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Energy in Brazil: a historical overview

Abstract
The rapid demographic growth Brazil has experienced since the installation of the First Republic (1889) was mediated by the large size of its territory and the abundance of natural resources. Industrialization was perceived by part of the Brazilian elite as a necessary step to promote economic development, but the country started very slowly to consider the exploitation of its own energetic sources as relevant to achieve the social gains that would be compatible with the desired material progress. The panorama afforded by this article will present some highlights of this process, as it unfolded in the main components of the energetic mix, i.e. fossil fuels, biofuels, nuclear energy, and electricity.

Plan of the article

INTRODUCTION

1 This paper presents an overall panorama of the history of energy in Brazil, and more specifically since the Republic replaced the Empire, in 1889. Some political and economic history aspects are mentioned where they contribute to a better understanding of the energy issues at stake, as it will become clear along the text. Brazil was a latecomer to industrialization, having long lived according to the elite's belief that it should be primarily a raw material exporter. Therefore, industry was viewed by its policy makers as fulfilling only a complementary function, both under the Empire and during significant periods of the Republic. After World Wars I and II this theme returned to politics, and the economic growth intensified the discussions and legislations that affected energy production and use.

2 Aiming at a wide scope of over a century of history of energy in Brazil, this text does not intend to be a comprehensive source of information on this matter, it rather intends to supply a survey of relevant topics that are part of that history. Some results stem from original research, while the very nature of the material presented also relies on secondary sources. The reader is referred to specialized literature in the notes, which provide detailed information.

3 Although only in recent decades the concept of energy matrix has been used by Brazilian energy authorities, the more significant sources that comprise the present matrix will be discussed - oil, gas, coal, alcohol, and nuclear fission fuel. Electricity deserves special attention, since it epitomizes very well the bottlenecks, impasses and contradictions of the national energy history. Moreover, electric power has massively meant hydroelectricity, and in Brazil rivers are considered renewable energy sources, and that will be our focus, instead of eolic or solar energy. Also lesser components of the energy array, such as turf, shale, hydrogen and others, will be not be dealt with for our purposes here.[1] Before dealing with these subjects, it is convenient to briefly consider some aspects of Brazilian history in general.

GENERAL HISTORICAL OVERVIEW

4 Brazil's independence was formally declared in 1822, later than in most other Latin America countries, which were ex-Spanish colonies whereas Brazil had been practically the only Portuguese possession in America. Another difference singled out Brazil: after independence, it became a monarchy, rather than a republic – and the first sovereign of the empire was Peter I. He was also the would-be Portuguese crown heir, who later resigned the Brazilian Empire, and became King Peter IV of Portugal. Economy during this monarchical period followed in part the general pattern of the colonial times, driven mainly by slave labor and agricultural exports, especially sugar, cotton, and later on, coffee. During colonial times, the country experienced a boom of gold and diamond exploitation, but in the 19th century the known mines were practically exhausted.

5 Although there was a public debate about industrializing the country during the monarchy, the majority of the 19th Century politicians were closely related to large plantation landowners and slave masters, who considered the absence of a local significant industry a result of some "natural" order. The population was predominantly rural, and the social framework comprised a tiny upper elite, a small middle class, and a larger impoverished population - ca. 30 million people altogether at the beginning of the 20th Century, occupying for the sake of comparison an area larger than continental USA.

6 It is therefore understandable that during much of the Brazilian history, energy proceeded directly either from animals or from the slave arms.

1 A more extensive treatment of these other matters may be found in: Antônio Leite, *A energia do Brasil* (Rio de Janeiro: Nova Fronteira, 1997); José Goldemberg, "Energia no Brasil e no mundo", *in* Adriano Branco (org.), *Política energética e crise de desenvolvimento* (Rio de Janeiro: Paz e Terra, 2002); Eduardo Rodrigues, *Crise energética* (Rio de Janeiro: José Olympio, 1975); Arnaldo Barbalho, *Energia e desenvolvimento no Brasil* (Rio de Janeiro: Eletrobrás: Centro de Memória da Eletricidade no Brasil, 1987).

