POLITECNICO DI MILANO

Facoltà di Ingegneria Civile, Ambientale e Territoriale

POLO REGIONALE DI COMO

Master of Science in
Environmental and Land Planning Engineering

ENERGY ASSESSMENT IN BRAZIL FOCUSED ON ETHANOL AS A BIOFUEL

Supervisors:

Prof. Fabio INZOLI
Eng. Irene BENGO

Master Graduation Thesis by:

Felipe Draque Vasconcelos
Student ID number 733766

Academic Year 2009/2010

POLITECNICO DI MILANO

Facoltà di Ingegneria Civile, Ambientale e Territoriale

POLO REGIONALE DI COMO

**Corso di Laurea Specialistica in
Ingegneria per l'Ambiente e il Territorio**

ANALISI ENERGETICA IN BRASILE FOCALIZZATA SU ETANOLO COME BIOCARBURANTE

Relatori:

Prof. Fabio INZOLI
Ing. Irene BENGO

Tesi di laurea di:

Felipe Draque Vasconcelos
Matr. 733766

Anno Accademico 2009/2010

Abstract

The present study is divided into 3 parts. The first part will present a detailed description of the traditional unit operations for ethanol production from sugarcane in Brazil. Furthermore, this part will deal with the promising technology of producing ethanol from cellulosic materials. The second part consists of an energy assessment in Brazil, taking into account, besides the aspects related to energy, also social, economical and environmental aspects, in order to compose a complete panorama of the country. The last part deals with ethanol production in Brazil: its history, opportunities and barriers for its production, sustainability of its production and use and, finally, the perspectives for the next years. The main purpose of this study is to analyze the feasibility of sugarcane ethanol production and use in Brazil.

Riassunto

Il presente studio è diviso in 3 parti. La prima parte presenterà una descrizione dettagliata delle operazioni unitarie tradizionali per la produzione di etanolo dalla canna da zucchero in Brasile. Inoltre, questa parte si occuperà della promettente tecnologia di produzione di etanolo da materiali cellulosici. La seconda parte consiste in una analisi energetica in Brasile, tenendo conto, oltre che gli aspetti legati all'energia, anche gli aspetti sociali, economici e ambientali, al fine di comporre una panoramica completa del paese. L'ultima parte si occupa della produzione di etanolo in Brasile: la sua storia; opportunità e ostacoli per la sua produzione; la sostenibilità della produzione e l'uso; e, infine, le prospettive per i prossimi anni. Lo scopo principale di questo studio è quello di analizzare la fattibilità della produzione e dell'uso del etanolo di canna da zucchero in Brasile.

ENERGY ASSESSMENT IN BRAZIL FOCUSED ON ETHANOL AS A BIOFUEL

Table of contents

1. Introduction

Global population continues to grow, especially in developing countries. Clearly, the demand for food, fuel and energy will increase, and limitations worldwide will become more evident. The development model based on fossil fuels has proved to be unsustainable, for the simple reason that they are finite and the demand for energy will only increase in the years to come.

Diversification of energy sources has become a keyword in this context. Recently, it has been observed an increase on the renewable sources share in the world total primary energy supply. The policies of incentive to the production and use of renewable sources, observed in many countries around the world, aim mainly at the energetic security. The objective is to reduce the dependence on petroleum and its derivates. Moreover, the use of renewable sources leads to a reduction on environmental impacts, especially by means of GHGs emission reductions. A third factor is the strengthening of the rural economy, especially in developing countries, thus contributing to avoid the rural exodus phenomenon.

Brazil occupies a relevant position in this context. The renewable sources exert a very important role in the country's total primary energy supply. Almost half of the primary energy supplied in Brazil comes from renewable sources. Their share in the electric energy production is even higher: more than 80% of the electricity in Brazil comes from renewable sources. These are the facts that make Brazil have a unique energy profile.

Brazil was a pioneer in the intensification on the use of renewable fuels. In 1975, Brazilian government created the National Ethanol Program (in Portuguese: ProAlcool, Programa Nacional do Alcool), in response to the oil crisis of the 1970s.

The objective of this study is to analyze the feasibility of sugarcane ethanol production and use in Brazil. In order to reach this objective, firstly it will be presented the detailed description of the traditional unit operations for ethanol production from sugarcane in Brazil, in order to have a general picture of the technologies behind the production. In addition, cellulosic ethanol, the great promise for the future of renewable fuels, will be analyzed.

The description of ethanol production technologies will be followed by the energy assessment in Brazil, by presenting an overview of Brazilian total primary energy supply and important aspects related to each primary source. The objective of this part is to understand the role of sugarcane and ethanol within the total primary energy supply. Furthermore, also some socio-economic and environmental indicators will be analyzed, in order to have a complete panorama.

Finally, important aspects related to sugarcane ethanol will be analyzed, such as the history of its production in Brazil, going back to the ProAlcool; internal and external opportunities and barriers for its production in Brazil; sustainability of its production and use; perspectives and implications in the near future.

In the end of this study, from all the analysis to be carried out, it will be discussed the feasibility of ethanol production and use in Brazil.

2. Production of ethanol from sugarcane

This chapter has the main goal of showing how simple the process of ethanol production is, by presenting a detailed description of the unit operations. However, as it is going to be discussed later, there has been a continuous improvement at both agricultural and industrial practices, resulting in costs reduction and, consequently, in a high competitiveness in the international market.

Furthermore, the promising cellulosic ethanol and its technology development current state are discussed, in order to understand the feasibility of its large scale production in the next years.

Figure 1: Cut sugarcane - source: Diva Envitec - Filtration India

The most likely origin of the sugarcane is South Asia, where it has been known since about 6000 BC. In the 12^{th} century, sugar arrived in Europe. The interest for this spice increased after the 15^{th} century, when new beverages, like coffee, tea and chocolate were sweetened with sugar. In 1493, Christopher Columbus began the sugarcane cultivation in the Antilles. Since then, the history of sugar in the world gained new dimensions.

Sugarcane Composition	
Components	%
Water	73-76
Total solids	24-27
Soluble solids	10-16
Fibers (dry base)	11-16

Table 1: Sugarcane composition - source: Carlos Rossell (Unicamp)

The most unit operations described below were taken from Copersucar S.A. website. Copersucar S.A. is the largest Brazilian sugar, ethanol and bioenergy company and a significant player in the major world markets.

2.1 Unit operations for both sugar and alcohol production

Transport, weighing and storage: The transport of the sugarcane to the plant, in Brazil, is mainly made by roads, by trucks that carry the whole cane (manual harvest) or in pieces of 20-25 cm (mechanic harvest). The trucks are weighted before and after the unloading, therefore obtaining the real mass of the cane by the difference between the two measurements. Some loads are randomly selected and sampled, for further determination, in laboratory, of the saccharose content in the raw material. The saccharose content determines the price paid for the sugarcane. The stocked cane must be renewed in short periods of time, to reduce the sugar losses by bacteriological decomposition.

Milling: The cane is washed to remove the soil, sand etc, in order to obtain a juice of better quality and increase the life of the equipments. Then the cane is cut and compacted, in order to increase the efficiency of the milling, and finally it is conveyed to the mills. The milling is a strictly volumetric process, in which the juice is extracted from the sugarcane by mill rollers connected in series. As the cane passes through the rollers, the juice is extracted and its proportion with respect to the total mass of cane decreases.

Water is then added to the bagasse (process called Soaking) in order to dilute the remaining juice in the bagasse, therefore increasing the extraction of saccharose. A secondary - but very important

- objective of the milling is the production of a final bagasse able to burn fast in the boilers to produce energy.

Energy generation: After the extraction of the juice, the remaining substance is the bagasse, which consists of fiber (46%), water (50%) and dissolved solids (4%). The quantity of bagasse obtained ranges between 240-280 kg of bagasse per ton of cane, and the sugar contained in the bagasse represent one of the major losses in the process (further it is explained how this bagasse can be used to produce ethanol from the cellulose, the so-called second-generation ethanol).

The bagasse feeds the boilers where it is burned, and the released energy transforms water into steam. This steam moves turbines, converting thermal energy into mechanic energy.

These turbines are responsible for the activation of all the equipments of the process (choppers, mill rollers etc), and also the generators for the production of electric energy used in the various sectors of the plant.

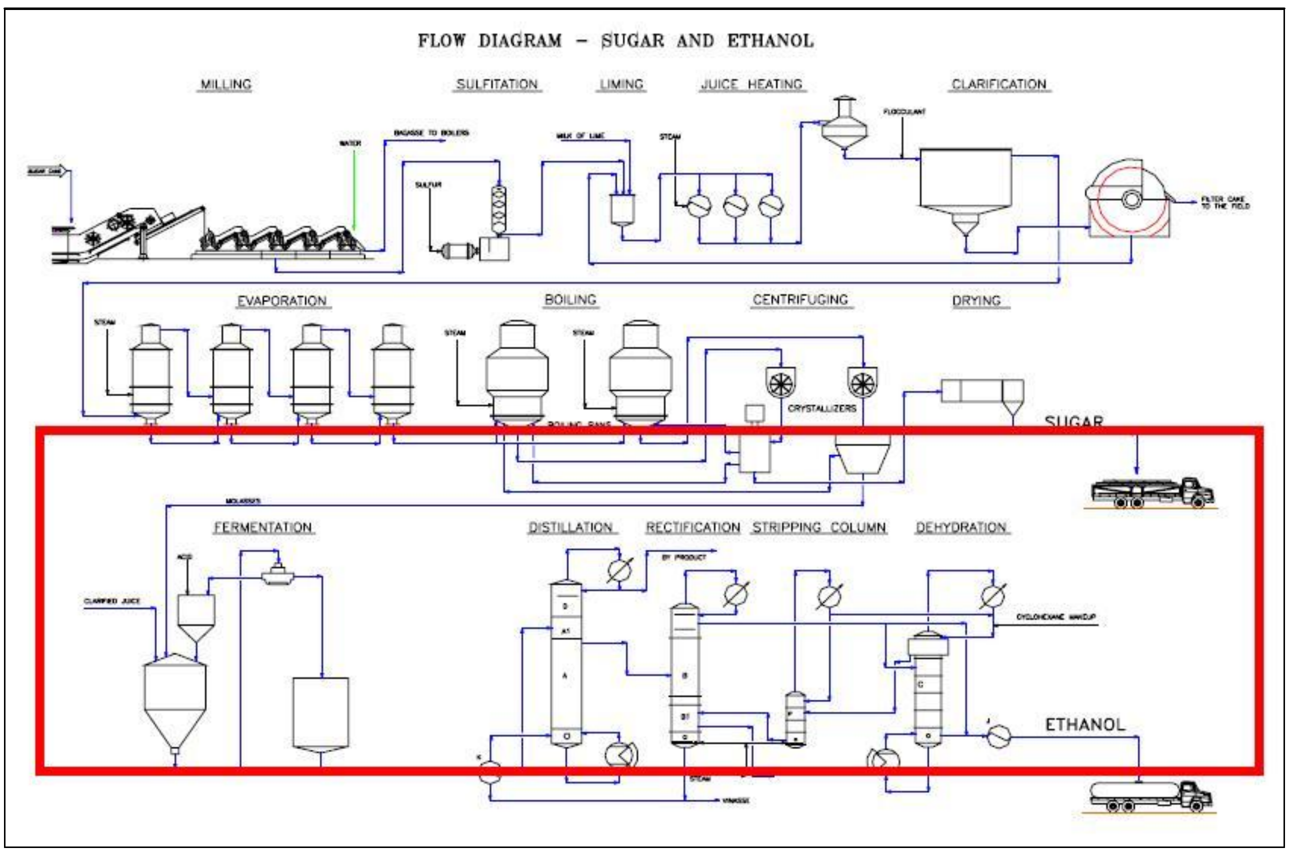


Figure 2: Sugar and ethanol flow diagram - source: CTC – Centro de Tecnologia Canavieira (Sugarcane Technology Center)

Pre-treatment of the juice: The juice obtained in the extraction process has a variable quantity and quality of impurities, which may be soluble or insoluble. The pre-treatment aims at maximum elimination of the insoluble impurities (sand, clay etc), whose contents vary from 0.1-1%. The elimination of this material benefits the process and increases the working life of the equipments, and also contributes to obtaining final products of better quality. The basic equipments used in the pre-treatment are sieves and hydrocyclones.

Chemical treatment of the juice: Despite the pre-treatment, the juice still contains smaller impurities that can be soluble, colloidal or insoluble. Therefore, the chemical treatment is directed at the coagulation, flocculation and precipitation of these impurities, which are then removed by sedimentation. It is also necessary to correct the pH, to prevent saccharose decomposition.

<u>Sulfirizing</u>**:** consists of absorption of the SO_2 (sulfur dioxide) by the juice, lowering its original pH to 4.0– 4.5. SO_2 is produced in the plant by burning sulfur in the presence of air, in special sulfur burners, according to the reaction:

$$S + O_2 \rightarrow SO_2$$

The sulfirizing, besides lowering the pH, aims also at the inhibition of the coagulation of soluble colloidals and to decrease the viscosity, which facilitates the following steps of evaporation and cooking.

<u>Liming</u>: consists of adding $Ca(OH)_2$ to the juice, raising its pH to 6.8-7.2. This substance is also produced directly in the plan, according to the reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2 + \text{heat}$$

The objective of this addition is to neutralize organic acids and to produce calcium phosphate and sulfate, which are products that, on sedimentation, carry with them impurities present in the liquid.

Heating: The juice is warmed to approximately 105°C, in order to accelerate and facilitate the coagulation and flocculation of impurities. This increases the efficiency of the next step, the sedimentation.

Sedimentation: The juice is purified by removing the flocculated impurities from the previous treatments. The equipment called decanter has several trays to increase the decantation surface. The time the juice remains in the decanter ranges from 15 minutes to 4 hours, and the amount of sludge removed represents 15% to 20% of the weight of the juice that enters the decanter.

Filtration: The sludge removed from the decanter is filtrated, in order to recover the sugar contained in it. The material removed from the filter is called cake. It is sent to the plantation to be used as a fertilizer. The sugar contained in the cake should be less than 1%.

Evaporation: The decanted juice undergoes a concentration process by removing the water contained in it. The evaporation is carried out in the evaporator, which consists of four or five tanks connected in series, so that the juice is progressively concentrated from the first the last. This procedure is maintained by a vacuum generation system connected to the final tank.

2.2 Unit operations for alcohol production

Fermentation: The juice is cooled and then mixed with a sugar solution. This mixture is called must, and has an optimal concentration to facilitate its fermentation. The Melle-Boinot fermentation process is widely spread in Brazil. Its main characteristic is the recovery of yeasts through fermented wine centrifuging. Before being returned to the fermentation process, this yeast undergoes strong acid treatment: it is diluted with water and sulfuric acid is added, normally to a pH of 2.5-2.8 to prevent bacterial infection.

In the fermentation process, the sugars are transformed into alcohol. The reaction takes place in tanks called fermentation vats, in which the must and the treated yeast are mixed in a proportion of 2:1, respectively. This is the reaction of the fermentation process:

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 + 23.5\ kcal$$

1 mol of saccharose is broken into 2 mols of glucose, and then each mol of glucose is transformed into 2 mols of ethanol, 2 mols of carbon dioxide and heat. Fermentation time ranges between 4 and 12 hours. In the end of the process, the average ethanol concentration in the vats varies from 7% to 10%.

Due to the large amount of heat released during the process and the need to maintain a low temperature (32ºC), it is necessary to cool the wine.

After fermentation, the fermented wine is sent to the centrifuges, where the yeast is recovered.

The recovered yeast concentrate, called yeast milk, returns to the storage tanks for acid treatment. The light centrifuged phase, or “deyeasted” wine, undergoes the next step: the distillation.

Distillation: The alcohol contained in the wine (7-10%) is recovered by distillation, a separation method based on the different boiling points of the substances in the mixture. In this process, the vinasse - which consists of water, soluble and suspended solids - is also removed and used as fertilizer in the plantation. The alcohol obtained in the end of the distillation is hydrated (96% alcohol and 4% water) and is commercialized in the fuel stations.

If the desired product is the anhydrous alcohol, which will later be mixed with gasoline, there must be a dehydration process. The most common dehydration process is the addition of cycle-hexane to the hydrated alcohol. This mixture is vaporized and then condensed, and two phases are formed: one of them is constituted of anhydrous alcohol (99.3%), and the other one constituted of water and cycle-hexane. The cycle-hexane is later separated from the water and recycled in the process.

Alcohol storage: The alcohols produced – hydrated and anhydrous are sent for storage in high volume tanks, where they wait for marketing and later removal by trucks.

2.3 New technologies – Cellulosic Ethanol

The main new technology that has been developed – and American energetic policy great bet - is the production of ethanol from lignocellulose, a structural material that composes great part of the weight of plants. In theory, any organic matter contains sugar and can, therefore, be transformed into ethanol fuel. The ethanol produced by this process is considered a second-generation biofuel, contrasting with the conventional production process described above (first-generation).

The main components of the cellulosic biomass are:

Cellulose: the most common form of carbon in biomass, representing 40%-60% by weight of the biomass. It is a complex sugar polymer (polysaccharide), made from glucose, a six-carbon sugar. Due to its crystalline structure, it is resistant to hydrolysis, the chemical reaction that converts the polysaccharide into simple sugars with the use of acids and enzymes.

Hemicellulose: represents 20%-40% by weight of the biomass. It is a complex polysaccharide made from five and six-carbon sugars. Although it is quite easy to hydrolyze it into simple sugars, it is difficult to ferment these sugars to ethanol.

Lignin: structural component that hardens and strengthens the cell walls of plants. It represents 10%-24% by weight of biomass. After the sugars in the biomass have been fermented to ethanol, the lignin remains as a residual material but still contains a great quantity of energy, and therefore can be burned to produce steam and electricity.

The main steps of the ethanol production from cellulosic biomass are represented in the figure below:

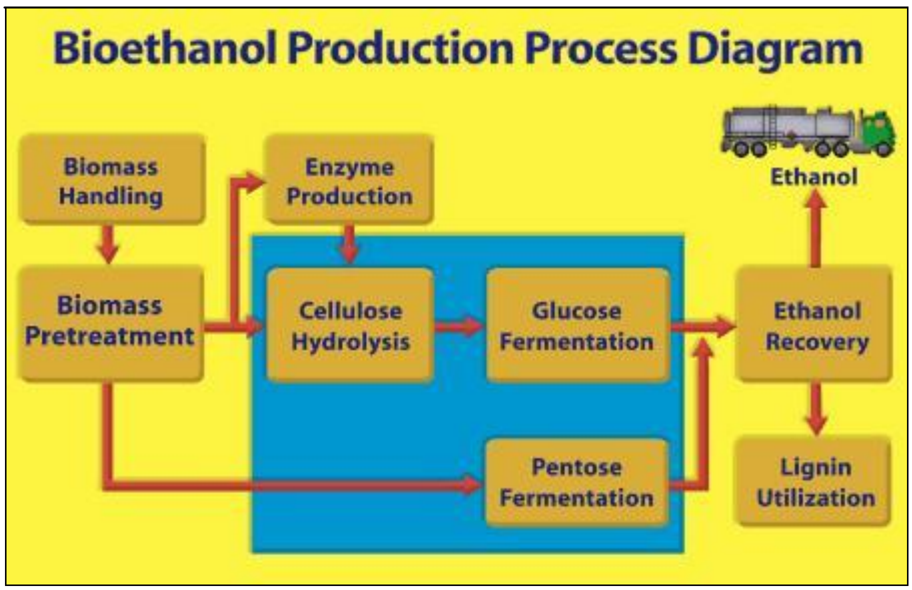


Figure 3 Bioethanol production process diagram - source: U.S. Department of Energy

Biomass Handling: The biomass has its size reduced and achieves a uniform particle size, in order to make the ethanol production process more efficient.

Biomass Pretreatment: Dilute sulfuric acid is mixed with the biomass (acid hydrolysis) and the hemicellulose fraction of the biomass is broken into a mix of soluble five and six-carbon sugars.

Enzyme Production: The enzymes that are used to hydrolyze the cellulose fraction of the biomass can be grown or purchased from companies that commercialize them.

Cellulose Hydrolysis: The cellulose is broken into simple sugars (glucose) by the enzymes.

Glucose Fermentation: The glucose is transformed into ethanol, exactly like the conventional ethanol production process described above.

Pentose Fermentation: the 5-carbon sugars (also called pentoses) released from the hemicellulose hydrolysis (biomass pretreatment) are fermented and transformed into ethanol.

Ethanol Recovery: The ethanol broth produced from the glucose and pentose fermentation is distilled and then dehydrated, just like the conventional ethanol production process.

Lignin Utilization: The lignin and other residual materials can be burned to produce steam and electricity to be further used in the production process. The electricity production is often higher than the plant consumption, so it can be also sold to the grid.

In the conventional ethanol production in Brazil, the bagasse is a potential biomass feedstock to further increase the ethanol production. Nowadays it is simply a residual material that is burned to obtain energy

The main problem of this new production technology is that it is currently too expensive to be used commercially. There are particularly 2 steps in the process that require further research and improvement: the first one is cellulose hydrolysis. As mentioned above, the crystalline structure of cellulose makes it very difficult to be broken into simple sugars. New enzymes have been developed to do this hydrolysis more efficiently. The second problematic step is pentose fermentation. Although it is easy to ferment six-carbon sugars (glucose), the fermentation of five-carbon sugars is still a challenge. Genetic research has been done to design microorganisms capable of efficiently ferment these five-carbon sugars.

Some recent factors contributed to the decrease of investments in the cellulosic ethanol technological development. The decreasing price of oil made it more attractive; the global financial crisis of 2008 made investors run away from any kind of risk. In fact, the investments on cellulosic ethanol in the USA went from US$ 538 million in 2008 to US$ 180 million in the following year, according to Bloomberg Energy Finance.

However, these investments tend to increase again in the next years. In fact, many big oil companies are interested in the technology and have invested a large amount of money in the sector. Also the USA government is a great supporter and sponsor of the development of this new technology.

In Brazil, a demonstrative cellulosic ethanol plant will be operative in 2010. It will have a capacity of 50 000 liters/day.

3. Energy assessment in Brazil

After having a deep look into the sugarcane ethanol traditional production method, and also into the promising cellulosic technology for ethanol production, this study proceeds with the energy assessment in Brazil. The objective of this chapter is to draw a panorama of Brazil and to analyze how sugarcane and ethanol are inserted in the Brazilian total primary energy supply.

Besides the energy aspects, also the socio-economic and environmental aspects have been considered, in order to have a more complete panorama. Furthermore, comparisons have been made in relevant geographic and economic contexts. Whenever it was possible, indicators in Brazil have been compared to Latin America countries and BRIC countries (Brazil, Russia, India and China).

3.1 Socio-Economic Indicators

The socio-economic indicators considered in this study were: population, education, economy, human development index and social contrast.

