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EXPANSION OF NATURAL GAS MARKET IN BRAZIL: SOLUTION FOR GROWTH OF PRODUCTION AND THE DIVERSIFICATION OF ENERGY MATRIX

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Abstract. *In the coming years global energy demand will continue to grow at high rates. It is estimated that between 2011 and 2030 the global demand for energy will grow 36% and the most responsible for this increase are the developing countries, like Brazil. However, the necessity imposed by environmental agencies, of control and reduction of emissions of pollutants should limit the use of coal and oil. In this sense, the natural gas presented as an energetic economically and environmentally viable. The growth in world consumption of natural gas by 2030 should be close to 50%. In Brazil, for the same period, it estimated that the increased production of gas is more than 140%, while the consumption is expected to increase more than 130%. One of the directives of the Brazilian Energy Policy, prepared by the National Council for Energy Policy, is the increased use of gas. The objective of this paper is to discuss the expansion of consumption of gas in Brazil, analyzing ways to internalization of this fuel in the country and presenting the economic and environmental advantages the substitution of more polluting fuels (such as fuel oil and coal) for gas natural.*

Keywords: *Natural gas, Energy matrix, Energy demand, Energy policy, Emission of pollutants.*

1. INTRODUCTION

Brazilian Energy Balance - BEN 2011 (EPE, 2012) shows that in the base year 2010 the natural gas accounted 7% of the energy matrix, being that the average production per day, in 2010, was approximately 63 million m³, while on average, 34.6 million m³ were imported daily, mainly from Bolivia. This value includes the gas supplied to the consumer market (industry, electricity generation, vehicles and residential market) and the gas used by Petrobras in the exploration and production of oil and oil products. Preliminary data from the Brazilian Energy Balance (EPE, 2013), base year 2011, show a 6.2% growth in natural gas consumption, in front of a growth of 2.7% of GDP and 1.3% in the domestic supply of energy, which points to a significant increase in the share of natural gas in the national energy matrix.

Recent data, published by Abegas - Brazilian association of piped gas companies (2013a), showed a growth of over 50% in natural gas consumption in the first two months of 2013 compared to the same period of last year. The average daily gas consumption was 70.5 million m³. This statistic just considered the volume available to the market through the states gas companies.

Predictions of British Petroleum - BP (2013) about the world energy consumption for the period 2011-2030, show that the consumption of natural gas will be present to greater growth among fossil fuels. While global demand for natural gas will grow at around 2% per year, the demand for oil and its derivatives should grow less than 1% per year. Figure 1 shows the evolution of the share of fuels in the global energy matrix. Natural gas, with renewables should present increased participation, while oil and coal shall suffer great reductions.

For Brazil predictions for the growth of natural gas consumption is even stronger. Also according to BP (2013) growth in the production of all kinds of energy, through 2030, should be greater than 80%. In turn, the production of natural gas will grow more than 140%, outpacing the growth of oil production expected in 87%. However, demand for natural gas is expected to have increased by more than 130%, the highest increase among the fossil fuels.

The growth of the supply and demand of natural gas in Brazil must pass necessarily by increasing the transportation infrastructure and distribution of this fuel.

Currently, there is a large concentration of gas pipelines in the Brazilian coast, while a good part of interior of Brazil, with major economic and industrial hubs, do not have transportation infrastructure, and consequently distribution systems, of this fuel.

Figure 2 shows the gas pipelines in operation, under implementation and study in Brazil and neighboring countries.

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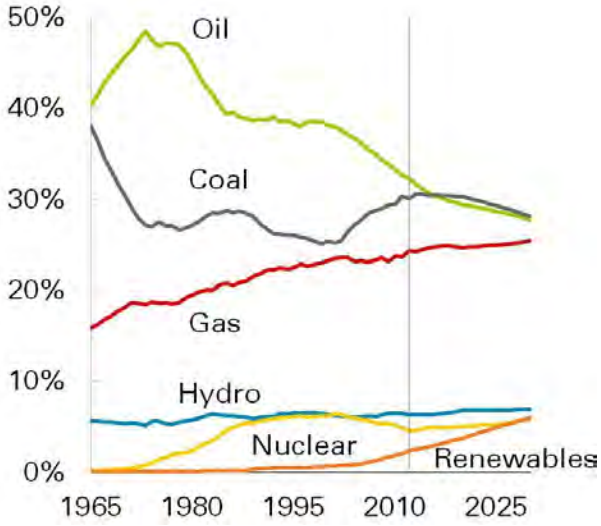

Figure 1 - Share of fuels in the global energy
Source: BP, 2013

Figure 2 - Infrastructure transportation of natural gas in Brazil
Source: Tavares and Mendonça, 2013

Considering the prediction of strong growth in consumption of natural gas, it becomes necessary to expand the infrastructure for the distribution of fuel. The objective of this study is to evaluate the measures being adopted for regions of the country with great potential for natural gas consumption can be serviced with pipelines. Also, will be presented economic and environmental benefits arising from the replacement of the more traditionally used fuels (fuel oil and coal) for natural gas.

2. NATURAL GAS

Although already exists in nature for millions of years, humans just started using natural gas about a thousand years before Christ. The first recorded use made in China, where the gas distributed through a system of bamboo and used primarily in lighting. In the Occident, the discovery made thanks to the Italian scientist Alessandro Volta. Walking along the shores of Lake Maggiore, in North Italy, he accidentally discovered that, stirring the waters of a swamp with a rod, producing bubbles that gave off a flammable gas. The West discovered natural gas. In the XVIII century defined by science characteristics of combustible gases and Alessandro Volta and other scientists have identified methane, the main element of the constitution of natural gas. Commercial exploitation began in earnest in 1820 with the discovery of a mine in Pennsylvania (USA). In 1930, other deposits discovered, encouraging research for better equipment operation

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and better pipes for gas transportation. Another breakthrough came because of large deposits discovered in the North Sea in 1965 (Gasmig, 2004).

