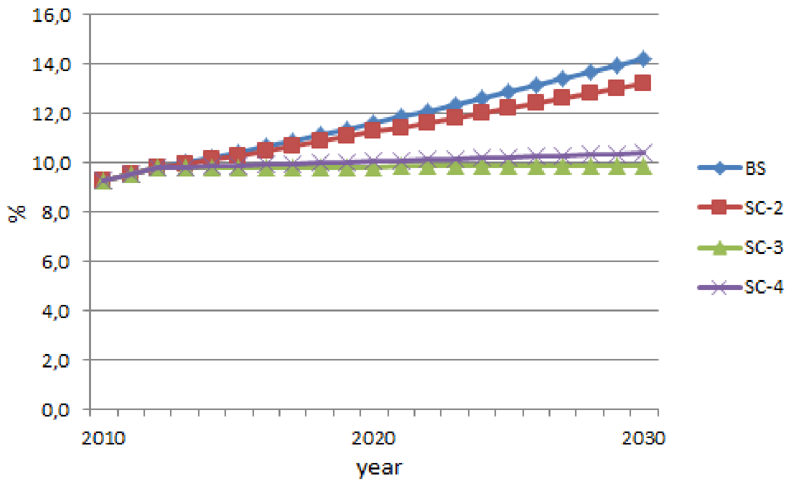

Figure 29. Brazilian energy consumption of motor gasoline for the four scenarios for the period 2010-2030.

On the other hand, Figure 30 and Appendix 16 demonstrate that the gas/diesel oil consumption was 17.2% in 2010, and rises up to 21,2% in the BS scenario and up to 18.9% to the SC-2. It had hardly any accretion on SC-4 to 17.4% and a decrease on SC-3 to 16.7%.

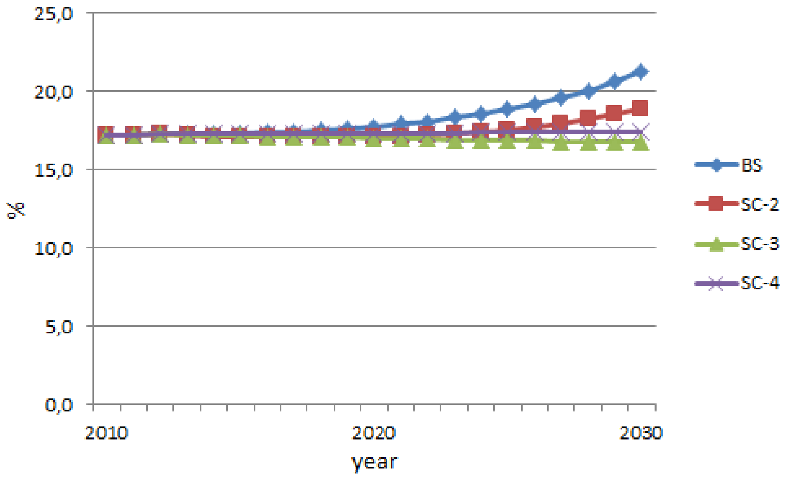

Figure 30. Brazilian energy consumption of gas/diesel oil for the four scenarios for the period 2010-2030.

The representation of fuel oil in total energy consumption had a decline in all projections (Figure 31 and Appendix 17), in 2010 it was 2% however in 2030 it will be 0.2% to BS scenario and SC-2 and 1.4% for SC-3 and SC-4.

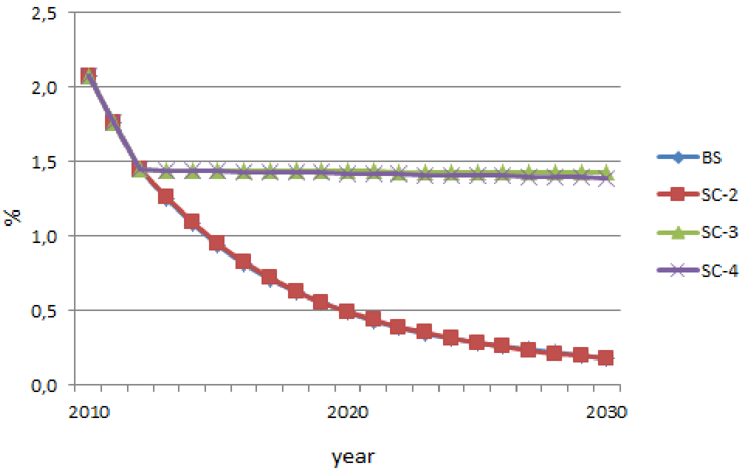

Figure 31. Brazilian energy consumption of fuel oil for the four scenarios for the period 2010-2030.

In 2010, the petroleum coke was nearly to 9% of all energy consumption, in 2030 the prevision results in a decrease for all scenarios, being 7.3% for BS scenario, 8.5% to SC-2, 8.8% to SC-3 and finally 8.2% to SC-4 (Figure 32 and Appendix 18).

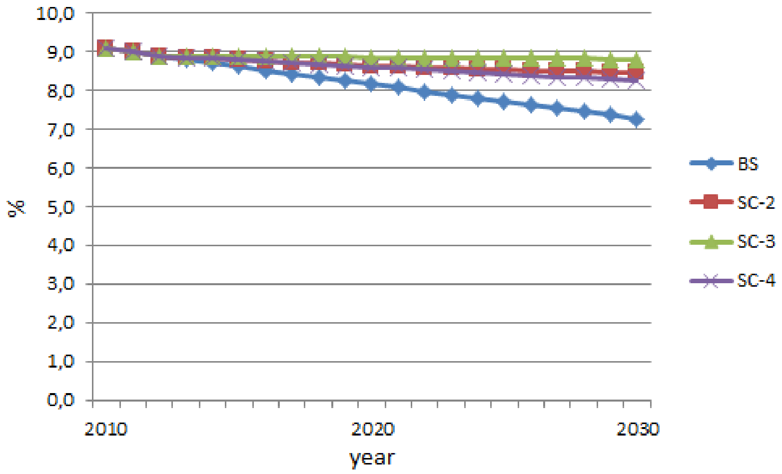

Figure 32. Brazilian energy consumption of petroleum coke for the four scenarios for the period 2010-2030.

Figure 33 and Appendix 19 show that in 2010 the renewable energy accounted for 51% of all energy consumption of Brazil, the forecast reveals a similar increase in all scenarios, achieving 52.7% for BS scenario, 53.5% for SC-2, 52.3% for SC-3 and 51.7% for SC-4.

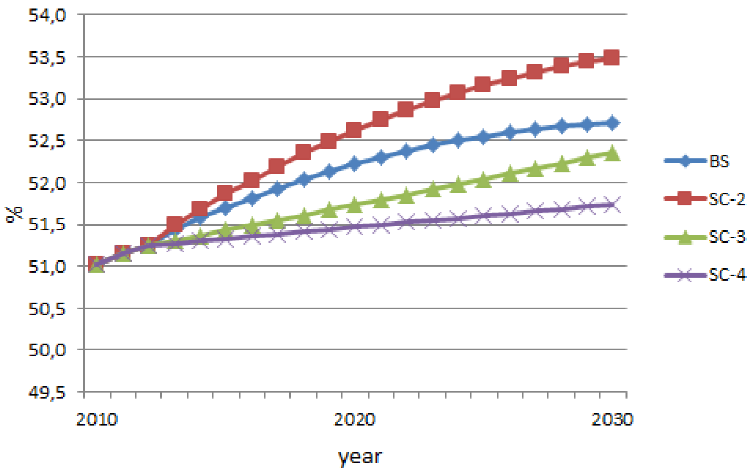

Figure 33. Brazilian consumption of renewable, alternative and nuclear energies for the four scenarios for the period 2010-2030.

4.2.5 CO2 emissions

Figure 34 and Figure 35 show CO_2 emissions as a function of time for the period 1971-2030 under the four considered scenarios.

In 2030 the highest emission coincides to the SC-2 scenario (1357 million tonnes), follow by SC-3 (1154 million tonnes), posteriorly comes the SC-4 (945 million tonnes) which resulted in a similar value to BS scenario (927 million tonnes) (Appendix 20).