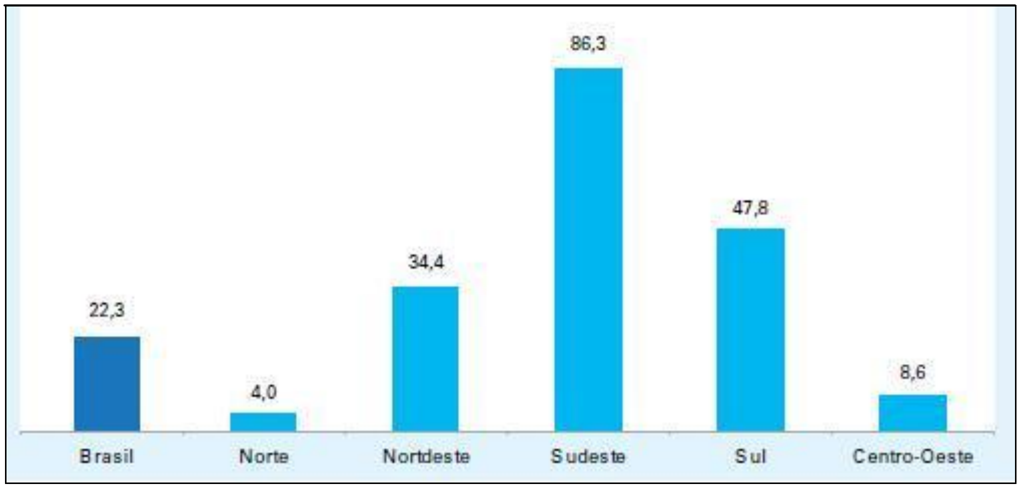
3.1.1 Population

Brazil has a population of 191,971,506 people (2008), which makes it the 5th most populated country. As it is visible from the table below, the population annual growth rate is decreasing, mostly due to the decrease of the fertility rate. It is also evident the gradual increase of the urbanization process: in 2008, 85.58% of the total population lived in cities and urban areas. The life expectancy, which is the number of years that a person would expect to live when the person is born, has slowly and continuously increased, reaching 72.4 years in 2008.

	2004	2005	2006	2007	2008
Population, total	183,863,524	186,074,634	188,158,438	190,119,995	191,971,506
Population growth (annual %)	1.27	1.20	1.11	1.04	0.97
Fertility rate (births per woman)	2.14	2.08	2.01	1.94	1.88
Urban population (% of total)	83.60	84.20	84.66	85.12	85.58
Life expectancy at birth (years)	71.38	71.65	71.91	72.16	72.40

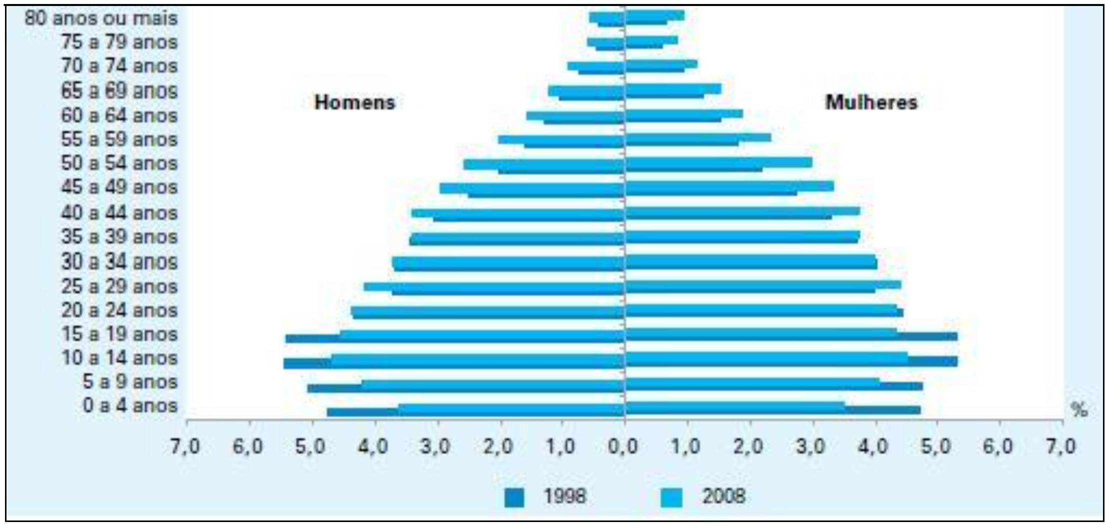
Table 2: Population facts in Brazil - source: World Bank

The population in Brazil is not uniformly distributed along its territory. The average demographic density, as it is possible to see from the figure below, is 22.3 inhabitants/km^2 (2008). The North region, with 45.2% of Brazil total area and 8.1% of the population, has only 4 inhabitants/km^2. This is due to the region vast territory and large areas occupied by the Amazon Forest. The Southeast region, the most economically evolved region in Brazil, with 42% of the total population, has the largest demographic density: 86.3 inhabitants/km^2.



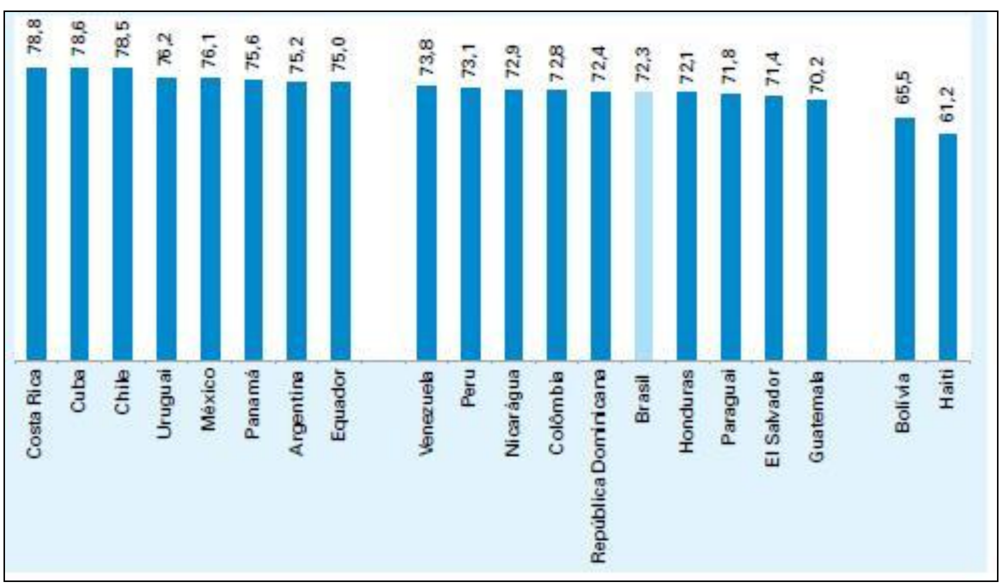
Graph 1: Demographic density in Brazil- source: IBGE

The following graph shows that the number of children and teenagers up to 14 years old represents 24.7% of the total population (2008), whereas in 1998 it represented 30.0%. This means a reduction of 17.7% over the last 10 years. It is also important to observe the increase of the population over 70 years old. It went from 3.8% of the total population in 1998 to 4.9% in 2008. The reduction of the younger population and increase of the older population are associated with the constant decrease of the fertility rate and increase of the life expectancy.



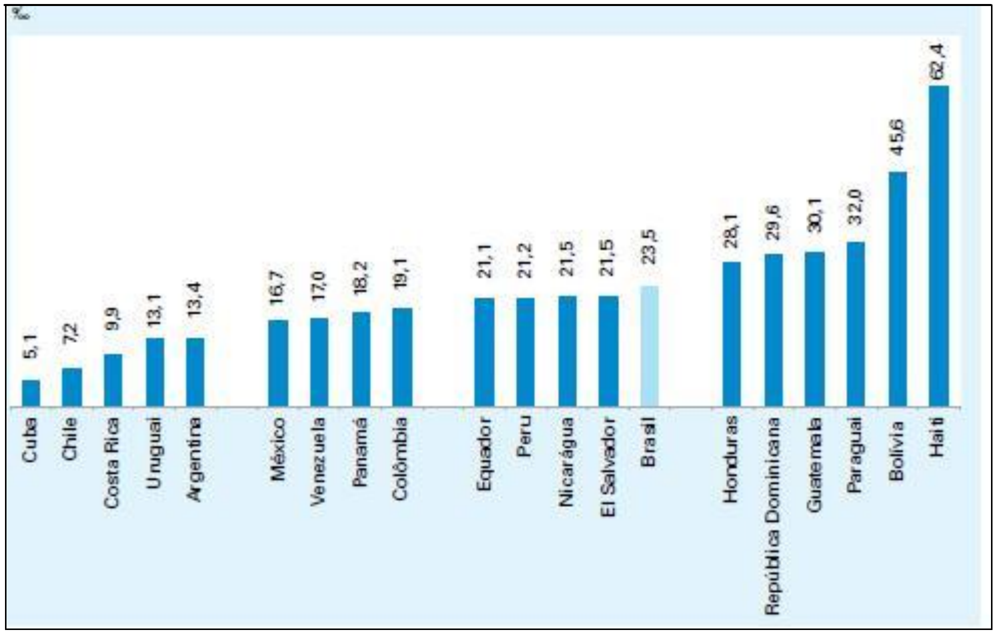
Graph 2: Population pyramid in Brazil – Source: IBGE

It is possible to compare some of those indicators with countries in Latin America and Caribbean. In the graph below, regarding life expectancy, the countries are divided in 3 groups: the first one is composed by countries in which the life expectancy is between 78.8 and 75.0 years (Costa Rica and Ecuador, respectively). In the she second group, life expectancy varies from 73.8 years (Venezuela) to 70.2 years (Guatemala). Brazil belongs to this group, with 72.3 years. The lowest values are 65.5 years in Bolivia and 61.2 years in Haiti.

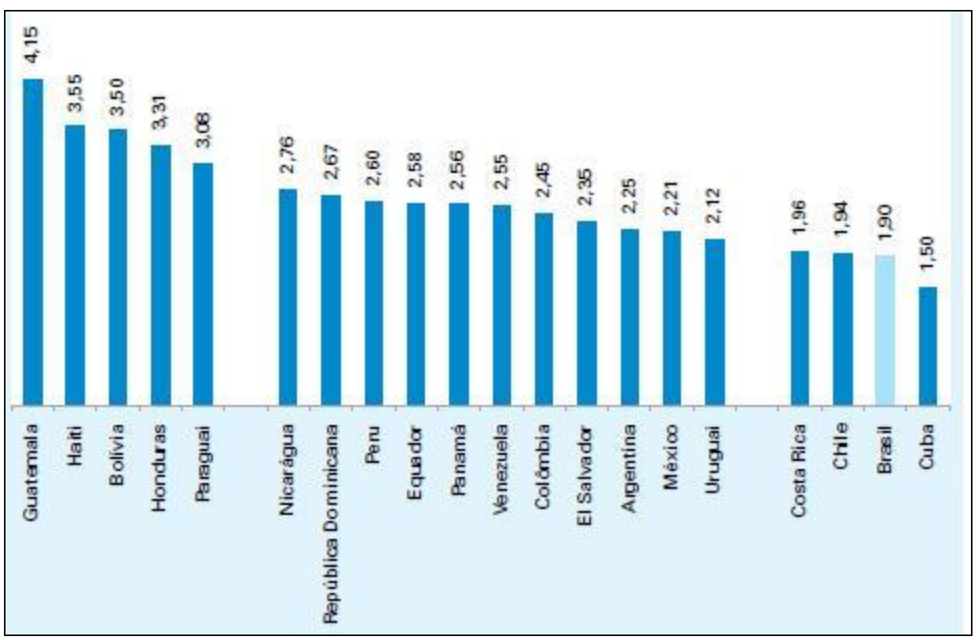


Graph 3 Latin America: life expectancy – source: IBGE

In the next graphs it is possible to see that, although the infant mortality rate in Brazil is relatively high, the fertility rate is one of the lowest, larger only than Cuba's rate.



Graph 4: Latin America: infant mortality rate – source: IBGE



Graph 5: Latin America: fertility rate – source: IBGE

3.1.2 Education

Literacy is defined as the ability to read and write. The adult literacy rate, that is, the percentage of the population over 15 years old that are literate, is an important indicator of the education status of a country. This indicator has slowly and continuously increased in Brazil over the past years.

	2000	2004	2006	2007
Literacy rate (%)	86.4	88.6	89.6	90.0

Table 3: Brazil: literacy rate (%) – source: World Bank

On the other hand, when compared to other countries in South America, Brazil has one of the lowest adult literacy rates.

Uruguay	97.9
Venezuela, RB	95.2
Paraguay	94.6
Colombia	92.7
Bolivia	90.7
Brazil	90.0
Ecuador	84.2

Table 4: Latin America: adult literacy rate (2007) – source: World Bank

3.1.3 Economy

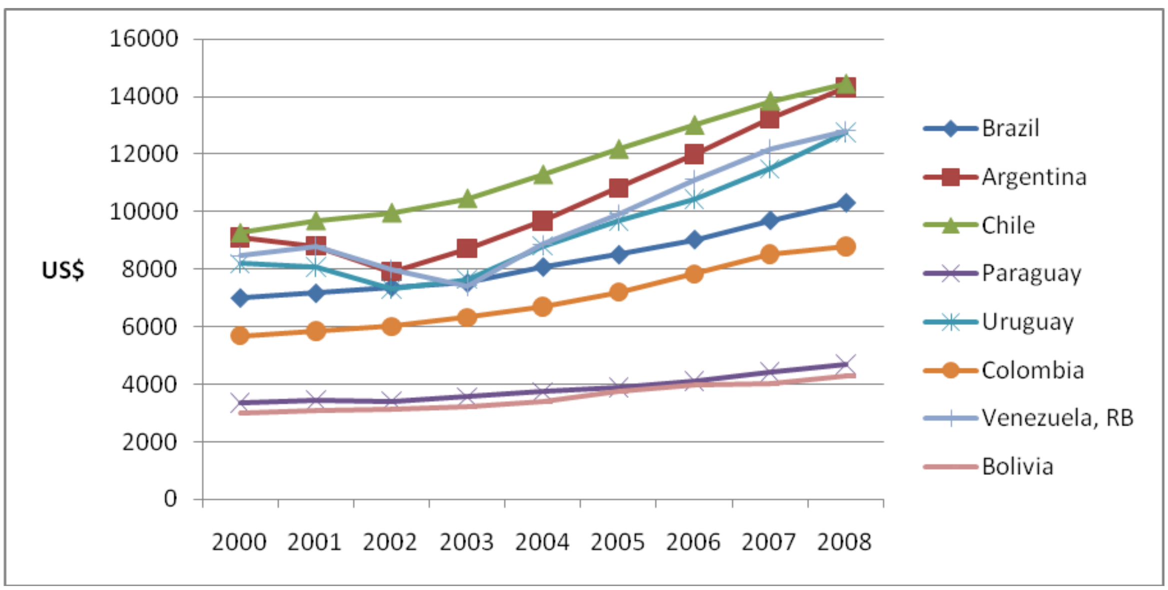
	2004	2005	2006	2007	2008
GDP (billion US$)	664	882	1,089	1,333	1,575
GDP growth (annual %)	5.7	3.2	4.0	5.7	5.1
GDP per capita, PPP (US$)	8,080	8,505	9,026	9,693	10,304

Table 5: Brazil: GDP facts – Source: World Bank

Brazil, with a GDP (Gross Domestic Product) equal to US$ 1.575 trillion (World Bank, 2008), is one of the 10 largest economies in the world. The GDP annual growth over the past 5 years varied between 3.2% and 5.7%. Despite what happened to the vast majority of countries in 2009 with the global financial crisis, Brazil had a satisfactory performance. Its GDP decreased 0.2% in the period, which is definitely not bad if compared to the decrease of 5% to 7% in many countries. This fact shows the maturity and solidity of Brazilian economy. According to the Brazilian Ministry of Finance, the forecast for 2010 is a growth of 5.2%.

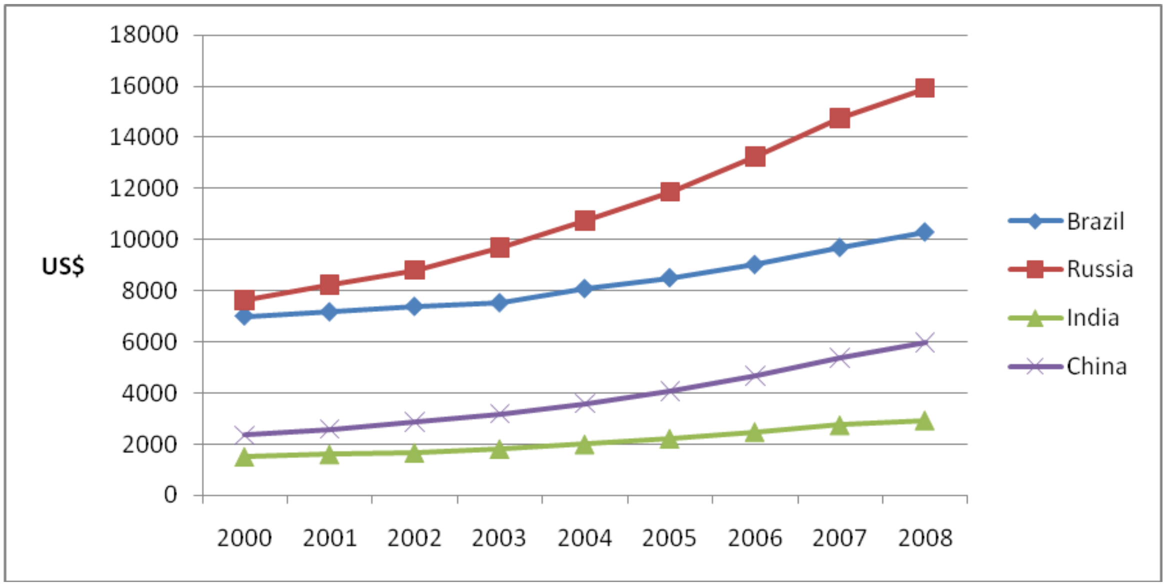
The GDP per capita PPP (Purchasing Power Parity) is a better measurement of the people's wealth in a country, because it considers the cost of living and the inflation rates of the countries. This indicator has steadily increased in Brazil over the past five years, but it is still very low (64th in the world, according to World Bank), which puts in evidence the great disparity in income distribution.

The following two graphs show a comparison of Brazilian GDP per capita (PPP) in two different contexts: inside South America and inside BRIC (group composed of the following emerging economies: Brazil, Russia, India and China).



Graph 6: GDP per capita (PPP): South America – source: World Bank

Brazil (US$ 10,000) occupies an intermediate position in South America, way behind Argentina and Chile (US$ 14,000), but also way ahead Paraguay and Bolivia (US$ 4,500), for example. The figure regarding the BRIC countries, on the other hand, shows that Russian increase in GDP per capita is very fast over the past decade. In fact, it is much faster than the increase of the other countries of the group.



Graph 7: GDP per capita (PPP): BRIC – source: World Bank

3.1.4 HDI (Human Development Index) and Social Contrast

The HDI is a summary composite index that measures a country's average achievements in three basic aspects of human development: health - measured by life expectancy at birth; knowledge - measured by the adult literacy rate and the gross enrolment ratio; and decent standard of living – measured by GDP per capita (PPP US$). The following figure illustrates how the HDI is calculated.

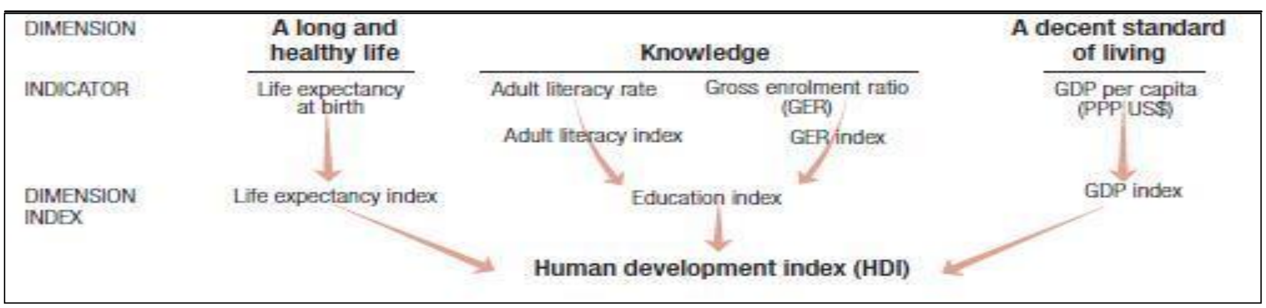
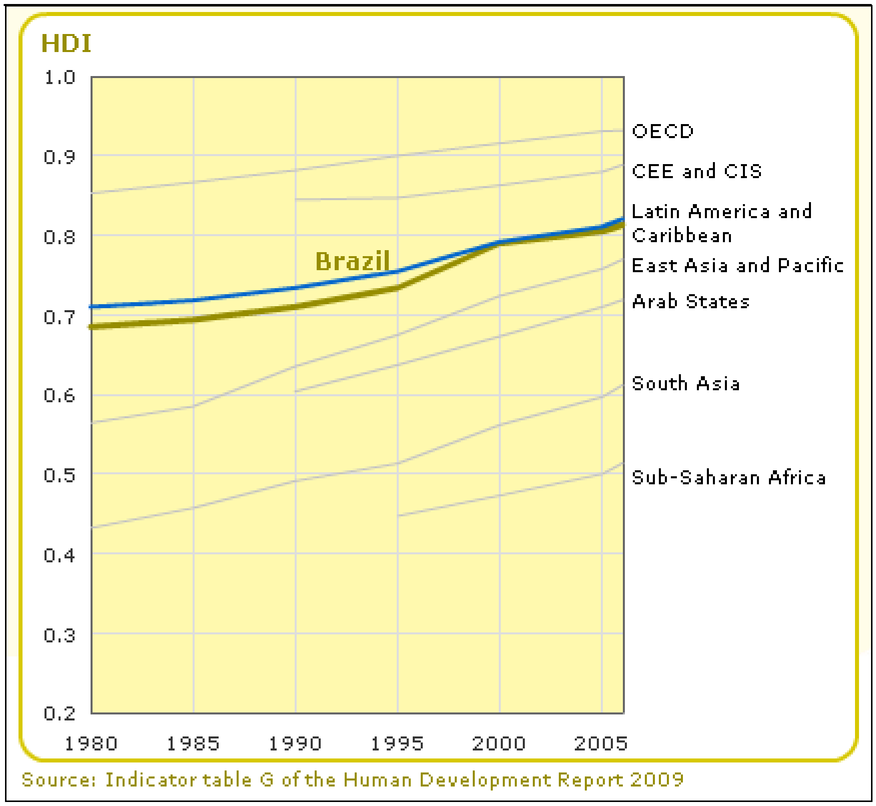


Figure 4 HDI calculation – source: UNDP – United Nations

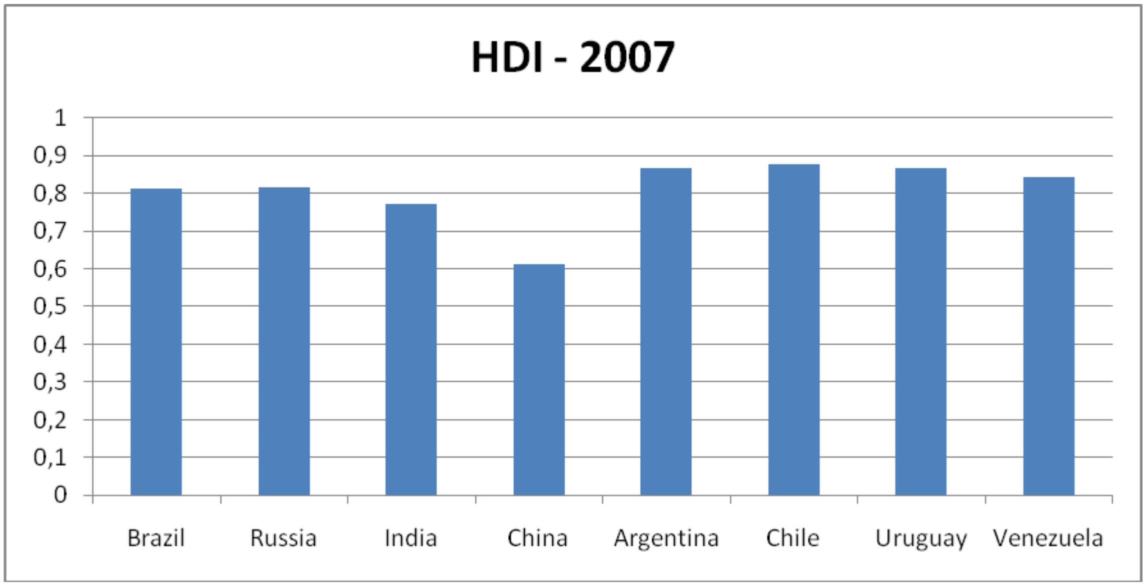
The HDI is considered to be a good manner of assessing the development of a country, and has therefore progressively substituted this assessment by means of a purely economic point of view. The HDI looks beyond the GDP to a broader definition of well-being. It takes into account also the health and the education, which are equally important for the quality of life of people.