Law 9.478/97, known as the oil law, gives the formal definition of natural gas in Brazil. Chapter III, Section I, Article 6, Item II, gives the following definition: Natural gas is any hydrocarbon that remains in gaseous under normal atmospheric conditions, extracted directly from oil reservoirs, including wet gas, dry gas, residual and rare gases (Brazil, 1997).

For Garcia (2002), the natural gas is a fossil fuel formed primarily of methane, in a proportion of 80 to 90%, ethane (5 to 10%) and other gases smaller proportions (propane, butane, pentanes, hexanes, carbon dioxide, nitrogen and rare gases). Also according to Garcia (2002) natural gas can be found underground or under the sea, on natural deposits of sedimentary rocks, with or without oil. Their origin is the decomposition of plants and animals, a process result of millions of years. Figure 3 illustrates the shapes of the occurrence of natural gas.

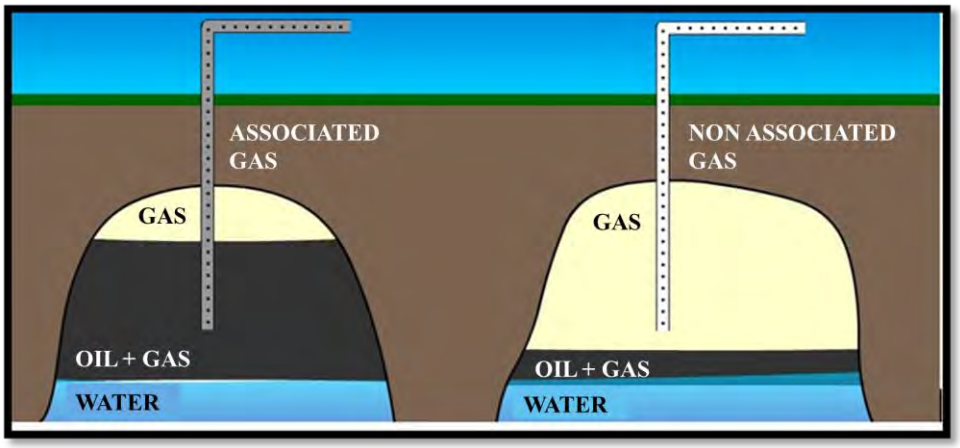

Figure 3 - Forms of occurrence of natural gas
Source: Tavares and Mendonça, 2013

The National Agency of Petroleum, Natural Gas and Biofuels, by ANP Resolution No. 16, dated June 17, 2008, presented in Tab. 1, regulate the quality of the natural gas marketed in Brazil, national origin or imported origin.

Table 1 - ANP Resolution 16 - 17/06/2008

Feature	Unit	Limit		
		North	Northeast	Midwest, Southeast and South
Gross calorific value	kJ/ m³	34.000 a 38.400	35.000 a 43.000	
Wobbe Index	kJ/m³	40.500 a 45.000	46.500 a 53.500	
Number of methane min.		note	65	
Methane, min.	% mol.	68,0	85,0	
Ethane, max.	% mol.	12,0	12,0	
Propane, max.	% mol.	3,0	6,0	
Butanes and heavier, max.	% mol.	1,5	3,0	
Oxygen, max.	% mol.	0,8	0,5	
Inert (N2 + CO2), max.	% mol.	18,0	8,0	6,0
CO2 max.	% mol.	3,0		
Total Sulfur, max.	mg/m3	70		
Hydrogen Sulfide (H2S), max.	mg/m3	10	13	10
Dew point of water at 1 atm, max.	ºC	-39	-39	-45
Hydrocarbon dew point at 4.5 MPa Max.	ºC	15	15	0
Mercury, max.	µg/m³	note		

Source: ANP, 2008

2.1 Natural gas market

According to figures from BP (2012) the total consumption of primary energy in 2011 was 2.5% higher than in 2010, closing the period with a total consumption of more than 12 billion tons of oil equivalent. Of this total, about 4 billion tons supplied by oil, representing the main source of energy, followed by coal at 3.7 billion tons and natural gas with 2.9 billion tons of oil equivalent.

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About natural gas, the countries with the highest consumption are the United States and Russia. Brazil, which has the seventh largest economy in the world, ranks eighth in world consumption of primary energy, but the country occupies a modest 29th position in world consumption of natural gas (BP, 2012). Figure 4 shows the 30 countries that have the highest consumption of natural gas.

