Energy Restrictions to Growth: the past, present and future of energy supply in Brazil♦

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Abstract

At the end of World War II, Brazilian authorities perceived energy supply as a major constraint to economic growth. To remove this constraint, state-owned energy companies (Petrobras and Eletrobras) were created to develop an energy system that should be able to supply the demand emerging from industrialization and urbanization, operating under a monopolistic regulatory regime. This regulatory regime was set up to face the elastic energy demand in the country. In the 1980's, this institutional arrangement was no longer able to match the growing demand of energy, especially in the power sector. Radical reforms were implemented to open the energy sector to private investors and to competition but power shortage restricted economic growth at the beginning of this decade. Reforms were introduced in the wholesale power market but the specter of a new shortage of energy supply is regularly haunting consumers, especially after the Brazilian imports of energy from neighbor countries (Paraguay and Bolivia) became a political issue. The recent discovery of large offshore oil fields, the large potential for hydropower and the leadership in the supply of ethanol offer an optimistic scenario for the Brazilian supply of energy. In addition, since the 1990´s, the energy demand elasticity has fallen to unity, easing energy restrictions to growth. However, to remove the specter of energy shortages it is crucial to put in place a regulatory regime that can be able to attract the substantial financial resources needed to develop the energy system.

Keywords: energy supply, economic growth, energy regulation, demand elasticity.

Resumo

Após a Segunda Guerra Mundial, o governo brasileiro identificou a oferta de energia como uma restrição fundamental ao crescimento econômico. Para removê-la, empresas estatais (Petrobras e Eletrobras) foram criadas com o objetivo de desenvolver um sistema energético capaz de atender a demanda decorrente dos processos de industrialização e urbanização. O regime de monopólio era justificado pela elevada elasticidade da demanda, que implicava em forte ampliação da infra-estrutura. Na década de 1990, esse arranjo institucional, principalmente no setor elétrico, se mostrou incapaz de necessidade de investimentos apesar da redução da elasticidade da demanda. As reformas liberalizaram o setor energético brasileiro, mas o racionamento de eletricidade comprometeu o crescimento econômico no início da década atual. O mercado de eletricidade sofreu novas alterações, mas o risco de desabastecimento energético é ainda relevante, especialmente após as importações de energia se tornarem um assunto político. A recente descoberta de petróleo no pré-sal, o elevado potencial de hidreletricidade e a liderança no mercado de etanol oferecem um cenário otimista para o setor energético brasileiro. No entanto, para eliminar a ameaça de novas crises energéticas é crucial desenvolver um regime regulatório capaz de atrair os recursos financeiros necessários para aproveitar esse cenário.

Palavras-chaves: Oferta de energia, crescimento econômico, regulação e elasticidade da demanda
JEL: N76, O13,Q43.

Área Anpec: 5 - Crescimento, desenvolvimento econômico e instituições

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1. Introduction

It is widely accepted that energy is a critical input for economic and social development (WEA, 2000). Energy is used in every sector of human activity, and data correlating energy and GDP indicates that energy consumption increases with economic growth. Unsurprisingly, the reliability of energy supply is a centre piece of economic development policies. Shortages in the supply of energy, like the ones experienced by the Brazilian economy in 1974 and 1978 (oil), 1990/1991 (ethanol) and 2001 (electricity), have an abrupt impact on economic growth.

Our paper looks at the relationship between economic growth and the energy system. The first section investigates the impacts of the industrialization and urbanization of the second half of the XX Century in the energy consumption in Brazil. We provide a historic overview of energy supply and evaluate the growth energy elasticity for the first time in the Brazilian literature using modern econometric techniques. The second examines the possible contradiction of energy supply shortages in a resource rich environment over the coming years. This is the challenge that the current institutional and regulatory arrangements that were put in place to develop the domestic supply of energy needed to avoid the risk of energy shortages, to guarantee energy supply in the future has to focus.

After the Second World War, Brazil experienced not only a significant economic growth, but also a remarkable change in its energy system. Over the period, industrialization and urbanization drastically changed the landscape of both the Brazilian society and the energy sector. In 1950, 63.8% of the population was living in rural areas and industry was 24.1% of GDP. Nowadays, the rural population is only 19.8% and industry 37.5 % of GDP (UN, 2007 and Baer, 2008). The change in the energy system was radical as well (see Figure 1). Wood, a non commercial energy source, was substituted for commercial fuels, and large companies developed a modern energy system that are able to supply modern energy sources to all urban areas of the country and to most of the rural areas as well. External dependency on oil was removed, as far as oil supply is concerned. And a national grid has integrated all country but the Amazon region.

Two basic energy forms, power and fuel have been supplied at higher rates over time, from varying sources. While in the 1970´s electricity supply was guaranteed from the large hydro plants, at least in the South and Southeast regions, the country was dependent on foreign imports for its oil refined fuel needs. In the 1980´s such fuel needs for transportation were eased with the use of ethanol. In 1986, about 95% of all automobiles sold were ethanol powered (Anfavea, 2008). In the 1990´s oil production rose significantly, and in the 2000´s natural gas became an important non-renewable energy source. In non-renewable sources, ethanol output rose significantly, at increasing productivity rates, up to the point that there is excess supply (Sandalow, 2006).

Nevertheless, the energy system had come under stress over the period. In the 1970´s the oil shock led to significant gasoline and diesel rationing –or at least restricted access to. In 1990, changing relative prices of sugar and lack of internal support for ethanol production led to a shortage that shattered consumer confidence in this fuel. The same hydroelectric system and a more interconnected grid system that guaranteed power for larger and larger parts of the country over the 1980´s came to a near halt in its supply expansion in the 1990´s, leading to the 2001 power shortage in the face of below average rains (Oliveira, 2001).

For the early XXI Century, the energy system in Brazil is at a cross road with significant resources at its disposal for the first time in its history. The available resources come from large oil and natural gas proven reserves, including the recently discovered "pre-salt" (extremely deep water oil field) break-though. There is also large output at competitive prices in the form of ethanol from sugar-cane, a renewable energy resource. The electricity supply is consolidated, and based on a complementary system of thermal and hydraulic (and nuclear) plants, with thermal plants fired either on oil or natural gas.