Brazil, with an HDI equal to 0.813 (2007, United Nations) occupies the 75th position in the world rank. It is classified as a country with high human development. The graph below shows the evolution of Brazil's HDI compared to Latin America and to the rest of the world over the past decades. An important thing to notice is that Brazil has not reached yet 1980's HDI levels of OECD, putting in evidence the delay of Brazil in comparison to the so-called developed countries regarding human development. Moreover, other regions such as Asia and Arab States show a much greater increasing rate on the HDI.



Graph 8: *HDI evolution: comparison – source: UNDP*

The following graph shows a comparison of 2007 HDI values among the BRIC countries and some countries in South America.



Graph 9: *HDI: comparison - source: UNDP*

Brazil and Russia have a similar HDI, slightly higher than India's and much higher than China's. Inside South America, there are countries in a much better situation than Brazil regarding human development.

The classification of Brazil as a country with high human development does not reflect at all the enormous social contrast existent in Brazil.

The Gini coefficient is the most commonly used measure of inequality. It varies from 0, which reflects complete equality, to 1, which indicates complete inequality (one person has all the income, all others have none). The figure below shows the Gini coefficient for the countries in the world.

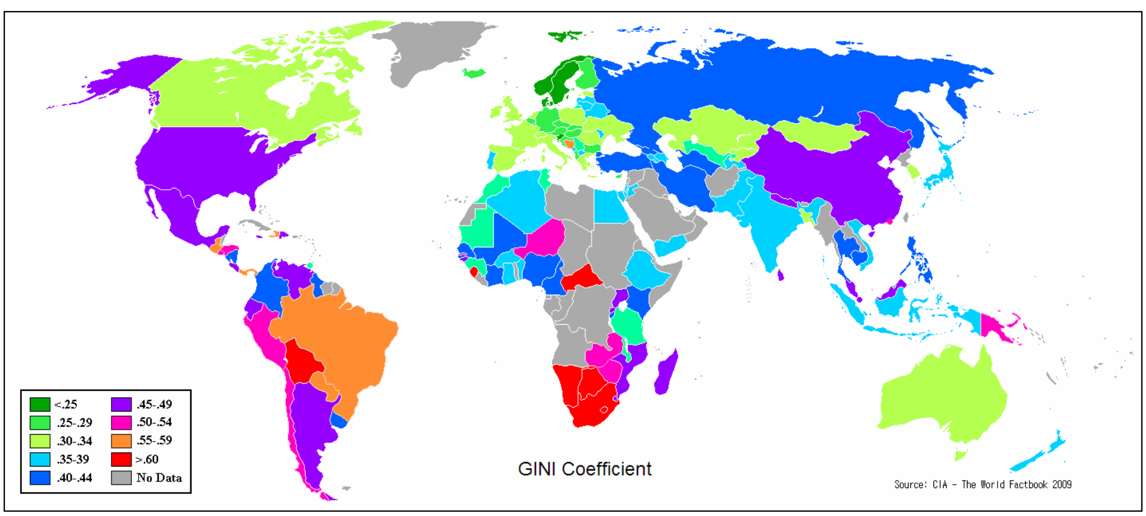


Figure 5: *Gini coefficient in the world – source: CIA*

Brazil, with a very high Gini coefficient (between 0.55 and 0.59), is among the countries with the largest inequality in the world.

The following figure shows a luxury residential building right next to one of Sao Paulo's largest favelas. It is clear from this picture that Brazil, even with a huge economy and relatively good HDI, is still far from being considered a developed country.

Figure 6 Social contrast in Brazil - source: Tuca Vieira, As Cidades do Brasil

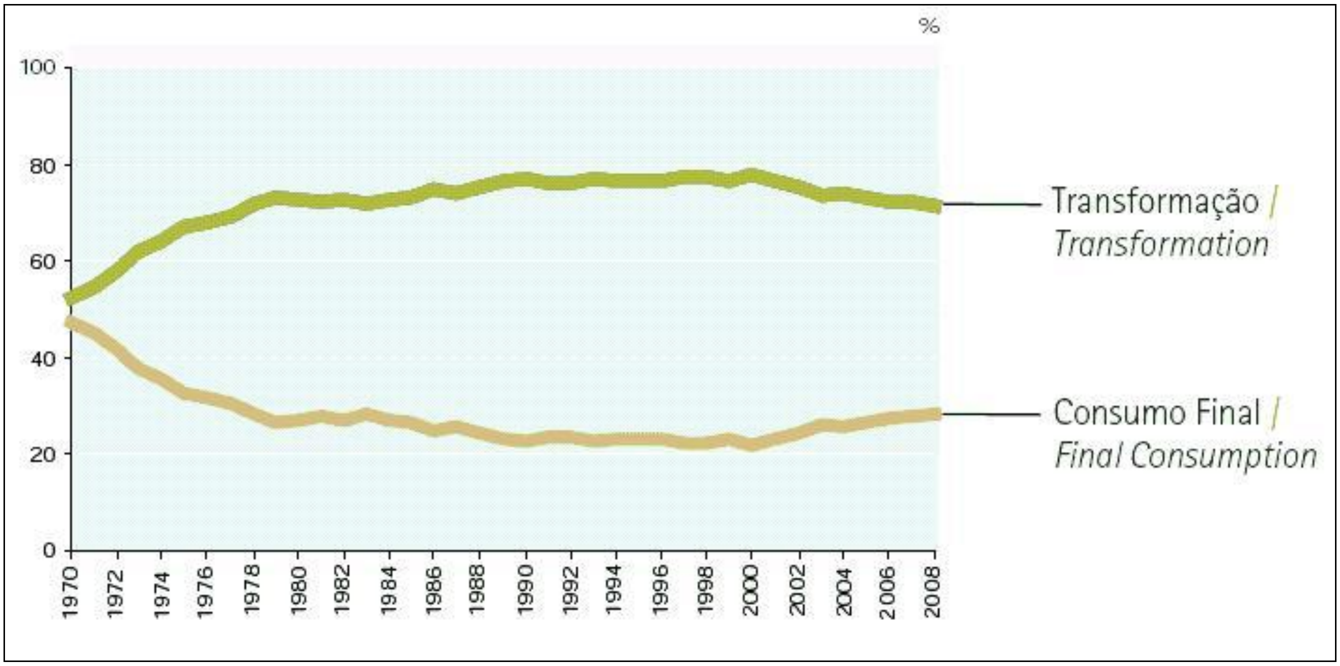
3.2 Energy

In the sequence, the study presents an overview of Brazilian total primary energy supply and an analysis of supply and consumption by each primary source.

3.2.1 Total Primary Energy Supply

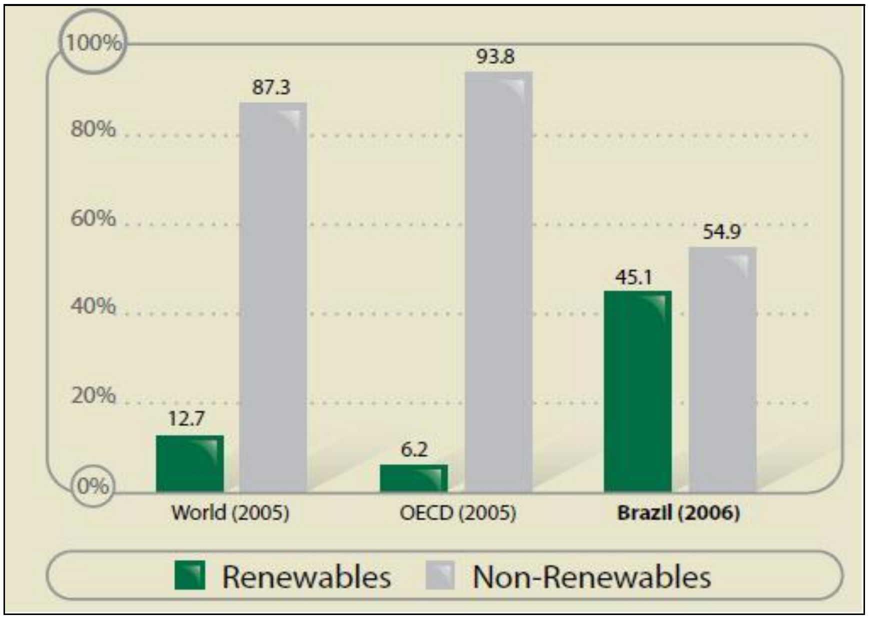
The primary energy supply consists of energy products found in nature in an immediately available form, such as natural gas, coal, animal and vegetable residues, solar and wind energy etc. This amount of energy is available for transformation and/or final consumption. The graph below shows the evolution of the primary energy supply share between transformation and final consumption.

In 1970, the final consumption of primary energy was almost the same as the amount of the primary energy undergoing transformation. This can be explained due to the importance that products such as firewood had back then, being directly used for heating in residences, industrial furnace feeding etc. As time went by, the primary energy has increasingly been transformed, especially with respect to petroleum by-products. In the last years there is again an increase of the share of final consumption, but this time it is related to the development of new renewable technologies such as wind and solar energy.



Graph 10: Primary energy consumption in Brazil - source: Balanço Energético Nacional 2009

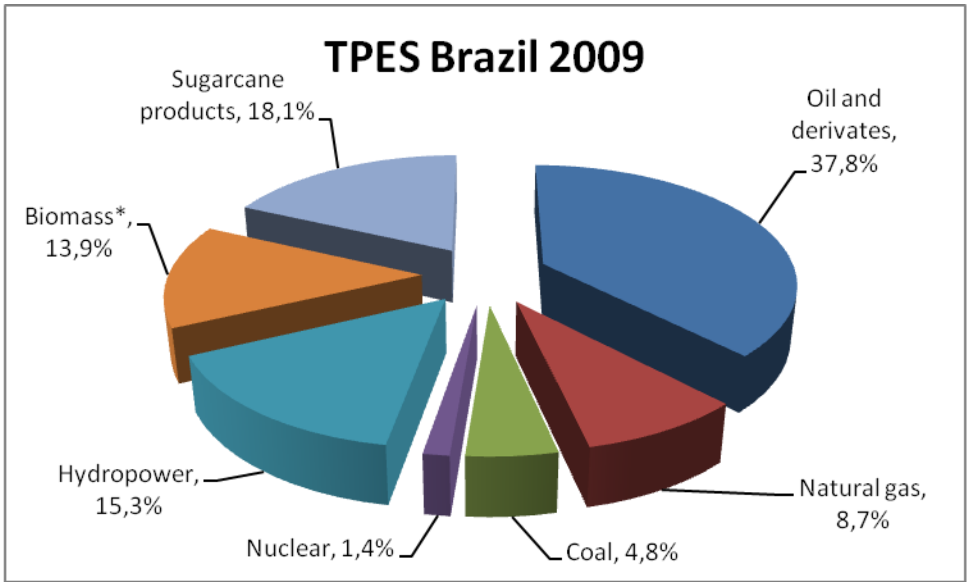
An important thing to notice is the significance of renewable sources in the Brazilian energy mix, which accounted for 45.1% of the total primary energy supply in 2006. This amount is way higher than the world average, and even higher than the OECD average, which was only 6.2% in 2006.



Graph 11: Renewables x Non-Renewables: comparison – source: Balanço Energético Nacional 2007

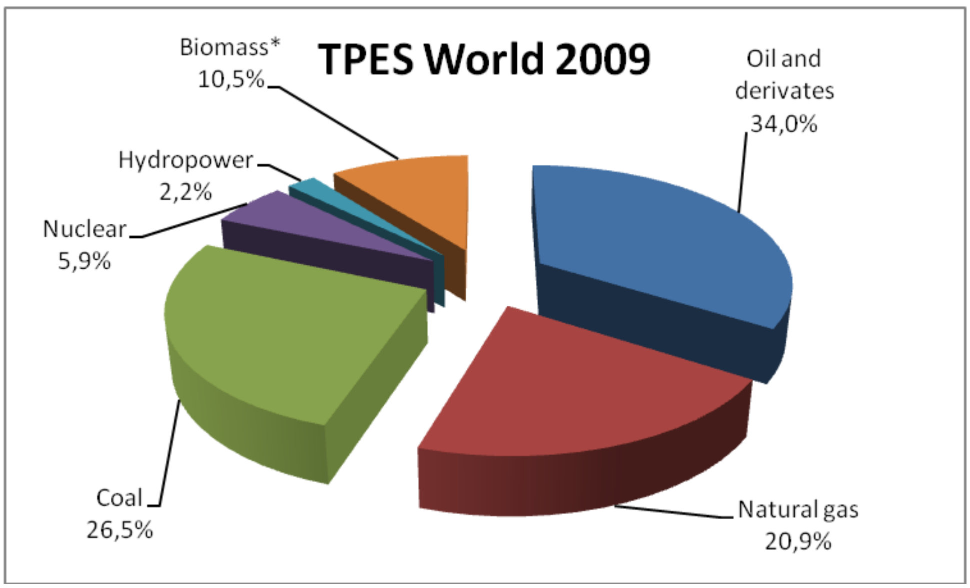
Having a high share of renewable sources in the energy mix means lower CO2 emissions and, in general, lower environmental impacts. Moreover, a diversified energy mix prevents a country from being dependent on a determined energy source, and therefore vulnerable from the political and economic point of view.

The detailed energy mix in 2009 is presented in the graph below. The high participation of renewable energy in the total primary energy supply can be explained by the effort by the government on developing alternative sources of energy to reduce the country's dependence on oil, especially after the oil shocks in the 70s. Ethanol from sugarcane was the main product developed through the Pro-Alcool program, as mentioned before.



Graph 12: Brazil TPES 2009 – source: Balanço Energético Nacional 2010, preliminary results

Note: *includes firewood, vegetable coal and other renewables



Graph 13: World TPES 2009 - source: Balanço Energético Nacional 2010, preliminary results

Note: *includes renewable fuels, urban solid waste, solar, wind and geothermal energy, among others

The Brazilian TPES is rather different than the world average, as it can be observed from the graphs above. The only source with similar share is the oil and derivates. The other non-renewable sources are much less significant in Brazil than the world average. Natural gas share in Brazil energy mix is less than half of this source share in the world. Regarding coal, the situation is even more dramatic: it is a major component of energy supply worldwide (26.5% of the total) but accounts for only 4.8% of Brazil energy mix.

The renewables, as seen before, are much more significant in Brazil than in the world average. Hydropower participation in Brazil energy mix is almost 7 times its participation in the world mix, whereas biomass participation in the Brazilian TPES (taking into account sugarcane products) is 3 times its value in the world TPES.

Graph 14: TPES Brazil – source: Balanço Energético Nacional 2009

The graph above shows the evolution of the total primary energy supply in Brazil. In 1940 the main and almost exclusive energy source was firewood. From 1960, oil, by-products and natural gas supply start to grow very rapidly. From 1970, 2 sources start to be significant: hydropower and sugarcane products. Hydropower seems to have stabilized, whereas sugarcane products supply tends to enlarge especially due to the increasing demand (both domestic and international) for ethanol.

3.2.2 Energy supply and consumption by source

The primary sources considered are the most relevant to the TPES: oil and derivates, natural gas, coal, nuclear energy, hydropower and biomass. For each source it will be considered the potential, production and consumption in the world and in Brazil.

3.2.2.1 Oil and derivates

The table below shows the flow of oil in Brazil over time. 2008 was a non-usual year since oil prices raised strongly from January to June and then dropped more than 70% due to the global financial crisis, to a closing price of US$ 40 per barrel. This impacted imports and consumption of oil and its derivates, especially diesel oil which showed an increase of 7.5% in the consumption. The oil production in 2008 was 105,618 m^3, considerably higher than the total consumption which was 102,431 m^3.

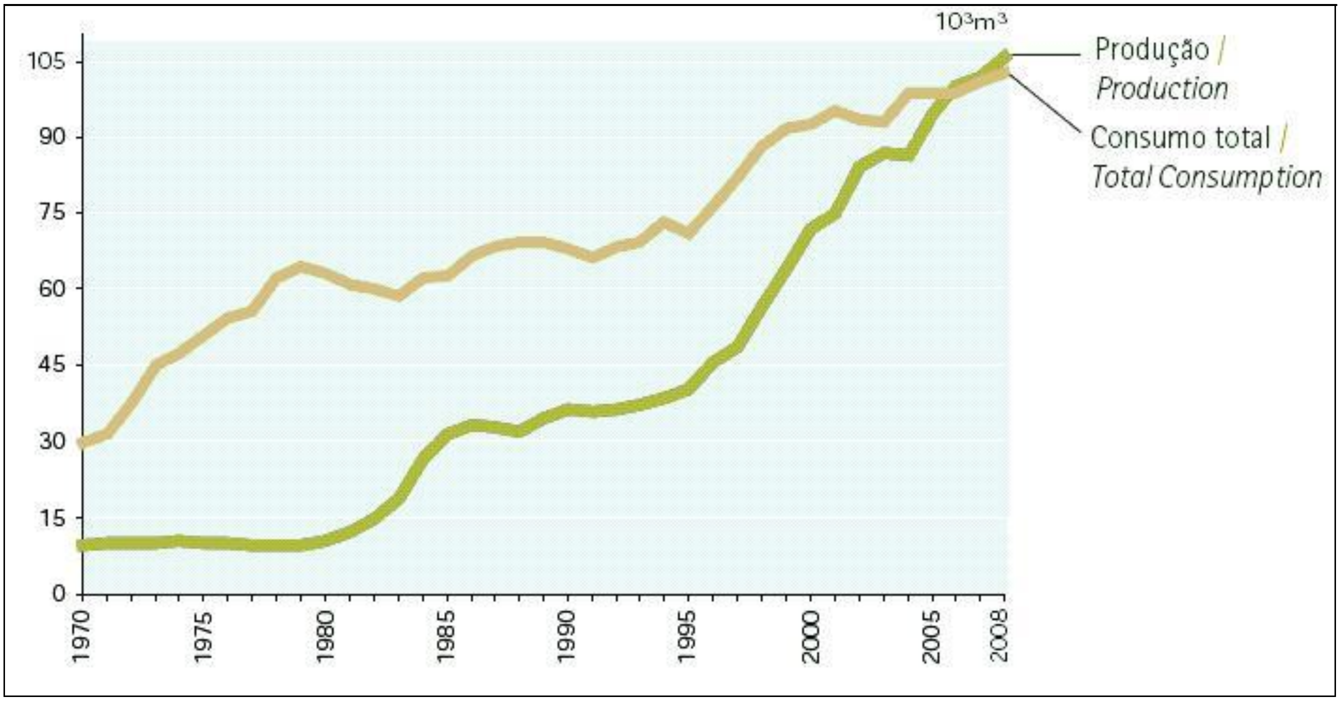
Unidade: 10^3 m^3											Unit: 10^3 m^3
FLUXO	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	FLOW
PRODUÇÃO[1]	63.921	71.844	75.014	84.434	87.024	86.211	94.997	100.241	101.755	105.618	PRODUCTION[1]
IMPORTAÇÃO[2]	27.289	23.109	24.243	22.165	19.885	26.162	19.916	19.421	24.120	22.122	IMPORT[2]
EXPORTAÇÃO	-34	-1.084	-6.428	-13.635	-14.030	-13.395	-15.930	-21.357	-24.454	-25.138	EXPORT
VAR.EST.PERDAS E AJUSTES	574	-1.432	2.655	601	135	-130	-156	804	-363	-171	VAR.INV.,LOSSES AND ADJUSTMENTS
CONSUMO TOTAL	91.750	92.437	95.484	93.565	93.014	98.848	98.827	99.109	101.058	102.431	TOTAL CONSUMPTION
TRANSFORMAÇÃO	91.750	92.437	95.484	93.565	93.014	98.848	98.827	99.109	101.058	102.431	TRANSFORMATION

[1] Não inclui líquido de Gás Natural / [1] *Does not include domestic NGL*
[2] Inclui condensados de Nafta e LGN importado / [2] *Includes condensed naphta and imported NGL*

Table 6: *Oil in Brazil - source: Balanço Energético Nacional 2009*

The self-sufficiency in oil was confirmed in 2009, according to the preliminary results of the national energy balance 2010. For the 4th consecutive year, the oil production was higher than its total consumption, as it can be seen from the graph below (until 2008).

Still according to the preliminary results of the national energy balance 2010, the production of crude oil in 2009 grew by 7.3% with respect to the previous year, placing Brazil among the 15 biggest producers in the world.

