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Future scenarios and trends in energy generation in brazil: supply and demand and mitigation forecasts

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RESUMO

A estrutura da matriz energética brasileira define o Brasil como líder mundial na geração elétrica a partir de fontes renováveis. Em 2011, a participação de fontes renováveis na produção de eletricidade atingiu 88,8%, principalmente graças ao grande potencial hídrico nacional. Ainda que o modelo energético brasileiro apresente um forte potencial de expansão, o total de energia que poderia ser aproveitada com tecnologias renováveis, mais atuais, supera em muitas vezes a demanda nacional. A composição atual da matriz energética nacional tem destacada participação da energia hidráulica, ainda que o país tenha grande potencial para exploração de outras fontes de energias renováveis, como a eólica, a solar e a biomassa. Este documento refere-se, portanto, à tendência de evolução da Matriz Energética Brasileira e expõe cenários prováveis de mitigação, considerando também as mudanças climáticas. A metodologia a ser utilizada na modelagem inclui a aplicação do programa LEAP (Sistema de Planejamento Energético de alternativas de Longo Prazo), desenvolvido pelo Instituto Ambiental de Estocolmo, que permite a proposição de diferentes cenários sob a definição de cenários socioeconômicos e base de energia, desenvolvido no contexto do projeto REGSA - Promoting Renewable Electricity Generation in South América. Os resultados vislumbram possibilidades de cenários futuros e tendências na geração de energia no Brasil, além de projeções de demanda e de oferta de eletricidade para até o ano 2030.

ABSTRACT

The structure of the Brazilian energy matrix defines Brazil as a global leader in power generation from renewable sources. In 2011, the share of renewable sources in electricity production reached 88.8%, mainly due to the large national water potential. Although the Brazilian energy model presents a strong potential for expansion, the total energy that could be used with most current renewable technologies often outweighs the national demand. The current composition of the national energy matrix has outstanding participation of hydropower, even though the country has great potential for the exploitation of other renewable energy sources such as wind, solar and biomass. This document therefore refers to the trend of evolution of the Brazilian Energy Matrix and exposes possible mitigation scenarios, also considering climate change. The methodology to be used in the modeling includes the implementation of the LEAP System (Long-range Energy Alternatives Planning) program, developed by the Stockholm Environment Institute, which allows us to propose different scenarios under the definition of socioeconomic scenarios and base power developed in the context of the REGSA project (Promoting Renewable Electricity Generation in South America). Results envision future scenarios and trends in power generation in Brazil, and the projected demand and supply of electricity for up to 2030.

1. Introduction

This paper describes the trends of the Brazilian energy matrix and exposes the possible scenarios of mitigation for climate change. The

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methodology used in the modeling included the application of the software LEAP – Long-range Energy Alternatives Planning System, developed by the Stockholm Environment Institute, which enables the proposition of different possibilities taking into consideration the definition of socioeconomic scenarios and base powers.

Our aim is to construct the following energy projections based on information collected from the national energy reports of 2000–2007 and other industry sources:

a) A base scenario to project the Brazilian energy system of demand and supply up to year 2030;
b) A mitigation scenario, including variations in relation to the scenario of reference, considering changes to the present energy matrix.

This document is structured as follows: Section 2 presents the review of literature considering the evolution of the Brazilian energy sector between 2000 and 2010, with a highlight on our base year 2007, when we show the evolution of energy use by each of the following segments: transportation, trade, public, residential and industrial subsectors. The next section presents the methodology employed in the research as from the country's socioeconomic perspective, crucial for the formulation of energy projections of several sectors included in such scenarios. The following section refers to the energy scenarios by presenting the outcomes of the trend and mitigation scenario, allowing us to project and quantify how these scenarios would affect energy consumption and CO_2 emissions in Brazil. Lastly, we present the conclusions of the research.

2. Review of literature

Brazil first used electricity in 1883, when a line of battery-powered electric trams were installed in the municipality of Niterói in the State of Rio de Janeiro (Gomes et al., 2014). In Campo de Goitacazes, the first public lighting system was supplied by a small coal thermopower plant, and the year ended with the implantation of the first 2 km long electricity transmission line, originating from a hydropower plant in Jequitinhonha Valley, in the state of Minas Gerais.

However, it was from World War II on that the energy consumption in Brazil started to change, mainly owing to three factors: the quick demographic growth and urbanization; the implantation of industries, which are the biggest electric energy consumers; and the development of the road network in the country.

The traditional model of energy generation in Brazil, established between 1940 and 1960, put companies that were responsible for a great part of the production and distribution of electricity, oil and gas in the hands of the government. Petrobrás, Eletrobras and several state-owned companies, in addition to an energy planning entity, were created to that end. The Brazilian experience with the public monopoly of the energy industry, supported by the regulation by service costs, operated quite well for a long time, enabling the expansion of the country's capacity to supply energy.

Nevertheless, as a consequence of the country's debt crisis during the late 1970s, precipitated by changes in U.S. interest rates, the capitalization of the Brazilian government was drastically reduced (Oliveira and Araújo, 1996). The alternative of having the capital of the state owned companies supporting the expansion of the energy supply drained during the 1980s, with the anti-inflationary policy for rate reduction. Furthermore, there was a gradual loss of efficiency from the companies due to an intra-sectorial compensation mechanism of commercial results that discouraged the search for productivity gains, since a surplus would have to be passed on to other companies of the sector (Pires and Goldstein, 2001).

The Brazilian National Economic Development Bank (Banco Nacional de Desenvolvimento Econômico – BNDES) was already a financial agent between the years 70 and 80 who participated in the power generation process. Between 1990 and 1994, it was restricted to credit for state. From 1995 onwards, BNDES became the largest agency of long-term financing of power generation, serving both the private generators and the state. This allowed the progress of the power generating system (Gomes et al, 2014).

However, significant changes have occurred since the 1990s. The first change was the reformulation of the energy sector, which began with the Law of Public Service Concession n.8987 of February 14, 1995, and Law n.9074 of May 19, 1995, which laid the foundations for a new institutional model for the energy sector. At the same time, the organizational and property restructuring of the sector was consolidated through the privatization of companies and the attraction of private investments to ensure its expansion.

In 1997 and 1998 the new regulations, especially Law 9648/98 that instituted the Wholesale Energy Market/Mercado Atacadista de Energia – MAE and the National Electric System Operator/Operador Nacional do Sistema Elétrico – ONS (2012), authorized the executive branch to promote the restructuring of Eletrobras and its affiliates, and establish the transition of models with new contracts. This law promoted the sector's segmentation and defined the gradual opening to market competition.

Decree 2003 enacted in 1996 regulated the action of the Independent Producers and the Self-producers. Simultaneously, Law n.9427 created the Brazilian Electricity Regulatory Agency/Agência Nacional de Energia Elétrica – ANEEL (2012), aiming at regulating and controlling the production, transmission, distribution and commercialization of electricity.

In 1998 the National Council for Energetic Policy/Conselho Nacional de Política Energética – CNPE was created. Its goals were: to promote the rational use of energy; protect the consumer in terms of price, quality and supply; protect the environment; increase the use of natural gas; use renewable sources of energy; promote free competition; increase competitiveness and attract capital for energy production.

The privatizations consolidated the macroeconomic policy of the Real Plan, trying to stabilize the balance of payments, sustain the exchange rate, maintain low inflation, and decrease political interference in companies. The initial strategy was to privatize the distribution companies, then the generators, and finally the transmitters. To that end, investments were granted to amplify private initiative, mainly for supply expansion, to enable the creation of a wholesale energy market that would strengthen with the reforms of the sector. The second strategy, was the introduction of a new model for the electric sector in 2004, which aimed to ensure supply. One of the main alterations carried out in 2004 was the substitution of the conditions for new generation companies to operate. The investor who offered the lowest selling price for the energy produced in their future power plants would win the auction. Furthermore, the new model instituted two basic venues or "environments" for buying and selling energy contracts: The Regulated Contracting Environment/Ambiente de Contratação Regulada (ACR), only for generators and distributors, and the Free Contracting Environment/Ambiente de Contratação Livre (ACL), for generators, businesspeople, importers, exporters and, more recently, free consumers. To Lennard (2014), the "capacity payments and a forward capacity market are designed to ensure future peak demand will be met and to encourage investment in existing and new power sources. Paying generators for capacity they make available, as well as energy they actually supply, addresses these issues and improves the future stability of the grid."

We observe that, although Brazil relies mostly on renewable power generation, the changes incorporated by the new model did not make the national industry more competitive. We add to this the current situation of the global market which demands daily challenges from the companies to survive in a market where competition is always growing, and where economic development, workers' well-being, and environmental sustainability must be guaranteed (Henriques and Catarino, 2015).