In short, the power shortage spectrum firmly set in the population´s mind, as put in the famous carnival song from 1954 at the country´s capital and largest city, mentioned above has been reduced. But the euphoria over the energy non-renewable (oil and natural gas) and renewable (ethanol and hydropower) resources available has to be translated into actual energy supply. This is the challenge for the XXI Century for Brazil, a challenge that the 2001 power shortage is keen to expose. We discuss such challenges are discussed in the last part of the paper.

2. The evolution of Energy Supply in Brazil, 1948-2008.

The energy supply system changed significantly after the Second World War. Such changes in two complementary ways, namely, an institutional change perspective and a statistical perspective.

2.1 Institutional overview

During the last six decades, the Brazilian energy system has been struggling with the specter of energy shortages. In the 1950's, the main source of energy used in the country (firewood) was unfitted to supply the demand emerging from industrialization and urbanization. To develop the supply commercial energy sources, government build up an institutional arrangement that delegated to Petrobras the monopolistic development of oil supply and to a set of monopolistic regional power companies, coordinated by Eletrobras, the development of electricity supply (de Melo, de Oliveira e de Araújo, 1994).

Actually, the cornerstones for the development of a modern energy system in Brazil were laid in the 1930´s by the federal government. The Water Code and the Mining Code assigned to the federal government the property rights of the energy resources (Dias Leite, 1997). However, by the end of Second World War, amid a wave of nationalizations that discouraged foreign investors, Brazil was facing large difficulties to supply a rapid increasing energy demand.

A consensus emerged between nationalists and liberals that state owned companies should control the energy sector. Petrobras, a federal government monopoly, was created in 1954 to develop the incipient oil market while regional state-owned power companies were cretaed to develop the electricity market. In 1962, the federal government created Eletrobras as a holding company to coordinate the regional power companies.[1] These state-owned enterprises operated with the mandate to spread the

[1] Besides the nuclear power plants and the Brazilian share of Itaipu, Eletrobras had the control of the four regional generation and transmission companies (Eletronorte, Eletrosul, Furnas and CHESF), and minority shares in every other power company.

supply of modern energy sources, at prices that would foster industrialization (de Oliveira, 1977). The rationale for a state enterprise was to guarantee control over resources, and to induce forward linkages and multiplicative effects over the economy.

These state-owned companies used the large financial and regulatory incentives received from the State to remove the critical shortages of energy supply in the industrializing and urbanizing regions of the country. Until the 1970’s, a period of rapid economic growth, regionally concentrated in the South-Southeast, was pursued with no major energy constraint in these two regions. Shortages were still a problem in the North-Northeast where the hydraulic power supply was lower and the interstate power grid was incomplete.

Passed its infancy, the 1970’s oil crisis headed the modern energy system of Brazil to new challenges. The brutal increase in both oil prices and international interest rates disorganized the macroeconomic fundamentals of the country. Government introduced radical measures to put the rampant inflation under control (Baer, 2007). The Brazilian economy entered into a phase of low growth but urbanization kept its momentum moving up energy consumption, although at lower pace. Energy companies had to develop the system to keep supply and demand balanced but their financial situations were deteriorating as result of government control of energy prices.

From the 1950´s until the 1990´s Petrobras is recognized as playing its role as inductor of the Brazilian infrastructure and base manufacturing, both in production, refinery and chemicals. Yet, by the 1970´s other energy sources received heavy government subsidies and incentives, to counteract the oil crisis effects, namely ethanol. Anhydrous ethanol was used as an anitcombustant in gasoline, reducing pollution emissions from led, and regular ethanol as fuel itself. In 1986 about 90% of new automobiles sold were regular ethanol fuelled. Yet in 1990 there were shortages that shattered consumer confidence on ethanol supply. The shortages culprits are usually pointed as the changes in relative prices for sugar and domestic price controls.

Indeed, price control problems were wide spread in the sector. Energy companies were not allowed to increase their prices tandem with their rapidly increasing costs. Moreover, government incentives to the energy introduced in the 1950’s were gradually removed. Inevitably, the financial situation of the energy companies deteriorated, reducing their ability to develop the energy system. Investments, especially in the power sector dwindled, and eventually the specter of energy shortage reemerged in the 1990’s (de Oliveira, 2007). To move forward the development of the energy system radical reforms were introduced in its regulatory and institutional arrangement. Privatization and competition were used to attract private investors to the energy system and to remove economic inefficiencies.

The early reforms of the 1990’s were unable to remove the specter of energy shortages. While sustainable economic growth was back, pushing energy consumption to increase rapidly, investments in the energy sector remained lagging behind. At the beginning this decade (2001), Brazil faced a severe shortage in the supply of electricity that forced industry to reduce its output. This time the energy shortage became dramatic because of the maturity of the system that had completed the link between the four power systems, South-Southeast-North-Northeast.

To remove the specter of energy shortages, government decided to get large control on the wholesale power market. New regulations were introduced that gives government close monitoring of the development of power system but the specter of energy shortages was not fully removed, especially after the Brazilian imports of energy from neighbor countries (Paraguay – hydropower – and Bolivia– natural gas –) became a political issue.