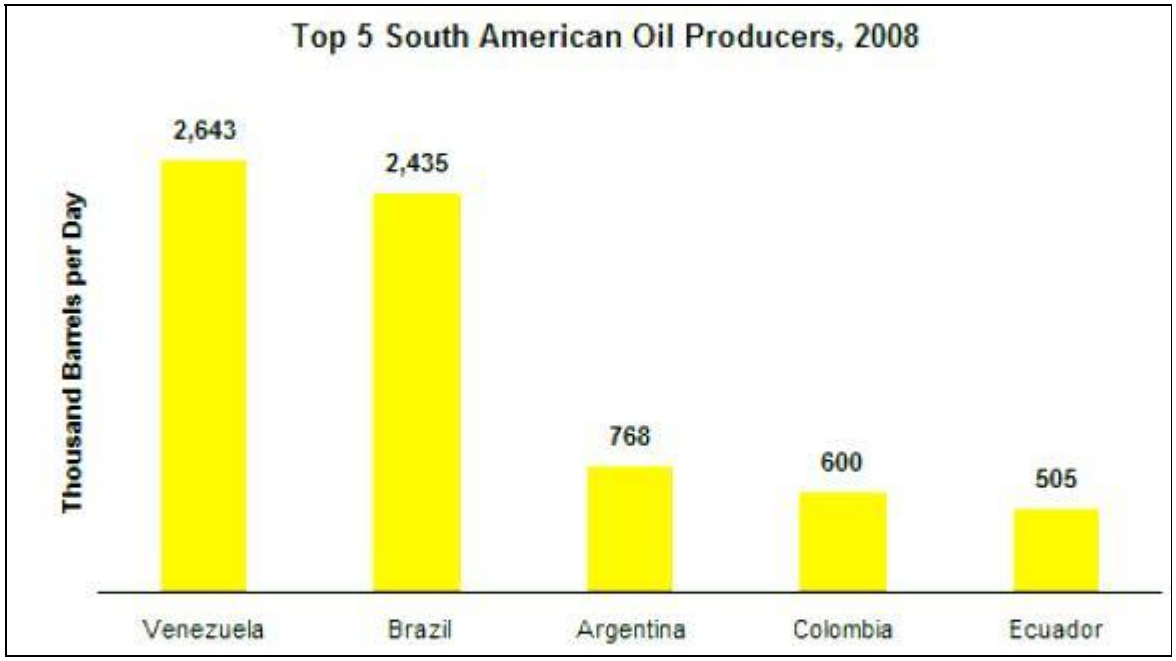


Graph 15: Oil production x consumption in Brazil - source: Balanço Energético Nacional 200909

The Brazilian oil company Petrobras, which is controlled by the government, is the dominant player in Brazil's oil sector. The company held a monopoly on all activities related to oil until 1997, when the sector was opened to competition. The National Petroleum Agency (ANP, acronym in Portuguese) was then created to monitor the oil sector. This governmental agency is responsible for issuing exploration and production licenses and ensuring compliance with regulations.

Despite the opening of the sector to private actors in the late 1990s, foreign-operated oil projects are not common in Brazil and represent a small share of total oil production.

The largest oil-production region of the country is Rio de Janeiro state, which contains over 80% of Brazil's total production. Most of Brazil's crude oil production is offshore in very deep water.



Graph 16: Top 5 South American Producers - source: EIA

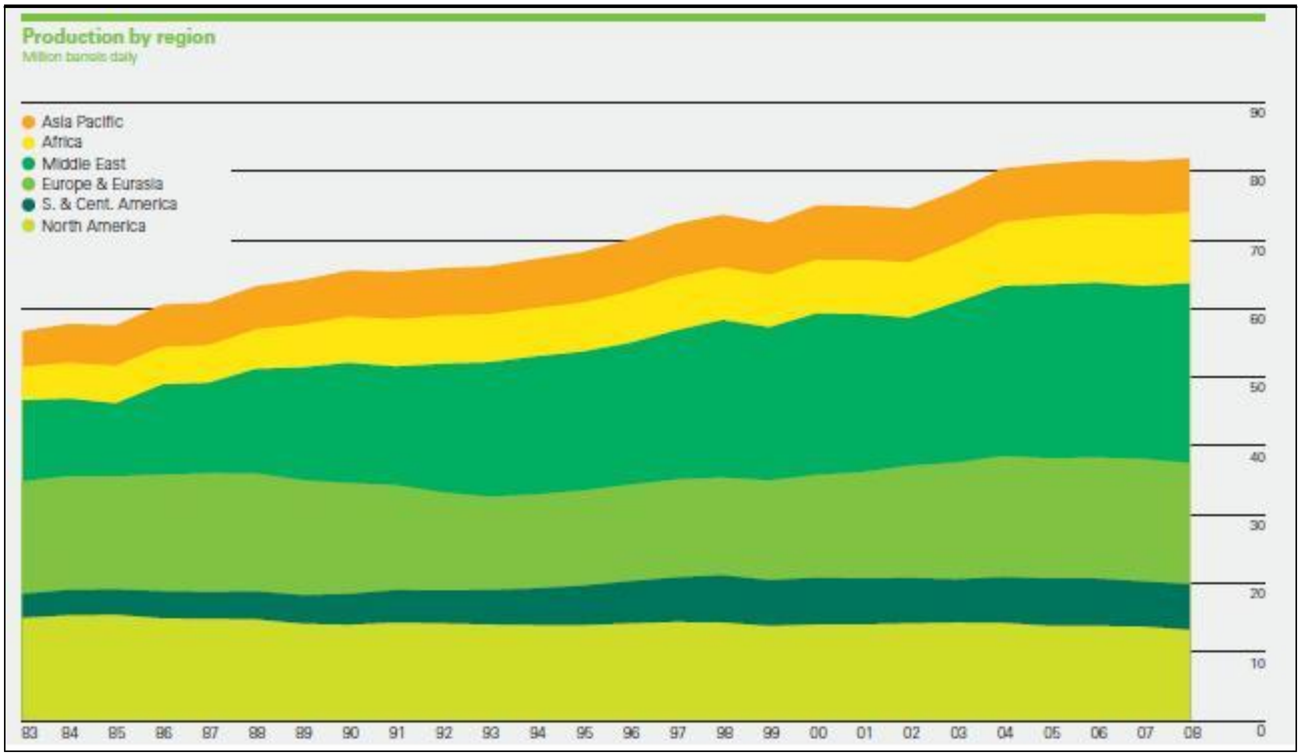
A consortium headed by Petrobras discovered, in 2006, a pre-salt field containing an estimated number of 5-8 billion barrels of recoverable resources (including both oil and natural gas). The subsalt zone is between 5 and 7 thousand meters below the ocean surface. This field, named Tupi, was the largest oil discovery since the supergiant Kashagan field in Kazakhistan. Following Tupi, many other pre-salt discoveries were announced. Estimates of the total extent of oil and natural gas reserves in the entire subsalt reserve have exceeded 50 billion barrels of oil equivalent.

The pre-salt discoveries immediately transformed Brazil's oil sector, and the potential impact over world oil markets is vast. However, the difficulty of access to the reserves, due to large depths and pressures involved with subsalt oil production, confirms that there are many technical issues that must be overcome. Large-scale production from the pre-salt reserves will probably not occur in less than 5 years.

Transpetro, a subsidiary of Petrobras, operates Brazil's crude oil transport network. The system consists of 7,000 kilometers of pipelines, which enables the transportation of crude oil from production facilities and import terminals on the coast to inland refineries and consumption centers.

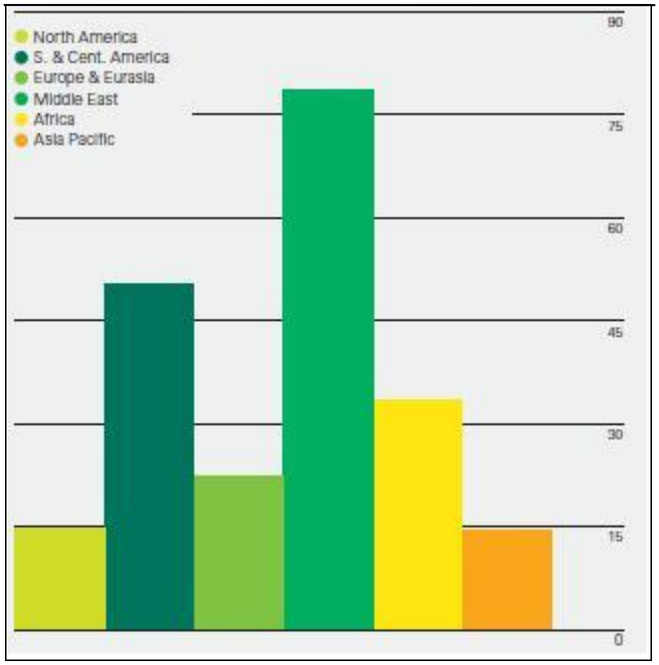
Brazil has a crude oil refining capacity of 1.9 million barrels per day distributed among 13 refineries, 11 of them operated by Petrobras. Brazil exports some of its heavy crude oil production and imports light crude oil. Gasoline prices in Brazil are relatively high when compared to international levels: according to the International Fuel Price Survey conducted by GTZ, regular gasoline prices averaged US$ 1.26 per liter in November 2008, against US$ 0.56 per liter in the United States and US$ 0.78 per liter in Argentina.

The oil production in South America is much lower than the production in other regions of the world, as it can be observed from the graph below. In fact, South America is the region that produces less oil – approximately 6 million barrels daily, whereas the Middle East region produces around 25 million barrels daily.



Graph 17: Oil production by region - source: BP report 2009

On the other hand, the reserve-to-production ratio (remaining amount of a non-renewable resource) in South America is very high: 50 years, as it can be derived from the graph below. This ratio is only smaller than the ratio in the Middle East. This can be explained by the large reserves in Venezuela and the recently discovered pre-salt reserves in Brazil.



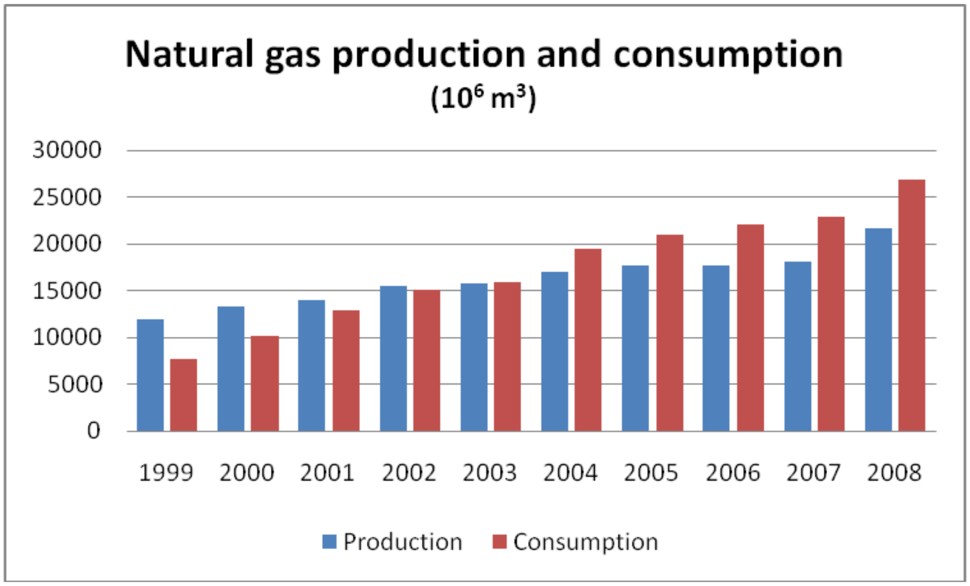
Graph 18: Oil reserve-to-production ratio - source: BP report 2009

3.2.2.2 Natural Gas

Natural gas accounts for a small part of Brazil's total energy mix: only 8.7%, while the world average is 20.9% of the TPES (2009). It is mostly used as a substitute for fuel oil in industrial and power-generating applications; therefore natural gas demand is expected to rise whenever oil prices go up. The raise of natural gas imports, especially from 2004, has increased available supplies, facilitating the growth in domestic consumption.

Unidade: 10^6 m³											Unit: 10^6 m³
FLUXO	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	FLOW
PRODUÇÃO	11.898	13.283	13.998	15.525	15.792	16.971	17.699	17.706	18.152	21.593	PRODUCTION
IMPORTAÇÃO	400	2.211	4.608	5.369	5.055	8.086	8.998	9.789	10.334	11.348	IMPORT
VAR.EST.PERDAS E AJUSTES [1]	-4.566	-5.403	-5.777	-5.839	-4.906	-5.619	-5.719	-5.458	-5.573	-6.105	VAR.INV.,LOSSES AND ADJUSTMEN. [1]
CONSUMO TOTAL	7.732	10.091	12.829	15.055	15.941	19.438	20.978	22.037	22.913	26.836	TOTAL CONSUMPTION

Table 7: Natural Gas in Brazil - source: Balanço Energético Nacional 2009

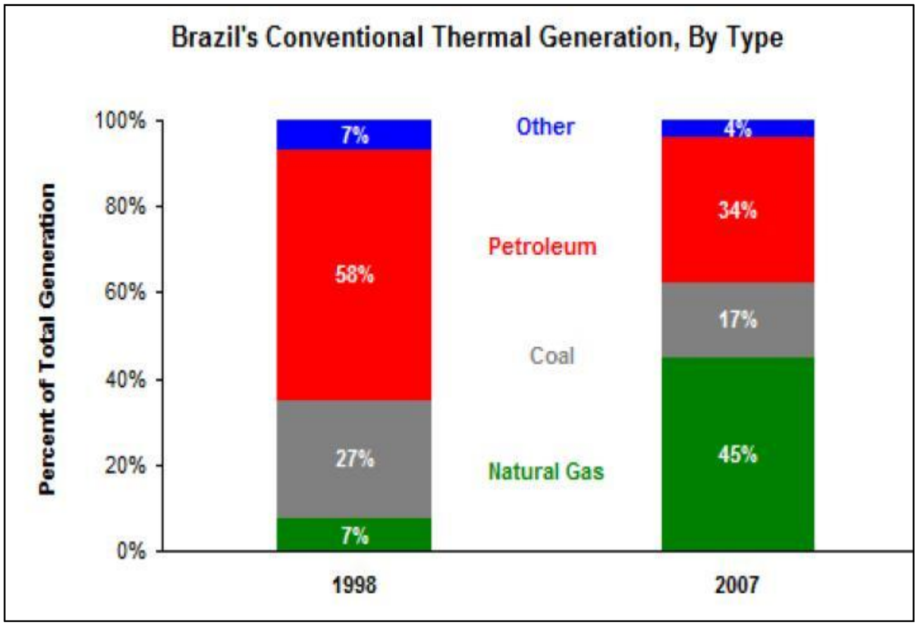


Graph 19: Natural gas production and consumption in Brazil
Source: Balanço Energético Nacional 2009

Most of the production occurs from offshore fields in the Campos Basin in Rio de Janeiro state. Onshore production occurs in Amazonas and Bahia and is mostly for local consumption due to the shortage of transportation infrastructure. Petrobras is the largest producer of natural gas in Brazil, controlling over 90% of Brazil's natural gas reserves.

As it happened for oil, recent discoveries in Brazil's offshore subsalt have increased significantly the potential of natural gas production in the country. The subsalt areas are expected to increase Brazil's total natural gas reserves by 50%, according to EIA.

The figure below shows that the share represented by natural gas in thermal electricity production has grown substantially in recent years, from 7% in 1998 to 45% in 2007.



Graph 20: Brazil's conventional thermal generation, by type - source: Ministry of Mines and Energy

Brazil's domestic natural gas transport system is operated by Petrobras. The network has over 6,500 km of pipelines, mostly in the southeast and northeast parts of the country, as it can be seen from the figure below. The network consists of main systems in the southeast, northeast and the state of Espirito Santo. These systems were not interconnected until the inauguration of GASENE (Southeast Northeast Interconnection Gas Pipeline), on 30 March 2010. It covers a total distance of 1,387 km and transports natural gas produced in Southeast Brazil, imported from Bolivia, or regasified at the Guanabara Bay LNG terminal, to the Northeastern states.

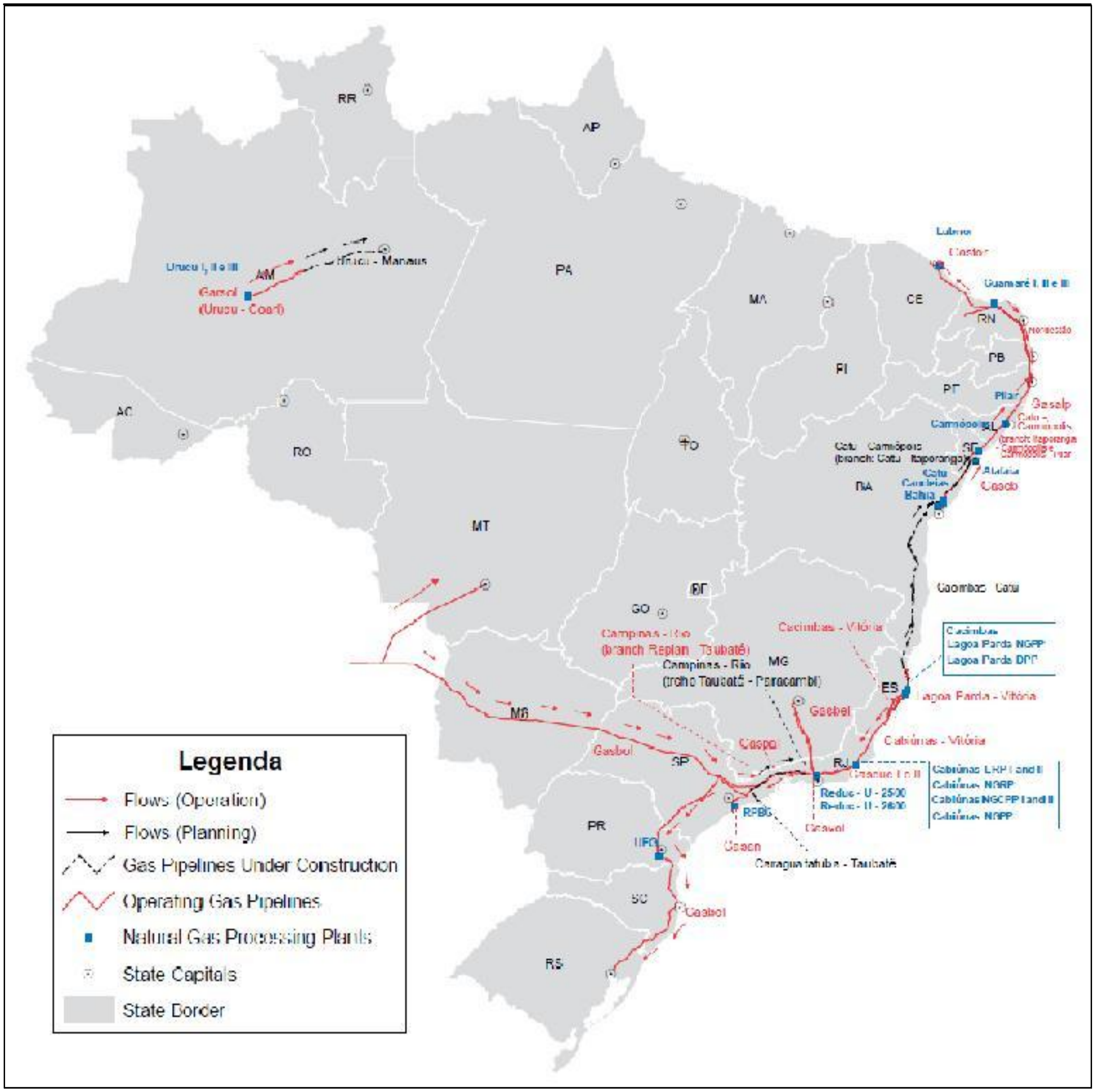


Figure 7: Infrastructure for natural gas production and transportation - 2008
Source: ANP

A lack of natural gas transportation infrastructure has delayed exploration and production in the interior regions of the country. On 26 November 2009 the Urucu-Manaus pipeline was inaugurated, allowing the use of natural gas from Urucu, in the Amazonas state. It is Brazil's largest onshore natural gas reserve. The gas is used to substitute diesel and fuel oil for the electricity production in the state of Amazonas, especially in Manaus, its capital.

Brazil currently imports natural gas from three sources: Bolivia, Argentina and liquefied natural gas (LNG). Natural gas imports have nearly doubled over the past five years, and according to Petrobras, they will continue to rise in the medium term. Most of the additional import volumes will probably come in the form of LNG.

Country	Natural gas imports (10^6 m^3)										08/07 %
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Total	**400**	**2,211**	**4,603**	**5,269**	**5,947**	**8,086**	**8,998**	**9,789**	**10,334**	**11,348**	**9.81**
Argentina	-	106	753	492	350	451	349	475	166	135	-18.50
Bolivia	400	2,105	3,850	4,777	5,597	7,635	8,648	9,314	10,168	11,178	9.93
Trinidad e Tobago [1]	-	-	-	-	-	-	-	-	-	35	-

Source: ANP/SCM, as per Ordinance ANP nº 43/1998.
Note: Brazilian natural gas imports started in July, 1999.
[1] Refers to the imported NGL considering its volume in gaseous state.

Table 8: Natural gas imports, Brazil - source: ANP

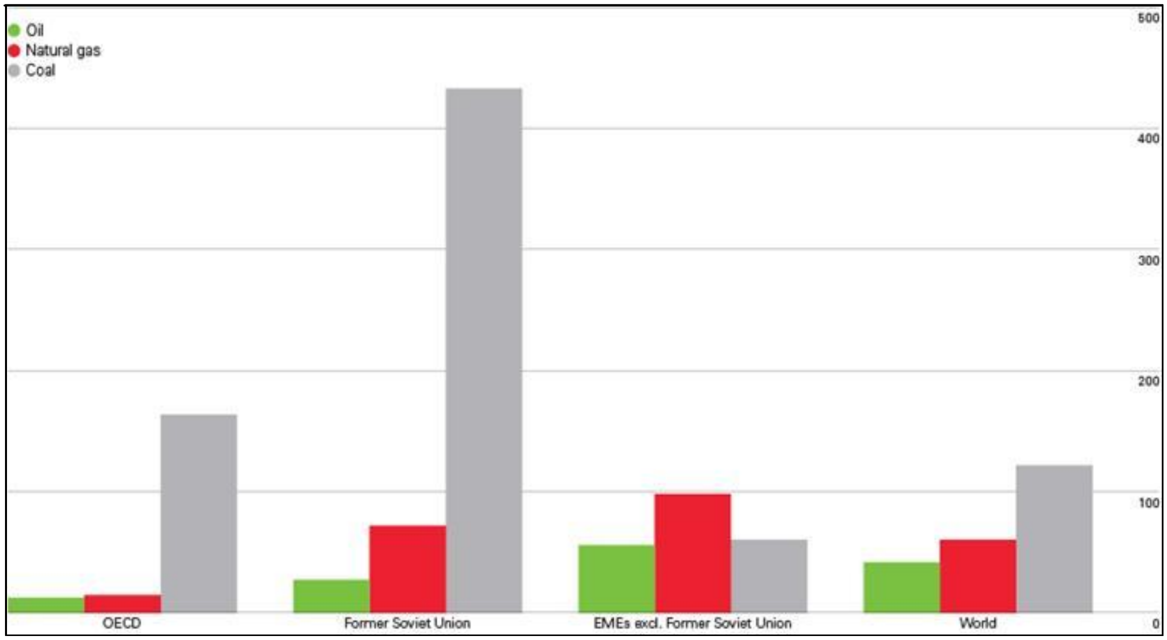
The natural gas imported from Bolivia comes through the Gasbol pipeline, which links Santa Cruz (Bolivia) to Porto Alegre (Brazil) via Sao Paulo. It is the longest natural gas pipeline in South America, measuring 3.150 km. Brazil imported 11.178 million m^3 of natural gas from Bolivia in 2008, which means 98.5% of the total imports.