Most of the demand growth has been supported by investments in hydropower generation. Even though that allowed Brazil to generate power with relatively low prices through the use of renewable resources, the limited diversification of the electric matrix leaves the pricing sensitive to climactic changes in which the hydrologic cycles are impacted. This is the reason why the prices of energy in Brazil have periods of significant growth due to droughts, submitting the country to the fragility of the pricing system.

A growing number of studies and scholars agree that the era of cheap petrol and fossil fuel-energy is coming to an end (Kunze and Busch, 2011; IEA, 2013;). This necessitates a change to renewable energy sources. In spite of the failure of the political effort and of the social and ecological responsibilities to promote any important changes in national energy policy, the lack of resources and rises in petroleum prices tend to force many of these changes. Nevertheless, Kunze and Busch (2011) observe that, without assertive decisions, the transition will have a high ecological cost. These studies are related to the European situation, where the electric energy supply serves practically all regions.

The emissions of domestic CO_2 have been increasing in many countries in spite of their commitment to their reduction, as in Japan, where the use of wind and solar generation is restricted and the construction of new coal and petroleum power mills seem to be an undesirable choice, even in a situation of electricity scarcity. On the other hand, the potential of renewable energy – mainly including the photovoltaic and wind power – is limited in Japan due to geographic reasons and limitations of the technology and system integration. Therefore, it is crucial to reconsider the energy policies in the whole country in the medium to long run to build a clean and safe electric system in the future, considering constraints from several perspectives (Zhang et al., 2012). In a highly attractive geographic position for the growth of solar and wind power generation, Brazil still presents little initiative for its adoption, even in distributed energy systems and lacks the regulation for its application and control.

Although Brazil, the largest economy in Latin America, has recently made great progress economically, there are still substantial differences between the rural and urban populations, between the states and mainly between different income levels, with the poor rural population in the north and northeast as the most affected by the lack of energy distribution.

3. Research methodology

This study will work on one socioeconomic scenario and two energy scenarios, the new trend, known as Business as Usual (BAU), and the Mitigation scenario.

The formulation of the socioeconomic scenario is required to predict the evolution of the main variables, which may encourage power generation policies, and to project the consumption and corresponding emissions of greenhouse gases. The present investigation uses as a base reference the most general variables, collected from the forecasts reported in official documents published in Brazil.

To reach our aims, the methodology included the modeling software LEAP (Long-range Energy Alternatives Planning System), developed by the Stockholm Environment Institute. The choice of an analytic model such as LEAP responds to the critical discussion about the structural changes in energy systems, and better clarifies the quantification of the effects of those measures on national policies. In this way, this research presents, from the several studies, a forecast for the Brazilian energy sector, and gives important recommendations for the formulation of public policies for the sector.

3.1. Methodology of energy demand estimates

Future energy demand is calculated by analyzing the final energy use, where the demand for energy (e) is equal to the product of the final energy intensity (i) and the level of activity (a).

$$e = iXa$$

The activity level is a driver that determines the path taken by each item of energy fuel demand in the sector, together with the energy intensity. This model is considered to be an activity level in the residential sector and as an activity level in the industrial, agriculture and livestock, commercial, public services, transport, and energy sectors within the Brazilian GDP.

This demand is then distributed according to each fuel's share in each sector. The demand is then obtained for each fuel for each sector.

3.2. Base year

The base year is 2007, because the preliminary data of the simulation in BEN 2012 had not yet been published. In that year, the actual demands of the different sources in different sectors, according to information available in the Balanço Nacional de Ministério de minas e energia, 2008/National Energy Balance (EPE, 2008), were used for the model. We defined that the energy intensity of base year 2007 is the demand of energy of each sector, divided by the driver (level of activity) associated with each sector, as presented below.

3.3. Drivers

3.3.1. Demographic evolution

According to the Brazilian Institute of Geography and Statistics – IBGE (2014), in 2007 Brazil had 183,987,291 inhabitants distributed in 5564 Brazilian municipalities. Most of the population (83.5%) lived in urban areas. This urban transition has brought the largest cities to their maximum capacity. Nevertheless, the birth rates in those places are decreasing in relation to the replacement level, indicating that in the future the population will move to medium sized cities rather than large ones.

3.3.2. GDP behavior

Goldemberg and Lucon (2013) highlights that in the last thirty years there was an increase in the production of primary energy in Brazil, following the increase of the GDP. In the same period, the energy consumption had a faster growth due to either the evolution of the electrification in the country and the electro-intensive industries, such as aluminum production.

We considered the GDP projection used in the 2030 National Energy Plan's energy projections (MME, 2012a). The growth of the energy rate value in relation to workers' earnings, as well as inflation rates can be seen in Fig. 1, published in the 2008 BNDES journal (BNDES 2008).

Fig. 2 shows the domestic energy supply per capita (EPE 2012a).

3.3.3. Evolution of the vehicle fleet

In 2007 the country had a fleet of 25,806,813 vehicles, including passenger cars, light commercial vehicles, trucks and buses. The

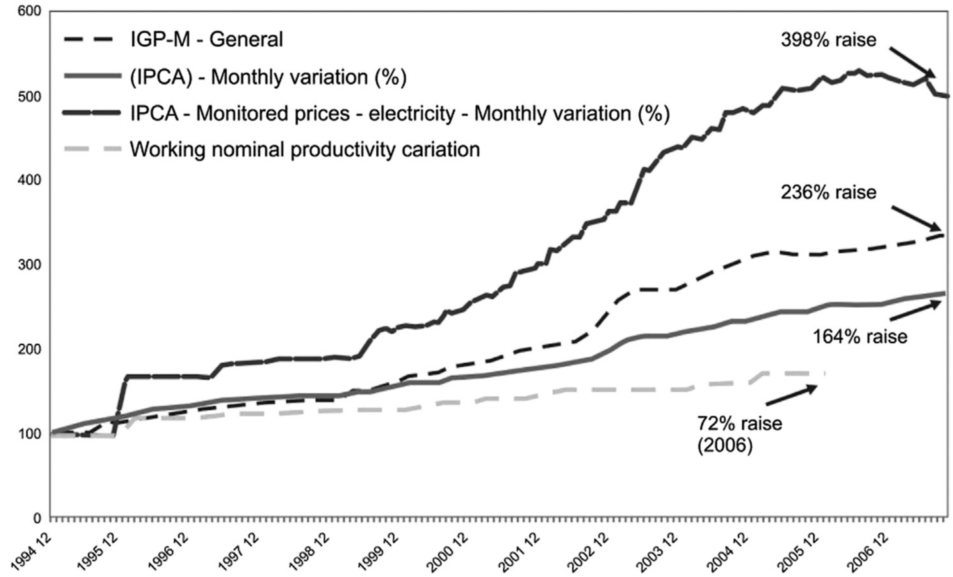

Fig. 1. Price evolution indexes.
Source: BNDES (2008).

growth registered from 2000 until December 2007 was 2.9% per annum, the percentage also used in EPE forecasts. For transportation, a slow transition from fossil fuels to biofuels is projected, remembering, however, that biofuels' accelerated production for energy purposes can become a further social problem, because of the privileges granted to plantations. Brazil and its fostering programs in the area have already demonstrated the viability of the large-scale production of ethanol and biodiesel. The new fleets in production must be adapted, and it is necessary to have the costs reduced to make their use more attractive.

3.4. Demand projection

The information contained in table 4-12 of the national energy matrix of 2007 (MME, 2008), which consists of final consumption of energy by source and sector, was used for the demand projection. This table follows a percentage variation in the participation of different sources to each sector for the periods of 2010–2020 and 2020–2030. In addition, in conjunction with the projection of the GDP in table 6-1 of the same document, expressed in Brazilian currency in 2010, it is deduced from a percentage variation of the intensity of energy from each sector in the period 2010–2020 and 2020–2030.

As an exception, it was an alteration in the cellulose consumption data in the energy sector until 2020. Such value suggests an anomaly of great intensity of energy in the same year. The value proposed considers the growth of the electricity production based on bagasse, thus, the growth of the demand of this energy in the energy sector is proportional to the growth of electricity generation.