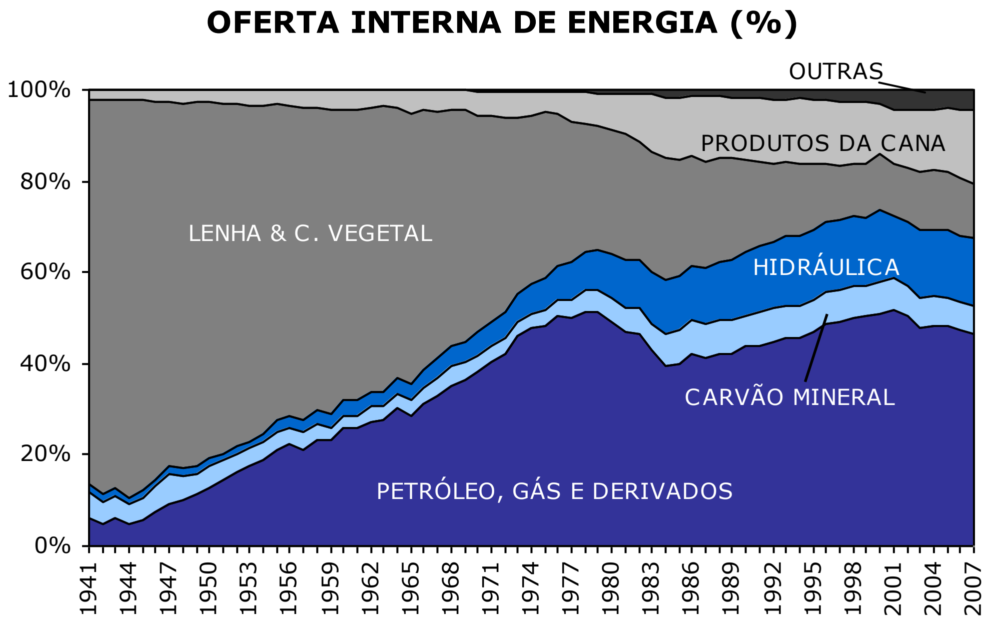
The recent discoveries of very large offshore hydrocarbons fields in a period of high oil prices generated strong optimism among Brazilian authorities about the future supply of energy. Government is envisaging institutional and regulatory changes, especially in the oil sector, that should enhance the fiscal flow to the Treasury. Plenty of energy resources, Brazil is in a privileged position to move along the transition from fossil fuels to renewable sources of energy, a major comparative advantage in a world that has to cope with the climate change issue. However, it is important to have in mind that the institutional and regulatory arrangements are a critical piece in the development of the energy system. If these arrangements are unable to attract financial resources to invest in the system, the energy resources will remain in the ground and will remain under with the specter of energy shortages whenever economic growth get momentum.

2.2. Statistical overview

The historical summary presented above can be indentified in the historical data. Energy supply in Brazil can be characterized by three remarkable changes over the past 70 years. First, the replacement of non-commercial fuel (wood and coal) to economic energy sources such as electricity and oil. This movement was particularly acute up to the mid 1970´s, where the thrust of the industrialization[2] and urbanization process took place. The substitution of wood had positive impacts, given the poor efficiency of wood and its heavy environmental costs. In addition, Second, a strong, albeit irregular, move towards renewable resources over time, with sharp reductions in wood use, namely sugarcane products (ethanol) and hydraulic power. Hydraulic power was the chosen source for power generation in the state energy planning from the 1950´s, taking advantage of the favorable river basins conditions, particularly in the rich southeast, and to lesser the dependency in imported oil. Ethanol received heavy incentives after the oil shocks as an alternative for gasoline (transportation) In 1965 while hydraulic power generated about 5% of all internal energy supply, it accounted for more than 15% in 2000. Ethanol reached 5% of all internal energy supply in 1995.

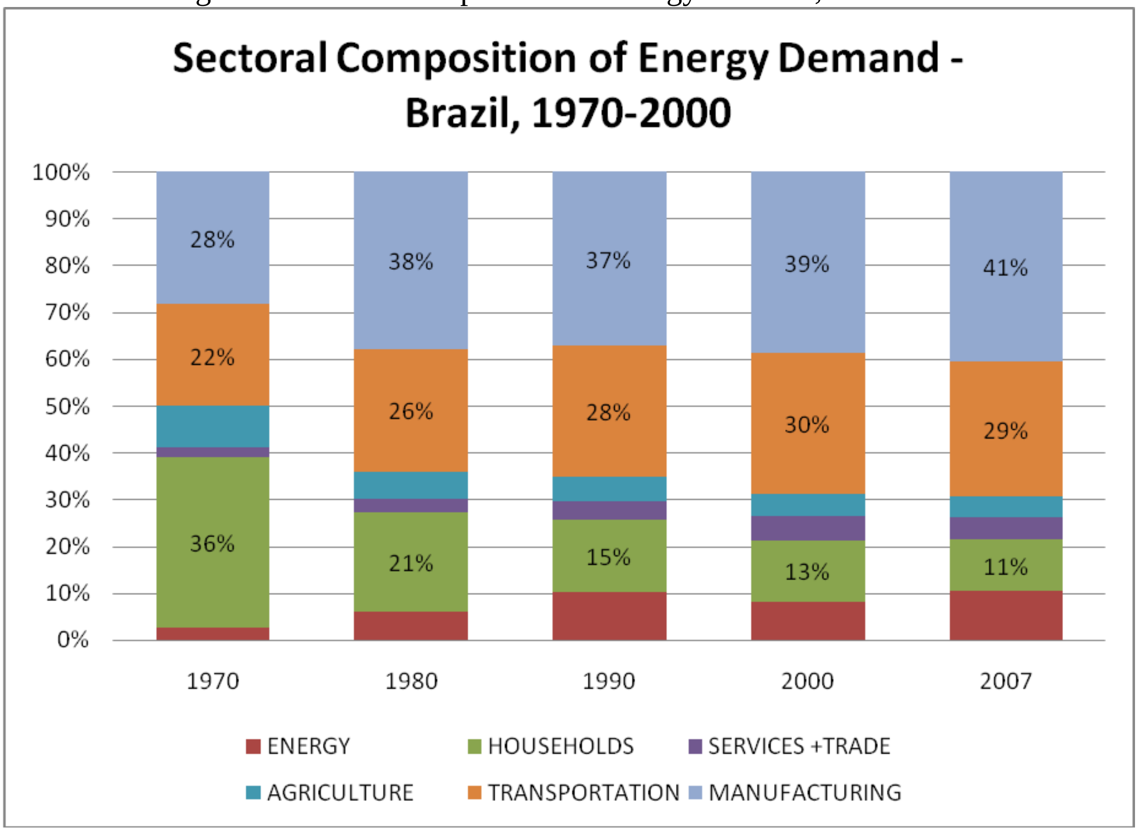
[2] Emerging manufacturing in Brazil used wood for energy generating, since the early stages of industrialization (Branstrom, 2005).

Figure 1 – Internal Energy Supply Structure, 1940-2007



Source: BEN (2007)

Figure 2 – Sector Composition of Energy Demand, 1970-2007



Source: BEN (2007).