The SC-3 and SC-4 scenarios imply on the continuous growth of the GDP and also added mitigation measures, like reduction of the fossil energy contribution to the energy matrix and changes in the productive sectoral structure. With the reduction of fossil energy, down to 10% in SC-3, without modifying the energy intensity, one reaches a decrease of 203 million tonnes, while implementing energy efficiency measures in the productive sectoral structure (SC-4) emissions are reduced down to 412 million tonnes.

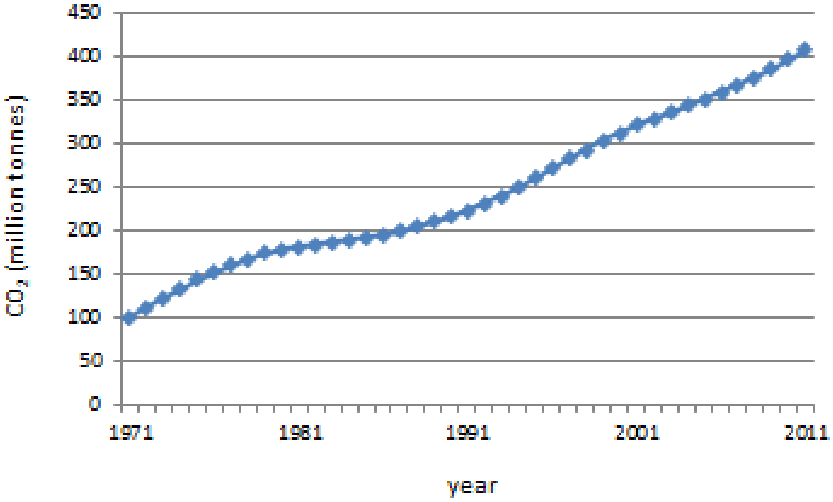

Figure 34. CO_2 emissions of Brazil for the period 1971-2011.

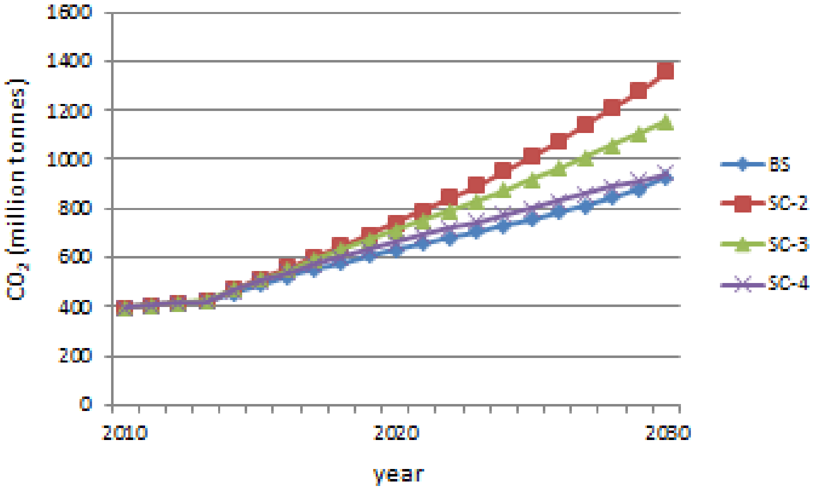

Figure 35. CO_2 emissions of Brazil for the period 2010-2030.

In particular, BS scenario presents CO_2 emissions in 2030 222% higher than in 2012.At the same time the SC-2 scenario increases 6.8%, which implies that the amount of CO_2 emissions in SC-2 will be 429 million tonnes higher than in the BS scenario.

Those scenarios where renewable energy and efficiency goals are implemented show that it is possible to increase the GDP in a constant way while the CO_2 emissions are being mitigate. For instance, the SC-4 presents almost the same value of CO_2 emission growth rate of the BS scenario during the same period, being 4.6% and 4.5%, respectively. However the SC-4 has a GDP average growth rate of 5.2% while BS scenario has a GDP average growth rate of 4.4%.

4.2.4.1 Brazil and the COP21

The Brazilian Intended Nationally Determined Contribution committed itself to reduce greenhouse emissions by 37% below 2005 levels by 2025, and also proposed for reference purpose only, a subsequent indicative contribution of 43% below 2005 levels by 2030.

In 2005 Brazil's total greenhouse gas emission was 2,386,440 kt of CO_2 equivalent (GWP-100). According to the Brazilian intentions of reduction GHG emission at COP-21 this number will decline to 1,503,457.2 kt of CO_2 equivalent by 2025 and to 1,360,270.8 kt of CO_2 equivalent by 2030.

Despite the fact that this research focused only on CO_2 emissions and did not include CH_4, N_2O, perfluorocarbons, hydrofluorocarbons and SF_6, we may conclude that Brazil will probably not comply with the agreed value estimated at the United Nations Framework Convention on Climate Change in Paris.

According to our forecasts, in 2025 CO_2 emissions could be 216% higher than in 2005 levels in the BS scenario, 289% higher in the SC-2, 262% in the SC-3 and 229% in the SC-4. In addition, these percentages in 2030 would be 265% higher than in 2005 levels in the BS scenario, 387% higher in the SC-2, 330% in the SC-3 and 270% in the SC-4. However, our forecasts don't match the COP-21 Brazilian commitment for 2025, which also proposed a reduction of 43% of GHG below 2005 levels by 2030.

5. CONCLUSIONS

This research discusses the GDP, energy consumption and CO_2 emissions of Brazil in a medium term from 2013 to 2030 based on a model introduced by Robalino-López et al. (2014 , 2015). This model analyzes the direct influence of renewable energies on the GDP, creating a feedback mechanism between income and CO_2 emissions.

The official data set (1971-2012) was used to parameterize the model, whereas in the period 2013-2030, an estimation of different variables, including the CO_2 emissions, was carried out. Beyond that, for a more complete analysis, four different scenarios were proposed. They represent the development of GDP, energy matrix and productive sectorial structure, which were previously defined.

First, a BS scenario (baseline scenario) has been established, based on the model variables that were parameterized according to the observed tendency during the period 1971-2012. In this scenario, the CO_2 emission in 2030 was 222% higher than in 2012.

Suchlike, the second scenario, called SC-2, was characterized not only by the doubling of GDP during the 2013-2030 period, but also by a change in the productive sector. This change would be caused by a stabilization of the primary sector, a reduction of 4.5% in the industrial and energetic sector and an increase in service sector of 9%. As a result, the emissions in 2030 were 325% higher than in 2012.

In the third scenario, SC-3, it was assumed the increase in GDP, the change in the productive sector and an imposing increase of 2% in natural gas consumption and 9% in renewable, alternative and nuclear energy consumption. At the same time, a decrease of 10% in fossil energy consumption was also taken into consideration. In this case, the CO_2 emissions in 2030 were 276% higher than in 2012. Finally, the fourth one, SC-4, had the same variables as SC-3 but complement with a 5% reduction in the sectorial energy intensity. This scenario in 2030 is 226 % higher than in 2012.

It is important to highlight that the BS scenario corresponds to a modest GDP increase, whereas in the three other scenarios the GDP increases heavily. The SC-2 was the scenario with the highest CO_2 emission value, precisely the very one for which no mitigation measures were taken.

In addition, the SC-3 and SC-4 indicate that it is possible to maintain the CO_2 emissions while the GDP is growing. However, this can only happen by promoting the renewable energy (as in the SC-3 scenario) and reducing the energy intensity (likewise in the SC-4 scenario). So, the promotion of renewable energy and improvement of the energy intensity are effective in attenuating CO_2 emissions.

It is worth noting that the main outcome of this research is the estimation of CO_2 emissions of Brazil in the medium term, until 2030. That's why it's so important to compare these results with the Brazil's commitment in Paris Agreement.

Brazil defined a reduction of greenhouse emissions to 37% below 2005 levels by 2025. According to our CO_2 emission forecast, the BS scenario corresponds to CO_2 emissions 216% higher than in 2005 levels in the BS scenario, 289% higher in the SC-2, 262% in the SC-3 and 229% in the SC-4.