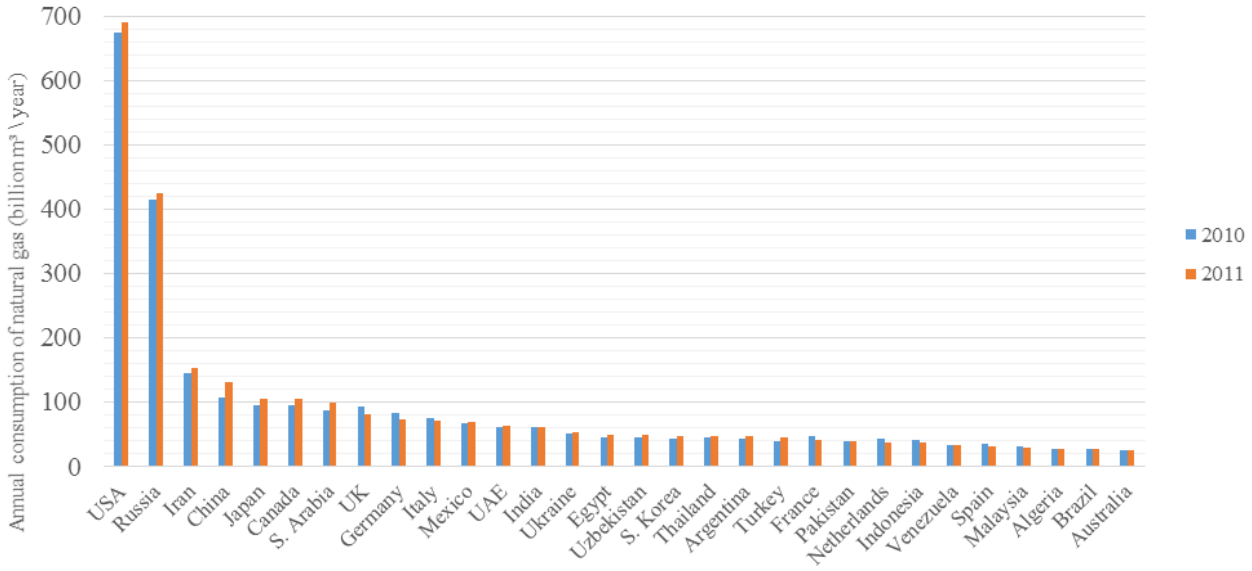

Figure 4 - Major consumers of natural gas from 2010 to 2011
Source: Prepared by the author based on BP, 2012 and EPE, 2012

Predictions for the coming decades indicate a large growth in global energy consumption, higher than the population growth. For BP (2013) the prediction is a growth of over 1.5% per year in the global demand for energy. The greatest growth will occur in developing countries, such as Brazil. The main use will be for fuel to generate electricity, and for this purpose the demand should grow at rates above 2% per year.

Growth predictions in demand for fossil fuels indicate that natural gas should be present that the largest increase, about 2% per year, while the demand for coal should rise just over 1% per year and oil will grow less 1% per year. Thus, the share of natural gas in the world energy should increase from the current 24% to about 26% (BP, 2013).

Energy Information Administration (EIA, 2011), linked to the U.S. government, provides that energy consumption should grow more than 50% between the years 2008 and 2035, with fossil fuels correspond to about 80% of demand. However, liquid fuels must show a decrease in participation, while the natural gas consumption should grow about 1.5% per year, as can be seen in Fig. 5.

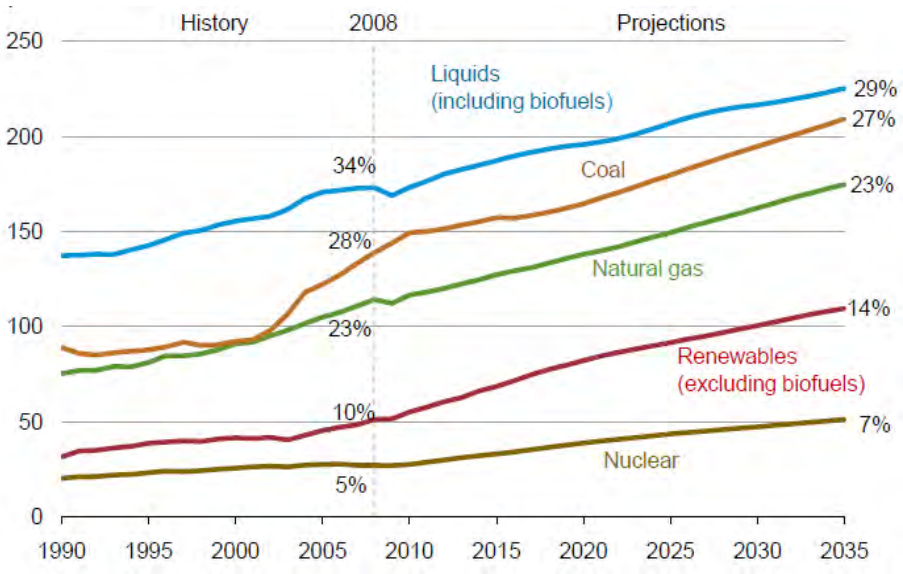

Figure 5 - Evolution of global energy consumption
Source: EIA, 2011

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It can be observed, therefore, that main predictions held around the world on the evolution of energy consumption for next years show high growth scenarios for consumption of natural gas, which is due to increasingly relevant role in composition of global energy matrix.

According to BEN (EPE, 2012) natural gas represents 7.2% of total primary energy, well below world average which indicates a greater than 20% in the share of natural gas in total energy consumption. The Brazilian energy matrix, despite having great growth between the years 2001 and 2010, almost did not change in their percentage composition, as can be seen in Fig. 6.

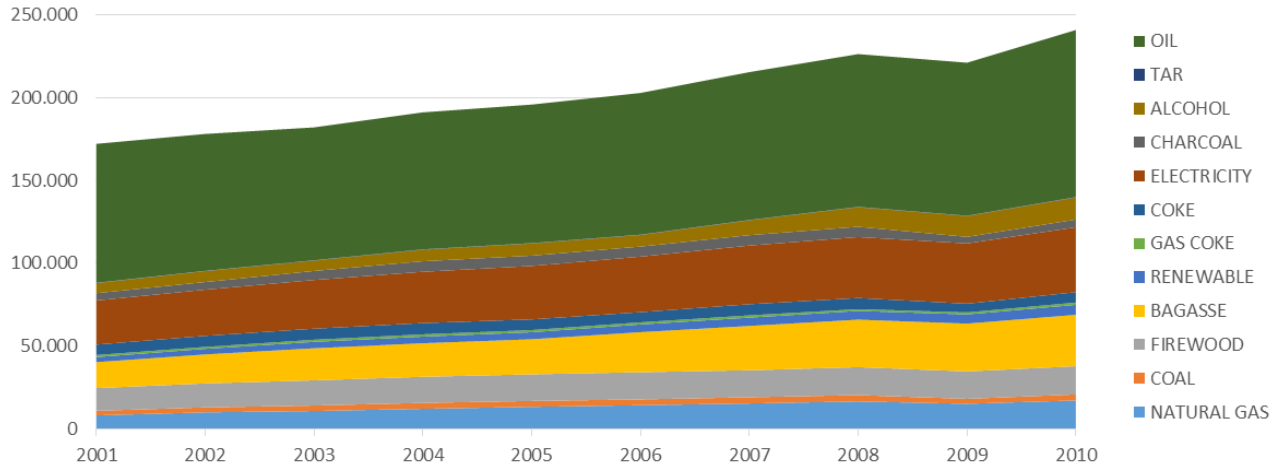

Figure 6 - Brazilian energy matrix by primary source, 2001-2010 - million toe
Source: Prepared by the author based on the BEN 2011 (EPE, 2012)