It should be noted that oil use increased dramatically over the period, due to different rationales. Oil based fuels replaced wood and charcoal in a much more efficient way and they were irreplaceable in the transportation sector. As the economy grew, energy use in manufacturing rose particularly fast (figure 2). From 1970 to 1980, manufacturing share of the total energy consumption rose 10% from 28% to 38%. of all energy used. Energy consumption in transportation followed a similar trend. The share of energy used among householders diminished mainly as result of the fact that the wood used has been replaced with commercial energy sources (electricity and fuel), that are much more efficient[3]. It is remarkable the increase of energy use in the energy sector. This is largely a result of a growing share of the use sugar cane to produce ethanol[4].

The third structural change in the energy balance was the significant reduction in dependency of energy imports (table 1). While in 1970, 27% of Brazilian energy needs were imported, in 2007 this figure was below 10%. This outcome is largely the result of a substantial increase in the domestic production of oil. Recently, the country reached oil self sufficiency, although oil imports are still necessary due to the quality of the fuels needed to feed the domestic refineries. Brazil should become a net oil exporter in the coming years.

Table 1- Energy External Dependency – Brazil - 1970-2007

Year	**Energy**	Oil and Natural Gas	Coal	Electricity
1970	**27.1**	**67.6**	**50.2**	**0.0**
1975	**39.9**	**79.8**	**57.9**	**0.1**
1980	**42.6**	**83.0**	**52.6**	**-0.2**
1985	**20.1**	**43.1**	**48.3**	**1.0**
1990	**25.2**	**43.4**	**69.6**	**10.6**
1995	**30.2**	**49.0**	**72.0**	**11.4**
2000	**22.2**	**27.1**	**68.1**	**11.3**
2005	**10.2**	**-0.1**	**71.6**	**8.8**
2007	**8.0**	**0.1**	**73.5**	**8.0**

Source BEN 2007
Note: Dependency=(Total Demand – Domestic Supply), as % of Total Demand

The careful reader may have noticed the increase of imported electricity in the 1990. Electricity imports are due to Itaipu, a large dam (12 600 MW capacity), built as a joint project between Paraguay (50%) and Brazil (50%) on the Paraná river. Brazil

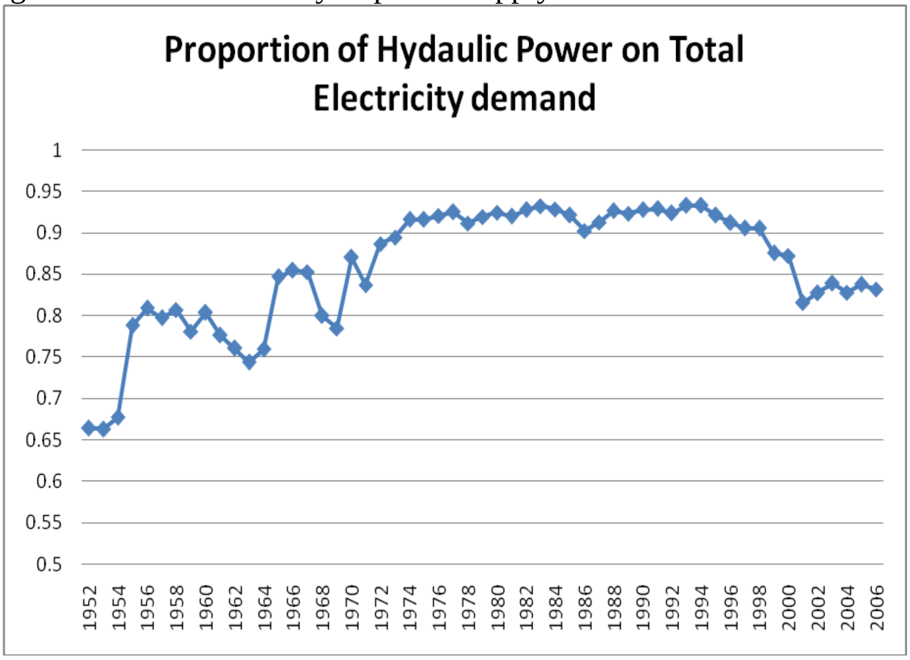
[3] It may be the case that the sector use shares are being unduly influenced by energy use imputation, particularly for wood. This has been pointed out as a limitation to BEN statistics (De Oliveira and Gutierrez, 1998).

[4] Sugar cane produces large amounts of the bagasse that is used in the ethanol producing plants.

consumes most of Paraguay´s energy share in the plant output, thus registered as imports.

Since the 1990´s there have been increases in the use of fossil fuels for power generation (Figures 3 and 4). From 1950´s to the 1980´s, the supply of hydropower plants increased steadily. This period represents Eletrobras (and before that state firms such as Furnas and Chesf) heyday. During the 1990´s the construction of large dams came to a halt due to environmental concerns, but also as result of the economic crisis that kept energy demand growing at a relatively slow pace.

Figure 3 – Evolution of Hydropower Supply – 1954-2007

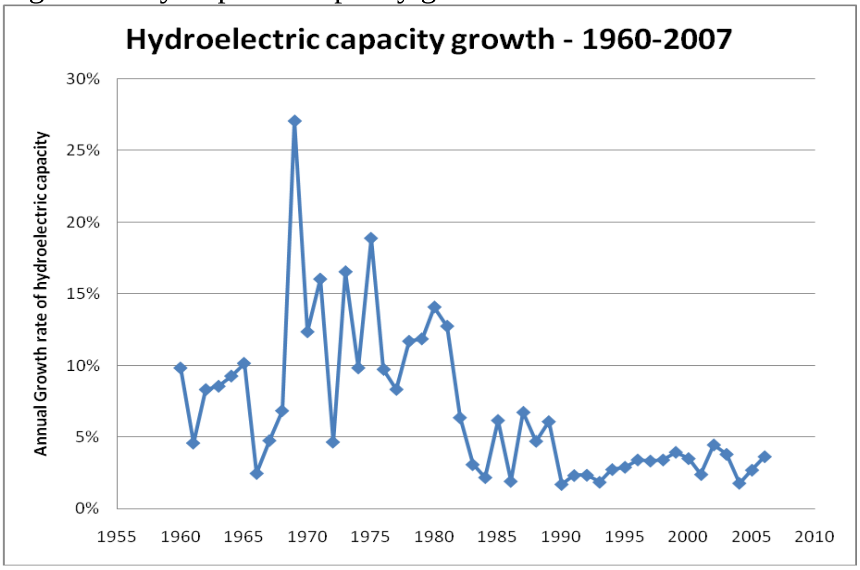


Source: www.ipeadata.gov.br, From Eletrobras data.