3.5. Capacity transformation and projection

Information relating to the generating resources contained in table i.1 of attachment I of the National Energy Balance of 2011

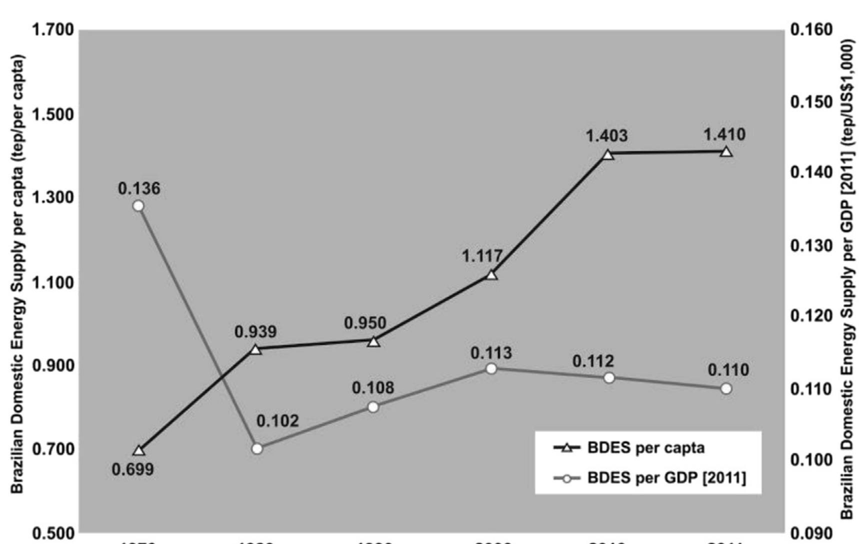

Fig. 2. Domestic energy supply per capita.
Source: Empresa de Pesquisa Energética – EPE, 2012a.

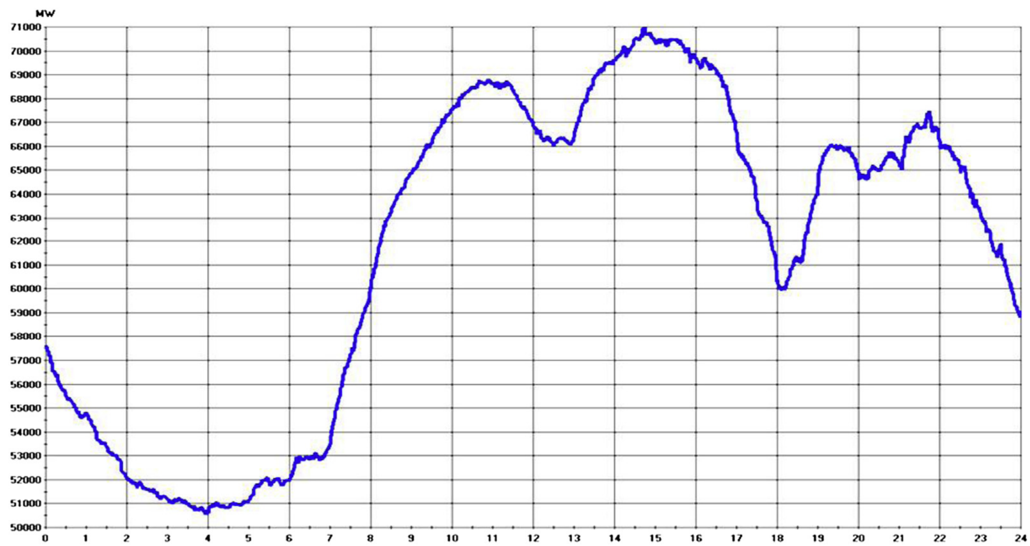

Fig. 3. Daily load curve from SIN (ONS, 2012).

(EPE, 2011) was used to model the benchmark year for the electric power generation sector. This table shows the aggregated thermal power generation. This was divided according to the various fuels' share of the thermogeneration capacity (natural gas, diesel, charcoal, and oil) as published by the Union of Bioenergy Producers – União dos Produtores de Bioenergia – (2013). The capacity of the independent (self) producers during the baseline year is obtained by using the same procedure, but the information for the year 2010 in table 5.4 of the 2011 National Energy Balance (NEB) is also included. Specific facts about self-producing plants were obtained using this information plus the data from table i.1.

The importation of electricity was modeled with an additional power station generation operating in max capacity and considering a physical capacity of 8.1 GW, according to the Union of Bioenergy Producers – União dos Produtores de Bioenergia – (2013). Considering the imported electricity in the previous years demonstrated in the energetic balance, we obtain a plant factor for the importation of 50.6%.

For the projection of the electrical generation capacity, we used the forecasts proposed in table 5-33 from the 2007 National Energetic Matrix (MME, 2008). In the individual producers sector, we used the public service growth rate.

3.6. Waste

The estimate of the transmission waste from the feeding system was evaluated from 2008 to 2010, resulting in an average waste of 17.7%. The calculation is a fraction of the waste indicated in the heritage balance, divided by the public service generation, enhanced by imports.

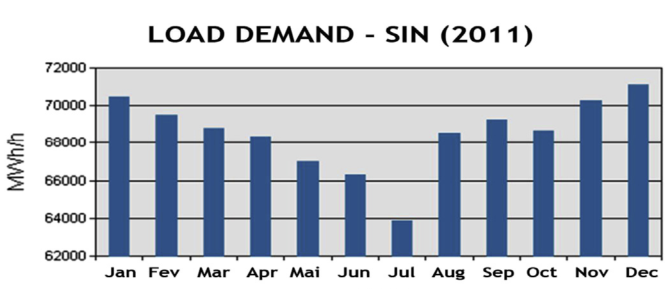

Fig. 4. Monthly energy consumption from the SIN (ONS, 2012).

3.7. Load curve

The load curve is based in Figs. 3 and 4. The first represents a typical daily load curve of the SIN. The second figure shows the monthly energy consumption of the SIN.

Based on this information, that is, the distribution of the monthly demand and the total demand every month, it is possible to project the profile of the load curve throughout the year. This method is a simple approximation of the curve, thus, we recommend deepening the necessary information in order to improve this variable. Fig. 5 shows the curve of the resulting load.

3.8. Endogenous liberation of electricity

What happens if the electric demands are not satisfied by supply? There are two possibilities for this situation: the addition of capacity from a predetermined source, or the importation of electricity. Since Brazil already imports electricity, we may consider this in the future and increased import level, if those are not much higher than the present ones. On the other hand, the model is more dependable when looking at the projection of demand and the projection of capacity, providing an elastic demand for the model over almost the whole projection period. There has only been a capacity deficit of 40% fulfilled by annual imports over the last few years. In this context, the model is programmed to cover the deficit by importing electricity.

3.9. Mitigation in 2007

In 2007, Brazil was already in a distinguished position in comparison with other countries in terms of international indexes of emission of CO2 equivalent (CO2e). Today, 1.5% of the emissions of greenhouse gases originate from the electric sector in Brazil, whereas that percentage reaches 24% globally (Pires and Holtz, 2013).Table 1.

The Brazilian territory has almost all feasible types of primary sources of electric energy generation, and the country has advanced in comparison with its global peers, in its relatively low levels of carbon emission. In addition, Brazil's coefficient of imports to meet

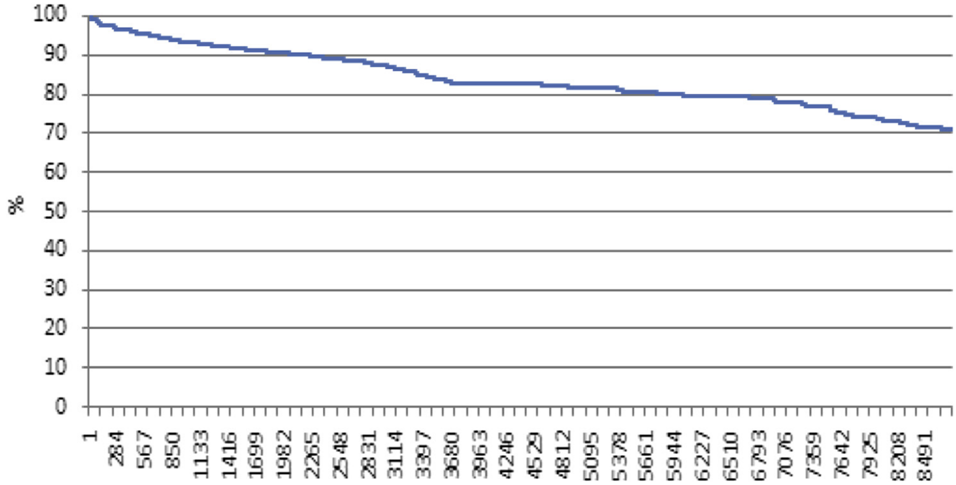

Fig. 5. Resulting load curve per hour.

demand is close to zero. The country's national energy planning also emphasizes the importance of increasing renewable generation.

It was only in the 1980s that efficient energy actions began, with the implementation of the Electrical Energy Conservation Program – Programa de Conservação de Energia Elétrica – Procel, of Eletrobras. The program, instituted by the federal government, aims to coordinate activities in fighting electricity waste. Today Brazil is experienced in the area of electricity efficiency and conservation, having developed projects such as The Brazilian Labelling Program/Programa Brasileiro de Etiquetagem (PBE), the above mentioned Electrical Energy Conservation Program/Programa Nacional de Conservação de Energia Elétrica (PROCEL) and the National Program for the Rational Use of Natural Gas and Oil Products/Programa Nacional de Racionalização do Uso dos Derivados do Petróleo e do Gás Natural (CONPET). The country, with the involvement of several actors, has been working hard to promote actions to mitigate the inefficient consumption of energy and achieve its goals, which are essential for the welfare of the nation.