Brazilian law since the 1990s, points to the increased participation of natural gas in the national energy matrix. Law No. 9478 of August 6, 1997, which provides for a national energy policy, the activities related to the oil monopoly, establishing the National Council for Energy Policy and the National Petroleum Agency, provides in Article 1 that national policies energy use should increase, on an economic basis, the use of natural gas (Brazil, 1997). The National Council for Energy Policy, created by Decree No. 3520 of June 21, 2000, also provides in its Article 1 that the Brazilian Energy Policy should, among other principles, increase the use of natural gas (Brazil, 2000).

Primary energy production in Brazil, until the year 2030 will grow by about 80%. Energy sources that will grow more biofuels, with a growth of over 200%, and natural gas, with growth close to 150%. Oil production will also grow, but at a slower pace, about 85%. Already demand for energy in Brazil, for the same period should grow about 60%, and natural gas is expected to increase more than 130%. It can be observed, so that the portion of the energy belonging to the natural gas will experience a considerable increase (BP, 2013).

2.2 Transport and distribution of natural gas

According to Pereira (2010) more than 70% of the world natural gas movement occurs through pipelines. Being leading exporters of natural gas by pipelines, Russia, Norway and Canada, while the world's largest importers are the United States, Germany and Italy. Russia is the largest supplier of gas to Europe. The other major type of movement of natural gas is LNG - Liquefied Natural Gas, being the largest exporters Qatar, Indonesia and Malaysia. The biggest importer of LNG is Japan, accounting for about 30% of the world market, followed by South Korea and the United Kingdom. Japan is one of the largest natural gas consumption in the world, with all its demands met through LNG.

According to GasLocal (2013) a cryogenic process in which natural gas is cooled to a temperature of -162 °C produces LNG and has its volume reduced by approximately 600 times, enabling thus transportation to areas unmet by pipeline.

In Brazil, according to Petrobras (2013a), there are two LNG regasification terminals, one in Pecém Terminal in São Gonçalo do Amarante (CE), and another in the Guanabara Bay, in Rio de Janeiro. In operation since January 2009, the terminals have, together, capacity to process 21 million cubic meters / day of natural gas.

Another form of transportation and distribution of natural gas, to areas not served by pipelines, is by Compressed Natural Gas - CNG. In this process, natural gas is compressed and stored at a pressure of 250 bar, for transportation and distribution, and can meet demands of industries, vehicles and residences in a radium of 300 km from the compression unit (White Martins, 2013).

Constitutional amendment No. 5 (Brazil, 1995) establishes that the States operate, directly or through concessions, local services of piped gas. Law 9478/1997, defines as piped gas distribution services local marketing of gas, to the end users, to be done exclusively by the States, directly or through concessions under § 2 art. 25 of the Federal Constitution (Brazil, 1997).

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According to Almeida (2010) before the 1988 Constitution only states of Rio de Janeiro and São Paulo owned gas distribution companies, and in the remaining states Petrobras supplying gas directly to a few industrial consumers. From the 1990s several states have created distribution companies of piped gas. Figure 7 shows the state distribution companies of gas.

Figure 7 – States companies of distribution of piped gas
Source: Abegas, 2013b

Although Brazil had 27 gas distribution companies, and the state of São Paulo has 3 companies and the state of Rio de Janeiro 2, some companies still not effectively distribute gas and other exhibit incipient market, as can be seen in Tab. 2 .

Table 2 - Volume of natural gas distributed in Brazil, by company (thousand m³/day)

UF	Companies	Oct\2012	Nov\2012	Dec\2012	Average 12 months
SP	Comgás	16,212	15,854	14,538	14,407
RJ	CEG	11,529	13,069	11,705	8,982
RJ	CEG Rio	9,915	10,554	8,938	6,338
BA	Bahiagás	3,545	3,540	3,567	3,743
MG	Gasmig	3,955	4,299	3,964	3,619
ES	Petrobras Distribuidora	2,790	3,090	3,261	2,969
AM	Cigás	2,698	2,862	2,838	2,458
PE	Copergás	2,956	3,117	2,866	2,432
PR	Compagas	2,956	3,204	3,091	2,169
SC	SCGás	1,891	1,899	1,632	1,840
RS	Sulgás	2,032	1,861	1,716	1,668
SP	GasNatural Fenosa	1,402	1,374	1,140	1,364
CE	Cegás	1,938	1,869	1,951	1,256
MS	MS Gás	1,941	1,967	1,993	992.26
SP	Gás Brasiliano	827.15	821.57	817.78	828.31
AL	Algás	543.33	560.57	561.54	541.06
PB	PBGás	370.69	372.86	363.74	361.7
RN	Potigás	339.89	324.66	271.52	349.04
SE	Sergás	288.64	291.33	288.28	277.86
DF	CEBGás	8.19	7.79	7.91	8.96
MT	MTGás	9.15	12.13	13.11	7.85
GO	GoiasGas	3.54	3.52	3.01	3.55
PI	Gaspisa	0	0	0	0
MA	Gasmar	0	0	0	0
AP	Gasap	0	0	0	0
PA	Gás-Pará	0	0	0	0
RO	Rongás	0	0	0	0
	Total	68,156	70,959	65,532	56,623

Source: Abegas, 2013a

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Comparing information of Fig. 7 with those of Tab. 2, is observed that almost all the distribution companies, effective in operation are located in coastal states, except the states of Amazonas, Mato Grosso do Sul and Minas Gerais. Even in coastal states, most of pipelines are located in a narrow range near the sea. Especially in the northeast, almost all municipalities supplied with natural gas are located on the coast (Abegas, 2013b).