The new institutional arrangement of the mid 1990´s led private investors to focus their attention on thermalpower plants (induced also by relatively cheap natural gas supply from Bolivia). The hydropower capacity growth averaged 13% in the 1970´s but fell to below 5% since 1990.

One major limitation of hydropower is its exposition to precipitation rates. In case of below average precipitation, the hydropower plant has limited generation capacity and this has a direct effect on the system availability. Hydropower systems have to operate with a certain level of thermal power installed capacity to avoid the risk of power shortages.

Figure 4 - Hydropower capacity growth - 1960-2007



Source: www.ipeadata.gov.br, From Eletrobras data.

After the 1990´s reform, the electric system was built basically around two economic players: state hydraulic energy generators and private thermal energy operators. The latter would provide energy based on reservoir conditions of hydropower plants. When the energy available in the reservoir were unable to avoid a certain risk of power shortage, thermal power plants would light up and produce the additional power needed to supply demand. Given the lack of thermal power expansion in the 1990´s, the risk of power shortage increased continually in that period, culminating into the power shortage of 2001.

3. Economic Growth and Energy Consumption

In Brazil there are many studies that measure the GDP elasticity of electricity consumption. Their results indicate that the manufacturing sector demand is elastic, while household consumption is inelastic (Schmidt and Lima, 2004, *e.g.*). This would suggest that the supply of electricity must increase faster than income to keep up with demand, at least for manufacturing, so not to avoid energy price increases or actual blackouts.

We propose a broader view, estimating a model for measuring the GDP elasticity of *energy* consumption. There are many sources of energy, and over time there may be substitution effects due to technological changes or relative price shocks. Hence, focusing only on de GDP demand of one source of energy (namely, electricity), provides a limited view of the issue.

We associate an energy hurdle to growth if the energy income demand elasticity is greater than one. In this case, energy supply must increase faster than GDP, to avoid shortages.

Our modelling recognizes the dual role of energy in GDP. First, energy is an intermediary input and final consumption good. This leads to the use of a system of equations, where GDP level and energy use are jointly determined. The time series model use will be a Vector Auto-Regressive (VAR) model, namely.

$$Y_t = \beta_{01} + \beta_{11} Y_{t-1} + \beta_{12} E_{t-1} + v_{1t}$$

$$E_t=\beta_{02}+\beta_{21}\, Y_{t-1} + \beta_{22}\, E_{t-1} + v_{2t}$$

where Y_t and E_t represent log GDP (in constant prices) and log energy use (in tep, or other energy units), respectively. Shocks to GDP and energy use are modeled as a jointly Normal vector of possibly correlated error terms (v_{1t}, v_{2t}).

The above specification does not lend itself to the identification of the long run energy consumption to GDP elasticity. At the same time, we consider the long-run relationship between the variables that suggest the existence of a co-integration vector between the two non-stationary variables[5]. Under co-integration, the above VAR model can be written as a Vector Error Correction Model (VECM):

$$Y_t=\alpha_{01}+\alpha_1\, u_{t-1} + v_{1t}$$
$$E_t=\alpha_{02}+\alpha_2\, u_{t-1} + v_{2t}$$
$$u_{t-1}=E_{t-1} - \delta_0 - \delta_1\, Y_{t-1}$$

The long run elasticity of energy demand is given by δ_1. (Enders, 2004 and others).

Last, but not least, energy demand differs across sectors (manufacturing, agriculture and services). If GDP growth over time is followed by structural changes we should expect a changing demand elasticity and a structural break in the estimated relationship. While this can lead to non-cointegration, we specifically test for changes in the co-integration vector.

The variables used are GDP in constant prices, obtained from *ipeadata*, and energy production in Brazil, obtained from the Energy Balance (*Balanço Energético Nacional*, BEN, 2008), from the Ministry of Energy. Energy production is measured in *tep* (oil equivalent tones), to allow aggregation of different energy types. We consider only commercial energy sources (oil derived, natural gás, coal, alcohol, electricity), as these are less prone to imputation errors in BEN and are the relevant energy supply sources for policy. Our sample covers from 1970 to 2007.

There is co-integration among the variables with the long run co-integration vector, estimated from the vector error correction form for a VAR(1) model with unconstrained constant[6]. The long run equation (co-integration relationship), is given by (standard errors in parenthesis)

$$Ln(Energy) = 11.38 + 1.6045\, Ln(GDP)$$
$$(0.0706)$$

Imposing the restriction that the energy demand is elastic yields a p-value of 0.0091, rejecting the hypothesis at the 1% level. Thus, there is evidence that the Energy demand is elastic. At the same time, there is clear endogeneity between the variables, as the estimated VECM has both adjustment coefficients significant, suggesting Granger causality from GDP to Energy and from Energy to GDP. Table 2 has the details:

The endogeneity of Energy and GDP precludes any objective impulse response analysis, to evaluate the most significant feedback effect, as the decomposition ordering influences the result. Nevertheless, such effects are illustrated using Pesaran and Shin (2001) Generalized Impulses. The impulse response of each variable to one standard deviation changes is presented in Figure 6 below. The most relevant information comes

[5] Variables non-stationarity was tested using standard Dickey-Fuller tests, available upon request. They are not presented to save space.

[6] The deterministic term selected was indicated by the Schwartz criteria.