Brazil has two LNG regasification terminals, both installed in the last two years: the Pecem terminal in the northeast, and the Guanabara Bay terminal in the southeast. Pecem received its first LNG cargo from Trinidad and Tobago in July 2008, while the Guanabara Bay terminal was inaugurated in May 2009. Brazil received from Trinidad and Tobago 35 million m^3 of natural gas in the form of LNG in 2008.

3.2.2.3 Coal

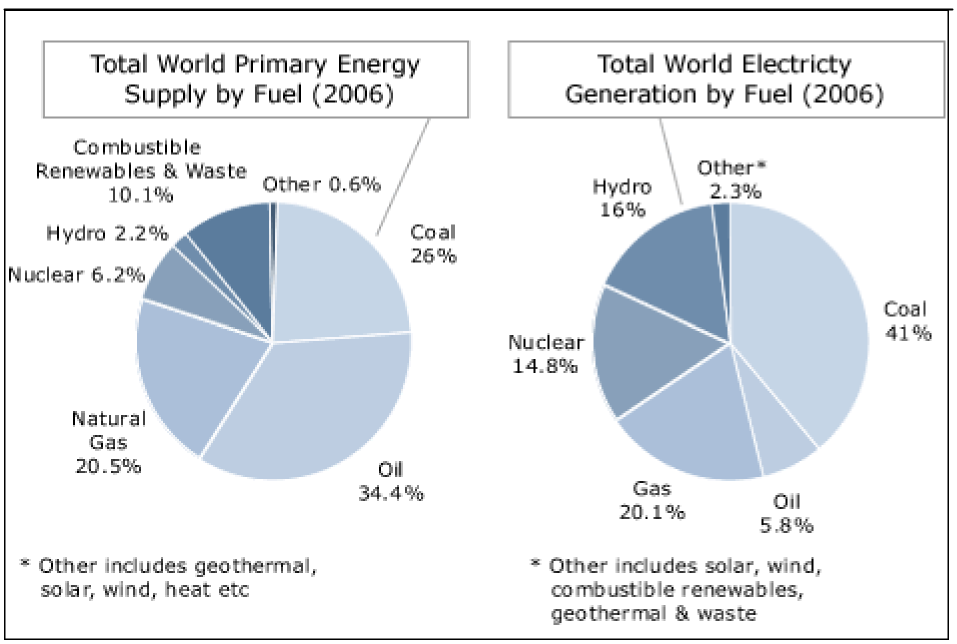
Coal is largely used in the world for electricity production in thermoelectric plants and for industrial purposes, especially steel production. There are many kinds of coal, according to the percentage of carbon in it. Coal containing low percentage of carbon is mainly used for electricity production, whereas industrial usage requires coal containing a higher percentage of carbon.

The figure below shows that coal is the world's most abundant fossil fuel, with a global reserve-to-production ratio of more than 120 years. In former Soviet Union, the R/P ratio is higher than 400 years.



Graph 21: Fossil fuel reserves-to-production (R/P) ratios at end 2008

Source: BP



Graph 22 World TPES by fuel and total world electricity generation in 2006 – source: WEO 2006

Coal represents 26% of the Total Primary Energy Supply, an amount which is smaller only than oil. When it comes to electricity generation, it responds for impressive 41% of the total world generation.

In Brazil, it represents only 4.8% of the TPES. According to the 2008 BP Statistical Energy

Survey, Brazil had at the end of 2007 coal reserves of 10,113 million tonne, occupying the 10th place in the world rank. In spite of this, the coal industry does not constitute a large part of the country's mineral industry. It is in fact Latin America's largest coal consumer based on its well developed steel industry. In 2008 Brazil consumed 15 Mt of metallurgical coal, most of it imported mainly from the US, Australia, China, Canada and South Africa.

For electricity generation, the coal used is the steam coal, a low-carbon type of coal produced in Brazil. There is no import/export of this type of coal, as it can be seen from the figure below. Brazil produced in 2008 6.3 Mt of steam coal.

Unidade: 10^3 t											Unit: 10^3 t
FLUXO	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	FLOW
PRODUÇÃO	5.630	6.791	5.639	5.046	4.587	5.192	6.045	5.745	5.821	6.351	PRODUCTION
EXPORTAÇÃO/IMPORTAÇÃO	0	0	0	0	0	0	0	0	0	0	EXPORT/IMPORT
VAR.EST.PERDAS E AJUSTES	1.116	176	1.278	-316	316	160	-212	604	100	-898	VAR.INV.,LOSSES AND ADJUSTMENTS
CONSUMO TOTAL	6.746	6.967	6.917	4.730	4.903	5.352	5.833	6.349	5.920	5.453	TOTAL CONSUMPTION

Table 9: Steam Coal in Brazil – source: Balanço Energético Nacional 2009

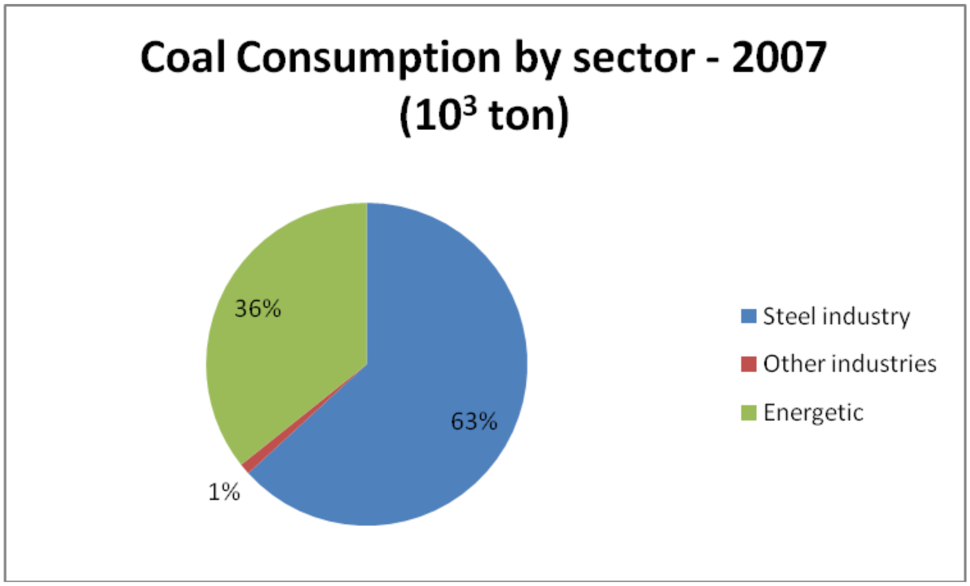
Unidade: 10^3 t											Unit: 10^3 t
FLUXO	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	FLOW
PRODUÇÃO	30	15	15	98	59	214	210	136	144	260	PRODUCTION
IMPORTAÇÃO	12.772	13.234	13.000	13.012	13.493	14.081	13.699	13.398	14.864	15.311	IMPORT
VAR.EST.PERDAS E AJUSTES	-406	-23	-158	-101	-330	82	107	111	-46	-376	VAR.INV.,LOSSES AND ADJUSTMENTS
CONSUMO TOTAL	12.396	13.226	12.857	13.009	13.222	14.377	14.016	13.645	14.962	15.195	TOTAL CONSUMPTION

Table 10: Metallurgical Coal in Brazil – source: Balanço Energético Nacional 2009

Brazil's leading coal producer is Copelmi Mineraçao. The company holds the concession of more than 3 billion tons of coal in several areas of the State of Rio Grande do Sul and currently achieves a production of more than 2 Mt of raw coal per year, generating more than 1 Mt of product per year through its mining operations.

The biggest coal deposits in Brazil are located in the south, at Rio Grande do Sul and Santa Catarina states. These states respond for 89.25% and 10.41% of the total volume of reserves, respectively.

The graph below shows coal consumption in Brazil by sector. Almost 2 thirds are used in the steel industry (metallurgical coal) and 1 third is used in electric power production (steam coal).



Graph 23: Coal consumption by sector in Brazil - source: Ministério de Minas e Energia

When projecting the diversification of the TPES, the 10-year Electric Energy Expansion Plan (2006/2015) forecasts the growth in coal usage. The federal government reserved approximately 25 million Euros to the thermoelectric plants, through the Program for the Growth Acceleration (in Portuguese, PAC: Programa de Aceleraçao do Crescimento). Two new plants are under construction and are supposed to be operating by the end of 2010 and 5 others projects, with total power of 3,148 MW, are being analyzed.

3.2.2.4 Nuclear

Nuclear energy, produced from the atom of uranium, is an important alternative to fossil fuels. In the past years it has been considered a clean source, because of the low levels of CO2 emissions, the main greenhouse gas responsible for global warming. Besides this environmental advantage, another factor that contributes to the expansion of nuclear energy is the existence of abundant uranium reserves in the planet, which ensures the supply security in medium and long terms.

The opposition to nuclear energy is based on some factors: occurrence of major accidents in the past, such as Three Mile Island and Chernobyl; the waste produced in the process, which is very difficult to dispose of; and the fact that the uranium atom fission process used in power generation is the same used to produce the atomic bomb.

País	tU
Austrália	1.143.000
Cazaquistão	816.099
Canadá	443.800
Estados Unidos	342.000
África do Sul	340.596
Namíbia	282.359
Brasil	**278.700**
Nigéria	225.459
Rússia	172.402
Ubequistão	89.836
Jordânia	78.975
Índia	64.840
Mongólia	61.950
China	59.723
Outros Países	227.588
Total	**4.627.327**

(*) tU: toneladas de urânio.

Table 11: Uranium global reserves (2007) – source: World Energy Council

The table above shows that the uranium global reserves in 2007 were in total 4.6 Mt. Australia, Kazakhstan and Canada respond for more than 50% of the total volume. Brazil is the 7th on the ranking, even though only 25% of its territory was prospected in search of this mineral, according to Aneel (Electric Energy National Agency – in Portuguese, Agencia Nacional de Energia Elétrica). The main uranium deposit in Brazil, in Bahia state, has a volume of uranium sufficient to supply Brazil's nuclear needs for 100 years.

Brazil has two nuclear power plants, the 657-megawatt (MW) Angra I and the 1,350-MW Angra II. State-owned Eletronuclear, a subsidiary of Eletrobras, operates both plants. Construction of a third plant, the 1,350-MW Angra III, started in 1986, but was never finished. In 2008, construction began again, with completion scheduled for 2014.

In 2008, Angra I and Angra II were responsible for 2.8% of the total electricity production of the country. When it comes to TPES, the participation of nuclear energy in 2009 was 1.4%, whereas the global average is 5.9%.

The figure below shows the flow of uranium in Brazil over the past years. The production/import of this mineral has varied largely. In 2005, for example, Brazil imported almost 4 times the volume of uranium produced in the same year. In 2008, on the other hand, the production was 389.6 t, whereas the import responded for only 36.6 t. The total amount of uranium consumed is transformed into electricity.

Unidade: t / *Unit: t*

FLUXO	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	*FLOW*
PRODUÇÃO	0,0	13,0	66,0	328,9	270,7	352,1	129,1	230,6	357,2	389,6	*PRODUCTION*
IMPORTAÇÃO	0,6	61,0	161,0	353,1	212,5	50,0	508,5	195,8	247,1	36,6	*IMPORT*
VAR.EST.PERDAS E AJUSTES	18,7	126,0	219,0	-94,8	-41,1	180,3	-182,7	113,5	-12,3	24,8	*VAR.INV.LOSSES AND ADJUSTMENTS*
CONSUMO TOTAL	19,3	200,0	446,0	587,2	442,1	582,3	454,9	539,8	592,0	451,1	*TOTAL CONSUMPTION*
TRANSFORMAÇÃO [1]	19,3	200,0	446,0	587,2	442,1	582,3	454,9	539,8	592,0	451,1	*TRANSFORMATION [1]*

[1] Produção de urânio contido no UO2 dos elementos combustíveis / [1] *Input for production of uranium contained in UO2*

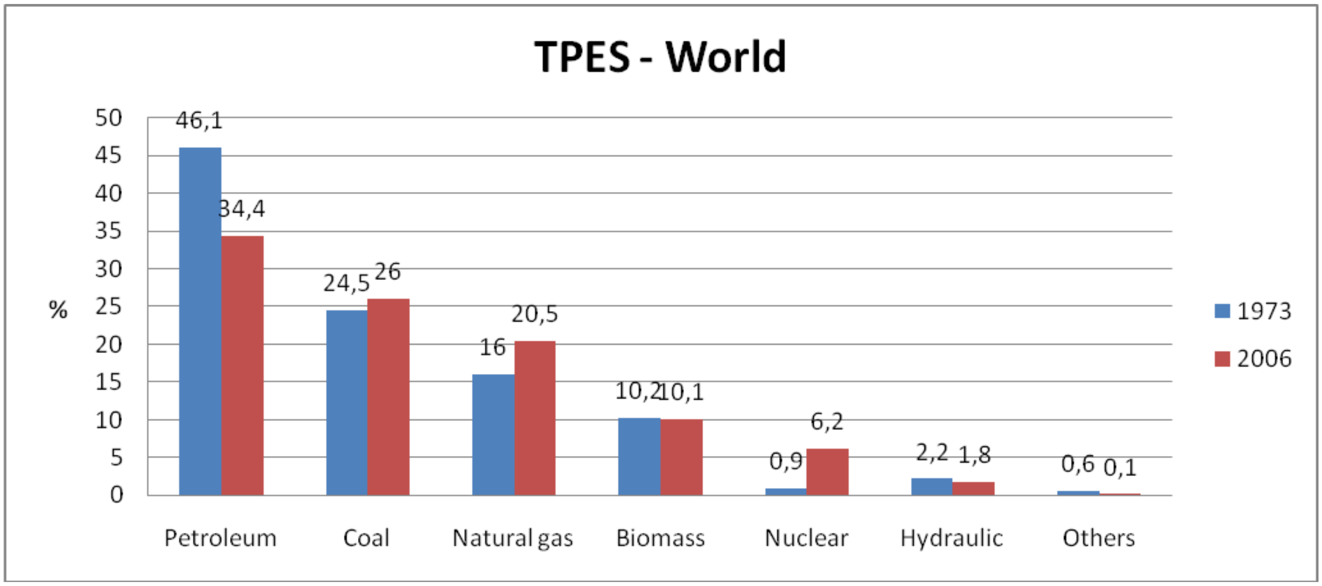
Table 12: Uranium in Brazil – source: Balanço Energético Nacional 2009

The expansion of nuclear energy in Brazil is part of the 10-year Electric Energy Expansion Plan (2006/2015). Electronuclear plans to build at least four new nuclear power plants (in addition to Angra III) by 2030, in order to meet expected growth in Brazilian electricity demand. The country presents two competitive advantages in this segment: abundant uranium reserves and the domain of the uranium enrichment technology – even though it is not yet applied in commercial scale.

3.2.2.5 Hydropower

Water is the most abundant natural resource on Earth. It covers 2/3 of the planet's surface in the form of oceans, icecaps, rivers, lakes and groundwater. Water is one of the few sources for energy production that do not contribute for the global warming and it is, of course, renewable.

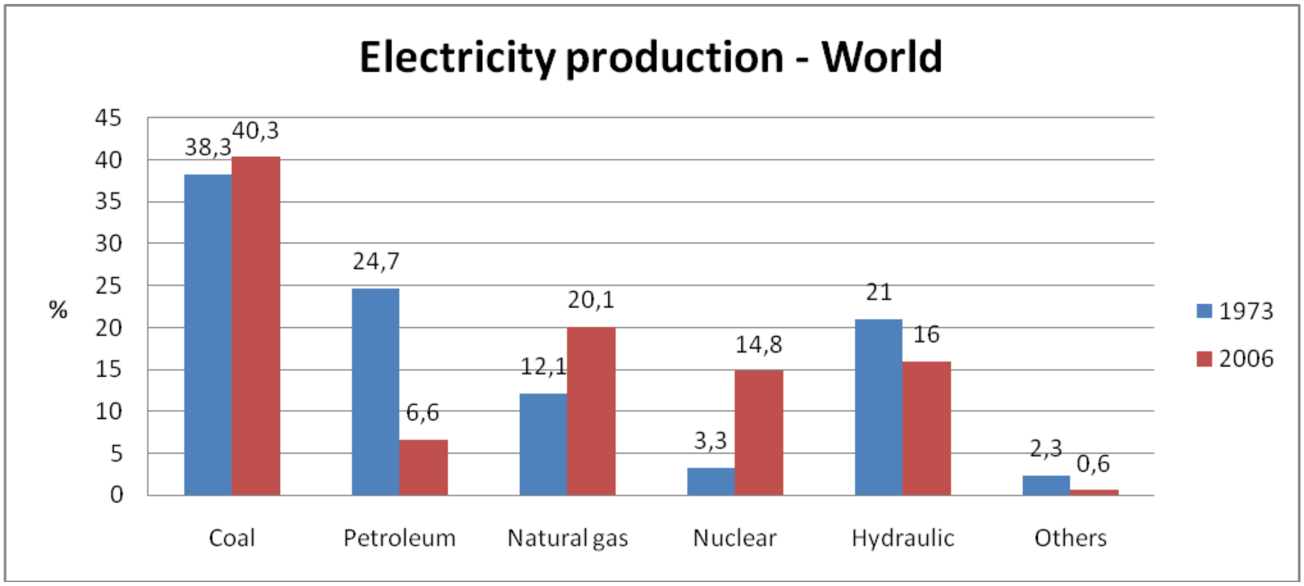
Nevertheless, the share of water in the word TPES is inexpressive: according to the Key World Energy Statistics 2008 report, by International Energy Agency (IEA), the participation of water in the total production of energy went from 2.2% in 1973 to only 1.8% in 2006.



Graph 24: World TPES - source: IEA 2008

During the same period, as shown in the next figure, the share of hydropower in electricity production fell from 21% to 16%, lower than coal and natural gas shares, both non-renewable fossil fuels. The low share of hydraulic energy in the TPES is due to the fact that nowadays, hydraulic energy is used almost exclusively to produce electricity, therefore its use for mechanical purposes (such as milling) has substantially decreased.

On the other hand, the low share of hydraulic energy in electricity production can be explained by the decreasing potential of the developed countries in producing hydroelectricity. These countries have already exploited most of their potentials. In fact, in the last 30 years, according to IEA, the supply of hydroelectric energy has increased in only two regions of the world: Asia, particularly China, and Latin America due to Brazil, in which the hydroelectricity accounts for most of the electric energy production.



Graph 25: Electricity production in the world - source: IEA 2008

The main arguments contrary to the construction of the hydroelectric plants are: the impact over the local population, fauna and flora; formation of big ponds or reservoirs; increase of the rivers' levels or alterations of their flows after the creation of the reservoirs. However, it is necessary to build new plants – with minimum social and environmental impacts – in order to produce energy for the country's economic growth and electricity needs.

In spite of environmental pressures, China has recently completed the construction of the Three Gorges Dam, the largest hydroelectric plant in the world, with installed capacity of around 18,200 MW. It overcame the Itaipu bi-national (Brazil/Paraguay), which has an installed capacity of 14,000 MW.

The world's largest consumers of hydroelectric energy are China, Brazil and Canada, as it can be seen from the table below. Their shares in the world total consumption are 15.3%, 11.8% and 11.7% respectively. When it comes to installed capacity, the USA occupies the second place in the world ranking with 99 GW. The three most dependent countries on hydroelectricity are Norway, with 98.2% of hydro in total electricity production, Brazil with 84% and Venezuela with 72.3%.

2007				2006			2007		
Produtores	TWh	Mundial World %	*Producers*	Capacidade Instalada [1]	GW	Installed Capacity [1]	País [2]	Hidro [3] *Hydro* [3] %	*Country* [2]
China	485	15,3%	*China*	China	126	China	Noruega	98,2	*Norway*
Brasil	374	11,8%	*Brazil*	Estados Unidos	99	United States	Brasil	84,0	*Brazil*
Canadá	369	11,7%	*Canada*	Brasil	73	Brazil	Venezuela	72,3	*Venezuela*
Estados Unidos	276	8,7%	*United States*	Canadá	73	Canada	Canadá	57,6	*Canada*
Rússia	179	5,7%	*Russia*	Japão	47	Japan	Suécia	44,5	*Sweden*
Noruega	135	4,3%	*Norway*	Rússia	46	Russia	Rússia	17,6	*Russia*
Índia	124	3,9%	*India*	Índia	35	India	india	15,4	*India*
Japão	84	2,7%	*Japan*	Noruega	29	Norway	China	14,8	*China*
Venezuela	83	2,6%	*Venezuela*	França	25	France	Japão	7,4	*Japan*
Suécia	66	2,1%	*Sweden*	Itália	22	Italy	Estados Unidos	6,3	*United States*
Demais Países	987	31,2%	*Rest of the world*	Demais Países	314	Rest of the world	Demais Paises [4]	13,5	*Rest of the world* [4]
Mundial	3.162	100,0%	*World*	Mundial	889	World	Mundial	15,9	*World*

[1] Baseada na produção / [1] Based on production

[2] Baseado nos 10 maiores produtores mundiais / [2] Based on top 10 producers in the world

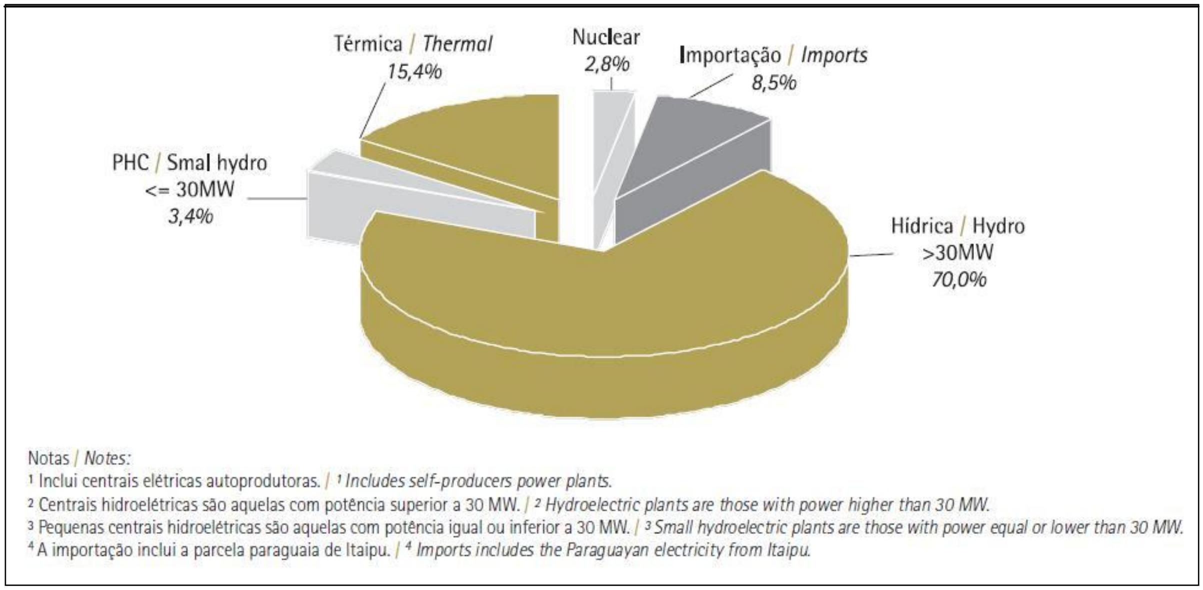
[3] Percentual na geração interna total / [3] Percentage of hydro in total electricity production

[4] Exclui países sem geração hidrelétrica / [4] *Excludes countries that do not use hydraulic energy*

Table 13: *Hydro Power in the world – source: Balanço Energético Nacional 2009*

According to IEA, in the period from 1973 to 2006, the share of hydroelectric energy produced in developing countries increased substantially with respect to the total hydroelectricity produced in the world. The share of China went from 2.9% of the total in 1973 to 14% in 2006. In Latin America, the share was from 7.2% of the total in 1973 to 21% in 2006. This was stimulated mainly by investments made in Brazil.