Initially native Indians were enslaved, but they proved difficult to adapt to regular work, and they were soon substituted by slaves imported from Black Africa, coming from the Atlantic West Coast, as well as from Mozambique in the East Coast. Statistics were deliberately destroyed after the end of slavery, but a rough estimation gives a total number of at least around 4 million slaves introduced in the country in three and half centuries.[2] The only relatively reliable census during the Empire (1872) registered a population of 1,510,806 slaves living in the country, or 15.2% of the total population. It should be noted that Brazil was the last American country to end slavery, in 1888. One year later, a coup replaced Emperor Peter II by the military, and the First ("Old") Republic commenced.

7 In the rural areas, the large plantation system introduced during the colonial years by the Portuguese recruited large numbers of slaves for the sugarcane farms and sugar mills. Slave labor also was extensively employed in the mining and refinery of precious metals (gold, silver), and the extraction of diamonds. Slaves worked in the civil construction (houses, roads and bridges, harbors). After proclamation of the independence, Negro slaves worked in the new cotton plantations and in what became Brazil's most lucrative business for a long time, coffee farming. With the abundance of slave labor, practically very little energy was required from sources other than that provided by photosynthesis in the form of food for cattle and men. The landed aristocracy refused any manual work as debasing and proper only to slaves or poor people.[3] Despite the general elite contention that slave labor made unnecessary the introduction of machines and their energy sources, the international competition drove a first attempt of modernization in the sugarcane plantations in the Northeast of Brazil at the end of the Empire and the first decades of the Republic. Animals and slaves used in the fabrication of sugar were gradually replaced by watermills, and finally by steam engines, technical changes that were implemented thanks to the action of British capitalists and government subsidies.[4]

8 Most of the population lived in warm climate regions, with scant need for heating, and the highest demand on energy were cooking stoves that burned any kind of available wood. As for illumination, rich houses and sugar mills used whale oil, material that also provided for public illumination in the larger cities in the first half of the 19th century, gradually later substituted by kerosene, and coal gas.

9 Despite large reserves of high-purity iron ore, the independent Brazilian government moved slowly towards steel production, a vital process for industrialization that was even more difficult because local coal was scarce and energetically very poor. Industrialization lagged behind more developed nations, as national political economy continued to back up exporters who defended that the country had an agrarian "vocation". According to this dominant line of thought, the country had been endowed with an exuberant nature. Most of the ruling elite attacked industrialization as superfluous, preferring that the surplus obtained with the export of land products be traded to buy manufactured goods, according to the economic liberal credo adopted by the Empire.[5]

2 Arthur Ramos, *A mestiçagem no Brasil* (Maceió: EDUFAL, 2004, 27-33). For the 1872 census, see www.nphed.cedeplar.ufmg.br/pop72. See also: Luiz Felipe de Alencastro, *O trato dos viventes. Formação do Brasil no Atlântico Sul* (São Paulo: Companhia das Letras, 2000); Emília Viotti da Costa, *Da senzala à colônia* (São Paulo: Editora da UNESP, 1998); Caio Prado Jr., *Formação do Brasil contemporâneo* (ed. revista. São Paulo: Companhia das Letras, 2011 [1942]).

3 Sérgio B. Holanda, *Raízes do Brasil* (25ª ed. Rio de Janeiro: José Olympio, 1993 [1936]). José Murilo Carvalho. *A construção da ordem. A elite política imperial* (Rio de Janeiro: Campus, 1980).

4 The land, however, remained concentrated in the hands of a few landowners up to the present days. This process is described as "modernization without change", a feature that applies to many other industrialization aspects of Brazilian history. See Peter Eisenberg, *Modernização sem mudança. A indústria açucareira em Pernambuco, 1840-1910* (Rio de Janeiro e Campinas: Paz e Terra e Editora UNICAMP, 1977).

5 Ernesto Carrara Jr, Helio Meirelles, *A indústria química e o desenvolvimento do Brasil. Tomo II: 1844-1889. De Pedro II à República* (Rio de Janeiro: Metalivros, 1999).

10 The situation described would change only slowly, as importation of oil and cars with internal combustion engine increased, and the tracks of steam-powered railways were financed by British capital since the 1870's. The first electric lamps were displayed in the capital, Rio de Janeiro, in 1880, and the country soon realized that it had an important asset in waterfalls that could be harnessed to generate electricity. More modern chemical plants started to be built in the 1920s, increasing the need for power, a demand already claimed by more food and textile industries. On the other hand, after the abolition of slavery, free labor received an impulse through the large influx of immigrants to Brazil, most notably Italians, Japanese, Portuguese, Spaniards and Germans, who came in at first to work in plantations in Southern Brazil, especially in the State of São Paulo. Soon the immigrants moved to cities, where they became the core of the emerging middle class, as well as small or even large-scale entrepreneurs.[6] In São Paulo a more continued industrialization surge began at the end of the Empire, and increased specially after the import substitution propitiated by the First Word War.