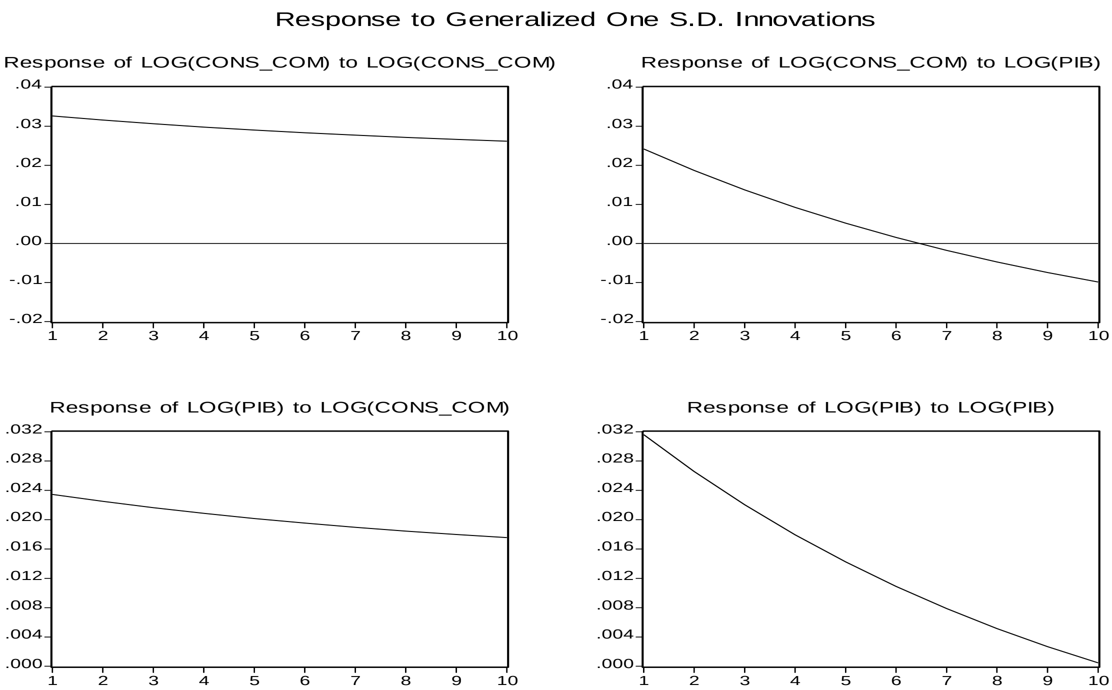
from the off diagonal graphs. In the upper right graph, we see that the effect of a one standard deviation percentage growth in GDP yields a decreasing 2% growth in demand per year in the first year, with negative effects after a decade. The lower left graph presents the effect a one standard deviation percentage growth in energy demand on GDP. This effect is similar at a 2% growth in the first year, but converging to the value of 1.6% per year. The larger multiplicative effect of Energy on GDP suggests that the sector has important linkages with the rest of the economy.

Table 2 - Error Correction model for Energy and GDP – Brazil 1970-2007

	ΔLn(Energy)	*ΔLn(GDP)*
Cointegration vector	0.20708*	0.18944*
	(0.03992)	(0.03870)
Constant	0.046087*	0.039366*
	(0.00536)	(0.00520)
R-squared	0.244535	0.533764
F-statistic	11.32909	40.06933
System Log Likehood	166.3054	

Source: authors calculations based on data from BEN and ipeadata
Note: * - indicates significant at 1% level.

Figure 6 – Impulse response functions for Energy-GDP VAR. Brazil 1970-2007.



Source: authors´calculations, based on Table 2 estimates.

One concern over the estimates is that structural change in GDP may be biasing the results. In the 1970´s, while manufacturing share of GDP was about 33%, and agriculture 18%, by 2007, manufacturing only accounted for 18% of GDP and the agriculture share fell to 5%. Given the known elasticity differences between sectors, may be biasing elasticity estimates.

To overcome this, we estimate two VEC models, for the 19701-1985 and 1986-2007 periods. The periods were chosen to accommodate the large structural changes in the economy (1985 is the end of the II PND development plan and the start of the near hyperinflation crises) and minimum sample sizes for econometric analysis.

Table 3 – Structural change in energy demand elasticitities.

	ΔLn(Energy)	*ΔLn(Energy)*
ΔLn(GDP)	1.289572* (0.03067)	0.930318* (0.19163)
Constant	-6.907*	-1.739*
Log-Lik.	65.67094	114.0948
Unit elasticity test		
(p-value)	0.0002	0.8116
Sample	1970-1985	1986-2007

Source: authors calculations based on data from BEN and ipeadata
Note: * - indicates significant at 1% level.

Focusing on cointegrating vectors, the GDP elasticity falls over time, as expected, given the fall in the share of manufacturing (an energy intensive sector) on GDP. While the elasticity for the period 1970-1985 is statistically greater than 1, we cannot reject the hypothesis that the energy elasticity in the second period is equal to one.

A Likelihood Ratio test for structural change over the period yield a statistic of 26.92. Under a chi-square with 12 degrees of freedom, the 1 and 5% critical values are 21.02 and 26.22, respectively. The test clearly rejects the coeffients stability over time.

In sum, the recent Brazilian experience indicates that Energy demand was elastic, but it has become unit elastic over time, due to the change in the GDP structure. Multiplicative effects from the energy demand seem to be larger than demand effects of GDP on this sector. In other words, not only Energy is a required input for value added, but its effect is larger than the demand increase from income growth. Providing a consistent, sustainable energy supply may have direct and positive effects on economic growth in Brazil. While the energy restriction steaming from an elastic energy demand seems to be weakening, supply must grow at pace of GDP to avoid energy shortages.

Such supply hinges on tackling a number of weaknesses in the current Energy Supply Model for Brazil. Namely: the role of Natural Gas, the role of Petrobras and pre-salt oil exploration and production, the extent of renewable fuels for automobile and power generation and the electricity supply at reasonable costs. This requires the discussion of the current regulatory framework for the main energy sources: electricity and oil.

4. Regulatory changes and challenges for the XXI Century.

From 1995 to 2000, there were significant changes in the regulatory framework of energy markets in Brazil, including constitutional amendments, as well as privatization of state enterprises, particularly in electricity distribution. These changes altered the roles of private and public players and one may argue that the regulatory changes effects have not been completely absorbed. Before discussing possible changes to the current regime, it is important to present briefly the current regulatory framework.

4.1 – Electricity Markets

Until the 1990s, the electricity sector in Brazil was based on State property. Companies had monopoly of regional markets and decisions regarding the sector were concentrated at Eletrobrás, the federal government's holding. With few exceptions, the federal government was the owner of the generation and transmission assets whereas the states held the distribution ones.

The 1990s reform meant to broaden the private participation in the Brazilian electricity sector and to introduce incentives to efficiency, mainly through liberalization of electricity generation. Following the international experience of electric sectors reforms, an independent regulatory agency (Aneel) was established as well as an independent operator of the system (ONS) and a wholesale energy market (MAE).