In 2009, according to the preliminary results of the National Energy Balance (Balanço Energético Nacional) 2010, the hydropower accounted for 15.3% of Brazil's TPES. As for electricity domestic supply, as it can be observed from the graph below, the hydraulic energy accounted for 81.9% of the total electricity supplied, considering the imports from Paraguayan part of Itaipu. It is important to underline that renewable sources account for only 15.6% of the world generation of electricity.



Graph 26 Electricity supply according to primary generation source: Brazil 2008

Source: Balanço Energético Nacional 2009

According to the National Energy Plan 2030, the hydraulic potential to be utilized is around 126,000 MW. More than 70% of this potential is located at Amazonas and Tocantins/Araguaia basins. The Tocantins/Araguaia basin has a potential of 28,000 MW, of which almost 12.200 MW have already been utilized by the hydroelectric plants Serra da Mesa and Tucurui. 90% of the remaining potential faces environmental restriction.

The main projects of plants, planned for the next years and included in the PAC (Growth Acceleration Program) are located at Amazonas basin, on Madeira River. These two plants are Santo Antonio, with installed capacity of 3,150 MW, and Jirau, with installed capacity of 3,300 MW. They are supposed to increase electric energy supply for the period 2006-2015. However, difficulties in obtaining the environmental licenses may delay the construction of Jirau.

Another important basin is the Tapajos. Aneel studies the viability of three projects at Teles Pires River, which sum 3,027 MW of installed capacity. Five other plants are supposed to be constructed at Tapajos River, with total installed capacity of 10.682 MW. At Xingu basin, the project of Belo Monte plant, with capacity of 5.500 MW, has many environmental issues but shall be constructed in the next years.

Because of the difficulty of local communities in accepting the projects of the plants, and the pressure of organized groups – particularly environmental NGOs – resources have been allocated for impact mitigation projects. The projects of hydroelectric plants have been mostly developed in a sustainable way in recent years, establishing a more integrated and long-term relationship with the affected communities.

3.2.2.6 Biomass

Biomass is a source for energy production which has a great potential for the next years. It is considered as one of the main alternatives to diversify the energy supply and, as a consequence, to reduce the dependence on fossil fuels. From biomass it is possible to obtain electric energy and biofuels, such as biodiesel and ethanol. The consumption of biofuels has gradually increased over the past years, hence substituting fossil fuels like diesel and gasoline.

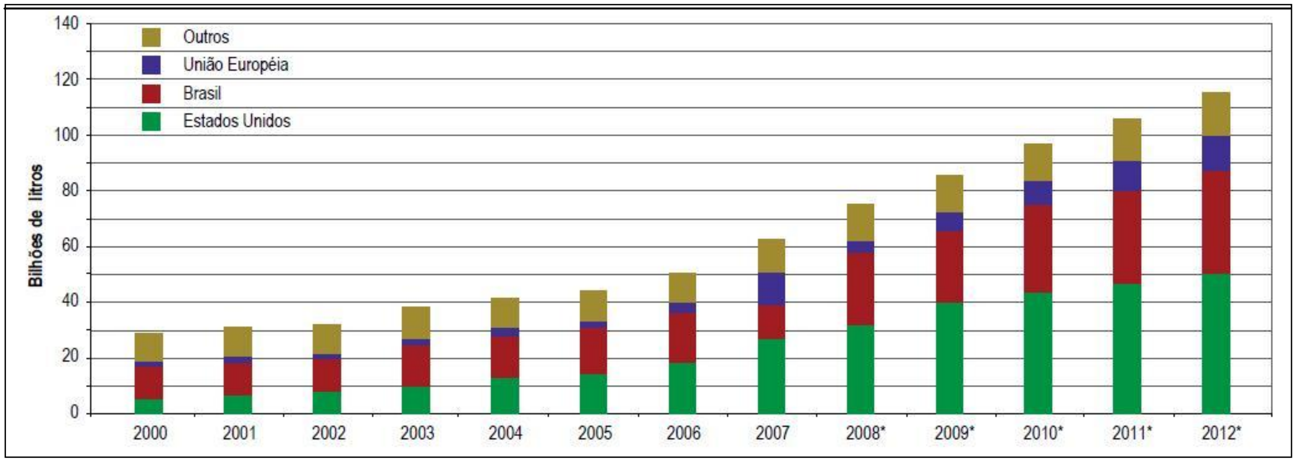
However, biomass has had a limited participation in the World Total Primary Energy Supply. It responded for 10.5% of the world TPES in 2009, according to BEN 2010. Also, it is not precisely quantified, as it happens to other sources such as coal and oil, because the definition of biomass is very comprehensive.

Any organic matter that can be transformed into mechanical, thermal or electric energy is classified as biomass. According to its origin, it can be: forest biomass (especially wood), agricultural (for example: soy, rice, sugarcane) and urban/industrial residuals (waste in general).

In the less developed regions, the forest biomass is the most utilized type. The processes to obtain energy are characterized by the low efficiency, that is, the necessity of a great volume of raw material in order to produce a small quantity of energy. One exception to this rule is the use of forest biomass in processes of industrial co-generation. For example, from the wood processing in the extraction of cellulose, it is possible to extract the black liquor used as a fuel in co-generation plants of the cellulose industry itself.

On the other hand, the large scale production of electric energy and biofuels is related to the agricultural biomass and to the use of efficient technologies. The precondition for its production is the existence of a strong agro industry, with large plantations (soy, rice, corn, sugar cane). The biomass is obtained from the processing of these plantations' residuals. In the sugar plane plantation, for instance, the residuals are bagasse, vinasse and straw.

Electric energy generation from animal biomass is still in an experimental phase. In fact, there are only few, small operating plants in the world. The vegetal biomass, on the other hand, faces a completely different situation. As it can be seen from the graph below, ethanol production more than doubled in the last years, going from 30 billion liters in 2000 to more than 60 billion liters in 2007.



Graph 27: Ethanol world production – source: UNICA (Uniao da Industria da Cana-de-Açucar)

According to the World Energy Council, The leader in the world energy production from biomass is the USA, which produced 56.3TWh in 2005, accounting for 30.7% of the world total. Germany and Brazil are behind, both responding for 7.3% of the total production with 13.4 TWh.

In Brazil, the biomass accounted for 32% of the TPES in 2009 (preliminary results of BEN 2010). It is only overwhelmed by oil and derivates, with 37.8% of the total. Brazil is the second biggest ethanol producer, only behind the USA. The Brazilian production in 2008 was 27.14 million m^3, from which 5 million m^3 were exported.

Unidade: 10^3 m^3											Unit: 10^3 m^3
FLUXO	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	FLOW
PRODUÇÃO	12.981	10.700	11.466	12.587	14.470	14.648	16.040	17.764	22.557	27.140	PRODUCTION
IMPORTAÇÃO	371	64	118	2	6	6	0	0	0	0	IMPORT
EXPORTAÇÃO	-405	-227	-320	-768	-766	-2.260	-2.494	-3.460	-3.533	-5.124	EXPORT
VAR.EST.PERDAS E AJUSTES	1.293	1.849	319	694	-1.798	897	444	-870	-1.748	788	VAR.INV.,LOSSES AND ADJUSTMENTS
CONSUMO TOTAL	14.240	12.386	11.583	12.516	11.912	13.291	13.989	13.435	17.276	22.804	TOTAL CONSUMPTION

Table 14: Ethanol in Brazil – source: Balanço Energético Nacional 2009

The biodiesel production is also growing, as it can be observed from the table below. In 2008 it was around 785 million m^3. Part of the production goes to developed countries, such as the European Union members. The biodiesel production in Brazil has been stimulated since 2004, with the implementation of the National Program of Production and Use of Biodiesel by the federal government.

2005	736
2006	69 002
2007	402 154
2008	784 832

Table 15: *Biodiesel production in Brazil (m^3) – source: ANP*

The international commerce of biofuels is growing fast. Bilateral and multilateral negotiations are needed in order to discuss the commercial and tax barriers imposed mainly by the USA and EU. The ethanol was one of the main points in the Doha Round in 2008. It was proposed to Brazil that ethanol exports from Brazil to EU until 2020 would have a share of 1.3 Mt per year with import tax of 10%. For volumes other than this threshold, the tax would rise to 35%. Brazil considered the proposal insufficient, given that current exports to EU reach 900 Mt per year, even though the taxes are 45%.

The use of biomass as a source for electric energy production has increased in Brazil, especially in co-generation systems of industrial and service sectors. According to ANEEL, in November 2008 there were 302 thermoelectric plants that used biomass as fuel, which correspond to a total installed capacity of 5.7 thousand MW. 13 plants are supplied by black liquor (cellulose residue), 27 by wood, 3 by biogas, 4 by rice husk, and 252 by sugarcane bagasse. These plants are generally small, which favors their installation near consumption and supply centers.

The sugarcane is a resource that presents great potential in electricity generation. It is important not only for the TPES diversification, but also because its harvest coincides with the drought period in the Southeast/Center-West region, where the biggest hydroelectric plants are concentrated. The electricity produced in these thermoelectric plants helps, therefore, to preserve the reservoir levels of the hydroelectric plants.

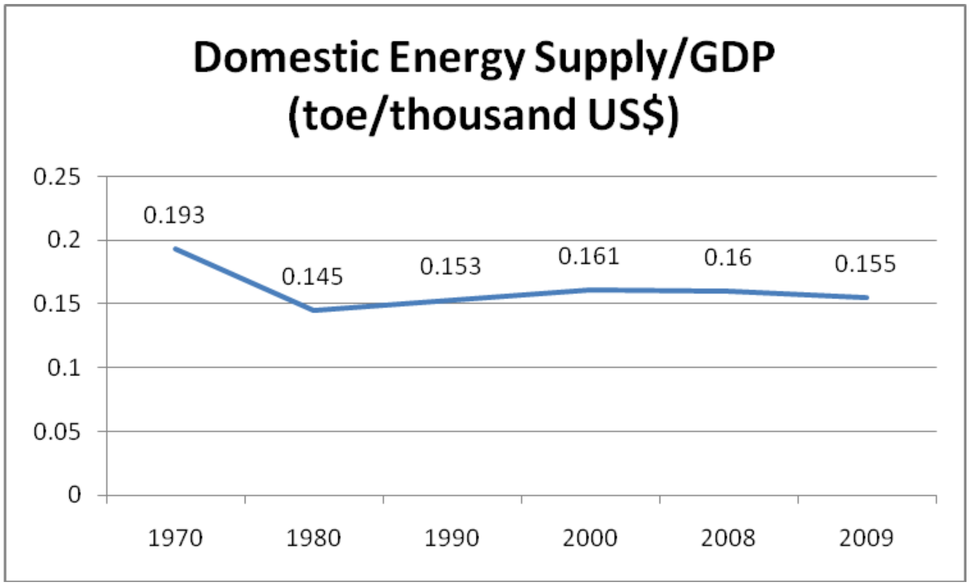
3.2.3 Energy indicators

Energy production and consumption in a country can be related to social, economical and environmental aspects. In this section two important indicators will be analyzed: energy intensity and carbon dioxide emissions.

3.2.3.1 Energy intensity

Energy intensity is a measure of the energy efficiency of a nation's economy. It is the ratio between the energy consumed by a country and the country's GDP. The higher is this indicator, the higher is the price or cost of converting energy into GDP, and therefore the lower is the energy efficiency.

The graph below shows the evolution of energy intensity in Brazil, measured in toe/thousand US$. This indicator shows a decreasing tendency in the last years, as a result of improvement in the energy efficiency.



Graph 28: Energy intensity in Brazil - source: preliminary results of BEN 2010

3.2.3.2 Carbon dioxide emissions

The table below summarizes the main indicators related to carbon dioxide emissions in Brazil and, for comparison purposes, the USA, Japan, Latin America and the world.

Indicator	Brazil	USA	Japan	Latin America	World
t CO_2/inhab	1.78	19	9.49	2.14	4.28
t CO_2/toe of DES	1.48	2.45	2.3	1.83	2.39
t $CO_2/10^3$ US$ of GDP	0.43	0.5	0.24	0.52	0.73
t CO_2/Km^2 of surface	41	630	3299	48	140

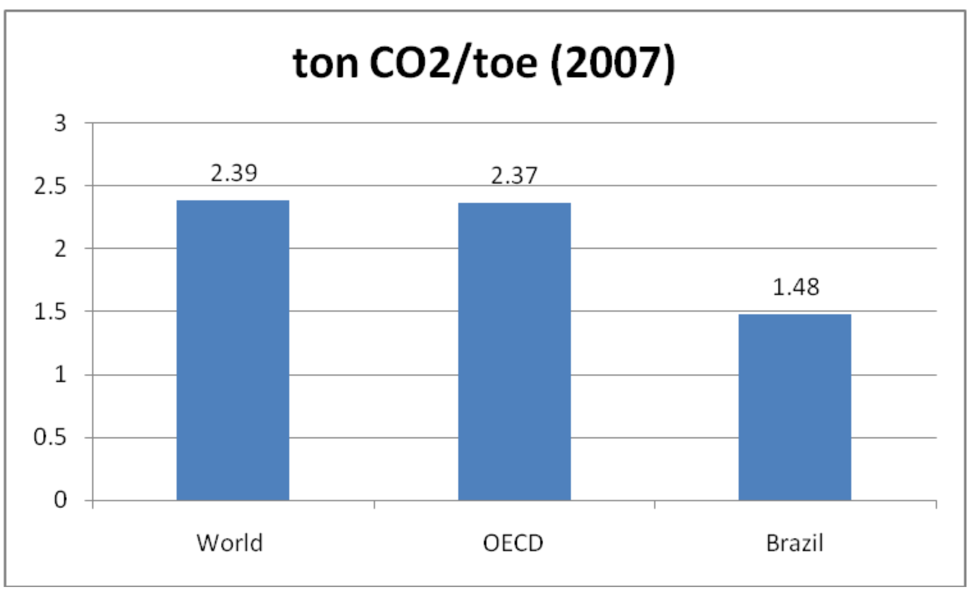
Table 16: CO_2 emissions indicators: comparison - source: Balanço Energético Nacional 2010, preliminary results

In 2007 the CO2 emission per capita in Brazil was 1.78 t CO2/inhabitant. It is a little lower than Latin America average, less than half of the world average and way lower than USA and Japan emissions per capita.

The CO2 intensity (ratio between carbon dioxide emission and energy consumed) is not as discrepant as the emission per capita, but the Brazilian indicator is still lower than the USA, Japan, Latin America and world. As for the ratio between the carbon dioxide emission and the GDP (also CO2 intensity), the Brazilian indicator is similar to the USA's and Latin America's indicators, but it is almost twice the Japanese indicator, which shows that the big emissions in Japan are offset by its very large GDP.

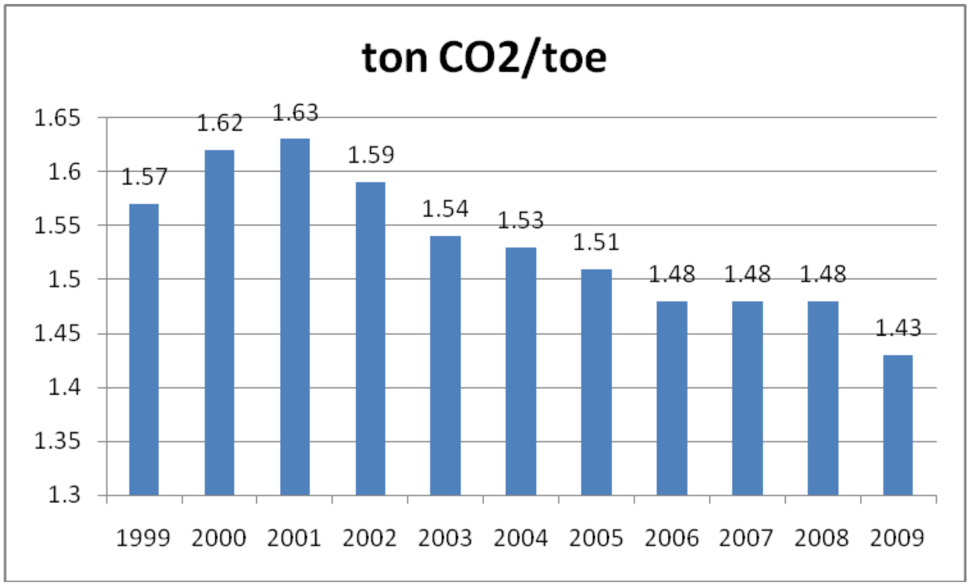
The emission of CO2 per unit area in Brazil is 41, similar to Latin America average. It is, however, less than one third of the world average, and much lower than the USA's and Japan's indicators.

The graph below shows a comparison of carbon dioxide intensity values for Brazil, the OECD and the world average. It puts in evidence that Brazil is fairly efficient from the environmental point of view, emitting much less carbon dioxide than the OECD and the world average in order to produce one toe.



Graph 29: CO_2 emissions: comparison - source: Balanço Energético Nacional 2010, preliminary results

It has been observed a decreasing of carbon dioxide emission in Brazil in the last years. The CO2 intensity in Brazil went from 1.63 ton CO2/toe in 2001 to 1.43 ton CO2/toe in 2009. This decreasing can be partially explained by the increase of the renewable sources' share in the TPES.



Graph 30: *CO_2 emissions in Brazil - source: Balanço Energético Nacional 2010, preliminary results*

4. Ethanol in Brazil

Up to now it has been discussed in this present study the main sources that compose the Total Primary Energy Supply in Brazil. It was observed that the biomass in Brazil occupies a very relevant position in Brazil's TPES, accounting for three times the world average and six times the consumption of biomass by the OECD countries. Biomass in Brazil represents approximately 30% of the Brazilian TPES. From the total biomass, almost 2 thirds are composed by sugarcane.

The objective of this chapter is to present an overview of the most important biofuel in Brazil, the sugarcane ethanol. In order to achieve this objective, it will be presented a brief summary of ethanol production history in Brazil, its main opportunities and barriers, its sustainability and the perspectives for the next years.

4.1 History

Brazil has been one of the biggest sugarcane producers in the world throughout history, since the Portuguese colonization. By the seventeenth century, Brazil had become the world's major source of sugar as a result of large sugarcane plantations in northeastern Brazil. Although surpassed by coffee in the nineteenth century as the largest valued agricultural crop in Brazil, sugarcane continued to be a major agricultural product up to now.

In 1975, Brazilian government created the National Alcohol Program (in Portuguese, Programa Nacional do Alcool, ProAlcool), in response to the oil crisis of the 1970s. Its objective was to reduce the great dependence on imported oil and to create an additional market for the sugar producers, encouraging the automotive industry in the development and manufacturing of cars moved exclusively by ethanol.

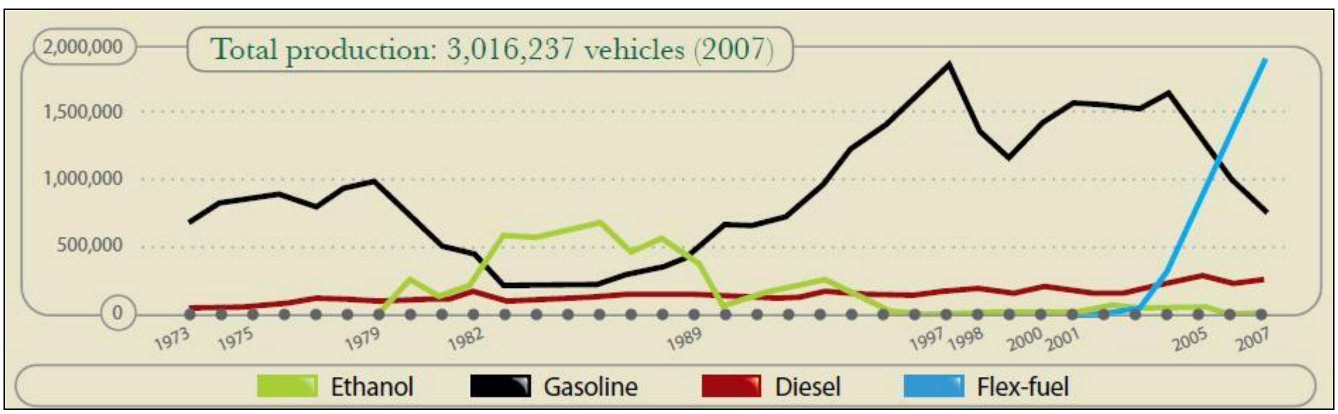
In the first phase of the program, its main objective was the production of anhydrous ethanol as an additive to gasoline. Efforts in R&D directed to the manufacturing of cars fueled exclusively by ethanol resulted in the creation of these first vehicles in 1978.

After the second oil shock in 1979, Brazilian government decided to increase ethanol production, signing agreements with automotive manufacturers and stimulating the construction of a large number of independent distilleries. In this way, the large scale hydrated ethanol production began.