11 The Republic proclaimed in 1889 had strong positivist influences (through the French philosopher Auguste Comte's philosophical system), visible even nowadays in the motto inscribed in the Brazilian flag ("Order and Progress"). However, despite the ideology of progress did bring a renewal of the debates in favor of modernization, it did not fulfill the promise of deeper industrialization, with the notable exception of São Paulo State, as cited above.

12 The Old Republic remained tied to economic free-trade liberal principles, which lasted until 1930, when another military coup started a new period. The "New Republic" of President Getúlio Vargas began as a nationalist dictatorship, but in some ways it meant a more progressive era, which lasted 15 years. It favored a stronger role of the State, with several implications on energy issues, specially electricity and oil, as subsequently presented in this paper. The fall of Vargas' regime resumed the democratic republic, which would continue as such until the military took over in 1964.

13 As consequence of the country's rising above what could be considered mostly a lethargic economic state, energy became an explicit concern for the government, and already in 1920 the Ministry of Agriculture, Industry and Commerce created a Commission to study hydraulic power.[7] After a sterile discussion that started in 1905 about who owned the title to inland water, President Vargas decreed the Water Code in 1933, and instituted the National Commission of Water and Electric Energy in 1939. Vargas was also responsible for later launching the state-owned oil and gas company Petrobrás, after a long struggle against privatizing and anti-nationalist interests.[8] The Ministry of Mining and Energy is, however, relatively a recent initiative (1960), so is Eletrobrás (1961), a state company in charge of electricity generation, and even newer is the National Council on Energy Policies (1997), responsible for planning resources of oil and natural gas, electricity, and biofuels.

14 Before proceeding to show some decisive developments in the history of the main energetic sources in Brazil, Table 1 sketches their relative distribution in a 70-year period, starting at the end of the first Vargas administration.

6 Nícia Luz, *A luta pela industrialização do Brasil* (São Paulo: Alfa-Omega, 1975). Luiz Carlos Bresser-Pereira, *Desenvolvimento e crise no Brasil. História, economia e política de Getúlio Vargas a Lula* (5ª ed. São Paulo: Ed. 34, 2003 [1968]), 77-98.

7 A noteworthy early exception to the lack of integrated discussion of energy sources in Brazil is the address given in 1928 by Calógeras, a mining engineer and Minister, to the student's body of the Politechnic School in São Paulo. Pandiá Calógeras, "Fontes de energia", *Revista Polytécnica*, nº 85-86, 1928, 103-132.

8 Getúlio Vargas returned to power after winning the democratic presidential election in 1950, until he committed suicide in 1954, after an insidious rightist press campaign against him.

SOURCES	1945	1955	1965	1975	1985	1995	2005	2015
Oil and natural gas	5.5	20.9	28.7	48.5	39.8	46.8	48.2	51.0
Coal	5.0	4.3	3.2	3.5	7.6	7.3	6.0	5.9
Hydroelectricity	1.6	2.3	3.8	6.8	11.8	15.3	14.9	11.3
Wood and charcoal	85.7	69.3	59.0	36.3	25.1	14.3	13.1	8.2
Sugarcane	2.2	3.2	5.2	4.6	13.6	14.0	13.8	16.9
Uranium and others	0.0	0.0	0.0	0.4	1.9	2.4	4.1	6.6

Figure 1: *Table 1 - Energy Supply in Brazil (%)*
Source: Balanço Energético Nacional (Rio de Janeiro: EPE/ Ministry of Mines and Energy, 2016) – data further compiled by the author

OIL AND GAS

15 The search for technical independence and capacity to extract and refine oil intertwines the main Brazilian political and social events in the second quarter of the 20th Century. By 1915, the Republic's Geological and Mineralogical Service, directed by engineer Pandiá Calógeras, concentrated its fossil fuel research looking for coal deposits. That Service had only 25 oil probes, and nothing resulted in this direction, while the main goal was to find more and better coal to foster the national steel production.