The privatization process started in 1995. 23 State owned companies of the electric sector were sold, which led to US$ 22 billions of revenue (Losekann, 2003). The privatization process has moved deep forward in distribution, but has faced many challenges in generation. Only four generation companies (three state owned and one federal owned) were privatized. Adding this up with the investments on new plants the private share in the generation market is of 20%[7].

Even before the transition to the competitive model was completed, Brazil faced a major crisis in electricity supply. Since the late 1990s the level of storage in the hydro-electric reservoirs has progressively diminished and it reached critical levels in 2001. On May 2001, the government rationed 20% of the electricity consumption in the sub-systems of the Southeast/Mid-West and Northeast. The rationing lasted until May 2002. The consumption of electricity was drastically reduced, resulting in major economic consequences. The estimated social cost of the rationing was close to 3% of the GDP (Sauer et al., 2003).

The second reform aimed at avoiding a new supply crisis with a concurrent rise of electricity prices. In 2004, the new regulatory framework re-established the planning role of the State and drastically altered the wholesale market.

The Energy Research Company (EPE, in Portuguese) was created to assist the Energy Minister in sector planning, playing an important role at the expansion auctions. It was decreed that all energy trade must be carried out by long-term contracts. The only function of the short-term market (Chamber of Electric Energy Trade – CCEE) is to correct imbalances between contracted supply and demand. Agents that are

[7] In the distribution activity, private share is about 60%.

systematically exposed to this market (contract less than necessary) are subject to financial penalties.

Two trade environments were created in the wholesale market: regulated contracting (ACR) and free contracting (ACL). At the ACR, distribution companies buy energy in public auctions. They submit demand projections in a five-year horizon to EPE. Based on those projections, EPE sets the total market that will be offered in the auctions.

The model distinguishes the energy coming from already existing plants ("old energy") from the energy coming from the new ones ("new energy"), both being negotiated in the ACR in different ways. The old energy was intended to respond to the existing market. In 2004 and 2005 four auctions negotiated the major part of old energy. As they took place in a moment of excess of supply due to consumption decrease after the rationing, the resulting energy prices were around half of the long run marginal cost (Losekann and De Oliveira, 2007).

Since December 2005, nine energy auctions have been carried out to set the expansion of the generating system. Hydro and thermo power plants were treated differently. Whereas the hydropower plants compete with prices for the generated energy, the thermoelectric plants bid for the generating capacity. The operational cost of thermoelectric plants that won the auctions is passed over to the final consumers.

The lower prices of old energy allows a smooth transition to higher energy prices as new energy increases its share on ACR total sales. Nevertheless, any unanticipated need to run thermoelectric plants can change this trend and may cause a sudden rise on energy prices.

The second electricity reform did not address the main challenge of the Brazilian electricity system: coordination between the power sector and the natural gas industry (Losekann and Oliveira, 2008). The dispatch rules of the power sector propose very low average operating rates for the thermalpower plants but ask these plants to be fully dispatched when rain precipitation is short. This arrangement is financially costly for the infant natural gas industry. The gas that should be available for thermal power plants is often diverted to other consumers instead.

Indeed, natural gas fuelled power plants are not participating in energy auctions. This situation gave opportunity to oil fuelled plants in the energy auctions.

4.2 – Oil Markets

By the end of Second World War, Brazil was amid a wave of nationalization in the face of increasing capital and energy imports driven by its development needs. The need to secure oil supplies fostered intense debate over the development of a national oil industry, reaching the 1954 campaign of "O Petróleo é Nosso" [Oil belongs to Brazilians]. Law 2004/1953 constituted Petrobras, a state enterprise that would explore, develop, produce and refine oil as a State Monopoly. The 2004/1953 Law declared all stages of the oil industry state monopolies but retail.

The rationale for a state enterprise was to guarantee control over resources, and foster an industry with strong internalized forward linkages and multiplicative effects over the economy. From the 1950´s until the 1990´s Petrobras is recognized as playing its role as inductor of the Brazilian infrastructure and base manufacturing, both in production, refinery and chemicals. Yet, by the 1970´s other energy sources received heavy government subsidies and incentives, to counteract the oil crisis effects, namely ethanol (álcool hidratado). Ethanol was used added to gasoline, reducing pollution emissions from led, and as fuel itself. In 1986 about 90% of new automobiles sold were ethanol fuelled. Yet in 1990 there were shortages that shattered consumer confidence on ethanol supply. Changes in relative prices for sugar and domestic price controls are usually pointed out as shortages culprits.

By the mid 1990´s there was a belief in the government that state enterprises, including Petrobras, did not have the financial stature to lead the development process in Brazil. The political mood for less state intervention induced regulatory reform across the oil sector. A Constitutional Amendment (EC nº 9, 9/Nov/1995) allowed a New Oil Law (9478/97) that regulated Article n 177 of the Constitution.

The Constitutional Amendment did not end the State monopoly over oil resources but allowed the State to franchise enterprises to operate at any stage of the oil industry, under a variety of contract conditions.[8] A regulatory entity (ANP[9] -*Agência Nacional do Petroleo, Gás Natural e Biocombustíveis*) was created to oversee and regulate the sector activities. Companies were offered the possibility to bid for concessions to explore oil and natural gas[10]. In the concession regime, firms bear the risk associated with exploration and production, but own the extracted oil. The state compensated by royalties, taxes and other fiscal mechanisms. ANP is responsible for the concessions auctions.

ANP has so far carried out nine auctions (called "rounds") with varying degrees of success. The table below presents a summary of the rounds.

The sharp decrease in the auction success ratio (conceded/auctioned blocks) may be attributed to two factors. First, a change in the "block" definition, from a rectangular, large area form (about 200x800kms) to a "exploratory cell" definition (used in the Gulf of Mexico). Second, a large portion of land blocks, that are known to have less oil and lower success ratio than deepsea blocks.

Later, in the eve of the Ninth Round (November, 2007), ANP withdrew from the auction 41 blocks neighboring the Tupi Oil Field. This was the Oil Field where pre-salt layer oil was found, on extremely deep waters and soil deeps, but with enormous output potential of high quality oil. (e.g. Petrobras, 2007).