In July 2000, the Brazilian Government enacted Law n.9991, binding the concessionaires and authorized contractors of the public service of electric energy distribution to invest a percentage of their revenues in research and development and in energy efficiency; and another percentage toward a research fund (MME, 2012b).

In 2009, Law n. 12187/2009 enacted the National Policy on Climate Change/Política Nacional sobre a Mudança do Clima (PNMC) making official Brazil's voluntary commitment to the UN Framework Convention on Climate Change of reducing the emission of greenhouse gases from between 36.1% and38.9% of the emissions projected for 2020. According to Decree n° 7390/2010, such data regulates the National Policy on Climate Change. The base line of greenhouse gas emission for 2020 was estimated to be 3.236 $GtCO_2eq$ (billion metric tons of CO_2 equivalent in greenhouse gas emissions). In this way, the corresponding absolute reduction was set between 1.168 $GtCO_2eq$ and 1.259 $GtCO_2eq$, or 36.1% and 38.9% of emissions, respectively (Safatle, 2014).

At the recent UN Conference on Sustainable Development Rio+20/Conferência das Nações Unidas sobre Desenvolvimento Sustentável Rio+20, Brazil's EPE distributed the primer “Brasil: Renováveis para o Desenvolvimento”.

Table 1
Brazilian emissions (mil t CO_2e).

	Years		
	1994	2005	2007
Agricultural	369	480	479
Industry and Waste	42	55	60
Energy	248	347	381
Deforestation	818	1.060	770
Total Emissions	1.477	1.942	1.690

Source: MMA, MAPA, MME, MF, MDIC, MCT, MRE (2012).

4. Scenarios

4.1. Trend scenario

Some of the most relevant outcomes provided by the LEAP model applied for the projection of energy demand and supply in Brazil are presented below.

Brazil has shown significant economic growth in the last decade. As the sixth largest global economy, it is recognized as one of the most powerful nations in the world. The industrial production has been expanding, on the one hand due to the solidity of the market, and on the other, to the low interest basic rates associated with the availability of credit offer, which encourages new investments in the segment. It should be mentioned that in the next years the population and income growth, together with the increasing urban population, will lead to higher demand for mobility which will lead to increasing participation of the vehicle fleet, especially of light vehicles.

Fig. 6 shows the projection of the demand per sector, clearly demonstrating that the demand in the industrial sector has a rising curve, followed by the use of energy to serve the national fleet.

Brazil's search for diversification of the energy matrix is demonstrated in Fig. 7, with the classification of the fuels to address the country's development needs. We highlight the strong increase in the use of sugar cane bagasse, important waste for the production of ethanol, an important fuel for transportation, mainly for vehicles. Ethanol can also be used for the production of more ethanol, thermo electricity and biogas.

Due to its huge territory, Brazil is also recognized as a great rural producer, being distinguished as one of the largest world producers of cereals, leguminous and oilseed plants, mainly rice, corn and soya. In 2011, the country was responsible for 160.1 million tons of these crops produced on 49.5 million acres, according to data collected from Rural Production Statistics/Estatística da Produção Agrícola, IBGE, published in August 2012 (IBGE, 2013).

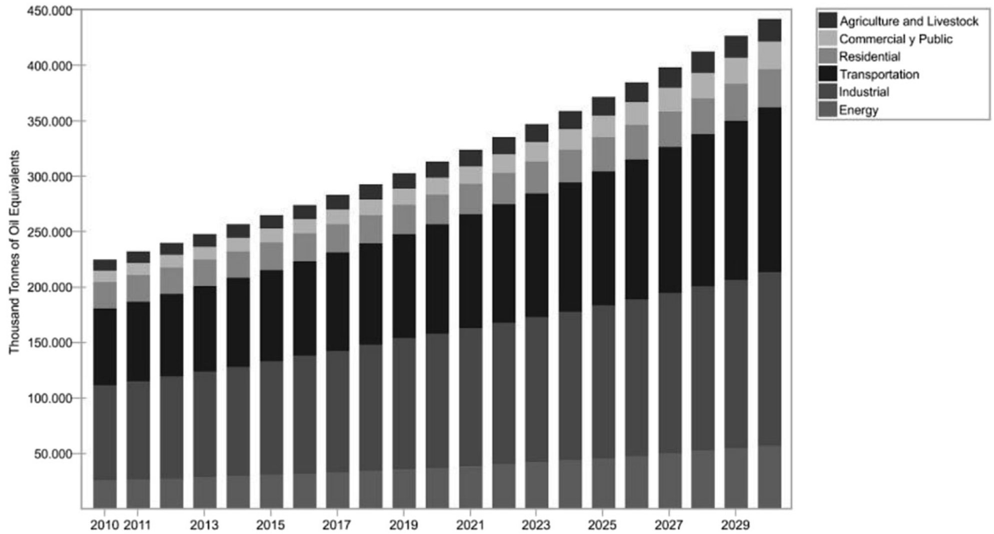

Fig. 6. Demand per sector (Thousands of tons of oil equivalents).

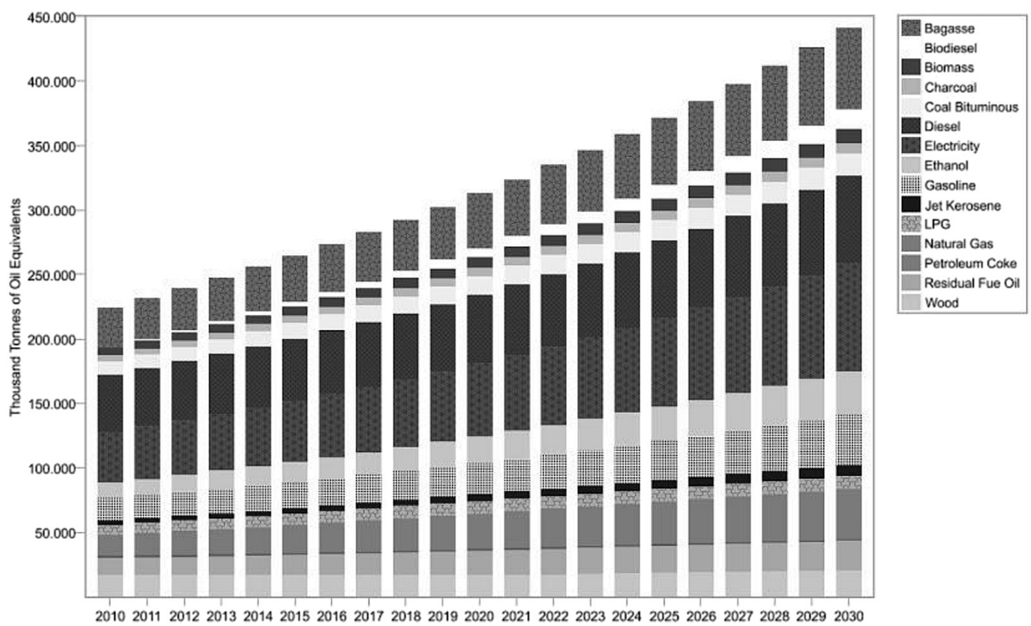

Fig. 7. Demand per fuels (Thousands of tons of oil equivalents).

In many states, the farming and livestock together showed to be a strong electricity consumer, mainly in the center-west and south of the country, where most of the biggest cereal rural properties are. In the agricultural sector, most of the energy consumption owes to the machinery for soil preparation and to the fertilizers either from fossil or from physicochemical process origin, according to Precci lopes (2012). This demonstrates that the Brazilian agriculture and livestock influences strongly the national energy balance, undoubtedly indicating that the segment should adopt renewable energy sources.

We can observe that the demand tends to grow due to the particularities of the expansion scenario of rural activity, which lead to the diversification of fuels in the sector, as shown in Fig. 8. Nevertheless, it must be emphasized that the changeover to renewable energy has been accelerating with the increased use of biodiesel in the agricultural sector.

With the increasing supply of credit and the upsurge of the lower and middle income classes, the demand for trade and service tends to grow, mainly the ones that predominantly use electricity, as presented in Fig. 9.

From the estimates of average GDP growth of 5% per annum in this decade, the Decennial Plan for Energy Expansion/Plano Decenal de Expansão da Energia 2020 (Empresa de Pesquisa Energética – EPE, 2012b) sees the future need of growth of the existing capacity in around 71.3 GW in the same period, which corresponds to an annual evolution of 5.2% of the energy demanded. We have to mention also that the country has been encouraging the use of alternative sources and actions for efficient energy in those segments.