16 Coffee prices had sharply dropped in the 1920's, and the economic crisis deepened after the 1929 Wall Street crash. The so-called "Revolt of Lieutenants" signaled the end of the Brazilian First Republic in 1930, accused of an oligarchical political attitude that favored rural landowners. The power was handed to Getúlio Vargas, who undertook a series of reforms aligned with modernization and economic development, enforcing the bourgeoisie and answering the appeal to accelerate the country's industrialization.[9] It was in this context that the search for oil was declared a matter of "national dignity", and in 1934 Vargas sanctioned the Mining Code, which defined the subsoil riches as national property, instead of private possession.

17 In 1936, the very popular writer and entrepreneur Monteiro Lobato criticized the government in a book, *The scandal of petrol and iron*, accusing the National Mineral Production Department of being allied to the international oil trusts (fig. 2). The federal government had hired American geologists as consultants, and they recommended abandoning oil prospection, alleging that their surveys indicated the non-existence of oil under the Brazilian soil. This conclusion gained support from some ministers otherwise known as leaning towards foreign investors.[10] On the other hand, years before that, foreign oil companies had already bought large extensions of land considered promising from the point of view of future oil prospection. The government image was shaken when a campaign led by Monteiro Lobato to increase the number of oil prospection drills did find petroleum in the state of Bahia in 1938.

18 The imminent war situation facilitated an industrialization surge, coupled with a thrust to improve the economic infrastructure, which resulted in duplication of existing roadways, thus incentivizing the use of gasoline. A new "Oil National Council" (CNP) was formed in 1938, headed by the nationalist General Horta Barbosa, and the CNP demanded the creation of a "national company" for oil refineries. An ideological battle ensued between defenders of

9 Pedro Fonseca, *Vargas; o capitalismo em construção, 1906-1954* (São Paulo: Brasiliense, 1989).

10 Gabriel Cohn, *Petróleo e nacionalismo* (São Paulo: Difel, 1968).

the national production of oil and the groups against it, which had the open support of Standard Oil. After World War 2 ended, Vargas was ousted and subsequently both the military and the civil society split around the issue of national petroleum. The group favoring a state monopoly of oil was led again by General Horta Barbosa, while the conservative political current around General Juarez Távora proposed an alliance between American and Brazilian capital. In 1948, the nationalist forces were able to launch the movement known as "Petroleum Campaign".

19 The dispute involving oil increased as the country had already experienced an industrialization surge during World War 2. The demand for refined oil after the war was the triple of the prewar years, and the federal government planned to buy tanker ships and build several oil refineries. Getúlio Vargas returned to the political scenario as President in 1951, winning a democratic election with support of the leftists, which reflected his personal popularity, despite having been a former dictator. One of the popular expectations was exactly the one related to the oil question, and Vargas' personal attempt was to find a middle term between the state oil monopoly, defended by leftists and nationalists, and the foreign presence, favored by economic liberalism forces. After long and fiery discussions in Congress, a law was approved in 1953, creating a new state company, Petrobrás. The company resembled more the monopoly defended by nationalists, who were accused by the Congressional right wing of being "communist". A strong opposition by rightist groups against Vargas culminated in his suicide in 1954, yet his death actually enforced the nationalist position. New refineries were built, which were instrumental to the economic development induced by the government of President Juscelino Kubitschek in the 1950's. However, the discovery of oil fields was not immediately so successful, bringing again the suspicion of merely small oil reserves in the subsoil deposits in the country. Even so, to this initial phase can be credited the creation of geology courses in several universities, a capacity which the country lacked until then. In 1963, Petrobrás decided to create its Research and Development Center (CENPES), which would prove essential in later years, and especially in the 21st century, for the exploitation of very deep reserves.[11]