Distribution networks for natural gas in Brazil has been constantly increasing. Currently, the distribution network for natural gas in Brazil has more than 23,000 km of pipelines, serving 400 municipalities. Over the past decade, the gas distribution network in Brazil grew by over 200% (Abegas, 2013a).

However, comparing the Brazilian gas pipeline network with other countries is possible to observe the gap of the national infrastructure. According to Ferraro (2010) the gas pipeline the U.S. in 2005, had more than two million kilometers of pipeline being planned by 2008, incorporating over 6,000 km at a cost of $ 11.4 billion.

Comparing the density of existing pipelines in Brazil with the countries of Europe and the United States can be seen that while the Netherlands have more than 3 km of pipelines for each km ² of area, Brazil has only 0.0026 km of pipeline for each km ² (Eurogas, 2012). Figure 8 shows the extents and density of gas in several countries.

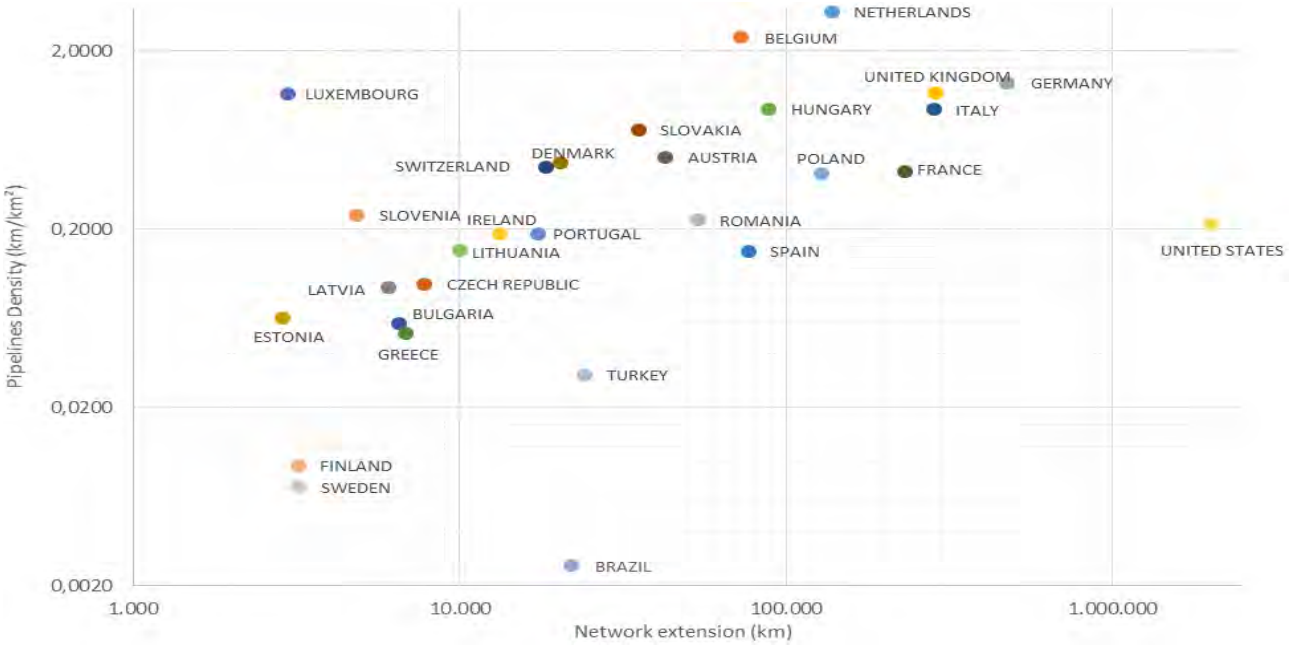

Figure 8 – Extension and density of gas pipelines
Source: Prepared by the author based on Abegas, 2013a, Eurogas, 2012 and EIA, 2011

Today, Brazil has more than 2.2 million natural gas customers, and more than 99% of customers belong to the residential segment and are mainly concentrated in the states of Rio de Janeiro and São Paulo, which companies have centenary distribution natural gas. Only in recent years other states, especially in the northeast, began to invest in the residential segment, but this market is still very low (Abegas, 2013a).

Figure 9 shows the number of natural gas consumers in Brazil, divided by segment.

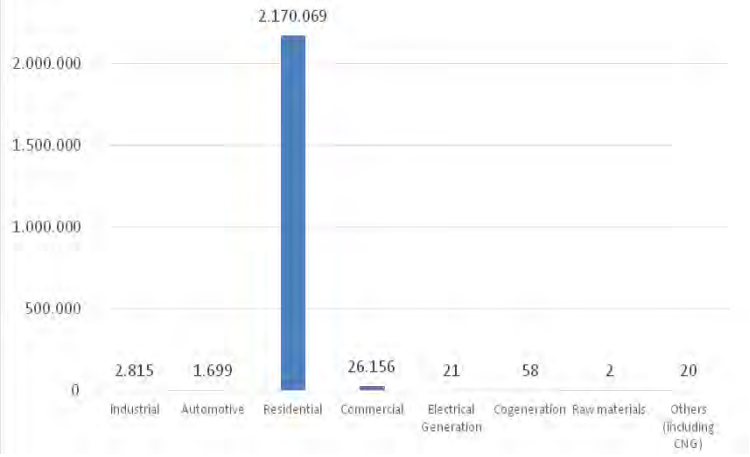

Figure 9 - Number of consumers of natural gas in Brazil
Source: Abegas, 2013a

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3. EXPANSION OF NATURAL GAS INFRASTRUCTURE IN BRAZIL

3.1 Transport pipelines

According to the Decennial Energy Plan 2021 - PDE, published by the Brazilian Ministry of Mines and Energy (MME, 2012), a national network of gas pipelines currently has a total of 9,489.2 km spread across all regions of Brazil.