The evolution of a more sustainable domestic economy, as a result of better income distribution, encouraged service and trade segments, for example, the hotel segment, which is growing due to

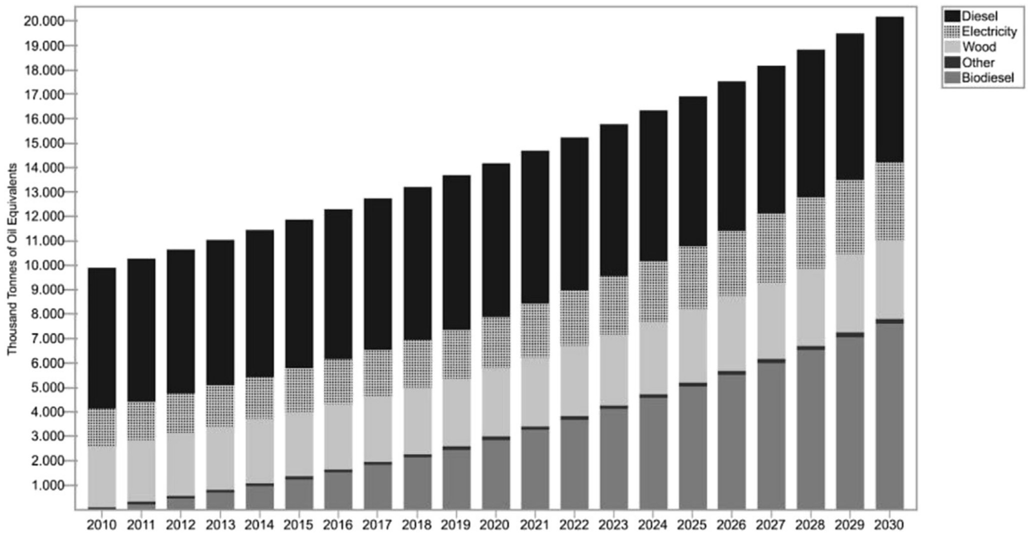

Fig. 8. Energy demand per farming and livestock activities (Thousands of tons of oil equivalents).

the country's tourism potential; and the shopping mall segment, which is contributing to the boost in consumption. In this way, the sector requires more availability of energy supplies. Fig. 9 identifies that the increase in energy demand generated by the trade sector evolved faster in comparison to the demand generated by the residential sector, shown in Fig. 10.

The electric energy consumption of homes grew rapidly in the last biennium, partly due to Federal Government measures to mitigate the effects of the world economic crisis by promoting an important reduction in the tax on manufactured products (IPI) for household appliances, and increasing housing programs, such as the program “My House My Life”/Programa Minha Casa Minha Vida. There was also the uninterrupted and significant growth of residences served by a universal electrification program. Furthermore, we must consider the results of the Brazilian Labelling Program/Programa Brasileiro de Etiquetagem – PBE that has been improving the energy performance of equipment and buildings. In this new context, more Brazilian houses will have electric energy, replacing the firewood for heating or cooking, as presented in Fig. 10 below.

Today Brazil finds itself in a very favorable situation, ascending in the global productive chain due to its growth in areas where it has an evident comparative advantage, mainly in iron extraction, steel, and pulp and paper industry segments. Initially, we expect higher productivity gains in these segments, which will call on different energy sources, as presented in Fig. 11.

Fig. 12 shows the possibility of growth in the demand for transportation, particularly due to the country's expansive national road network. Income growth has also promoted increased vehicle use, as well as intensified transportation of consumer goods.

To encourage the clean generation, investments on hydropower generation and other renewable sources have been intensified to

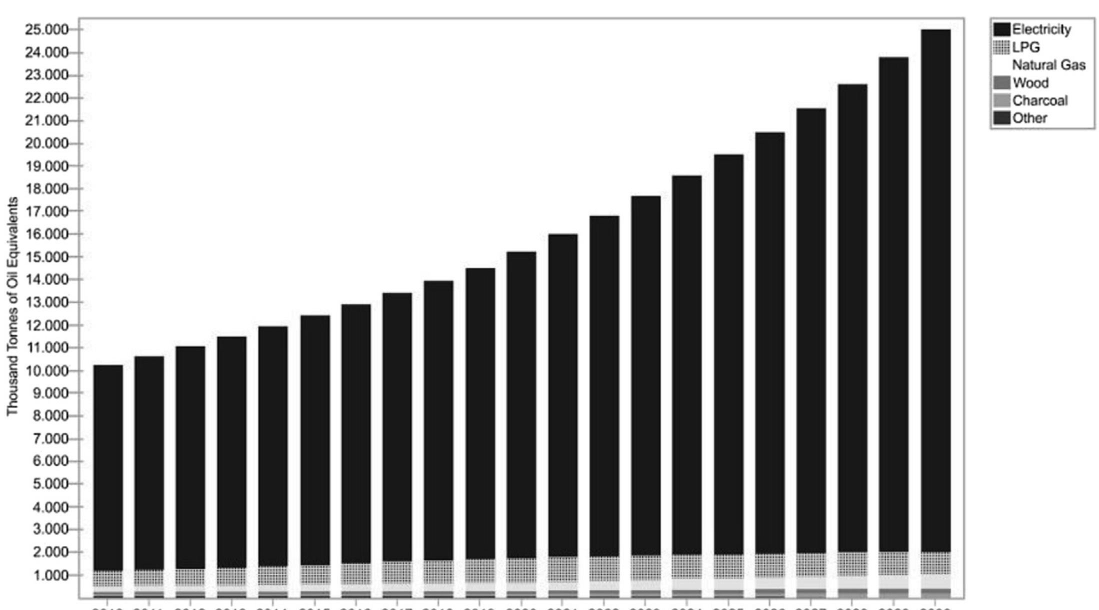

Fig. 9. Energy demand in trade and services (Thousands of tons of oil equivalents).

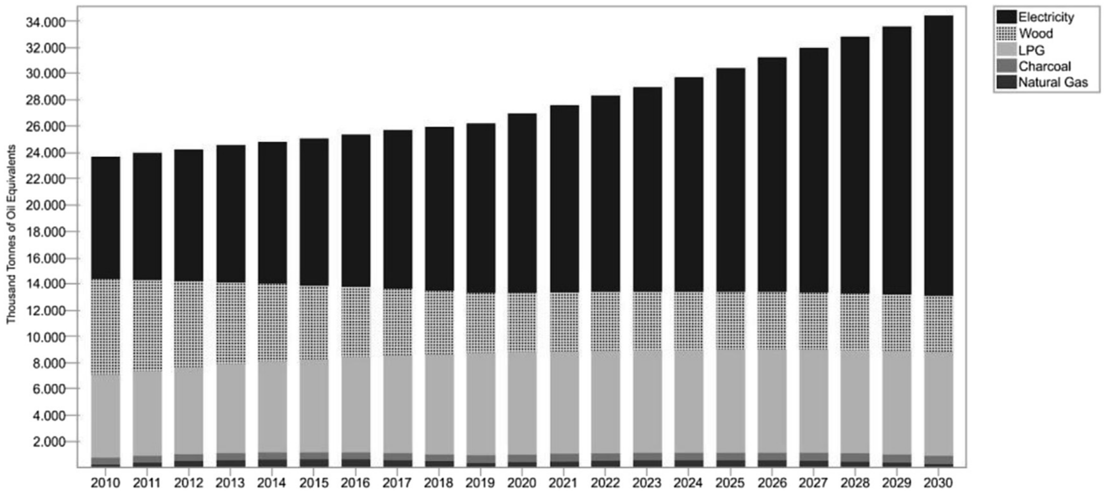

Fig. 10. Energy demand per homes (Thousands of tons of oil equivalents).

increase their participation in the national energy mix. Fig. 13 definitively illustrates the country's preeminence in hydropower. The government's strategy of expanding the energy supply has primarily consisted of the construction of the large-scale hydropower plants of Santo Antônio (3150 MW) and Jirau (3300 MW), both on Madeira River; and Belo Monte (11,233 MW), on Xingu River, all in the Amazon Basin; and the growing dissemination of smaller hydropower stations.

Individual production is configured as local electric energy generation to supply that particular plant and consuming unit without the need of the electric network of concessionaires of distribution and/or transmission. It is an important element to meet the demand for electricity. This mode of generation has been growing rapidly in the last ten years, and has great expansion potential for the coming decades. Fig. 14 confirms the trend, in particular in the industrial sector, where the cogeneration potential is seen in production processes. One example is the pulp industry, which is expected to be almost totally supplied by cogeneration in the near future.