Moreover, if we consider the Brazilian proposal for 2030, which is the reduction of 43% below 2005 levels, the values reached by CO_2 emissions are 265% higher than in 2005 levels in the BS scenario, 387% higher in the SC-2, 330% in the SC-3 and 270% in the SC-4. We can infer that Brazil's goals at the United Nations Framework Convention on Climate Change in Paris are very ambitious, and unlikely be achieved.

Nevertheless, the mitigation program for carbon emissions must be maintained. Among all shares assumed by Brazil, we emphasize the increase of 18% in the share of sustainable biofuels in the Brazilian energy mix to by 2030; the strengthening policies and measures achieve zero illegal deforestation in Brazilian Amazonia Rainforest by 2030; the achievement of 45% of renewables in the energy mix by 2030 and 10% of efficiency gains in the electricity sector by 2030.

This study has demonstrated the potential of a model applied to measure CO_2 emissions in a short term of Brazil, many opportunities for extending this work remain, such as:

- Create a bigger sectoral disaggregation. This means, study more than the four sectors approached in this research, which were: agriculture sector, industrial sector, energy sector and services, residential and transportation sector.
- Apply and extend the current methodology to other countries in order to compare the CO_2 emission results with those obtained in this work. It would be also useful to use the methodology to get results for other countries under development, as Russia, India, China and South Africa. Those results can be, then, compared with the results obtained for the Brazilian analysis.
- Perform a sensitivity analysis to check which variables have the most important impact on the proposed model. This analysis shall give an idea about the variables that should be prioritized by stakeholders in order to reduce the CO_2 emissions in the future.
- Monitors the CO_2 emissions in the country and calibrates the model based on the real data registered in the future. Also be aware of the policies proposed by Brazil at COP21 and consider them in order to improve the proposed model.
- Suggest political plans by determining which measures would imply in an increase of GDP and a reduction of CO_2 emissions. For instance, how Brazilian government should develop public transportation in order to be profit and reduce CO_2 emissions levels. Discuss economic and political plans with entrepreneurs and the Brazilian government; the objective is to find out a more sustainable way of increasing the GDP without compromising in terms of CO_2 emissions.

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7. APPENDIX

Appendix 1. GDP values. From 1971 to 2012 corresponds to official dataset and from 2013 to 2030 corresponds to predictions.

Year	GDP ($2005)			
	BS Scenario	SC-2	SC-3	SC-4
1971	268292950571	268292950571	268292950571	268292950571
1972	293609799387	293609799387	293609799387	293609799387
1973	318745465697	318745465697	318745465697	318745465697
1974	343385946002	343385946002	343385946002	343385946002
1975	367224921145	367224921145	367224921145	367224921145
1976	390006259509	390006259509	390006259509	390006259509
1977	411467114267	411467114267	411467114267	411467114267
1978	431468980995	431468980995	431468980995	431468980995
1979	449968466128	449968466128	449968466128	449968466128
1980	466953316290	466953316290	466953316290	466953316290
1981	482551474443	482551474443	482551474443	482551474443
1982	497283968389	497283968389	497283968389	497283968389
1983	511686511181	511686511181	511686511181	511686511181
1984	526190261193	526190261193	526190261193	526190261193
1985	540811797684	540811797684	540811797684	540811797684
1986	555255853302	555255853302	555255853302	555255853302
1987	569162423719	569162423719	569162423719	569162423719
1988	582389172071	582389172071	582389172071	582389172071
1989	595080070261	595080070261	595080070261	595080070261
1990	607526993468	607526993468	607526993468	607526993468
1991	620238654170	620238654170	620238654170	620238654170
1992	633624790909	633624790909	633624790909	633624790909
1993	647959408688	647959408688	647959408688	647959408688
1994	663218591598	663218591598	663218591598	663218591598
1995	679218855644	679218855644	679218855644	679218855644
1996	695801701916	695801701916	695801701916	695801701916
1997	712967642946	712967642946	712967642946	712967642946
1998	730863824248	730863824248	730863824248	730863824248
1999	74985356990	74985356990	74985356990	74985356990
2000	770362275762	770362275762	770362275762	770362275762
2001	792722085958	792722085958	792722085958	792722085958
2002	817271352880	817271352880	817271352880	817271352880
2003	844258854052	844258854052	844258854052	844258854052

2004	873837595472	873837595472	873837595472	873837595472
2005	905887039595	905887039595	905887039595	905887039595
2006	940187926923	940187926923	940187926923	940187926923
2007	976378427561	976378427561	976378427561	976378427561
2008	1013964262345	1013964262345	1013964262345	1013964262345
2009	1052519663836	1052519663836	1052519663836	1052519663836
2010	1091812351971	1091812351971	1091812351971	1091812351971
2011	1131404950049	1131404950049	1131404950049	1131404950049
2012	1171039027848	1171039027848	1171039027848	1171039027848
2013	1182969220492	1190509199691	1190509199691	1190509199691
2014	1297215859528	1321866265443	1318551328622	1315080420567
2015	1400733610660	1450986401408	1441693676151	1431235839146
2016	1495481918478	1578977217550	1561602739513	1540672769882
2017	1583175316389	1706906259293	1679659507289	1644861123102
2018	1665470046385	1835861903791	1797014252465	1745068947513
2019	1744467443361	1966857712272	1914611652057	1842386463221
2020	1820123024225	2100267040034	2033268065396	1937750157226
2021	1892226605171	2236484739751	2153681459911	2031961952868
2022	1961148454256	2375916016468	2276450455993	2125708236991
2023	2027360796401	2518927847949	2402094660203	2219576949436
2024	2091363976269	2665789289361	2531071118616	2314072812032
2025	2153676468257	2816637718635	2663792866143	2409630811190
2026	2215027920454	2971623319849	2800635254836	2506627703606
2027	2277538444272	3130885951893	2941943958375	2605392270319
2028	2349458033871	3294535066538	3088042706373	2706214140114
2029	2433155507941	3462642775668	3239239674482	2809351332840
2030	2537706500953	3635255186490	3395832803112	2915036664727

Appendix 2. Total energy values. From 1971 to 2012 corresponds to official dataset and from 2013 to 2030 corresponds to predictions.

Year	Total Energy (toe)			
	BS Scenario	SC-2	SC-3	SC-4
1971	71873660	71873660	71873660	71873660
1972	77144748	77144748	77144748	77144748
1973	82150776	82150776	82150776	82150776
1974	86875635	86875635	86875635	86875635
1975	91319144	91319144	91319144	91319144
1976	95498246	95498246	95498246	95498246
1977	99436658	99436658	99436658	99436658
1978	103163593	103163593	103163593	103163593
1979	106697324	106697324	106697324	106697324
1980	110068211	110068211	110068211	110068211
1981	113353692	113353692	113353692	113353692
1982	116670191	116670191	116670191	116670191
1983	120086093	120086093	120086093	120086093
1984	123603048	123603048	123603048	123603048
1985	127154334	127154334	127154334	127154334
1986	130645577	130645577	130645577	130645577
1987	134002054	134002054	134002054	134002054
1988	137200533	137200533	137200533	137200533
1989	140287006	140287006	140287006	140287006
1990	143363630	143363630	143363630	143363630
1991	146587524	146587524	146587524	146587524
1992	150087211	150087211	150087211	150087211
1993	153955841	153955841	153955841	153955841
1994	158233916	158233916	158233916	158233916
1995	162898485	162898485	162898485	162898485
1996	167888200	167888200	167888200	167888200
1997	173100450	173100450	173100450	173100450
1998	178425183	178425183	178425183	178425183
1999	183796182	183796182	183796182	183796182
2000	189204614	189204614	189204614	189204614
2001	194716118	194716118	194716118	194716118
2002	200438007	200438007	200438007	200438007
2003	206476391	206476391	206476391	206476391
2004	212910808	212910808	212910808	212910808
2005	219755198	219755198	219755198	219755198
2006	227004980	227004980	227004980	227004980
2007	234621361	234621361	234621361	234621361
2008	242524337	242524337	242524337	242524337
2009	250633841	250633841	250633841	250633841
2010	258922162	258922162	258922162	258922162
2011	267249494	267249494	267249494	267249494

2012	275535500	275535500	275535500	275535500
2013	277130556	279586116	279586116	278778771
2014	302594573	309872213	309095124	306478855
2015	325356491	339543142	337368566	331956602
2016	345884178	368852803	364794084	355633909
2017	364584109	398044454	391690608	377872666
2018	381844159	427360314	418317181	398981962
2019	398190459	457056868	444915969	419224528
2020	413615911	487215446	471673167	438823555
2021	428077040	517921826	498746365	457967755
2022	441665859	549265428	526270931	476816402
2023	454499232	581328184	554364956	495503809
2024	466701956	614172370	583134591	514143262
2025	478393681	647824423	612670229	532830524
2026	489740012	682314194	643053638	551646723
2027	501210877	717669766	674359994	570660933
2028	514610698	753912553	706659396	589932364
2029	530427537	791055350	740017969	609512223
2030	550593722	829104077	774498262	629445279

Appendix 3. Fossil energy values. From 1971 to 2012 corresponds to official dataset and from 2013 to 2030 corresponds to predictions.