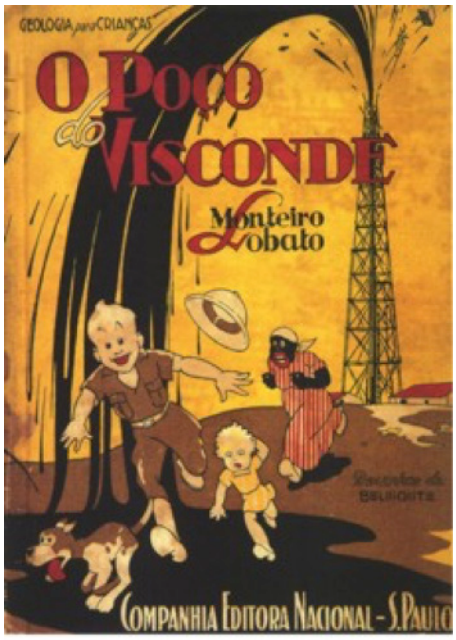

Figure 2: Cover (first edition, 1937) of Monteiro Lobato' children book *The Viscount's well* in favor of national oil policy. The previous book by Lobato, *The scandal of oil*, had been censored and apprehended, so Lobato transformed it into a successful book for the young readers. In the story American geologists try to hamper oil drilling, and afterwards international speculators try to buy the oil-rich lands. Oil was indeed found in Brazil in 1939, and Lobato's campaign arose public opinion to press Brazilian government to create Petrobras. Source: IEB, University of São Paulo

20 The *coup d'État* in 1964, which had a then secret participation of the American government, overthrew the government of President Jango Goulart, accused of leftist inclinations. The military regime would last 21 years, and a distinctive feature of the period was the strengthening of the petrochemical industry in Brazil, with the adoption of the so-called

11 Victor Mourão, "CENPES-Petrobrás: capacitação tecnológica e redes de conhecimento em uma empresa da periferia econômica Mundial". I Seminário de Pós-Graduandos em Ciências Sociais do Estado do Rio d Janeiro, 2011. Fábio Erber, Leda Amaral, "Os centros de pesquisa das empresas estatais: um estudo de três casos", *in* Simon Schwartzmann, *Política industrial, mercado de trabalho e instituições de apoio* (Rio de Janeiro: Fundação Getúlio Vargas, 1995).

tripod model, under which the government incentivized the association of Petrobrás with Brazilian private companies and foreign corporations.[12] in 1975, as a result of the world oil crises, President General Ernesto Geisel made an unexpected movement in terms of energetic policy, changing the law to break the state monopoly of Petrobrás. The prospection and exploitation of oil and gas in certain land areas and sea basins were allowed under risk contracts, a long-standing demand from oil multinationals like Shell.[13] in a first moment the resulting contracts were not very fruitful, however, except for the discovery of large deposits of natural gas, in the Amazon region and the Midwest, as well as in the continental maritime platform. These discoveries represented a considerable contribution given by the newly-developed Brazilian engineering expertise in geophysical seismic exploration.

21 The large reserves of oil and gas found between 2000 and 2002 in the basins of Campos and Santos, in the Southeast of Brazil, made it feasible to speak for the first time of the country's self-sufficiency in terms of oil and gas. The new status of oil exporter changed the traditional oil-importing profile of the country, yet the price paid by consumers continued to be high, relative to the low national average income. To better understand this, it is necessary to recall that in Brazil transportation of goods is primarily a function performed by trucks, given the inexistence or precariousness of railways or waterways. The same applies to public transportation, in charge of buses and not trains. As trucks and buses use diesel motors, the government has traditionally subsidized the price of diesel oil with taxes levied on gasoline. Even so, the cost of oil-based transportation has a strong impact on the budget of workers, and there is a consequent pressure on food prices as well, so that the burden of the transportation oil cost has been basically supported by the middle and lower classes.

22 The dawn of the 21st Century witnessed the internationalization of Petrobrás, which became very active in drilling and exploiting oil wells in Latin America and elsewhere. A technical landmark was achieved in 2005, when for the first time Petrobrás employed new techniques for deep sea drilling developed by its Research Center, and found immense oil and gas reserves in the "pre-salt" layer, located in the subsoil at a depth of 4,000 to 6,000 meters, and plus under an additional 1,000 to 2,000 meters of seawater.

23 Petrobrás' technical and economic success transformed the company in a gigantic political asset, which contributed significantly to its subsequent problems. As became worldwide known, after the end of the military regime and re-democratization of the country in 1985, and most notably during the neoliberal era of President Fernando Henrique Cardoso (1995-2003), unchanged by the Workers' Party governments (2003-2016) of Presidents Lula da Silva and Dilma Rousseff, Petrobrás made a series of dubious political and economic decisions, which brought huge losses.