The distribution of the pipelines is rather uneven, the North has a single pipeline, divided into two sections (Urucu - Coari and Coari - Manaus), this pipeline with a total length of 661 km, has a diameter of 18 inches in the first section and 20 in the second. Already a gas pipeline network in the Northeast total extent of 2,134 km with diameters ranging from 8-26 inches. The southeast represents over 40% of total Brazilian gas pipelines. The mesh for the region was enlarged in 194 km in the year 2011 with the entry into operation of the pipelines GASTAU (Caraguatatuba-Taubaté), Gasan II (Cubatão-Capuava) and GASPAL II (Guararema-Maua), all in the State of São Paulo. Today, the gas pipeline in the region amounts to the extent of 3,937 km and diameters 8-38 inch. The gas pipeline from the Southern totals extension of 1,379.2 km, with diameters ranging between 16 and 24 inches, and is made up of the southern section of GASBOL, and pipeline Uruguayana - Porto Alegre. Finally, the gas pipeline from the Midwest Region totals length of 1,531 km, divided between the northern stretch of GASBOL, with a diameter of 32 inches, and the import pipeline from Bolivia to the State of Mato Grosso, called Cuiabá Side, with a diameter of 18 inches (MME, 2012).

Also according to the PDE (MME, 2012), considering the approved projects under implementation included in the Growth Acceleration Plan (PAC) of the federal government and Anticipation Plan Gas Production Petrobras (PLANGAS) the following expansions in transportation network of natural gas are planned for the period up to the year 2021: a) Section I of Gasfor II (Pipeline Serra do Mel - Pecém), which goes from the Horizonte to Caucaia and is expected to go into production in 2014; b) Increase the capacity of the regasification terminal Guanabara Bay from 14 to 20 million cubic meters per day from the year 2014; c) Implementation of GASUBE, from 2015, to meet the Nitrogen Fertilizers Unit - UFN V, located in the State of Minas Gerais.

Some Brazilian states have not served by pipelines, are requesting the construction of transport infrastructure of natural gas for its markets. In these states, were created gas distribution companies that promoted estimates of potential markets (MME, 2012). The studies are based in the following states: a) Pará: studies are being prepared for market survey gas potential for the state. The supply of natural gas demand of Pará is being designed by Local Distribution Company from the interconnection with Maranhão (project Mid-North Pipeline); b) Maranhão: The study of the natural gas market for this state is being prepared by Gasmar. The supply to the state is based on the realization of the project called Mid-North Pipeline, connecting, in his main leg, cities of Fortaleza (CE), Teresina (PI) and São Luís (MA), and other extensions; c) Piauí: As in Pará and Maranhão, meeting the demand for natural gas in this state depends on the realization of a project of natural gas infrastructure; d) Goiás and Distrito Federal: These states are also doing market research potential of natural gas, whose supply would come from the completion of the Central-Brazil Pipeline, linking São Carlos (SP), Goiania and Brasilia, with 885 km in length, and two other extensions with over 595 km. Goiás and Distrito Federal, today, receive gas via LNG; e) Mato Grosso: Although this has been the Side Cuiabá Pipeline, this region is still isolated from the Brazilian gas pipeline.

The installation of LNG regasification terminals should complement and serve as an alternative to additional expansions in infrastructure pipeline until at least confirm that the large volumes of associated gas and non-associated with the new pre-salt areas still under evaluation. LNG, once delivered in a regasification terminal, can then be distributed by various modes available, including cryogenic trucks, which increases their use, including in locations not served by pipelines ever constructed mesh (MME, 2012).

It is planned for the coming years, a large amount of investment required for the expansion of natural gas infrastructure consisting of extensions and construction of new pipelines, the values can be checked in Tab. 3.

Table 3 - Planned investment in the expansion of the transmission of natural gas

Projects	Investments (R$ billion)
Pipelines	1.60
LNG	0.95
Total	2.55

Source: MME, 2012

Petrobras expects to your business plan investments in projects already under implementation in the amount of US$ 2.2 billion, with US$ 1.9 billion in pipelines and US$ 0.3 billion in LNG projects. Projects already under evaluation totaling over US$ 0.6 billion, with US$ 0.5 billion for LNG and US$ 0.1 billion for gas pipelines (Petrobras, 2013b).

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3.2 Distribution pipelines

According to Monteiro and Silva (2010) the distribution pipeline networks are composed of transport, pressure regulating stations and distribution networks, operated by companies state distribution of piped gas. It is through these pipelines that customers are supplied with natural gas.

Data from Abegas (2013a) indicate that all the distribution networks of the companies state gas account for about 23,000 km and serve 400 municipalities in the country. Projections indicate that the distribution pipeline should grow at an average rate of 1,200 km per year, considering the investments of all state companies. These projections consider an economic scenario with a GDP growth of industrial sector in the order of 3% per year (Tavares and Mendonça, 2013).

Based on this expectation distribution network for natural gas will grow by about 14,500 km over the period 2013-2030. Thus, in 2030 Brazil will have around 37,500 km of gas pipelines, which represents a growth of over 60% in the distribution network of natural gas.

4. EMISSION OF POLLUTANTS

Environmental pollution can be defined as the degradation of the environment through changes in the physico-chemical and biological characteristics of air, water or soil, adversely affecting the health, survival or activities of human and other living organisms (Lora, 2002).

Several factors contributed to the increase of environmental pollution in recent years. Lora (2002) states as major factors:

a) exponential increase of the world population;
b) exponential increase in energy consumption;
c) intensification of the process of industrialization;
d) the process of urbanization.

According to Monteiro and Silva (2010) fossil fuels to be released and burned produce oxides, such as carbon, nitrogen and sulfur, which are harmful to the health of every living being. One of the compounds produced is carbon dioxide (CO_2) that is released into the atmosphere. This gas is the main cause of the global warming process. In developed countries, three quarters of CO_2 emissions are from fossil fuel combustion and cement production, United States and China are major emitters (Baird and Cann, 2008).