Year	Fossil Energy (toe)			
	BS Scenario	SC-2	SC-3	SC-4
1971	32232092	32232092	32232092	32232092
1972	35740094	35740094	35740094	35740094
1973	39218337	39218337	39218337	39218337
1974	42584365	42584365	42584365	42584365
1975	45750636	45750636	45750636	45750636
1976	48634058	48634058	48634058	48634058
1977	51159016	51159016	51159016	51159016
1978	53278686	53278686	53278686	53278686
1979	54964133	54964133	54964133	54964133
1980	56230632	56230632	56230632	56230632
1981	57163972	57163972	57163972	57163972
1982	57903284	57903284	57903284	57903284
1983	58583962	58583962	58583962	58583962
1984	59332586	59332586	59332586	59332586
1985	60232566	60232566	60232566	60232566
1986	61318866	61318866	61318866	61318866
1987	62601071	62601071	62601071	62601071
1988	64088512	64088512	64088512	64088512
1989	65795989	65795989	65795989	65795989
1990	67748023	67748023	67748023	67748023
1991	69979292	69979292	69979292	69979292
1992	72518848	72518848	72518848	72518848
1993	75378359	75378359	75378359	75378359
1994	78523356	78523356	78523356	78523356
1995	81896958	81896958	81896958	81896958
1996	85405156	85405156	85405156	85405156
1997	88928900	88928900	88928900	88928900
1998	92353366	92353366	92353366	92353366
1999	95595496	95595496	95595496	95595496
2000	98609931	98609931	98609931	98609931
2001	101383825	101383825	101383825	101383825
2002	103953222	103953222	103953222	103953222
2003	106405419	106405419	106405419	106405419
2004	108846856	108846856	108846856	108846856
2005	111354771	111354771	111354771	111354771
2006	114002334	114002334	114002334	114002334
2007	116845122	116845122	116845122	116845122
2008	119917461	119917461	119917461	119917461
2009	123240091	123240091	123240091	123240091
2010	126823397	126823397	126823397	126823397
2011	130558568	130558568	130558568	130558568

2012	134322904	134322904	134322904	134322904
2013	134986833	136021416	136137177	135848020
2014	147471239	150662594	150360890	149305150
2015	158824807	165165938	163962638	161672586
2016	169271696	179659549	177128385	173156757
2017	179005021	194265899	190010248	183934646
2018	188229654	209129403	202731523	194157373
2019	197244747	224436570	215418043	203953015
2020	206053087	240247581	228157725	213430537
2021	214643198	256630733	241025034	222681993
2022	223080269	273668972	254084308	231785012
2023	231451796	291455395	267392242	240804988
2024	239853520	310081315	281000449	249797005
2025	248378515	329618587	294950757	258807615
2026	257154343	350153545	309281108	267876204
2027	266482676	371785500	324026455	277036257
2028	277406041	394623687	339219326	286316433
2029	290315882	418785957	354890154	295741476
2030	306448946	444402429	371067222	305332983

Appendix 4. Renewable energy values. From 1971 to 2012 corresponds to official dataset and from 2013 to 2030 corresponds to predictions.

Year	Renewable Energy (toe)			
	BS Scenario	SC-2	SC-3	SC-4
1971	38431711	38431711	38431711	38431711
1972	39668459	39668459	39668459	39668459
1973	40914082	40914082	40914082	40914082
1974	42189326	42189326	42189326	42189326
1975	43521479	43521479	43521479	43521479
1976	44945067	44945067	44945067	44945067
1977	46495617	46495617	46495617	46495617
1978	48197620	48197620	48197620	48197620
1979	50063939	50063939	50063939	50063939
1980	52084183	52084183	52084183	52084183
1981	54235345	54235345	54235345	54235345
1982	56488166	56488166	56488166	56488166
1983	58785393	58785393	58785393	58785393
1984	61031807	61031807	61031807	61031807
1985	63117370	63117370	63117370	63117370
1986	64958902	64958902	64958902	64958902
1987	66511926	66511926	66511926	66511926
1988	67759288	67759288	67759288	67759288
1989	68729041	68729041	68729041	68729041
1990	69484758	69484758	69484758	69484758
1991	70132334	70132334	70132334	70132334
1992	70766804	70766804	70766804	70766804
1993	71468244	71468244	71468244	71468244
1994	72292055	72292055	72292055	72292055
1995	73270454	73270454	73270454	73270454
1996	74440671	74440671	74440671	74440671
1997	75838468	75838468	75838468	75838468
1998	77497181	77497181	77497181	77497181
1999	79464031	79464031	79464031	79464031
2000	81790031	81790031	81790031	81790031
2001	84528931	84528931	84528931	84528931
2002	87699490	87699490	87699490	87699490
2003	91258051	91258051	91258051	91258051
2004	95122714	95122714	95122714	95122714
2005	99201526	99201526	99201526	99201526
2006	103402836	103402836	103402836	103402836
2007	107628070	107628070	107628070	107628070
2008	111782443	111782443	111782443	111782443
2009	115809544	115809544	115809544	115809544
2010	119714162	119714162	119714162	119714162
2011	123513554	123513554	123513554	123513554

2012	127264489	127264489	127264489	127264489
2013	142518649	143940511	143445582	142927365
2014	156067483	160165115	158777684	157216299
2015	168210533	176098971	173504912	170380008
2016	179207340	191896583	187828565	182633067
2017	189293533	207715368	201915302	194159720
2018	198684500	223701368	215900882	205117454
2019	207577625	239904831	229901693	215640596
2020	215978537	256378996	244016229	225843159
2021	223872045	273178415	258327923	235821678
2022	231306829	290351699	272908170	245657754
2023	238336162	307932589	287818781	255420313
2024	245011090	325934910	303114736	265167614
2025	251396898	344374131	318845124	274948955
2026	257580608	363263902	335054322	284806192
2027	263807114	382613044	351783144	294775047
2028	271023464	402424501	369069779	304886220
2029	279485440	422697023	386950576	315166338
2030	290212188	443429031	405460499	325638743