24 From 1997 onwards, the newly-created ANP (National Petroleum Agency) started auctioning oil areas, giving 30 year-concessions and the right to export oil. Foreign companies won 40% of the winning bids.[14] Contrary to expectations, instead of using the abundant gas reserves and the gas pipelines already built for distribution in the Southeast, Brazil invested heavily in Bolivia and signed a contract in 1996 to use their natural gas (fig. 3). However, in 2006 Bolivia expropriated and nationalized foreign companies, including Petrobrás, which suffered heavy economic losses. Additionally, the international price of oil dropped from US$ 130 a barrel to US$ 30, which made it uneconomical for Brazil to extract the pre-salt oil and gas. Only recently

12 Peter Evans, *A tríplice aliança. As multinacionais, as estatais e o capital nacional no desenvolvimento dependente brasileiro* (Rio de Janeiro: Zahar, 1980).

13 Getúlio Carvalho, *Petrobrás: do monopólio aos contratos de risco* (Rio de Janeiro: Forense Universitária, 1977). Fausto Cupertino, *Os contratos de risco e a Petrobrás* (Rio de Janeiro: Civilização Brasileira, 1976).

14 Sergio Ferolla, Paulo Metri, *Nem todo o petróleo é nosso* (Rio de Janeiro: Paz e Terra, 2006).

Figure 3: Piratininga thermoelectric station in São Paulo City. Built in 1954 to run with fuel oil, it changed in 2001 to use natural gas provided by Petrobrás' pipelines. Source: wikipamia

the slow elevation of prices has made it possible to resume the exploitation, so that the present daily production of oil and gas by Petrobrás is slightly below 3 million barrels equivalent of petroleum, and over 110 million cubic meters of natural gas, with a more significant contribution of the pre-salt layer.[15]

25 Table 2 shows the advances in the production of Brazilian oil and natural gas in about 50 years after the consolidation of Petrobrás. The domestic extraction of oil and gas has enabled the country to be potentially independent of the imported fuels, while Petrobrás' technological expertise led the company to be an important global partner, drilling oil in the North Sea and other places.

26 The most devastating effect for the company, however, came from a common evil, the charge of widespread practice of corruption. As the recent evidence demonstrated, there was deeply entrenched corruption involving civil construction companies, politicians and Petrobrás officers, and the value of the company in the stock market plunged substantially, contracts were cancelled, and very heavy losses followed as unemployment scaled up. In a climate already shattered by a severe economic recession in Brazil, politicians were framed, executives jailed, and the damage to the public image of Petrobrás contributed to the mounting opposition against the government of President Dilma Rousseff, leading eventually to her impeachment by Congress, and an unprecedented political crisis in the country, with far-reaching consequences.

15 Petrobrás, "Boletim da produção de petróleo e gás natural", Nº 77, 2017.

PRODUCTION	1970	1980	1990	2000	2010	2016
Oil	8161	9256	32550	63849	106559	130373
Gas	1255	2189	6233	13189	22771	37610

Figure 4: *Table 2 – National production of oil and gas (103 TOE)*
Source: *Balanço Energético Nacional* (Rio de Janeiro: EPE/Ministry of Mines and Energy, 2017)

COAL

27 Coal deposits in Southern Brazil were discovered as early as 1795, yet exploitation began only in 1855, when the first mine was opened in the state of Rio Grande do Sul.[16] A group of miners from Wales set up a company led by James Johnson, and was responsible for the creation of the "Imperial Brazilian Colleries", which however went bankrupt in 1880. A new company was established in 1882, "Companhia Minas de Carvão do Arroio dos Ratos", which operated until 1908. In the neighbor state of Santa Catarina, lower quality coal mines began operating also in the second half of the 19th Century as a concession to a British company, that later gave it up to Brazilian industrialists.

28 The use of coal increased considerably due to the opening of several railways in Brazil during the Empire and the early Republic. World War 1 curtailed importations, and national coal substituted the English product, albeit at a lower quality. After the war, Brazilian coal began to fuel thermoelectric plants, and to provide gas for street illumination.

29 During the Old Republic (1889-1930), better-quality coal was imported for use in steel mills, electric generation and steam locomotives, while steam machines in factories used national coal, or they burned directly wood for that purpose. The federal government created the Coal Commission in 1905 to evaluate the amount of national reserves, which confirmed that there was relatively little coal in the country and of inferior energetic quality. With the outbreak of World War 1, the difficulty of importing coal incentivized the opening of new coal mines, especially for use in the expanding railway network, but after the war imported coal predominated again. President Vargas in his first period of government issued a decree demanding the use of 10% of national coal for the fabrication of steel.