After meeting their demand for energy, individual producers can offer and sell the surplus to the electric system. It is the case of the integrated steel plants, where the use of more advanced ways of cogeneration through the use of coke oven and blast furnace — together with the non-existence of the lamination phase, an electricity-intensive activity — allows the generation of significant surplus of electricity, which can then be made available to the grid. Cogeneration is a form of efficient energy use because, by combining the production of thermal and electric energy, the performance of the production process of energy grow significantly, improving the use of the energy charge generated by the fuel chosen. The Brazilian potential market for cogeneration is constituted mostly by the pulp and paper, chemical and petrochemical, steel, sugar and alcohol, food and beverages, and textile industries, where a great quantity of vapor is used.

The Brazilian energy mix will have increased the participation of renewable sources by 2030 with the use of sugar cane bagasse, as presented in Fig. 15. Brazil is the largest global producer of sugar and second largest of ethanol. Ethanol production generates an excessive amount of bagasse that remains from the milling of the cane all year long that is used to feed the electricity generation units coupled to the sugar and alcohol plants. The surplus can be commercialized and resold onto distribution networks, as long as the action is authorized by the national electricity regulating agency, ANEEL.

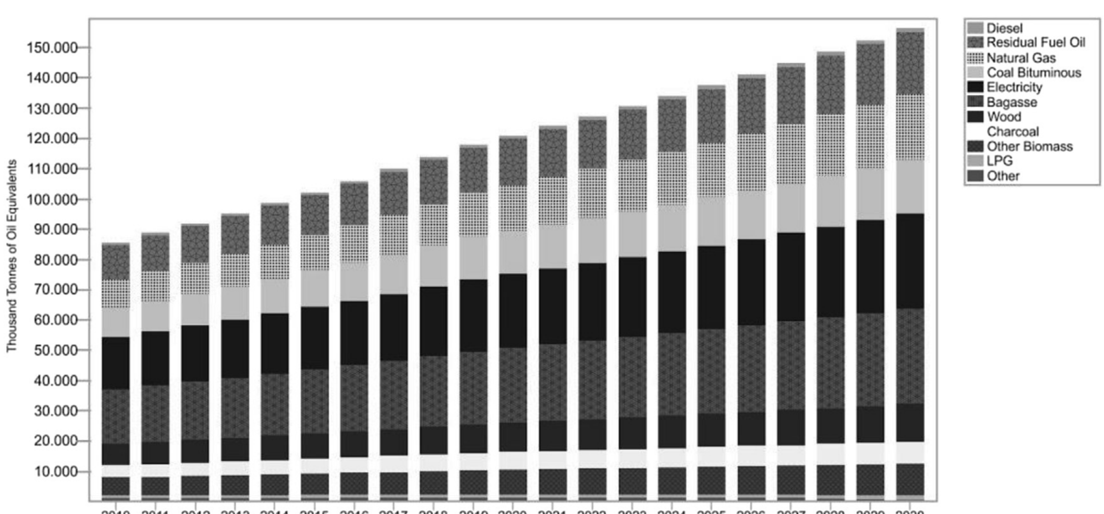

Fig. 11. Energy demand per industries (Thousands of tons of oil equivalents).

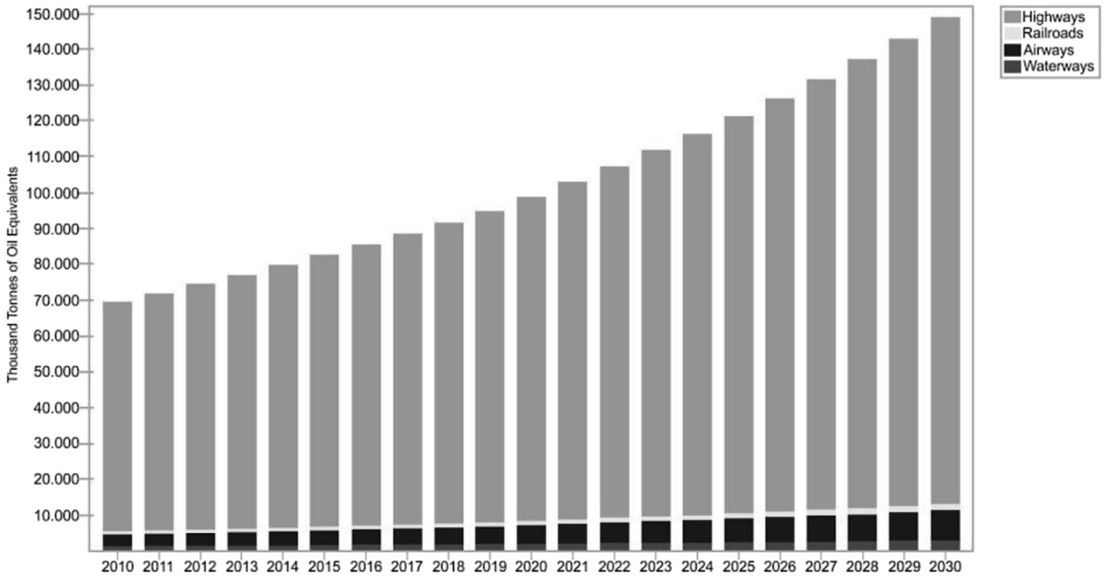

Fig. 12. Energy demand per Transportation (Thousands of tons of oil equivalents).

Fig. 16 projects the capacity of generation to be added for each energy source over the forecast period.

The availability projected for consumers can be seen in Fig. 17, showing that a need for the aggregation of endogenous capacity to the electric system should only happen at the end of the estimated scenario. Two possibilities to meet the electric requirements are either to add the endogenous capacity of some predetermined source, or to import electricity.

4.2. LEAP mitigation scenario

Considering the demand projected per sector, Fig. 18 presents a possible intense and growing energy activity in the transportation and industry sectors if the country continues to develop, which represents an increase in CO2 emissions in the planet.

However, this is decreasing in the industry sector, which is gradually using self-generation in the production processes where there is supply of renewable energy sources, with highlighted participation of the steel sector.

In addition, we observe the need to increase energy production with stronger participation of renewable sources, such as wind and solar sources, in order to mitigate the volume of the greenhouse gases on the planet.

We must emphasize that the projections lead to the need to correct the comparative curve, due to the actions implemented in the country, as shown in Fig. 19.

Among the several generating sectors, the highest volume of greenhouse – CO2 gases is emitted by the transportation, followed by the industry sector, as seen in Fig. 20. The trend can be mitigated if the country establishes medium and long-term strategies, especially with investments in renewable sources that will enable both the migration of the representative consumption units and the accelerated diffusion of concepts of energy efficiency applicable for each sector, including investments toward upgrading industrial plants.

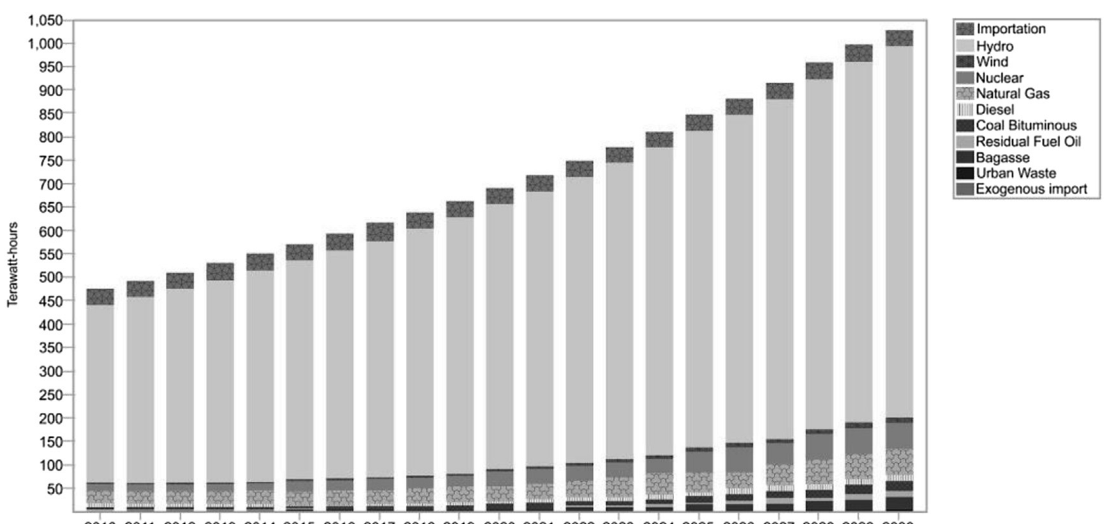

Fig. 13. Electricity generation per source (Terawatt-hours).