Appendix 5. Values of energy consumption of Brazilian primary sector for the BS and SC-2 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0	0.0017	0	0.6086	0.0118	0	0.3781
2001	0	0.0019	0	0.6053	0.0119	0	0.3811
2002	0	0.0021	0	0.6009	0.0117	0	0.3856
2003	0	0.0022	0	0.5957	0.0112	0	0.3911
2004	0	0.0022	0	0.5903	0.0106	0	0.3970
2005	0	0.0022	0	0.5852	0.0098	0	0.4029
2006	0	0.0021	0	0.5806	0.0090	0	0.4083
2007	0	0.0020	0	0.5767	0.0081	0	0.4131
2008	0	0.0019	0	0.5734	0.0072	0	0.4173
2009	0	0.0017	0	0.5706	0.0062	0	0.4212
2010	0	0.0016	0	0.5680	0.0052	0	0.4249
2011	0	0.0014	0	0.5655	0.0042	0	0.4286
2012	0	0.0012	0	0.5631	0.0031	0	0.4322
2013	0	0.0011	0	0.5601	0.0026	0	0.4359
2014	0	0.0009	0	0.5572	0.0021	0	0.4395
2015	0	0.0008	0	0.5542	0.0017	0	0.4430
2016	0	0.0007	0	0.5512	0.0013	0	0.4465
2017	0	0.0006	0	0.5481	0.0010	0	0.4499
2018	0	0.0006	0	0.5448	0.0008	0	0.4533
2019	0	0.0005	0	0.5416	0.0007	0	0.4566
2020	0	0.0004	0	0.5382	0.0005	0	0.4598
2021	0	0.0004	0	0.5348	0.0004	0	0.4630
2022	0	0.0003	0	0.5313	0.0003	0	0.4662
2023	0	0.0003	0	0.5278	0.0003	0	0.4693
2024	0	0.0003	0	0.5242	0.0002	0	0.4724
2025	0	0.0002	0	0.5206	0.0002	0	0.4754
2026	0	0.0002	0	0.5169	0.0001	0	0.4783
2027	0	0.0002	0	0.5131	0.0001	0	0.4812
2028	0	0.0002	0	0.5093	0	0	0.4841
2029	0	0.0001	0	0.5055	0	0	0.4869
2030	0	0.0001	0	0.5016	0	0	0.4896

Appendix 6. Values of energy consumption of Brazilian primary sector for the SC-3 and SC-4 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0	0.0017	0	0.6086	0.0118	0	0.3781
2001	0	0.0019	0	0.6053	0.0119	0	0.3811
2002	0	0.0021	0	0.6009	0.0117	0	0.3856
2003	0	0.0022	0	0.5957	0.0112	0	0.3911
2004	0	0.0022	0	0.5903	0.0106	0	0.3970
2005	0	0.0022	0	0.5852	0.0098	0	0.4029
2006	0	0.0021	0	0.5806	0.0090	0	0.4083
2007	0	0.0020	0	0.5767	0.0081	0	0.4131
2008	0	0.0019	0	0.5734	0.0072	0	0.4173
2009	0	0.0017	0	0.5706	0.0062	0	0.4212
2010	0	0.0016	0	0.5680	0.0052	0	0.4249
2011	0	0.0014	0	0.5655	0.0042	0	0.4286
2012	0	0.0012	0	0.5631	0.0031	0	0.4322
2013	0	0.0012	0	0.5626	0.0031	0	0.4327
2014	0	0.0012	0	0.5622	0.0031	0	0.4331
2015	0	0.0012	0	0.5617	0.0031	0	0.4336
2016	0	0.0012	0	0.5613	0.0031	0	0.4340
2017	0	0.0012	0	0.5608	0.0031	0	0.4345
2018	0	0.0012	0	0.5603	0.0031	0	0.4350
2019	0	0.0012	0	0.5599	0.0031	0	0.4354
2020	0	0.0012	0	0.5594	0.0031	0	0.4359
2021	0	0.0012	0	0.5590	0.0031	0	0.4363
2022	0	0.0012	0	0.5585	0.0031	0	0.4368
2023	0	0.0012	0	0.5581	0.0031	0	0.4373
2024	0	0.0012	0	0.5576	0.0031	0	0.4377
2025	0	0.0012	0	0.5572	0.0031	0	0.4382
2026	0	0.0012	0	0.5567	0.0031	0	0.4387
2027	0	0.0012	0	0.5562	0.0031	0	0.4391
2028	0	0.0012	0	0.5558	0.0031	0	0.4396
2029	0	0.0012	0	0.5553	0.0031	0	0.4400
2030	0	0.0012	0	0.5549	0.0031	0	0.4405

Appendix 7. Values of energy consumption of Brazilian manufacturing sector for the BS and SC-2 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0.0665	0.0344	0	0.0064	0.1086	0.2028	0.5816
2001	0.0721	0.0335	0	0.0065	0.0991	0.2043	0.5850
2002	0.0775	0.0326	0	0.0065	0.0893	0.2049	0.5896
2003	0.0827	0.0319	0	0.0065	0.0798	0.2046	0.5949
2004	0.0874	0.0313	0	0.0065	0.0709	0.2037	0.6006
2005	0.0917	0.0308	0	0.0064	0.0628	0.2026	0.6060
2006	0.0953	0.0305	0	0.0065	0.0555	0.2015	0.6109
2007	0.0985	0.0304	0	0.0065	0.0489	0.2007	0.6150
2008	0.1013	0.0304	0	0.0066	0.0430	0.2004	0.6183
2009	0.1039	0.0304	0	0.0067	0.0376	0.2006	0.6207
2010	0.1063	0.0306	0	0.0068	0.0324	0.2012	0.6226
2011	0.1087	0.0307	0	0.0069	0.0273	0.2021	0.6240
2012	0.1110	0.0309	0	0.0071	0.0223	0.2031	0.6253
2013	0.1136	0.0310	0	0.0072	0.0191	0.2034	0.6270
2014	0.1162	0.0311	0	0.0073	0.0162	0.2039	0.6285
2015	0.1188	0.0312	0	0.0074	0.0137	0.2045	0.6297
2016	0.1213	0.0313	0	0.0076	0.0115	0.2051	0.6307
2017	0.1240	0.0314	0	0.0077	0.0097	0.2056	0.6318
2018	0.1267	0.0315	0	0.0078	0.0082	0.2059	0.6327
2019	0.1294	0.0316	0	0.0079	0.0069	0.2063	0.6335
2020	0.1321	0.0317	0	0.0081	0.0058	0.2067	0.6342
2021	0.1349	0.0318	0	0.0082	0.0049	0.2071	0.6348
2022	0.1378	0.0318	0	0.0083	0.0041	0.2074	0.6354
2023	0.1406	0.0319	0	0.0085	0.0035	0.2076	0.6358
2024	0.1435	0.0320	0	0.0086	0.0029	0.2079	0.6361
2025	0.1465	0.0320	0	0.0088	0.0025	0.2081	0.6363
2026	0.1494	0.0321	0	0.0089	0.0021	0.2082	0.6364
2027	0.1525	0.0321	0	0.0090	0.0018	0.2084	0.6365
2028	0.1555	0.0322	0	0.0092	0.0015	0.2085	0.6364
2029	0.1586	0.0322	0	0.0093	0.0012	0.2086	0.6363
2030	0.1618	0.0323	0	0.0095	0.0011	0.2087	0.6361

Appendix 8. Values of energy consumption of Brazilian manufacturing sector for the SC-3 and SC-4 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0.0665	0.0344	0	0.0064	0.1086	0.2028	0.5816
2001	0.0721	0.0335	0	0.0065	0.0991	0.2043	0.5850
2002	0.0775	0.0326	0	0.0065	0.0893	0.2049	0.5896
2003	0.0827	0.0319	0	0.0065	0.0798	0.2046	0.5949
2004	0.0874	0.0313	0	0.0065	0.0709	0.2037	0.6006
2005	0.0917	0.0308	0	0.0064	0.0628	0.2026	0.6060
2006	0.0953	0.0305	0	0.0065	0.0555	0.2015	0.6109
2007	0.0985	0.0304	0	0.0065	0.0489	0.2007	0.6150
2008	0.1013	0.0304	0	0.0066	0.0430	0.2004	0.6183
2009	0.1039	0.0304	0	0.0067	0.0376	0.2006	0.6207
2010	0.1063	0.0306	0	0.0068	0.0324	0.2012	0.6226
2011	0.1087	0.0307	0	0.0069	0.0273	0.2021	0.6240
2012	0.1110	0.0309	0	0.0071	0.0223	0.2031	0.6253
2013	0.1109	0.0309	0	0.0070	0.0223	0.2029	0.6260
2014	0.1108	0.0309	0	0.0070	0.0223	0.2028	0.6266
2015	0.1107	0.0308	0	0.0070	0.0223	0.2026	0.6273
2016	0.1107	0.0308	0	0.0070	0.0223	0.2024	0.6280
2017	0.1106	0.0308	0	0.0070	0.0222	0.2023	0.6286
2018	0.1105	0.0308	0	0.0070	0.0222	0.2021	0.6293
2019	0.1104	0.0307	0	0.0070	0.0222	0.2019	0.6300
2020	0.1103	0.0307	0	0.0070	0.0222	0.2018	0.6306
2021	0.1102	0.0307	0	0.0070	0.0222	0.2016	0.6313
2022	0.1101	0.0307	0	0.0070	0.0222	0.2014	0.6320
2023	0.1100	0.0306	0	0.0070	0.0221	0.2013	0.6326
2024	0.1099	0.0306	0	0.0070	0.0221	0.2011	0.6333
2025	0.1098	0.0306	0	0.0070	0.0221	0.2009	0.6340
2026	0.1098	0.0306	0	0.0070	0.0221	0.2008	0.6346
2027	0.1097	0.0305	0	0.0070	0.0221	0.2006	0.6353
2028	0.1096	0.0305	0	0.0070	0.0220	0.2005	0.6360
2029	0.1095	0.0305	0	0.0070	0.0220	0.2003	0.6366
2030	0.1094	0.0305	0	0.0069	0.0220	0.2001	0.6373