30 The creation in 1941 of CSN - Companhia Siderúrgica Nacional (National Steel Company), a large steel mill in Volta Redonda, state of Rio de Janeiro, completed in 1946, prompted the government to issue a law, now demanding the use of 20% of national coal to produce pig iron. "Carbonífera Próspera", a private company founded in 1915 in Santa Catarina, became in 1943 state-controlled through CSN, and was very active in exploiting coal for metallurgical purposes until the 1980's.[17] With the oil shock of 1973 there was a renewed interest in using national coal. After the end of the military regime in 1985, the "New Republic" followed a neoliberal economic program, and this change of course was also felt by "Próspera", as President Collor de Mello closed their coal mines, and privatized the company in 1991. There was a large number of unemployed people and a regional economic crisis, until the mines were later reopened.

31 About half of the coal used in the country is still imported nowadays, as the Brazilian production is not enough to meet the demand, and in general that coal needs constant treatment, given its low energetic content, due to the high proportion of ashes (50%) and sulfur

16 Benedito Veit, *Assim nasce uma riqueza: a trajetória do carvão na Região Carbonífera* (Porto Alegre: Alcance, 2004).

17 Maurício Santos, Gisele Maciel, "A Carbonífera Próspera S/A: da estatização à privatização". *ABPHE*, V Congresso Brasileiro de História Econômica, 2003.

Figure 5: Coal mine workers (including women and children) in Criciúma (1938). The mandatory use of national coal prompted the increased exploitation of mines in Southern Brazil. This is the only part where coal mining is still active, especially in the states of Santa Catarina and Rio Grande do Sul. Source: Instituto Histórico e Geográfico de Santa Catarina

1970	1980	1990	2000	2010	2016
1,115	2,484	1,915	2,613	2,104	2,897

Figure 6: *Table 3 – National production of coal (103 TOE)*
Source: *Balanço Energético Nacional* (Rio de Janeiro: EPE/ Ministry of Mines and Energy, 2017)

(2.5%). The most recent estimates of coal reserves are concentrated in the states of Rio Grande do Sul (29 billion tons) and Santa Catarina (3 billion tons).

32 Thermoelectric power plants using coal as fuel were usually small, and their operational cost was disadvantageous in relation to hydroelectricity. Only in 1960 Candiota I, a larger coal-fueled electric generation unit (20 MW), was implanted in Rio Grande do Sul, followed during the military regime by Candiota II in 1974 (126 MW, presently 446 MW). Based on recent controversial decisions to implement thermoelectric plants instead of hydroelectricity, the use of coal has increased in the last decades, as shown in Table 3.

33 Charcoal is still widely used in Brazil. The average annual production of pig iron in recent years has been around 32.5 million tons, out of which roughly one third is produced with charcoal. Reforestation areas have been planted with eucalyptus and pine trees to provide most of the wood burned to this end. However, in the past, only native wood was employed for charcoal to be used in domestic stoves and diverse industries, which led to almost complete devastation of the original tropical forests.[18] Even nowadays around 40% of the charcoal proceeds from native woods, and small illegal charcoal burners spread out in vast rural and forest areas of Brazil, despite surveillance and repression of the practice.

18 Warren Dean, *A ferro e fogo. A história e a devastação da Mata Atlântica Brasileira* (São Paulo: Companhia das Letras, 1996). See also José Augusto Pádua, *Um sopro de destruição. Pensamento político e crítica ambiental no Brasil escravista (1786-1888)* (Rio de Janeiro: Jorge Zahar, 2002).

ALCOHOL AND BIOFUELS

34 The systematic study of sugarcane for ethanol production as a fuel substitution for gasoline dates from 1923, when it was conducted at the Fuel and Mineral Experimental Station in Rio de Janeiro by engineers Fonseca Costa and Heraldo de Souza Mattos. The studies included the corrosion effect of alcohol in explosion motors, and fuel efficiency. Souza Mattos was able to demonstrate the feasibility of pure (anhydrous) alcohol when he participated in the first official car race in Brazil using this fuel in 1923. During his research it was verified that adding alcohol to gasoline was better than predicted, however the miscibility was inadequate, because of using 96º GL alcohol.