Other gases are associated with the greenhouse effect as methane (CH_4), chlorofluorocarbons (CFCs), sulfur hexafluoride (SF_6), nitrogen oxides (NO_x) and tropospheric ozone (O_3). Some greenhouse gases are naturally produced in biological processes, such as CO_2 and CH_4, but the action of man has increased considerably, the concentration of these products in the atmosphere (Baird and Cann, 2008).

To calculate the amount of each of the emitted pollutant gases are used emission factors, which are factors which indicate the amount of exhaust gases due to the use of a quantity of fuel (Lora 2002). Tables 4 and 5 show the pollutant emissions for different types of fuels.

Table 4 - Emission factors for SO_2, NO_x and CO for different fossil fuels

Fuel and combustion technology	Units	SO_2	NO_x	CO
Fuel oil Nº 5 (burning conventional thermal power plant in front - CTE)	kg/m³	18.84 * S	8.04	0.6
Fuel oil Nº 5 (tangential firing in thermal power plant - CTE)	kg/m³	18.84 * S	5.04	0.6
Diesel (industrial boilers)	kg/m³	17.04 * S	2.4	0.6
Natural gas (large capacity boiler with burning front)	kg/10³m³	-	4.480	1.344
Natural gas (large capacity boilers with tangencial firing)	kg/10³m³	-	2.720	0.384
Bituminous coal (high capacity boilers burning front)	kg/ton	19 * S	6	0.25
Bituminous coal (high capacity boilers burning tangencial)	kg/ton	19 * S	5	0.25
Bituminous coal (spreader-stocker boilers)	kg/ton	19 * S	5.5	2.5
Wood waste (spreader-stocker boilers)	kg/ton	0.0375	0.75	6.8
Wood waste (fluidized bed boilers)	kg/ton	0.0375	1.0	0.7
Bagasse	kg/ton	-	1.2	-

S = sulfur content in the fuel elemental composition

Source: Lora, 2002

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Table 5 - Emission factors of particulate matter

Fuel	Combustion technology	Emission factor
Fuel oil Nº 5	Industrial boilers	0.24 kg/m³
Fuel oil Nº 5	CTE boilers	1.25 kg/m³
Natural gas	CTE boilers	0.016 – 0.08 kg/m³
Natural gas	Industrial boilers	0.016 – 0.08 kg/m³
Natural gas	Domestic and commercial boilers	0.016 – 0.08 kg/m³
Industrial diesel engines	-	4.01 kg/m³
Cane Bagasse	Spreder-stocker boilers	7.1 kg/ton

Source: Lora, 2002

For example, a boiler of a thermal power plant with a consumption of 1,000,000 kg / month fuel oil Nº 5 emits monthly about 5 tons of NO_x, 600 kg of CO and 1,250 kg of particulate material. If the fuel used is natural gas, there will be no emission of sulfur compounds and the monthly issue is 4.5 tons of NO_x, 384 kg of CO and 48 kg of particulate material. It is noted in this way, a 100% reduction in the emission of sulfur compounds, 10% in the emission of NO_x, 36% in the emission of CO and more than 96% reduction in the emission of particulate materials.

5. ECONOMIC ANALYSIS OF THE USE OF NATURAL GAS

Natural gas has an initial investment for their use less than for other fuels such as LPG - liquefied petroleum gas or fuel oil. Additionally, the costs of operation and maintenance of equipment that use natural gas are also lower (Comgas, 2013).

Monteiro and Silva (2010) provide an analysis of replacing current fuels with natural gas in various industries, showing the gain in efficiency and consequently reducing costs. The data of Tab. 6 consider the reference year 1997 and use the indicator Useful Energy / Final Energy, which actually represents the energy required to carry out certain work divided by the energy actually consumed to perform a job.

Table 6 - Energy efficiency in various sectors of industry

Industrial sector	Reference 1997	2010
	Useful Energy / Final Energy	Useful Energy / Final Energy
Cement	38 %	38 %
Pig iron and steel	61 %	62 %
Ferroalloys	24 %	28 %
Mining	30 %	31 %
Pelletizing	40 %	39 %
Nonferrous	27 %	27 %
Aluminum	19 %	22 %
Chemistry	46 %	47 %
Food and beverage	43 %	47 %
Sugar	58 %	58 %
Textile	37 %	39 %
Paper and cellulose	46 %	48 %
Ceramics	38 %	40 %
Others	29 %	30 %
Total	43 %	45 %

Source: Prepared by the author based on Monteiro and Silva (2010)

Table 6 shows that the use of natural gas in industry may increase by 2 percentage points (pp) efficiency in fuel consumption. Data of the BEN 2011 (EPE, 2012) indicate that the industry consumed 85.672 million tons of oil equivalent (toe). Therefore, a reduction of 2 pp would represent a saving of 1.713 million toe, or 11.72 million barrels of oil equivalent (boe). Considering the average price of oil in 2010 at US$ 79.5 per barrel, it can be concluded that the savings from the use of natural gas would be more than US$ 931 million in 2010. Table 7 presents these results.

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Table 7 - Potential gain efficiency with natural gas

	Efficiency (%)	Energy cosumption (10^3 toe)	Reduction in Energy cosumption (10^3 boe)	Economy (10^3 US$)
Without natural gas	43	85,672	---	---
With natural gas	45	83,959	11,720	931,740

Source: Prepared by the author with data from BEN 2011 (EPE, 2012) and Monteiro and Silva (2010)

6. CONCLUSIONS

The natural gas shows as a very efficient alternative to changing the oil and coal in industrial processes. Its use in boilers or furnaces, for example, is much simpler when compared to fuel oil, also natural gas issues a much lower amount of polluting the other fossil fuels, and the emission of sulfur compounds, one of constituent of acid rain, is practically zero in the burning of natural gas.