Appendix 9. Values of energy consumption of Brazilian energetic sector for the BS and SC-2 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0.1260	0.0227	0.0006	0.0201	0.1187	0.1895	0.5227
2001	0.1359	0.0218	0.0006	0.0193	0.1129	0.1945	0.5152
2002	0.1451	0.0208	0.0005	0.0187	0.1066	0.1979	0.5107
2003	0.1535	0.0196	0.0004	0.0184	0.0996	0.1996	0.5090
2004	0.1610	0.0184	0.0003	0.0186	0.0922	0.1995	0.5099
2005	0.1680	0.0170	0.0002	0.0194	0.0844	0.1978	0.5130
2006	0.1744	0.0156	0.0002	0.0209	0.0762	0.1945	0.5178
2007	0.1806	0.0141	0.0001	0.0233	0.0677	0.1901	0.5238
2008	0.1867	0.0126	0	0.0265	0.0588	0.1849	0.5300
2009	0.1929	0.0111	0	0.0307	0.0498	0.1792	0.5359
2010	0.1992	0.0097	0	0.0355	0.0406	0.1734	0.5413
2011	0.2059	0.0083	0	0.0407	0.0313	0.1675	0.5460
2012	0.2127	0.0069	0	0.0461	0.0220	0.1614	0.5505
2013	0.2196	0.0060	0	0.0528	0.0176	0.1562	0.5558
2014	0.2268	0.0052	0	0.0605	0.0138	0.1509	0.5608
2015	0.2341	0.0044	0	0.0693	0.0107	0.1457	0.5656
2016	0.2416	0.0038	0	0.0791	0.0082	0.1407	0.5702
2017	0.2494	0.0033	0	0.0903	0.0063	0.1358	0.5749
2018	0.2573	0.0028	0	0.1033	0.0049	0.1311	0.5796
2019	0.2654	0.0024	0	0.1181	0.0038	0.1265	0.5842
2020	0.2738	0.0021	0	0.1349	0.0029	0.1221	0.5886
2021	0.2824	0.0018	0	0.1541	0.0022	0.1178	0.5931
2022	0.2912	0.0015	0	0.1760	0.0017	0.1136	0.5975
2023	0.3002	0.0013	0	0.2010	0.0013	0.1095	0.6018
2024	0.3094	0.0011	0	0.2296	0.0010	0.1056	0.6061
2025	0.3189	0.0010	0	0.2621	0.0008	0.1018	0.6103
2026	0.3287	0.0008	0	0.2992	0.0006	0.0982	0.6144
2027	0.3386	0.0007	0	0.3414	0.0005	0.0946	0.6185
2028	0.3489	0.0006	0	0.3897	0.0004	0.0912	0.6225
2029	0.3594	0.0005	0	0.4446	0.0003	0.0879	0.6265
2030	0.3701	0.0004	0	0.5072	0.0002	0.0847	0.6304

Appendix 10. Values of energy consumption of Brazilian energetic sector for the SC-3 and SC-4 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0.1260	0.0227	0.0006	0.0201	0.1187	0.1895	0.5227
2001	0.1359	0.0218	0.0006	0.0193	0.1129	0.1945	0.5152
2002	0.1451	0.0208	0.0005	0.0187	0.1066	0.1979	0.5107
2003	0.1535	0.0196	0.0004	0.0184	0.0996	0.1996	0.5090
2004	0.1610	0.0184	0.0003	0.0186	0.0922	0.1995	0.5099
2005	0.1680	0.0170	0.0002	0.0194	0.0844	0.1978	0.5130
2006	0.1744	0.0156	0.0002	0.0209	0.0762	0.1945	0.5178
2007	0.1806	0.0141	0.0001	0.0233	0.0677	0.1901	0.5238
2008	0.1867	0.0126	0	0.0265	0.0588	0.1849	0.5300
2009	0.1929	0.0111	0	0.0307	0.0498	0.1792	0.5359
2010	0.1992	0.0097	0	0.0355	0.0406	0.1734	0.5413
2011	0.2059	0.0083	0	0.0407	0.0313	0.1675	0.5460
2012	0.2127	0.0069	0	0.0461	0.0220	0.1614	0.5505
2013	0.2125	0.0069	0	0.0460	0.0220	0.1613	0.5511
2014	0.2123	0.0069	0	0.0460	0.0220	0.1612	0.5517
2015	0.2122	0.0069	0	0.0459	0.0220	0.1611	0.5523
2016	0.2120	0.0069	0	0.0459	0.0220	0.1609	0.5529
2017	0.2118	0.0069	0	0.0459	0.0220	0.1608	0.5535
2018	0.2117	0.0069	0	0.0458	0.0219	0.1607	0.5541
2019	0.2115	0.0069	0	0.0458	0.0219	0.1605	0.5546
2020	0.2113	0.0069	0	0.0458	0.0219	0.1604	0.5552
2021	0.2111	0.0069	0	0.0457	0.0219	0.1603	0.5558
2022	0.2110	0.0069	0	0.0457	0.0219	0.1601	0.5564
2023	0.2108	0.0069	0	0.0456	0.0218	0.1600	0.5570
2024	0.2106	0.0069	0	0.0456	0.0218	0.1599	0.5576
2025	0.2104	0.0069	0	0.0456	0.0218	0.1598	0.5582
2026	0.2103	0.0068	0	0.0455	0.0218	0.1596	0.5588
2027	0.2101	0.0068	0	0.0455	0.0218	0.1595	0.5593
2028	0.2099	0.0068	0	0.0455	0.0218	0.1594	0.5599
2029	0.2098	0.0068	0	0.0454	0.0217	0.1592	0.5605
2030	0.2096	0.0068	0	0.0454	0.0217	0.1591	0.5611

Appendix 11. Values of energy consumption of Brazilian tertiary sector for the BS and SC-2 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0.0096	0.0822	0.1941	0.2951	0.0150	0	0.4040
2001	0.0118	0.0807	0.1930	0.2972	0.0144	0	0.4030
2002	0.0141	0.0789	0.1911	0.2987	0.0137	0	0.4035
2003	0.0164	0.0770	0.1889	0.2993	0.0130	0	0.4054
2004	0.0184	0.0748	0.1868	0.2992	0.0124	0	0.4084
2005	0.0201	0.0726	0.1850	0.2983	0.0118	0	0.4122
2006	0.0214	0.0702	0.1839	0.2968	0.0113	0	0.4163
2007	0.0223	0.0679	0.1837	0.2948	0.0108	0	0.4205
2008	0.0227	0.0655	0.1845	0.2927	0.0103	0	0.4243
2009	0.0228	0.0632	0.1865	0.2905	0.0098	0	0.4273
2010	0.0227	0.0609	0.1895	0.2884	0.0093	0	0.4292
2011	0.0225	0.0586	0.1933	0.2865	0.0087	0	0.4304
2012	0.0222	0.0564	0.1974	0.2846	0.0082	0	0.4313
2013	0.0222	0.0543	0.2002	0.2824	0.0077	0	0.4332
2014	0.0221	0.0522	0.2034	0.2803	0.0073	0	0.4348
2015	0.0219	0.0503	0.2069	0.2781	0.0068	0	0.4360
2016	0.0217	0.0483	0.2104	0.2760	0.0064	0	0.4372
2017	0.0216	0.0465	0.2139	0.2738	0.0060	0	0.4383
2018	0.0214	0.0447	0.2172	0.2715	0.0057	0	0.4395
2019	0.0213	0.0430	0.2207	0.2692	0.0054	0	0.4405
2020	0.0211	0.0413	0.2242	0.2669	0.0050	0	0.4414
2021	0.0209	0.0397	0.2277	0.2646	0.0047	0	0.4423
2022	0.0208	0.0382	0.2312	0.2623	0.0044	0	0.4431
2023	0.0206	0.0367	0.2347	0.2599	0.0042	0	0.4439
2024	0.0204	0.0352	0.2383	0.2576	0.0039	0	0.4446
2025	0.0203	0.0338	0.2419	0.2552	0.0037	0	0.4452
2026	0.0201	0.0325	0.2454	0.2528	0.0035	0	0.4457
2027	0.0199	0.0312	0.2490	0.2503	0.0033	0	0.4462
2028	0.0198	0.0299	0.2527	0.2479	0.0031	0	0.4467
2029	0.0196	0.0288	0.2563	0.2455	0.0029	0	0.4470
2030	0.0194	0.0276	0.2600	0.2430	0.0027	0	0.4473