The official argument was that the new discoveries open a new ground for production, with little risk involved, as well as significant risk of different blocks sharing the same oil field. To avoid the "commons tragedy" of overexploitation of any block by the aggressive companies, unitization of concessions is the usual solution in the oil business. While there are international experiences in solving the unitization problem, there is very little experience on this issue among Brazilian authorities[11]

[8] Actually, in the 1970´s other firms could explore and produce oil according to the "contraltos de risco" (risk service contracts), but with limited success and interest from other firms. (Campos, 2005).

[9] Law 11097 (Jan 13, 2005), included biofuels under ANP´s scope.

[10] Other types of state-firm contracts, with special emphasis for Latin America can be reviewed in Palacios (2002).

[11] Actually, there is only one unitization agreement signed as of writting of this paper, between Aurizônia Petróleos e a Petrobras, on output individualization of the Lorena Field (BT-POT-10) at Rio Grande do Norte. It is known that there are other unitization issues under analysis at ANP: Petrobras and Total on block BC-2; Petrobras and Shell on block BC-10, and El Paso and Queiroz Galvão on BM-CAL-4 (Alvite, 2008 apud Schüffner, 2008).

Table 1

Auction Rounds	Round 1 1999	Round 2 2000	Round 3 2001	Round 4 2002	Round 5 2003	Round 6 2004	Round 7 2005	Round 9 2007
Auctioned Blocks	**27**	**23**	**53**	**54**	**908**	**913**	**1.134**	**271**
Auctioned Area (Km^2)	**132.178**	**59.271**	**89.823**	**144.106**	**162.392**	**202.739**	**397.600**	**73.079**
Avg. Block Size (Km^2)	**4.895**	**2.577**	**1.695**	**2.669**	**179**	**222**	**351**	**270**
Conceded Area	**54.660**	**48.074**	**48.629**	**25.289**	**21.951**	**39.657**	**171.007**	**45.329**
Conceded Blocks	**12**	**21**	**34**	**21**	**101**	**154**	**240**	**108**
Conceded/Auctioned Blocks	**44,4%**	**91,3%**	**64,2%**	**38,9%**	**11,1%**	**16,9%**	**21,2%**	**39,9%**

Source: Alvite et al. (2008).

Nevertheless, the potentially enormous Pre-Salt reserves prompted Federal Government officials to question the concession framework, that gives away the oil property, once extracted, echoing “O Petroleo é Nosso” arguments. While “previous contracts will not be broken” according to the Energy Minister E. Lobão (Zacconi, 2008), a new regulatory framework is being drafted.

While pre-salt reserves are indeed significant, and may increase by at least 200% the Brazilian Oil and Natural Gas reserves, its cost and technical difficulties are of equal stature. In addition, there is the oil price uncertainty to render economic exploration a real challenge. Regulatory uncertainty may push the area development many years forward.

Under current rules, Petrobras estimates that the Tupi field will be operational only after by 2012 or 2015. It must be noted that the Tupi field was auctioned in the *second round*, back in 1999. Although future time lags should decrease there was almost a decade of exploratory effort to reach the Pre-Salt oil, and the financial resources required to actually exploit its reserves are substantial. Should the exploratory regime change, there is a good chance that the exploitation of pre-salt will be postponed.

Concluding Remarks

In the past 50 years Brazil experienced radical changes in its energy sector. The energy matrix changed radically. There is now (in 2009) widespread use of commercial energy sources, such as electricity and oil products replacing wood and charcoal. New energy sources were introduced, namely, natural gas and ethanol. External dependency was sharply reduced with the maturity of the oil industry in the country and the discovery of large oil fields in the continental shelf. Renewable resources are currently the main source of energy, either sugar cane derived ethanol or hydraulic power generation.

These changes reflected the effort to ease the energy restrictions to growth in the Brazilian economy, as discussed in the first section. Such restrictions were acute in the XX Century given the elastic income demand elasticity of energy consumption. Energy needs up to the 1980´s were growing faster than GDP, as expected in a development process with industrialization and urbanization.

Currently these energy restrictions have eased to the extent that the income elasticity of energy consumption has lowered and is estimated to be either proportional to income or even inelastic. This places a lesser burden on the energy supply growth rate for the coming years.

Nevertheless, the 2001 power rationing in most of the country made clear that energy supply must be secure to play a positive role in the Brazilian economic growth. Electricity supply is still very reliant on hydrology, with price shocks for consumers from the almost continuous use of thermal power plants during dry periods. And recent political changes have limited the supply expansion of natural gas. Supply restrictions have been reported in October 2007. These facts raise the issue of the state of the current regulatory regime for the energy sector.

The regulatory regime changed significantly over the past ten years, with pro-market based reforms with arguably varying degrees of success. The reforms, reviewed in the second section, focusing on two main energy sources, electricity and oil, the first still struggles with hydrology risks and have not recovered previous investment levels. The second is on the eve of a radically different scenario, both technologically and economically, given the “pre-salt” oil bearing discovered reserves off the coast of Rio de Janeiro and São Paulo at very deep waters.

Brazil is currently in a unique situation. On one hand it has large energy resources, both renewable and non-renewable. Its hydraulic resources have not been fully exploited. Its ethanol sector is the most efficient in the world and has been producing with some excess capacity. Its oil reserves have risen significantly and should at least double in the next years. Energy could be a growth inducer, as the country starts to export energy (oil and ethanol) to other countries.

On the other hand, resource availability itself does not guarantee energy supply. This requires a consistent regulatory framework for the whole energy sector. Whether it implies a renewed state participation as an energy producer and distributor, much like the 1960´s and 1970´s is an open issue. The past regulatory regimes must be evaluated recognizing the current and future resource availability, environmental and economic constraints and the integrated energy system for the XXI Century.

In conclusion, Brazil is in a privileged position to move along the transition from fossil fuels to renewable sources of energy, a major comparative advantage in a world that has to cope with the climate change issue. However, it is important to have in mind that the institutional and regulatory arrangements are a critical piece in the development of the energy system. If these arrangements are unable to attract financial resources to invest in the system, the energy resources will remain in the ground and will remain living with the specter of energy shortages whenever economic growth get momentum.

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