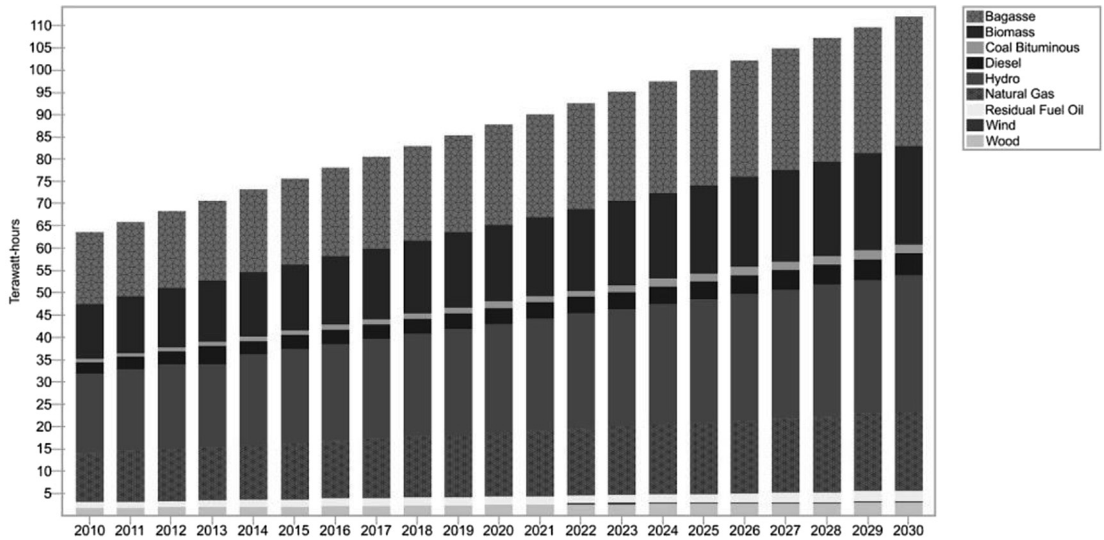

Fig. 14. Self-production per source (Terawatt-hours).

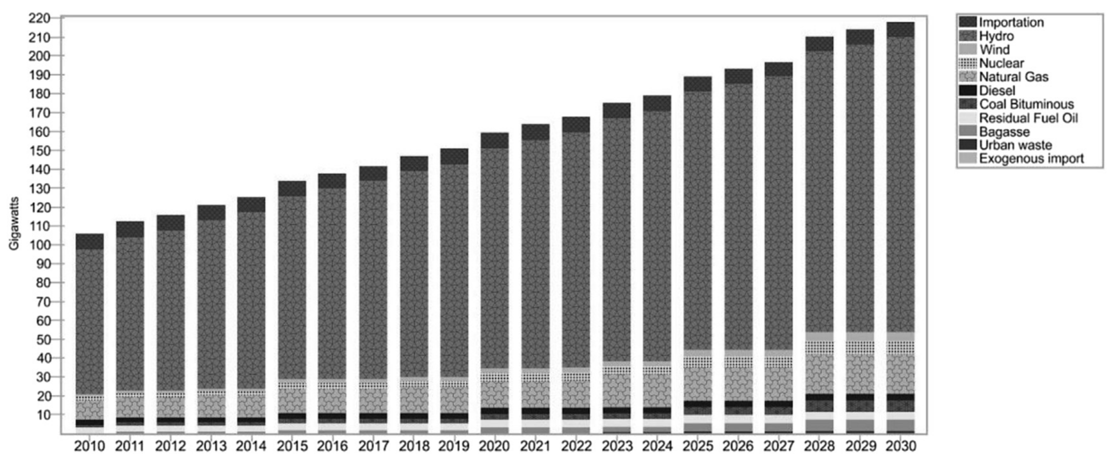

Fig. 15. Capacity per source (Gigawatts).

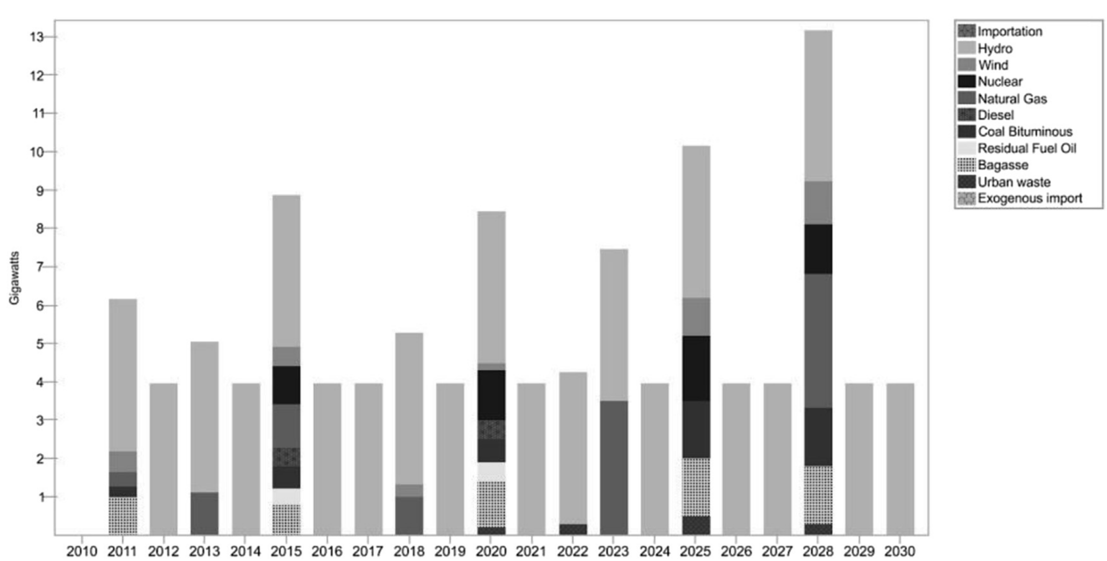

Fig. 16. Capacity added per source (Gigawatts).

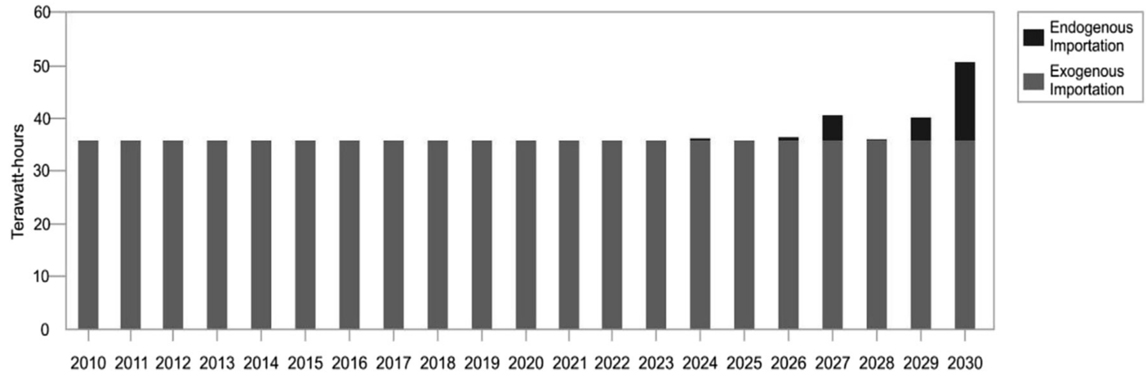

Fig. 17. Imported electricity (Terawatt-hours).

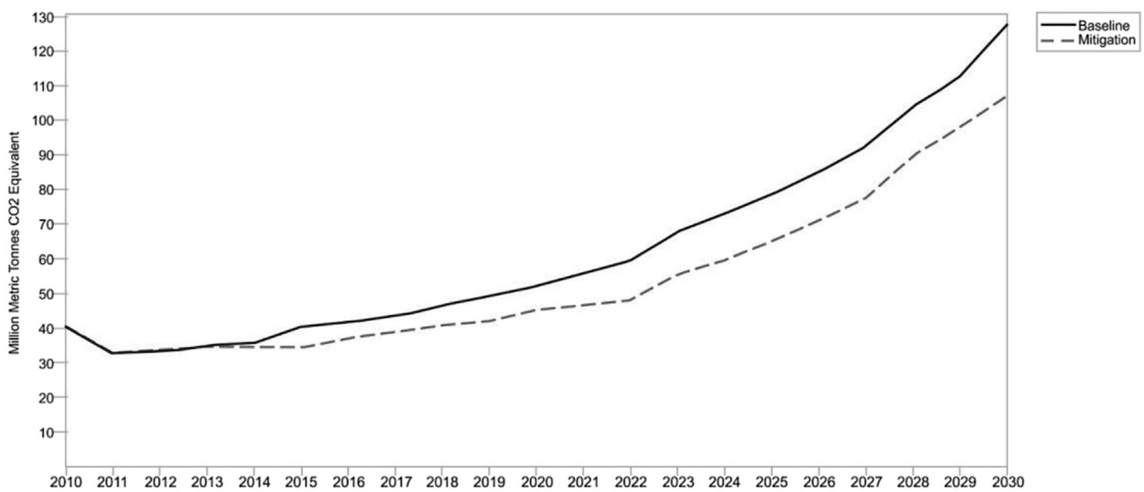

Fig. 18. National GHG (million TonCO_2e).