Appendix 12. Values of energy consumption of Brazilian tertiary sector for the SC-3 and SC-4 scenarios.

Years	E1	E2	E3	E4	E5	E6	E7
2000	0.0096	0.0822	0.1941	0.2951	0.0150	0.0000	0.4040
2001	0.0118	0.0807	0.1930	0.2972	0.0144	0.0000	0.4030
2002	0.0141	0.0789	0.1911	0.2987	0.0137	0.0000	0.4035
2003	0.0164	0.0770	0.1889	0.2993	0.0130	0.0000	0.4054
2004	0.0184	0.0748	0.1868	0.2992	0.0124	0.0000	0.4084
2005	0.0201	0.0726	0.1850	0.2983	0.0118	0.0000	0.4122
2006	0.0214	0.0702	0.1839	0.2968	0.0113	0.0000	0.4163
2007	0.0223	0.0679	0.1837	0.2948	0.0108	0.0000	0.4205
2008	0.0227	0.0655	0.1845	0.2927	0.0103	0.0000	0.4243
2009	0.0228	0.0632	0.1865	0.2905	0.0098	0.0000	0.4273
2010	0.0227	0.0609	0.1895	0.2884	0.0093	0.0000	0.4292
2011	0.0225	0.0586	0.1933	0.2865	0.0087	0.0000	0.4304
2012	0.0222	0.0564	0.1974	0.2846	0.0082	0.0000	0.4313
2013	0.0222	0.0563	0.1973	0.2844	0.0081	0.0000	0.4317
2014	0.0222	0.0563	0.1971	0.2841	0.0081	0.0000	0.4322
2015	0.0221	0.0562	0.1970	0.2839	0.0081	0.0000	0.4326
2016	0.0221	0.0562	0.1968	0.2837	0.0081	0.0000	0.4331
2017	0.0221	0.0561	0.1966	0.2834	0.0081	0.0000	0.4336
2018	0.0221	0.0561	0.1965	0.2832	0.0081	0.0000	0.4340
2019	0.0221	0.0560	0.1963	0.2830	0.0081	0.0000	0.4345
2020	0.0221	0.0560	0.1962	0.2828	0.0081	0.0000	0.4349
2021	0.0220	0.0559	0.1960	0.2825	0.0081	0.0000	0.4354
2022	0.0220	0.0559	0.1958	0.2823	0.0081	0.0000	0.4359
2023	0.0220	0.0559	0.1957	0.2821	0.0081	0.0000	0.4363
2024	0.0220	0.0558	0.1955	0.2818	0.0081	0.0000	0.4368
2025	0.0220	0.0558	0.1954	0.2816	0.0081	0.0000	0.4372
2026	0.0219	0.0557	0.1952	0.2814	0.0081	0.0000	0.4377
2027	0.0219	0.0557	0.1950	0.2811	0.0081	0.0000	0.4382
2028	0.0219	0.0556	0.1949	0.2809	0.0080	0.0000	0.4386
2029	0.0219	0.0556	0.1947	0.2807	0.0080	0.0000	0.4391
2030	0.0219	0.0555	0.1946	0.2805	0.0080	0.0000	0.4395

Appendix 13. Values of Brazilian energy consumption of natural gas from 2010 to 2030.

Year	%			
	BS Scenario	SC-2	SC-3	SC-4
2010	7.12	7.12	7.12	7.12
2011	7.25	7.25	7.25	7.25
2012	7.37	7.37	7.37	7.37
2013	7.52	7.52	7.35	7.35
2014	7.67	7.67	7.33	7.33
2015	7.81	7.82	7.31	7.31
2016	7.95	7.96	7.29	7.28
2017	8.10	8.11	7.27	7.26
2018	8.25	8.27	7.25	7.24
2019	8.41	8.42	7.23	7.22
2020	8.56	8.58	7.21	7.20
2021	8.72	8.74	7.19	7.18
2022	8.88	8.90	7.17	7.16
2023	9.04	9.06	7.15	7.13
2024	9.20	9.23	7.13	7.11
2025	9.37	9.40	7.11	7.09
2026	9.54	9.57	7.10	7.07
2027	9.71	9.74	7.08	7.05
2028	9.89	9.91	7.06	7.02
2029	10.07	10.09	7.04	7.00
2030	10.25	10.27	7.02	6.98

Appendix 14. Values of Brazilian energy consumption of liquefied petroleum gases from 2010 to 2030.

Year	%			
	BS Scenario	SC-2	SC-3	SC-4
2010	4.18	4.18	4.18	4.18
2011	4.07	4.07	4.07	4.07
2012	3.96	3.96	3.96	3.96
2013	3.85	3.85	3.96	3.96
2014	3.75	3.75	3.96	3.97
2015	3.65	3.66	3.97	3.97
2016	3.56	3.56	3.97	3.98
2017	3.46	3.48	3.98	3.98
2018	3.38	3.39	3.98	3.99
2019	3.29	3.31	3.98	3.99
2020	3.20	3.23	3.98	4.00
2021	3.12	3.16	3.99	4.00
2022	3.04	3.08	3.99	4.01
2023	2.97	3.02	3.99	4.01
2024	2.89	2.95	4.00	4.02
2025	2.82	2.88	4.00	4.02
2026	2.75	2.82	4.00	4.03
2027	2.68	2.76	4.00	4.03
2028	2.61	2.71	4.01	4.03
2029	2.55	2.65	4.01	4.04
2030	2.48	2.60	4.01	4.04

Appendix 15. Values of Brazilian energy consumption of motor gasoline from 2010 to 2030.

Year	%			
	BS Scenario	SC-2	SC-3	SC-4
2010	9.29	9.29	9.29	9.29
2011	9.54	9.54	9.54	9.54
2012	9.80	9.80	9.80	9.80
2013	9.99	9.95	9.80	9.84
2014	10.21	10.12	9.81	9.87
2015	10.44	10.31	9.82	9.90
2016	10.68	10.50	9.82	9.94
2017	10.91	10.69	9.83	9.97
2018	11.14	10.87	9.83	10.01
2019	11.38	11.06	9.84	10.04
2020	11.62	11.25	9.85	10.07
2021	11.87	11.44	9.85	10.11
2022	12.12	11.63	9.86	10.14
2023	12.36	11.83	9.86	10.17
2024	12.62	12.02	9.86	10.21
2025	12.87	12.22	9.87	10.24
2026	13.13	12.41	9.87	10.27
2027	13.39	12.61	9.87	10.30
2028	13.66	12.81	9.88	10.34
2029	13.92	13.00	9.88	10.37
2030	14.19	13.20	9.88	10.40

Appendix 16. Values of Brazilian energy consumption of gas/diesel oil from 2010 to 2030.