The substantial increase of the sugar exports, in the 1990s, resulted in the scarcity of ethanol, menacing the original objectives of the program. The decline of the consumption of this fuel went on until 2003. In that year, a new type of vehicle was introduced in the national market: the flex-fuel vehicle (FFV), also called bi-fuel vehicle. Its technology allowed using hydrated ethanol or gasoline, in any proportion of mixture. The consumers were given the freedom to choose the fuel or blend of fuels that best suits their needs.

Thanks to the great availability of ethanol and the pre-existing infrastructure of supplying at every gas station, this new technology boosted the market of this fuel. The flex-fuel technology allowed ethanol to compete with gasoline in the whole country. Ethanol is currently the most economically viable fuel in 19 states of Brazil (out of 27).

The economic growth, income distribution and raise of credit leaded to a significant increase on the sales of new light vehicles. As a consequence, there was a fast renovation of the fleet, with the increasing share of flex-fuel vehicles. According to EPE (Energetic Research Institute), the flex-fuel vehicles represented, in 2008, 87.4% of the light vehicles total sales.

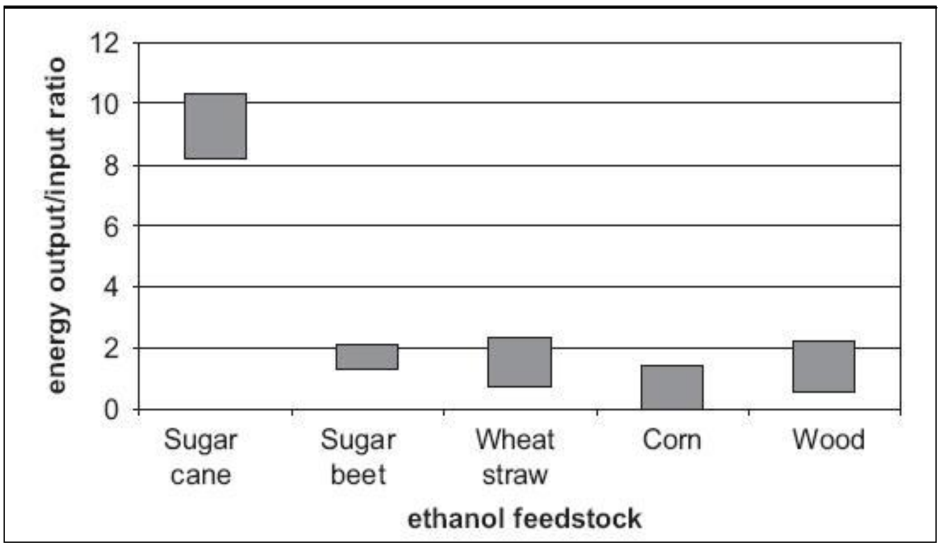


Graph 31*: Vehicle production in Brazil by fuel type – source: Anfavea*

4.2 Sustainability of ethanol production

The reason sugarcane ethanol is attractive as a replacement for gasoline is that it is essentially a renewable fuel while gasoline - a fossil fuel derived from petroleum - is not. The use of sugarcane ethanol does not result in a significant emission of GHGs (mainly CO2), because the CO2 releases related to ethanol production and use are reabsorbed by photosynthesis during the growth of sugarcane in the following season. All the energy needs for its production (heat and electricity) come from the bagasse, which can also generate additional electricity to be fed into the grid. The direct consumption of fossil fuels is limited to transportation trucks, harvesting machines and the use of fertilizers. Indirect consumption of fossil fuels is low due to the fact that renewable sources have a large share in the Brazilian TPES.

When compared to ethanol produced from other feedstocks, sugarcane ethanol has a very favorable energy balance, as shown in the figure below. In fact, sugarcane ethanol has an energy output/input ratio of 8-10, considering its life-cycle. It means that one unit of energy used in its production yields 8-10 units of energy. This ratio is way larger than the ratios for the other feedstocks, which require considerable imports of fossil fuels into the producing plants. The corn ethanol has a ratio that varies between 0 and 1.5.



Graph 32 *Energy balance of ethanol production from different feedstocks*
Source: Goldemberg (2005)

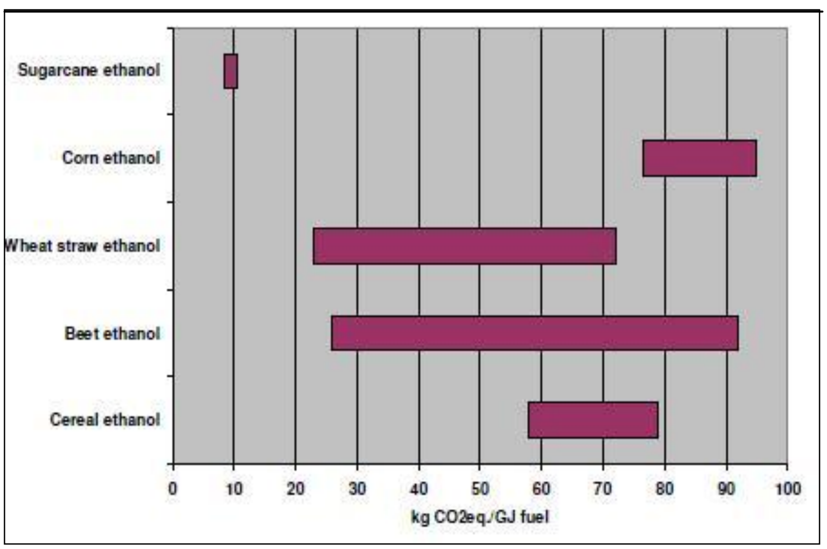
Even when ethanol from sugarcane is exported to other countries, and therefore the energy consumed in its transportation is also taken into account, the final energy balance is highly positive (around 5) when compared to other crops (Rodrigues and Ortiz, 2006).

Due to this positive energy balance, the sugar/ethanol sector avoids considerable CO2 emissions. According to UNICA (Sugarcane Industry Union), 33.2 t of CO2 equivalent were avoided in 2003, being 82.8% due to the replacement of gasoline by ethanol and 17.2% due to the use of bagasse in energy cogeneration in the plants, as well as supplying of electricity surplus to the grid. This fact, together with the use of hydroelectricity, is responsible for the low carbon emissions in Brazil. Most of the carbon dioxide emissions of the country (75% of all national emissions) are due to Amazonia Forest deforestation, according to the Science and Technology Ministry.

With respect to the impacts to the air quality, lead additives were reduced as the amount of ethanol in gasoline was increased and they were completely eliminated by 1991. Brazil was one of the first countries in the world to eliminate lead entirely from gasoline. The aromatic hydrocarbons (such as benzene), which are particularly harmful, were also eliminated and the sulfur content was reduced as well.

One drawback of pure ethanol combustion is the increase in aldehyde emissions as compared to gasoline or gasohol (blend of gasoline and ethanol). There is also a concern about the increase on peroxyacetyl nitrate (PAN) concentration, caused by the combustion of ethanol when compared to gasoline.

The most obvious pollution reduction effects associated with blends containing up to 10% ethanol by volume (E10 blends) include reduction of CO, harmful hydrocarbons (such as benzene and 1-3 butadiene that are carcinogens), sulfur oxides (Sox) and PM.



Graph 33: *CO_2 emissions from different types of ethanol. Reference for petroleum is 87 kg $CO_{2\ eq}$ / GJ fuel and for diesel 95 kg $CO_{2\ eq}$ / GJ fuel. Source: Coelho, Goldemberg, Lucon, Guardabassi, 2005*

In the ethanol production process, the emissions are mainly due to the bagasse boilers in the plants and due to the sugarcane burning (a practice used to facilitate the manual harvest of the stalks). Old boilers, which emit mainly PM and NOx, have been replaced by new and more efficient ones, reducing therefore the emissions. As for the sugarcane burning, it is being gradually eliminated due to the increasing use of mechanized harvest.

With respect to the impact to water, the use of crop irrigation is very small in Brazil, and sugarcane production is mainly rain-fed. However, the conversion of sugarcane into ethanol requires large amounts of water. Modern agricultural and industrial practices are allowing to recycle the water used in the production process, therefore reducing the water demand.

Regarding the water pollutants, the main effluents of ethanol production are the vinasse (byproduct from ethanol distillation) and the agrochemicals such as herbicides and pesticides. Disposal costs of vinasse are high, and it used to be released into rivers, polluting the water in each harvesting season. Nowadays such disposal is forbidden and vinasse is used in the crops as a fertilizer. As for the agrochemicals, genetic researches allowed the reduction of sugarcane diseases through the selection of resistant varieties, and therefore the reduction of agrochemicals consumption.

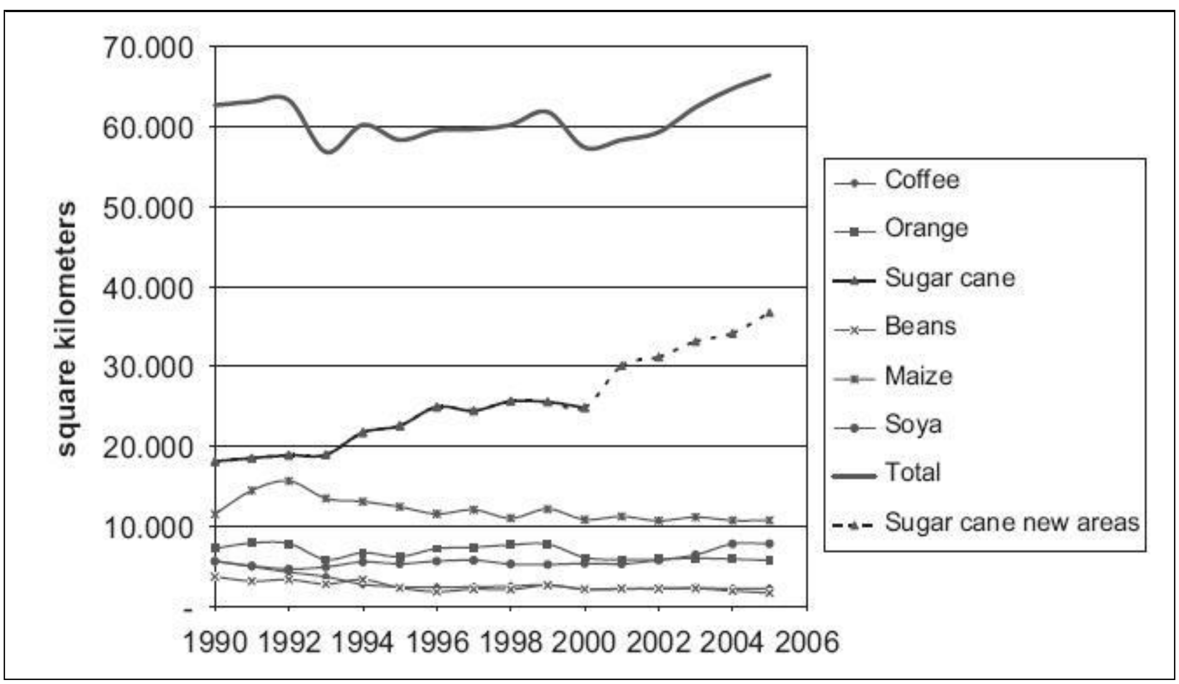
With respect to the land use, competition for land between biofuels crops and food crops is an often discussed issue. The sugarcane average productivity in Brazil is around 70 t/ha but it is as high as 80 t/ha in Sao Paulo State. Productivity has grown in Sao Paulo due to the development of new species and to the improvement of agricultural practices (protection against erosion and moisture losses, correct fertilization etc). Such improvements allowed the growth of sugarcane production without excessive land-use expansion.

Apart from the increase on the productivity, existing assessments show that there is space for a further increase of areas for sugarcane production, without putting pressure on natural environments. The table below shows that sugarcane crops area - 6 Mha - represents only 0.7% of the total territory.

Brazil's territory occupation chart	Mha	%
Amazon Rain Forest	350	41.1
Protected Areas	55	6.5
Cities, lakes, Swamps and Roads	20	2.4
Other Uses	54	6.3
Pastures	215	25.3
Cultivated Forests	5	0.6
Permanent Crops	15	1.8
Soy Crops	23	2.7
Sugarcane Crops	6	0.7
Other Annual Crops	18	2.1
Avaliable arable land	90	10.6
Brazil	851	100

Graph 34: Brazil's territory occupation chart - source: FIESP, IBGE

The graph below shows that sugarcane growth in Sao Paulo does not seem to have an impact in food areas, since the area used for food crops has not decreased.



Graph 35: Main Crops in Sao Paulo State – sources: Goldemberg (2008), IBGE

The expansion occurred mainly on land previously used for cattle feed. Pasture areas have very low densities compared to developed countries averages. There are large potentials for productivity improvements. In Sao Paulo, cattle population has been increasing, even with reduction of pasture land over time, as shown in the following table.

	2001	2005
Cattle (heads)	13,154,649	14,072,447
Pasture (hectares)	10,288,887	10,010,491
Density (heads/hectare)	1.28	1.41

Table 17: *Cattle population in Sao Paulo State – source: Instituto de Economia Agricola*

Land area available for biofuels must not depend on deforestation nor competition with food. Sugarcane crops do not create any pressure on Amazon deforestation, but attention must be paid to indirect effects of sugarcane expansion over cattle areas, which could push these activities over Amazon. The figure below shows that the sugarcane productive areas are far away from the Amazon.

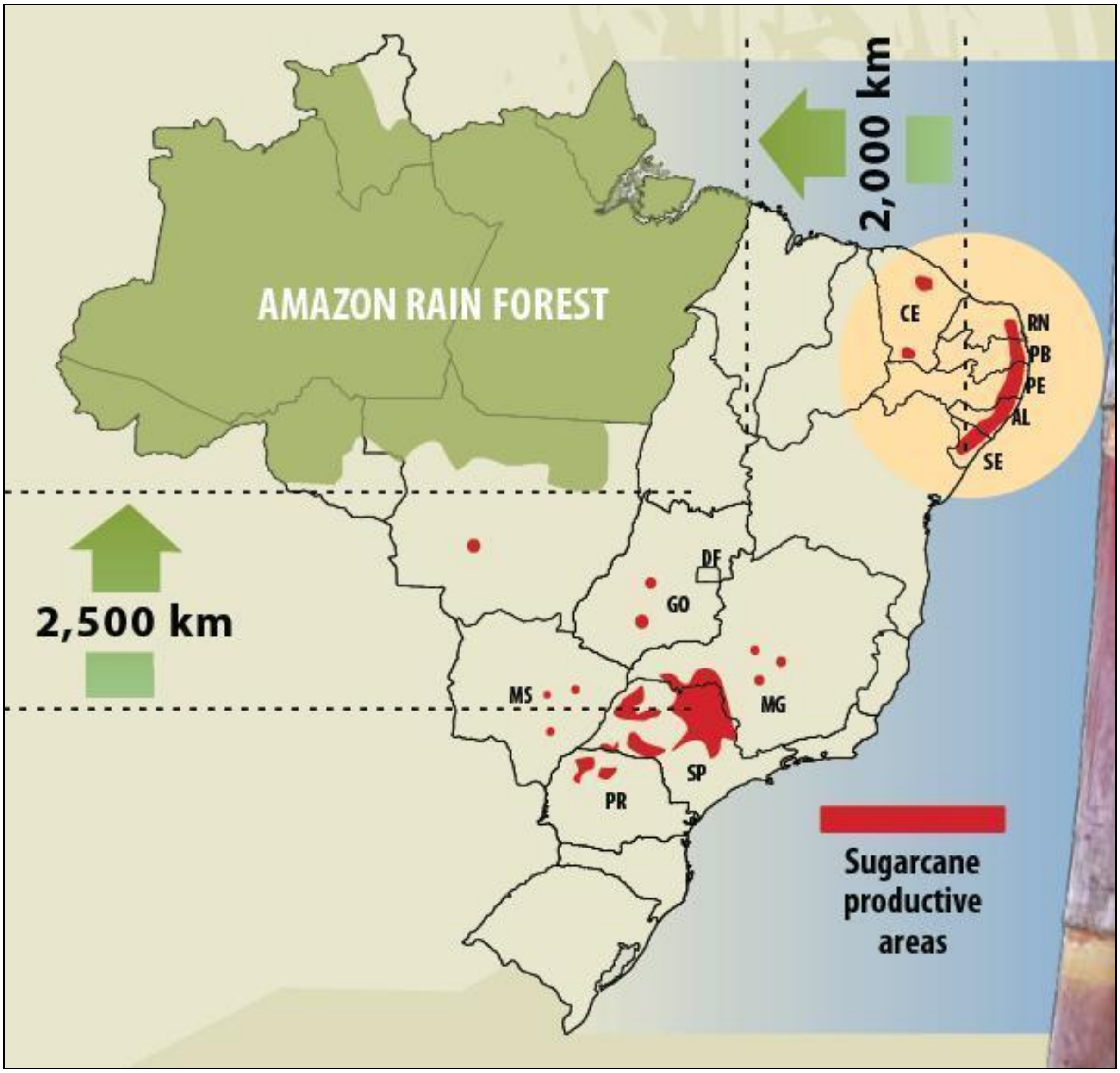


Figure 8: Sugarcane productive areas distance from the Amazon – source: FIESP

As mentioned before, the increase on productivity is the best way to increase the production, avoiding conflicts with other sectors (livestock, soy, corn) over the available arable lands. In Brazil, institutions such as CTC (Sugarcane Technology Center), sponsored by sugar-ethanol companies, increased the productivity by 30% in the last decade. It went from 53 t/ha in 1999 to 70 t/ha in 2009 (Brazilian average).

The genetic improvement is a well-known technique that helps increasing the productivity. The main objective of this technique is to find new sugarcane varieties, more resistant to droughts and plagues, and also containing larger quantities of sugar.

New techniques concerning genetic improvement have been developed in recent years. The technology of cell markers allows to decreasing the duration of sugarcane genetic improvement programs. Using the traditional technology, it takes from 10 to 15 years to find the desired sugarcane variety, after having crossed thousands of plants. The cell markers technology, on the other hand, allows to finding the desired variety in 6 years at most.

The last important point to be discussed involving sustainability is the increasing inspection by environmental agencies, as the ethanol production grows and exposes itself to the world. Also the regulations concerning the production tend to be more severe.

Many rules are already usually complied with, such as river water quality monitoring and proper disposal of vinasse. More complex rules have been implemented, such as suppliers tracing and fauna control in the area. There is also an increasing pressure on the plants to rationalize the natural resources. In Sao Paulo, there is now a limit of 700 liters of water that can be used to produce 1 t of sugarcane. 10 years before, some plants used to consume around 10 000 liters of water/t of sugarcane. The increasing exposition of ethanol to the international market shall increase the environmental constraints.

The creation of a quality seal for the Brazilian ethanol becomes necessary, to ensure that the product has complied with all the standards discussed above. This quality seal should be elaborated with many countries and international NGOs, in order to have a high international credibility. In this way, Brazilian ethanol could present itself as a sustainable alternative to petroleum and its derivates.

4.3 Opportunities

The policies of incentive to the production and use of ethanol as a fuel, in many countries, aim mainly at the energetic security. The objective is to diversify the TPES and to reduce the dependence on petroleum derivates. Moreover, there is a reduction on environmental impacts, as discussed on the sustainability section, especially by means of GHGs emission reductions. A third factor is the strengthening of the rural economy, thus avoiding the rural exodus phenomenon.

In the fuel world market, ethanol has been seen as the most feasible renewable fuel, at least at short term, to substitute gasoline or be used as an additive instead of hazardous additives such as MTBE.

The world increasing demand for ethanol represents an important opportunity for the Brazilian production insertion in this market, given the competitiveness of Brazilian industry. The costs of production, in fact, have declined over the years due to agricultural and industrial practices, as discussed before.

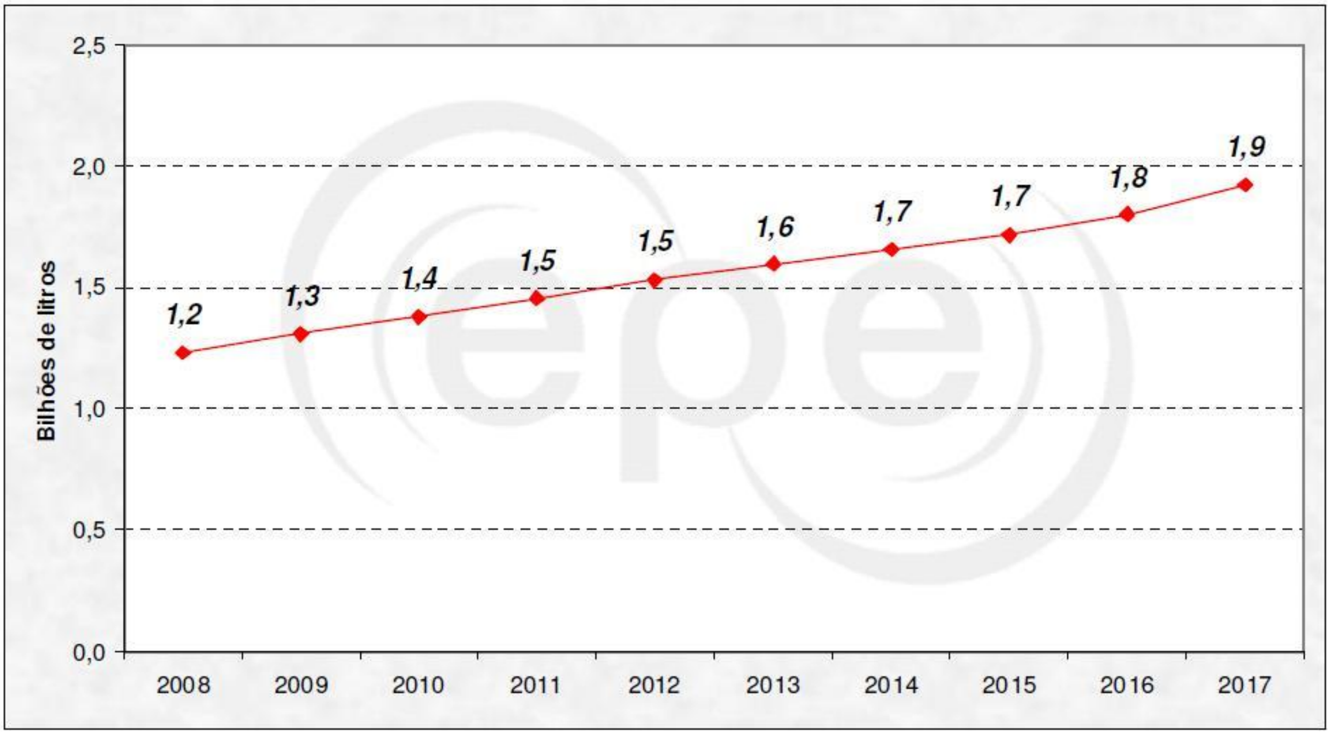
Ethanol produced in Brazil has been exported mainly to the USA and Europe, up to now. Japan is forecasted to become a major important, as it will be discussed in the sequence.