From an economic perspective, natural gas presents a very viable alternative to replace fuel oil or LPG, and the cost of maintenance and operation of equipment using natural gas are much lower. The efficiency of industrial processes that use natural gas as fuel is higher compared with other fuels. Data of the year 2010 indicate that the increased use of natural gas in industry could save more than US$ 931 million annually.

The main projections on the natural gas market in the world point to a large increase in fuel demand. For Brazil, these prospects are no different. It is expected that for the period between 2012 and 2030 the demand for natural gas will grow about 130% (BP, 2013). Considering data from Abegas (2013a) pointed out that an average consumption of 70.5 million cubic meters per day for the period of January and February of 2013 it is expected, therefore, that daily consumption of natural gas is higher than the 160 million m³ per day by the year 2030.

In order to demand that can be supplied to pipeline infrastructure should be expanded. Data published by Petrobras, the Ministry of Mines and Energy and the gas distibution companies indicate that the gas pipeline network, both as transport and distribution, grow considerably, and the distribution network from the current 23,000 kilometers to nearly 37,500 kilometers .

However, the available data and projections point a growth in infrastructure much lower than the projected growth in demand. The lack of pipeline transportation and distribution sufficient to drive natural gas could be a bottleneck in expanding the use of this fuel in Brazil, especially in states not bordering the sea.

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8. REFERENCES

ABEGAS, 2013a. “Report Abegas market and distribution in 2012”. 28 mar. 2013 <http://www.abegas.org.br>.

ABEGAS, 2013b. “Dealers of piped gas distribution by region”. 10 mar. 2013. <http://www.abegas.org.br/Site/?page_id=839>.

ALMEIDA, E. F., 2010. “Regulating of gas distribution in Brazil”. Rio de Janeiro: IE-UFRJ.

ANP, 2013. “Resolution Nº 16, of 17 jun. 2008”. 10 mar 2013. <http://www.anp.gov.br>.

BAIRD, C.; CANN, M., 2008. “Environmental chemistry”. New York: W. H. Freeman and Company, 2008.

BP, 2012. “Statistical Review of World Energy”. 01 mar. 2013. <http://www.bp.com/statisticalreview>.

BP, 2013. “BP energy Outlook 2030”. 03 mar. 2013. <http://www.bp.com/extendedsectiongenericarticle.do?categoryld=9048887&contentld=7082708>.

BRASIL, 1995. “Constitution (1988). Constitutional amendment. 5, to August 15, 1995. Modifies § 2 of art. 25 of the Federal Constitution and other provisions”. 15 mar. 2013 <http://www.planalto.gov.br/ccivil_03/constituicao/Emendas/Emc/emc05.htm>.

BRASIL, 1997. “Law No. 9,478, of 06 August 1997. Provides for the national energy policy, the activities related to the oil monopoly, establishing the National Council for Energy Policy and the National Petroleum Agency and other measures”. 01 mar. 2013 <http://www.planalto.gov.br/ccivil_03/Leis/L9478.htm>.

BRASIL, 2000. “Decree 3520 of 21 June 2000. Has on the structure and functioning of the National Council for Energy Policy - CNPE and other measures”. 10 mar. 2013 <http://www.planalto.gov.br/ccivil_03/decreto/D3520.htm>.

COMGAS, 2013. “Benefits and advantages of natural gas”. 03 jun. 2013 <http://www.comgas.com.br/quero_industria/gasnatural/beneficios.asp>

EPE, 2012. “BEN - National Energy Balance 2011”. 08 mar. 2013 <https://ben.epe.gov.br/>.

EPE, 2013. “BEN - National Energy Balance - Preliminary results 2012”. 08 mar. 2013 <https://ben.epe.gov.br/>.

EIA, 2011. “Internation Energy Outlook 2011”. 04 mar. 2013 <http://www.eia.gov>.

EUROGAS, 2012. "StatisticalReport 2012". 28 mar. 2013 < http://www.eurogas.org/publications_annualReport.aspx>.
FERRARO, M.C., 2010. "Structures to encourage investment in new pipelines: A neo-institutional analysis of the new Brazilian regulatory framework". Thesis submitted to the Graduate Program in Economics at the Institute of Economics of the Federal University of Rio de Janeiro.
GARCIA, R., 2002. "Fuels and industrial combustion". Interciência, Rio de Janeiro.
GASLOCAL, 2013. "LNG. What is?". 12 mar. 2013 <http://www.gaslocal.com.br/gnl_oque.html>.
GASMIG, 2004. "Natural gas in Minas Gerais". Belo Horizonte, 2004.
LORA, E. E. S., 2002. "Prevention and control of pollution in the energy, industrial and transportation". Interciência, Rio de Janeiro. 2nd edition.
MME, 2012. "Decennial Plan to expand energy - 2012". MME/MME, Brasília.
MONTEIRO, J. V. F.; SILVA, J. R. N. M., 2010. "Natural gas applied in industry and the large trade". Blucher, São Paulo.
PEREIRA, F. V. A. B., 2010. "Marketing and distribution of natural gas". Belo Horizonte: IBP.
PETROBRAS, 2013a. "Petrobras' LNG between major infrastructure projects in the world". 14 mar. 2013 <http://www.petrobras.com.br/pt/noticias/gnl-da-petrobras-entre-os-principais-projetos-de-infraestrutura-do-mundo/>.
PETROBRAS, 2013b. "Business Plan and Management 2013-2017" 19 mar. 2013 <http://www.investidorpetrobras.com.br/pt/plano-de-negocios-e-gestao/plano-de-negocios-e-gestao/ano/2013.htm>
TAVARES, M.; MENDONÇA, M., 2013. "Brazilian gas market and the development of unconventional in Minas Gerais". Gasenergy, Belo Horizonte.
WHITE MARTINS, 2013. "Natural gas: White Martins invests in future energy". 12 mar. 2013 <http://www.praxairglobal.com/sa/br/bra.nsf/AllContent/1FD9E99B52177C4E8525721A006431D0?OpenDocument&URLMenuBranch=DC14CA7E060AEBD2852571E100548039>.

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