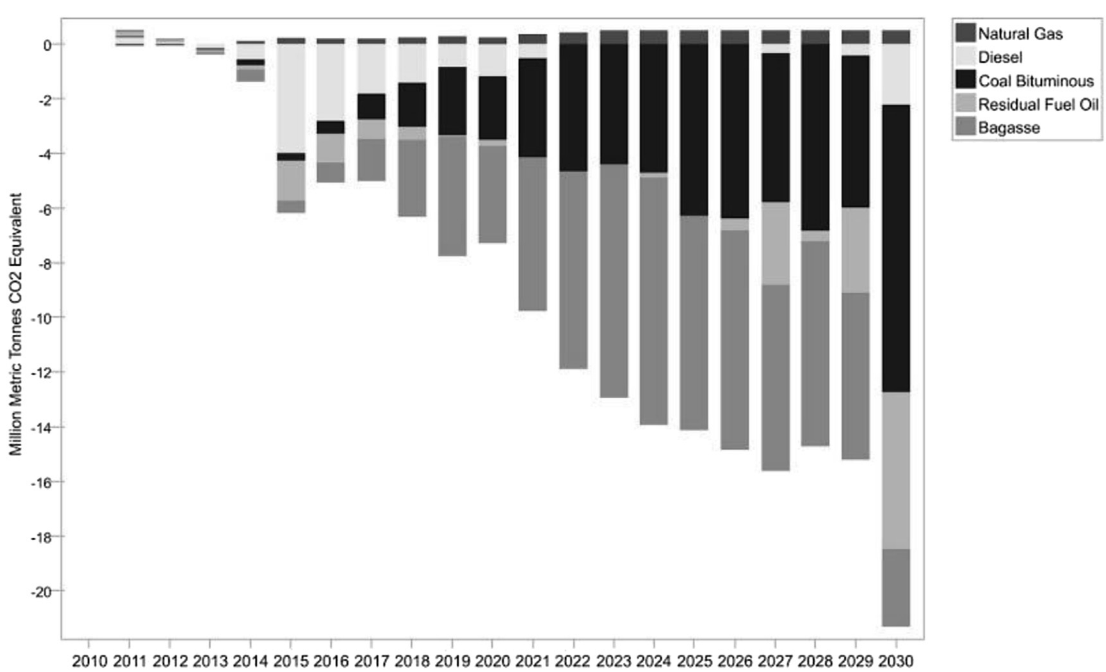

Fig. 19. Difference of emmisions between base scenario and mitigation-transformation (Million TonCO_2e).

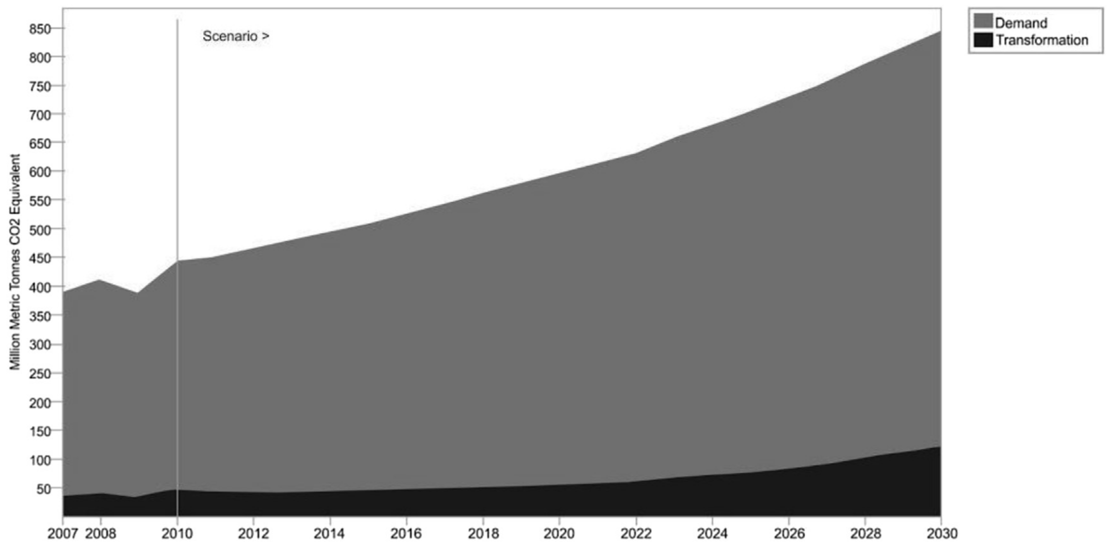

Fig. 20. National emissions, mitigation scenario.

This confirms that energy efficiency has become a recognized form of sustainable energy, and can be a great contribution to the Brazilian economy, if the country pursues this goal effectively through 2030.

5. Conclusion

Brazil is undoubtedly a country with considerable energy generation capacity, and its diversity enables it to improve the Brazilian energetic matrix by implementing the use of renewable energy sources.

The development of technologies and incentives for the use of renewable energies, along with actions in energy efficiency, will certainly confirm Brazil in an outstanding position among the most efficient clean energy generators, leading the country to stand, in the near future, as one of the lowest carbon generators globally.

We also emphasize that the LEAP scenarios demonstrate trends that have also been projected by the EPE, especially mentioning the promotion of the association of renewable sources and energetic efficiency, which enables the country to have a distinguished performance in energy production and use. It means that the Brazilian mix enables the national electricity sector, when producing 1 TWh, to emit eight times less carbon than the electricity sector in the United States, five times less than Europe, and twelve times less than China.

Brazil has an important production of primary energy, which does not fully satisfy demand, requiring imported sources. An interesting aspect of the primary production in Brazil is that it is highly diversified in terms of renewable and non-renewable sources. However, domestic consumption is highly dependent of fossil fuels.

Nevertheless, the highlight in the Brazilian energetic matrix beyond its high consumption of sugarcane alcohol in the country's vehicles, is its high capacity of hydropower production and the introduction of the wind and solar power production which together have significant potential in the total capacity of electricity production.

In comparison with the rest of the world, the matrix of electricity production of Brazil is highly clean and efficient.

Since the country's hydroelectric resources are huge, there is still much space for their expansion, either with large-scale power plants – when environmental interferences are controlled – or with small-scale hydro power stations, which can supply rural areas. However, we must consider the issue of unpredictable rainfall, which may require special attention for this type of supply.

The future seems to be promising for the energy domestic market. Nevertheless, we hope the necessary funds are applied for the development of technologies aiming at an efficient use of the resources available. Wind and solar capacity in Brazil is worth noting, so it is expected that the use of these sources will increase in the future. There should be a prevalence of solar energy because of the country's large available reserves of silicon, a key raw material used to produce photovoltaic cells.

Concerning the projections in the mitigation scenario, we expect the country to increase its total energy consumption by 67%. This happens in detriment to the participation of some renewable energy sources, especially biomass. This situation amplifies the growing dependence in the consumption of non-renewable fossil energy sources in the long run. We also mention the use of biomass, another renewable source of energy that can be used to a greater extent in the future, due to the several organic wastes that can be used to generate energy and decrease production costs, mainly in the areas of agriculture and livestock.

Except for the issues related to electricity production, it is not possible to verify the reduction of the consumption of oil derivatives and, on the contrary, a continuous increase of such consumption is expected, with severe implications for the environment.

For that reason, it is important that Brazil adopt energy efficiency and mitigation measures even deeper and more comprehensive than the ones presented in this study. International cooperation on this issue is crucial not only for funding reasons, but also in terms of transference of technology and formation.

Since 2006, Brazil has been a founding member of the International Partnership for Energy Efficiency Cooperation – Cooperação em Eficiência Energética (IPEEC), established with the European Union, directed to aspects concerned with the security and sustainability. Among these actions, we highlight the distribution of lessons in the formulation of public policies on energy efficiency and technology transfer, and joint revision of the follow-up plan until 2050.

Last, but not least, is the integration between the public and private sectors as significant economic resources are necessary to invest in programs of great impact for the reduction of energy consumption and emissions of GHG. The exercise of projecting the Brazilian energy scenario in this article using LEAP as a tool provided elements that enabled us both to evaluate the reflection of the socioeconomic interferences which the Brazilian electricity sector must consider and address; and to examine the evolution of trends for up to 2030. We conclude that the commitment the Brazilian Government made during the Conference Rio+20 will only be fulfilled if all involved actors join in their efforts to amplify the projects that aim for energy efficiency and at an increase in funding for renewable energy sources, such as wind, biomass and especially solar power. In this way, it will be possible to have the energy demand reduced by 38% in the country in 2030.

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