Year	%			
	BS Scenario	SC-2	SC-3	SC-4
2010	17.22	17.22	17.22	17.22
2011	17.24	17.24	17.24	17.24
2012	17.27	17.27	17.27	17.27
2013	17.28	17.21	17.23	17.28
2014	17.31	17.16	17.20	17.28
2015	17.35	17.12	17.18	17.29
2016	17.41	17.10	17.15	17.30
2017	17.47	17.08	17.12	17.30
2018	17.55	17.07	17.09	17.31
2019	17.65	17.08	17.06	17.32
2020	17.78	17.11	17.03	17.33
2021	17.92	17.15	17.01	17.34
2022	18.10	17.21	16.98	17.35
2023	18.31	17.30	16.95	17.36
2024	18.56	17.41	16.92	17.37
2025	18.85	17.55	16.89	17.38
2026	19.20	17.73	16.86	17.39
2027	19.60	17.95	16.83	17.40
2028	20.08	18.21	16.81	17.41
2029	20.63	18.52	16.78	17.43
2030	21.27	18.88	16.75	17.44

Appendix 17. Values of Brazilian energy consumption of fuel oil from 2010 to 2030.

Year	%			
	BS Scenario	SC-2	SC-3	SC-4
2010	2.08	2.08	2.08	2.08
2011	1.76	1.76	1.76	1.76
2012	1.45	1.45	1.45	1.45
2013	1.25	1.26	1.44	1.44
2014	1.09	1.09	1.44	1.44
2015	0.94	0.95	1.44	1.44
2016	0.81	0.82	1.44	1.43
2017	0.71	0.72	1.44	1.43
2018	0.62	0.63	1.44	1.43
2019	0.55	0.56	1.44	1.42
2020	0.49	0.49	1.44	1.42
2021	0.43	0.44	1.44	1.42
2022	0.39	0.39	1.43	1.42
2023	0.35	0.35	1.43	1.41
2024	0.31	0.32	1.43	1.41
2025	0.28	0.29	1.43	1.41
2026	0.26	0.26	1.43	1.40
2027	0.24	0.23	1.43	1.40
2028	0.22	0.21	1.43	1.40
2029	0.20	0.19	1.43	1.39
2030	0.18	0.18	1.43	1.39

Appendix 18. Values of Brazilian energy consumption of petroleum coke from 2010 to 2030.

Year	%			
	BS Scenario	SC-2	SC-3	SC-4
2010	9.08	9.08	9.08	9.08
2011	8.99	8.99	8.99	8.99
2012	8.90	8.90	8.90	8.90
2013	8.81	8.86	8.90	8.86
2014	8.71	8.82	8.90	8.83
2015	8.62	8.79	8.89	8.79
2016	8.53	8.76	8.88	8.76
2017	8.44	8.73	8.88	8.72
2018	8.35	8.70	8.87	8.69
2019	8.26	8.67	8.87	8.65
2020	8.17	8.65	8.86	8.62
2021	8.08	8.63	8.86	8.58
2022	7.99	8.60	8.85	8.54
2023	7.90	8.58	8.85	8.51
2024	7.81	8.56	8.84	8.47
2025	7.72	8.55	8.84	8.43
2026	7.63	8.53	8.83	8.40
2027	7.54	8.51	8.83	8.36
2028	7.45	8.50	8.83	8.33
2029	7.36	8.48	8.82	8.29
2030	7.28	8.47	8.82	8.25

Appendix 19. Values of Brazilian consumption of renewable, alternative and nuclear energy from 2010 to 2030.

Year	%			
	BS Scenario	SC-2	SC-3	SC-4
2010	51.02	51.02	51.02	51.02
2011	51.15	51.15	51.15	51.15
2012	51.25	51.25	51.25	51.25
2013	51.43	51.48	51.31	51.27
2014	51.58	51.69	51.37	51.30
2015	51.70	51.86	51.43	51.33
2016	51.81	52.03	51.49	51.35
2017	51.92	52.18	51.55	51.38
2018	52.03	52.34	51.61	51.41
2019	52.13	52.49	51.67	51.44
2020	52.22	52.62	51.73	51.47
2021	52.30	52.75	51.80	51.49
2022	52.37	52.86	51.86	51.52
2023	52.44	52.97	51.92	51.55
2024	52.50	53.07	51.98	51.57
2025	52.55	53.16	52.04	51.60
2026	52.60	53.24	52.10	51.63
2027	52.63	53.31	52.17	51.66
2028	52.67	53.38	52.23	51.68
2029	52.69	53.43	52.29	51.71
2030	52.71	53.48	52.35	51.73

Appendix 20. CO_2 emissios values. From 1971 to 2012 corresponds to official dataset and from 2013 to 2030 corresponds to predictions.

Year	CO_2 (kg)			
	BS Scenario	SC-2	SC-3	SC-4
1971	99506720602	99506720602	99506720602	99506720602
1972	110600634670	110600634670	110600634670	110600634670
1973	121654516122	121654516122	121654516122	121654516122
1974	132418863435	132418863435	132418863435	132418863435
1975	142622630207	142622630207	142622630207	142622630207
1976	152002953774	152002953774	152002953774	152002953774
1977	160312587371	160312587371	160312587371	160312587371
1978	167382562658	167382562658	167382562658	167382562658
1979	173097885639	173097885639	173097885639	173097885639
1980	177485461507	177485461507	177485461507	177485461507
1981	180799938992	180799938992	180799938992	180799938992
1982	183472248904	183472248904	183472248904	183472248904
1983	185917241973	185917241973	185917241973	185917241973
1984	188518417300	188518417300	188518417300	188518417300
1985	191524797521	191524797521	191524797521	191524797521
1986	195044885829	195044885829	195044885829	195044885829
1987	199116376857	199116376857	199116376857	199116376857
1988	203775649698	203775649698	203775649698	203775649698
1989	209083629225	209083629225	209083629225	209083629225
1990	215144247181	215144247181	215144247181	215144247181
1991	222099542311	222099542311	222099542311	222099542311
1992	230020720417	230020720417	230020720417	230020720417
1993	238921739206	238921739206	238921739206	238921739206
1994	248736208558	248736208558	248736208558	248736208558
1995	259286086663	259286086663	259286086663	259286086663
1996	270277784924	270277784924	270277784924	270277784924
1997	281335602205	281335602205	281335602205	281335602205
1998	292084285650	292084285650	292084285650	292084285650
1999	302237714722	302237714722	302237714722	302237714722
2000	311619094337	311619094337	311619094337	311619094337
2001	320158684782	320158684782	320158684782	320158684782
2002	327957197012	327957197012	327957197012	327957197012
2003	335291036612	335291036612	335291036612	335291036612
2004	342507666154	342507666154	342507666154	342507666154
2005	349868355777	349868355777	349868355777	349868355777
2006	357620323999	357620323999	357620323999	357620323999
2007	365953153994	365953153994	365953153994	365953153994
2008	374982637132	374982637132	374982637132	374982637132
2009	384783948142	384783948142	384783948142	384783948142
2010	395383935204	395383935204	395383935204	395383935204
2011	406425082982	406425082982	406425082982	406425082982

2012	417513967843	417513967843	417513967843	417513967843
2013	418991141182	422400142268	423248170736	422218915661
2014	457046239212	467374914132	467496347722	463940944539
2015	491489187189	511834115897	509808638400	502259069540
2016	523024840516	556174926904	550767592572	537816675776
2017	552260251043	600776582213	590850324577	571165155516
2018	579835966883	646083590141	630443556214	602775104932
2019	606686908949	692673542037	669929050664	633045264763
2020	632823875934	740727460770	709582780928	662314648635
2021	658214895529	790451004776	749638073136	690869516732
2022	683064642005	842094992052	790295773696	718951129877
2023	707646211590	895941304532	831731911293	746762603729
2024	732257706437	952266601529	874105728120	774474907483
2025	757186031782	1011285526834	917548366398	802232408112
2026	782822849798	1073257264580	962178413596	830157140720
2027	810088356443	1138480896639	1008104796326	858352747807
2028	842148173405	1207285848565	1055428750989	886907831217
2029	880178726089	1280027793030	1104245083774	915898790900
2030	927912337756	1357099551418	1154642295314	945392222167