The USA government determined that 15% of fossil fuels be substituted by renewables by 2022. As a result, the ethanol consumption in the USA, which is today 42 billion liters, shall reach 136 billion liters in 2022. The American ethanol supply will probably not be enough to cover the domestic market; therefore a large amount of ethanol shall be imported.

Part of ethanol consumed in the USA is reserved, by USEPA (United States Environmental Protection Agency) regulations, to the advanced fuels category. Fuels are classified by EPA according to their harmfulness to the environment. Recently, EPA classified sugarcane ethanol as an “advanced” fuel, whereas corn ethanol produced in the USA is classified only as “conventional”. It is important to underline that this classification upgrade regarding the Brazilian fuel was obtained only after a hard effort by a group of Brazilian scientists, coordinated by UNICA (Sugarcane Industry Association) executives, in showing to American technicians that the model used to calculate CO_2 emissions by the fuel presented distortions.

Another potential importer of the Brazilian product is Europe. A regulation approved in 2008 determined that, in all the countries of the block, the share of renewable sources must represent 10% of the energy consumed in the transportation sector by 2020. This decision might represent a need of approximately 30 billion liters of biofuels in 2016, according to EPE.

The production of ethanol in Europe went from 528 to 1770 million liters between 2004 and 2007, according to European Bioethanol Fuel Association. In 2007, France was the leader with 578 million liters/year against 394 million liters/year in Germany and 348 million liters/year in Spain. The production in these countries is predominantly from beet, cereals and wine production surplus. The figure below shows the projection of ethanol imports in Europe. Brazil shall be the preferential supplier, due to its high competitiveness.



Graph 36: Ethanol import projection – Europe Union. Source: EPE

The third big potential market for Brazilian ethanol is Japan. There is a proposal to increase the percentage of ethanol in gasoline from the current 3% to 10% in 2012. In this case, Japan might become a potential market of approximately 6 billion liters/year of ethanol.

Important agreements have been signed between Petrobras and Japanese companies for the production and export of Brazilian ethanol, including the distribution in the Japanese market. There is a Memorandum of Understanding between Petrobras and Mitsui, aiming at the export of up to 3 billion liters of ethanol per year, for 20 years. This volume would represent around 5% of the total gasoline consumed in Japan.

Another opportunity for Brazilian ethanol is the slow pace of cellulosic ethanol. In theory, this second-generation ethanol would be the main green alternative to fossil fuels. This new technology has always occupied an important role in the American plans which aim at reducing the consumption of fossil fuels. But the companies engaged in the creation of this new class of fuel have been facing every kind of difficulties, from the cost (cellulosic ethanol is much more expensive than first-generation ethanol) to the investors lack of reliability.

Even though there will be no cellulosic ethanol production at the short term, specialists affirm that the mandatory goals of mixing biofuels in gasoline will be kept. As a result, this might boost

Brazilian ethanol, since the countries will have to find ways to comply with the biofuels-mixing regulations, and the best alternative up to now is the sugarcane ethanol.

The big oil companies are having troubles in accessing new oil reserves, due to their increasing concentration in politically unstable areas. Apart from this fact, they are being gradually pressed to adopt more sustainable practices, and they cannot wait for the development and implementation of cellulosic ethanol. This explains the increase on the investments of these big companies in first-generation ethanol. In 2009, for example, Shell merged with Cosan, the biggest sugar-ethanol company in Brazil, in a US$ 12 billion transaction.

Another opportunity for ethanol production is represented by some natural advantages of Brazil with respect to other countries: large availability of arable lands (around 90 Mha), far from natural biomes such as Amazon Forest, as mentioned before; and climatic conditions suitable to sugarcane plantation.

4.4 Barriers

One of the big challenges that Brazilian ethanol faces is protectionism (mainly from the USA and Europe). In the USA, for instance, the classification of sugarcane ethanol as an "advanced" fuel by EPA does not imply in immediate access to the American market. Each gallon (which corresponds to 3.78 liters) of Brazilian ethanol has to pay a surcharge of 54 dollar cents. This surcharge has remote chances of being abolished in the short and medium terms, since the corn ethanol lobby in the USA is very strong.

UNICA has hired lobby and public relations companies in the USA to help it in this attempt. The shock with EPA was technical, scientific. Now there is a political dispute to finish or at least reduce the surcharge over Brazilian ethanol.

Brazil has found an interesting way to overcome the American surcharge, by exporting ethanol to CBI (Caribbean Basin Initiative, block of the 24 Caribbean countries). The ethanol exported to CBI is then re-exported to the USA, since products from the Caribbean countries are not surcharged.

The other challenge Brazilian ethanol faces is the lack of assurance in supplying the domestic market. This happens for some reasons. The increasing share of flex-fuel vehicles in the total fleet (they represent 40% of the total and 90% of the new vehicles) raised the ethanol demand by 23.9% from 2008 to 2009. There was also the diversion of part of the sugarcane for the production of sugar, since price has increased recently. Finally, there is also the problem of extreme weather conditions like harsh rainfalls, which can prevent the harvest to be done.

Eventual ethanol shortages in the domestic market prevent the sector ambitions to conquer the world market. The price of ethanol may vary, but it is fundamental to assure the supply for the whole year, in order to have credibility to export.

A solution for this problem is increasing the stock capacity, in order to sell the product at better prices in the periods between harvests. What happens now is that many plants are obliged to sell cheap ethanol in the peak of the harvest in order not to go out of business, and then there may be a shortage of the product during the period between harvests. Stronger, more capitalized companies, such as Cosan/Shell, are able to stock the product and increase the offer during the critical period between harvests.

These financially stronger companies will also be able to invest in the expansion of production and in new technologies to improve productivity, which is essential to guarantee that this expansion will not lead to damage to the environment. After all, foreign potential clients are concerned that the demand for ethanol might put the forests in danger. As already discussed in the sustainability section, this shall not happen due to the distance between the productive areas and the natural biomes.

4.5 Perspectives for the next years

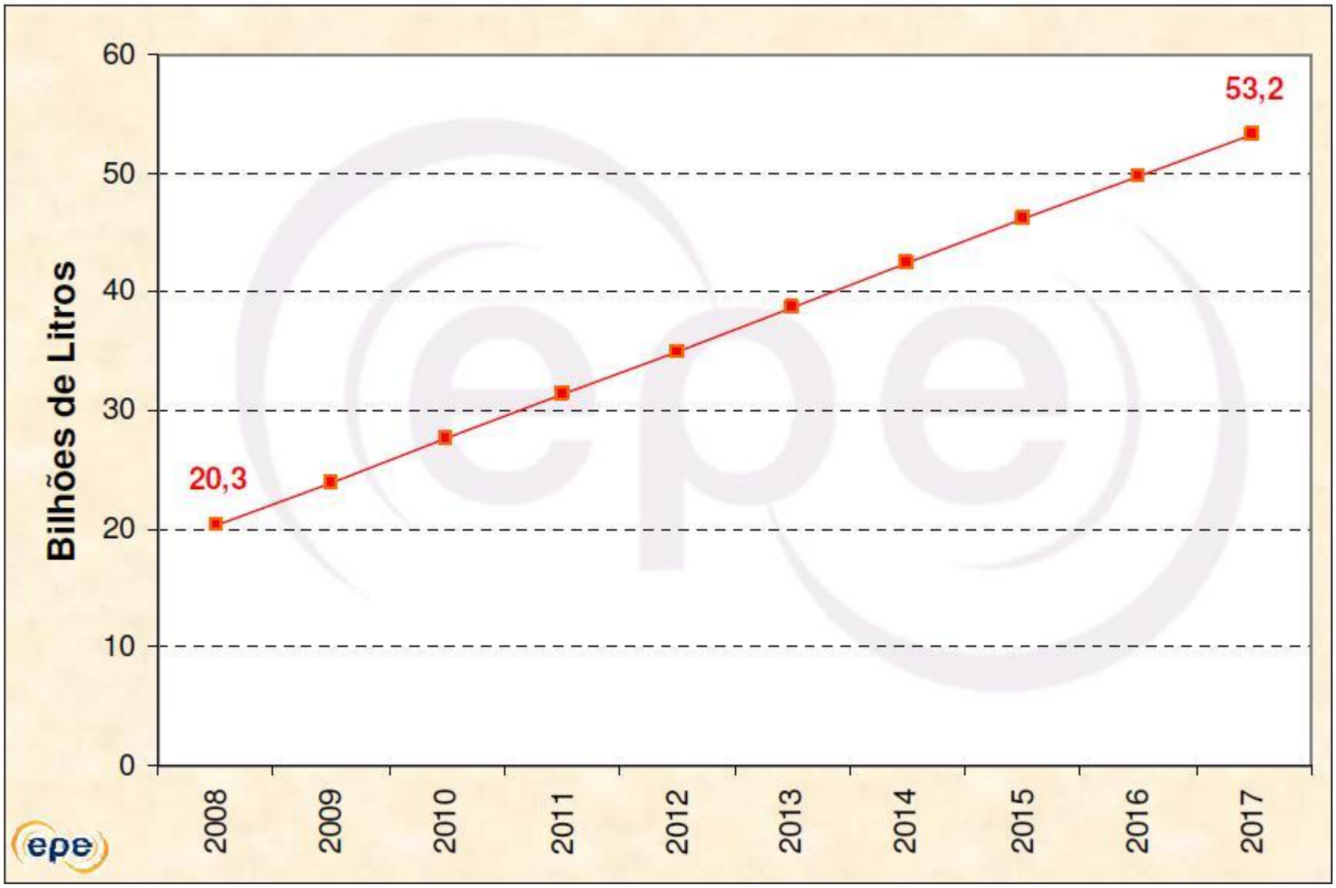
The flex-fuel vehicles shall represent almost 75% of the Brazilian fleet by 2017, according to estimates by EPE.

Type of fuel	**2008**	**2017**
Gasoline	63.4%	24.8%
Ethanol	7%	1.6%
Flex-fuel	29.6%	73.6%
Total	**100%**	**100%**

Table 18: *Share of vehicles according to type of fuel – source: EPE*

This increase on the share of flex-fuel vehicles on the light vehicles fleet is the main factor to the increase on ethanol domestic market. In 2017, the demand for ethanol is forecasted to be 53.2

billion liters, according to EPE. This will correspond to approximately 80% of the total consumption of liquid fuels.



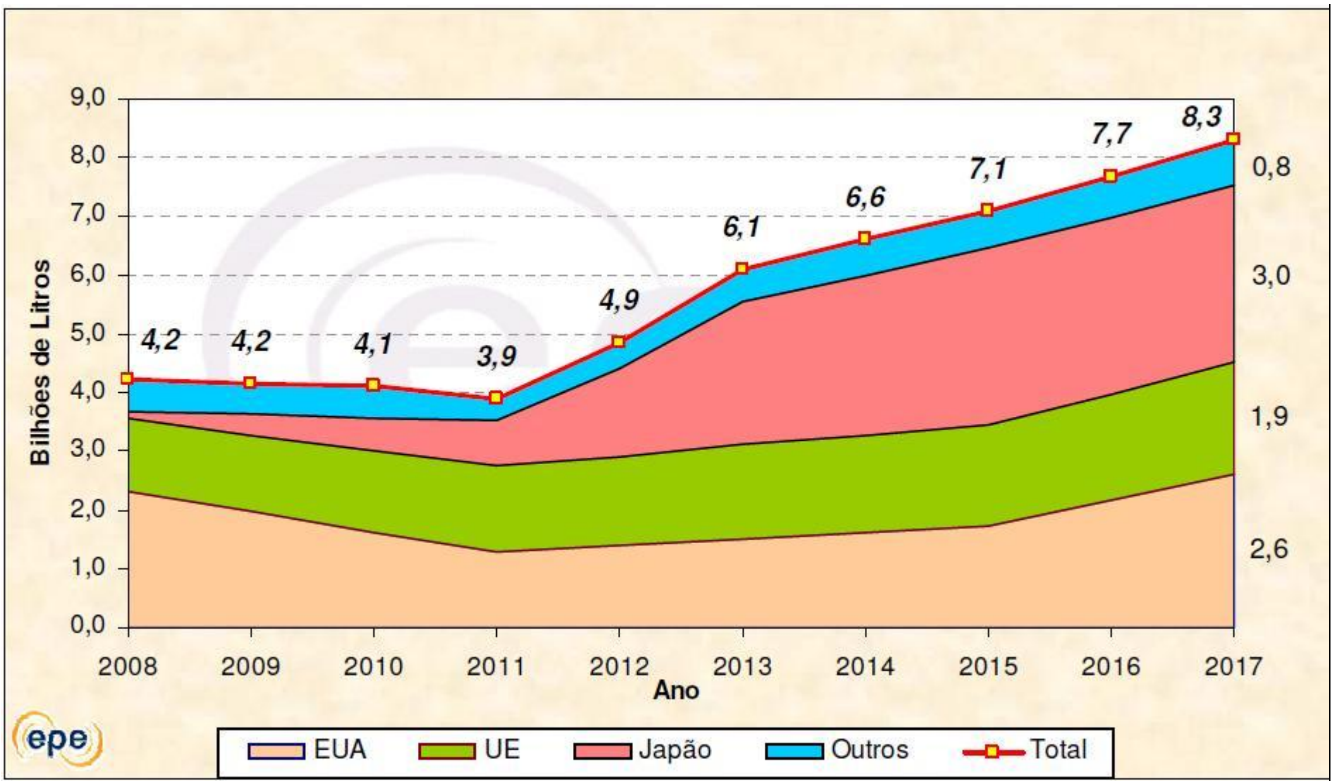
Graph 37: Ethanol demand in Brazil – source: EPE

This perspective confirms the Brazilian leadership on the substitution of fossil fuel in the transportation sector, which is an objective chased by many countries in the world.

In this context, there is the possibility of introducing in the future the flex-fuel technology in the diesel engines market, which would cause a new impact on the Brazilian fossil fuel market.

The increasing use of ethanol will continue impacting on the gasoline national market, pressing this fossil fuel to be exported. As a consequence, the quality of the petroleum derivates should adapt to this reality, in order to reach the largest markets abroad. These markets are more demanding with respect to the environmental quality of the fuels.

Regarding ethanol international market, Brazil shall keep its leadership. The projection by EPE for Brazilian ethanol exports is presented below. It is, in 2017, 8.6 billion liters, from which 3 billion liters shall be exported only to Japan.



Graph 38: Projection of Brazilian ethanol exports – source: EPE

In order to meet the total ethanol demand, which in 2017, according to EPE, will be of 63.9 billion liters (domestic market, exports and other uses), the industrial capacity must be expanded, trough the implementation of new plants. The emergence or discontinuity of these new projects will depend on the sugar-ethanol sector expectations, such as sugar international price, pressures for ethanol in the domestic market, perspectives for ethanol international market and the flex-fuel vehicles evolution in the Brazilian market. Furthermore, investments in stock capacity must be made, as it was discussed in the barriers section.

The sugar-ethanol sector in Brazil tends to get stronger and increase the scale. This can be verified by the fact that small producers are grouping themselves into cooperatives, bigger groups have been acquiring smaller groups, there is the formation of partnerships among producers and among producers and clients, and the plants are getting bigger, in order to reduce production and/or logistic costs.

Cosan, the largest individual company of the sector, merged with Shell in a 12 US$ billion joint-venture, as mentioned before. Companhia Energetica Santa Elisa and Companhia Açucareira Vale do

Rosario created, by merging, the second largest individual group of the sector (Companhia Nacional de Açucar e Alcool).

Foreign groups possess already 25% of the Brazilian ethanol sector capital, and the big oil companies are just beginning to invest in ethanol. All these acquisitions and mergings show a tendency of consolidation of the sector. It is getting stronger.

With respect to the logistics, many investments in the ethanol distribution infrastructure have been made, in order to reduce the costs of the product to be exported. Transpetro, for instance, is proposing to create a logistic infrastructure that involves the construction of pipes to transport ethanol and also water terminal transports, considering the future exports of the product. According to Transpetro, this infrastructure will guarantee the competitive advantage of Brazilian ethanol in the international market. The table below shows the estimated values for this project. The current installed capacity at the operating terminals is 3.6 million m^3/year of ethanol.

Region	**Maritime Terminal**	**Capacity (10^6 m^3)**	**Year**	**Cost (10^6 US$)**
South-East	Ilha d'Agua	4	2008	1,556
Center-West	Sao Sebastiao	8	2010	
South	Paranagua	5	-	*
Northeast	Maceio	0.75	2010	4
Total		**17.75**		**1,570**

Table 19 Transpetro investments on ethanol outflow infrastructure – source: EPE

**No defined estimate*

The competitive costs of ethanol with respect to gasoline in Brazil are explained by 3 factors: technological advancements incorporated by the sugar-ethanol sector, both in agricultural and industrial areas; improvement on all the steps of the supply chain; energetic integration by means of co-generation. These factors have been preponderant to maintain the competitiveness of Brazilian ethanol in world markets.

5. Conclusions

The description of the unit operations of sugarcane ethanol production currently in use in Brazil allows to concluding that it is a rather simple process, and each single unit operation finds itself in a very developed stage, due to continuous technological advancements incorporated by the sugar-ethanol sector. An important point in the productive chain that must be improved regards the mechanized harvest of sugarcane, which is still smaller than manual harvest in some productive regions. The mechanized harvest is important because it increases the productivity and avoids the emission of hazardous gases by sugarcane burning.

As for the production of ethanol from cellulosic materials, this promising technology was still not able to change its status from promise to reality. There are still many technical issues regarding the conversion of cellulose into ethanol, and this technology will not be available in a commercial scale in the near future.

The analysis of socio-economic indicators and the comparison with other countries in relevant geographic and economic contexts allows to concluding that Brazil is going in a fast pace towards development, by means of fast increasing GDP and not so fast increasing HDI. However, there are still many crucial issues concerning the parcel of the population enjoying these rising numbers. Brazil is one of the countries which present the highest social and economic disparities. As for the environmental indicators, Brazil has small emission of GHGs when compared to other countries, in spite of its huge GDP and population. This can be explained by the share of renewable sources in the Brazilian TPES. As discussed before, renewable sources emit less GHGs.

Regarding the energy itself, Brazil presents a unique energy profile, characterized by a large share of renewable sources in the TPES and an even larger share of renewable sources in electricity production. The oil shall continue having its importance in the TPES. Especially due to the pre-salt discoveries, but the tendency is to focus on the renewables, especially the ethanol with respect to transportation.

Sugarcane ethanol production and use in Brazil have proved to be sustainable. The energy balance is way higher than ethanol produced from other feedstocks and than fossil fuels. Its use contributes to the reduction of GHGs emissions and consequently increases the quality of the air. Finally, it does not compete with food production.

The main opportunities for the production of ethanol in Brazil are the increasing demand for ethanol all over the world (including Brazil itself), the slow pace of ethanol technology development, the large quantity of available arable lands and the strengthening of the sector by means of acquisitions and merging.

The main barriers are the protectionism practices (mainly by the USA and Europe) and the current lack of assurance in supplying the domestic market.

The sugarcane ethanol production and use in Brazil proves to be feasible, provided that the product supply be increased to guarantee the domestic demand and, in a step forward, to guarantee the exports. The increasing on the supply can only be achieved by means of increasing the production – obviously coupled with increasing the productivity; increasing the stock capacity – which is favored by the current consolidation tendency of the sector, by means of acquiring and merging processes; and increasing the investments in infrastructure.

6.Bibliography

- Rodrigues, D., Ortiz, L., 2006. “Em direçao à sustentabilidade da produçao de etanol de cana-de-açucar no Brasil”, Amigos da Terra and Vitae Civilis, October 2006.

- Coelho, S.T., Guardabassi, P., 2006. “Brazilian biofuels experience”, Iberoamerican Ministerial Meeting, Montevideo, September 26th to 27th, 2006.

- Coelho, S.T., Goldemberg, J., Lucon, O., Guardabassi, P., 2005. “Brazilian sugarcane ethanol: lessons learned”, STAP workshop on liquid biofuels, Delhi, August 29th – September 2nd, 2005.

- Goldemberg, J., Coelho, S.T., Guardabassi, P., 2008. “The sustainability of ethanol production from sugarcane”, Energy Policy 36 (2008) 2086 – 2097.

- Nass, L.L., Pereira, P.A.A., Ellis, D., 2007. “Biofuels in Brazil, an overview”, Crop Science, Vol. 47, November-December 2007.

- FIESP (Federaçao das Industrias do Estado de Sao Paulo). “Brazil: advancing future energy”, COP 15, 2009.

- EPE (Empresa de Pesquisa Energética), 2008. “Perspectivas para o etanol no Brasil”.

- International Energy Agency (IEA), 2006. “World Energy Outlook, 2006”.

- EPE (Empresa de Pesquisa Energética), 2009. “Balanço Energético Nacional 2009” (“Brazilian Energetic Balance 2009”).

- ANP (Agencia Nacional de Petroleo, Gas Natural e Biocombustiveis), 2009. “Oil, Natural Gas and Biofuels Statistical Yearbook 2009).

- BP, June 2009. “BP Statistical Review of World Energy”.

- EIA (USA Energy Information Administration), 2009. “Country Analysis Briefs”.

- EPE (Empresa de Pesquisa Energética), 2009. “Plano Decenal de Expansao de Energia 2008-2017”.

- EPE (Empresa de Pesquisa Energética), 2010. “Balanço Energético Nacional 2010, Resultados Preliminares”.

- ANEEL (Agencia Nacional de Energia Elétrica), 2009. “Atlas de Energia Elétrica do Brasil 2009”.

- Exame, March 24th 2010. “Estudo Exame: A hora da verdade para o etanol”.

- CIA (USA Central Intelligence Agency), 2009. “The world factbook 2009”.

- CENBIO (Centro Nacional de Referencia em Biomassa): www.cenbio.iee.usp.br/indexen.asp (version in English).

- MME (Ministerio de Minas e Energia): www.mme.gov.br

- Copersucar: www.copersucar.com.br/hotsite/2010/homepage_en.html (version in English).

- CTC (Centro de Tecnologia Canavieira): www.ctcanavieira.com.br

- U.S. Department of Energy: www.energy.gov

- World Bank: www.worldbank.org

- IBGE (Instituto Brasileiro De Geografia e Estatistica): www.ibge.gov.br/english (version in English).

- Ministério da Fazenda (Brazilian Ministry of Finance): www.fazenda.gov.br

- UNDP (United Nations Development Programme): www.undp.org

- World Energy Council: http://www.worldenergy.org

- Anfavea (Associaçao Nacional dos Fabricantes de Veiculos Automotores): www.anfavea.com.br

- eBIO (European Bioethanol Fuel Association): www.ebio.org

List of tables

List of figures

List of Graphs