35 New researches were led in the 1930's by engineer Eduardo Sabino de Oliveira at the National Institute of Technology (INT), the successor of the Fuel and Mineral Experimental Station. President Vargas' government decreed that gasoline importers must add 5% of national ethanol, and he created in 1933 the Institute of Sugar and Alcohol (IAA). This measure increased the alcohol production from 5 thousand liters/day to 225,000 liters/day in four years. Regulation of motor carburetors was hard to achieve, and the research concluded that 10% of alcohol to make the so-called "rose gasoline" could dispense with the regulation, and also that the motor could then become corrosion-free. For starting up the cold motor, Oliveira recommended an extra smaller gasoline tank.[19]

36 The Vargas administration later demanded a higher 20% addition of alcohol, a measure that lasted until the beginning of World War 2. During this time, ethanol made from manioc was also used as fuel in cars. An article published in 1946, and sponsored by the São Paulo Stock Exchange Technological Laboratory, explained how the manioc bagasse could be economically fermented using hydrolysis with sulfuric acid. They established the ideal mixture of water to the bagasse, as well as the temperature, pressure and additives necessary for the process.[20]

37 During the 1960's the National Petroleum Council authorized the addition of 10% ethanol to gasoline to compensate for the excess production and lower prices of sugar in the external market. Petrobrás was reticent as to the measure, afraid of losing its profit margin with gasoline. However, the Ministry of Industry and Commerce insisted on creating a national motor running with only hydrated ethanol, to become a basis for an automobile industry with genuine national technology and capital, and looked again at manioc alcohol production as a possible fuel source. After the oil shocks of the 1970's, the alcohol motor was finally developed by the Aeronautical Technological Center (CTA) in São Paulo state, and a caravan of cars equipped with this type of motor traveled in 1975 around the country to show its feasibility (fig. 7).

38 President Geisel then created the National Alcohol Program (Proálcool). It should be recalled that sugarcane in Brazil is overall a large monoculture plantation owned by rich landowners, while manioc is mostly planted by small farmers, and associated to several other farm and food products, such as beans and corn. It was known that the energetic content of manioc was inferior to sugarcane, yet the choice of sugarcane was a political decision, which affected the social struggle for a long-sought land reform that never occurred in Brazil, still in the hands of an extreme minority. As the sugarcane planters and alcohol distillers have had much more economic and political power, it came as no surprise that they were more effective in their lobby.

19 Eduardo Oliveira, *Álcool motor e motores a explosão* (Rio de Janeiro: Instituto Nacional de Tecnologia, 1937). See also Gildo Magalhães, "Energia e Tecnologia", *in* Milton Vargas, *História da técnica e da tecnologia no Brasil* (São Paulo: UNESP, 1994), 361-363.

20 Juvenal Godoy, Paulo Godoy, *Emprego do bagaço das fecularias de mandioca no fabrico do álcool* (São Paulo: Secretaria da Agricultura, Indústria e Comércio, 1946). See also João Luiz Meiller, *O álcool anidro puro como sucedâneo da gasolina* (São Paulo: Secretaria da Agricultura, Indústria e Comércio, 1946).

Figure 7: First Brazilian car to run with exclusive alcohol motor, developed in São José dos Campos by the Air Force Technological Center (1975). This Dodge Polara traveled all over the country leading other cars to show people the possibility of substituting ethanol for gasoline as fuel. Brazilian cars are now "flex", running on any mixture of gasoline and alcohol, including just any one of them. Source: Memorial Aeroespacial Brasileiro

39 The innovation was not used, however, for creating a national automobile industry, something the country never really achieved, for in another critical political decision the alcohol motor technology was transferred to the multinational industries operating in Brazil, which paid no royalties for this development. Those industries at first had underestimated the difficulties still present in the alcohol motor, such as cold ignition, corrosion, high consumption, and the necessary regulation of the carburetors. As a result, the alcohol-run car was a failure when sales began in 1980. The technical problems took about three years to be solved. Other measures taken by the government included the addition of 10-20 % anhydrous alcohol to gasoline, and as a consequence the urban air pollution diminished significantly. The good results became a focus of interest for other non-oil producing nations, as well as countries plagued by heavy atmospheric pollution.[21]

40 The Institute of Technological Research (IPT) and the University of São Paulo's Agriculture School in Piracicaba conducted an extensive research on using the residue of sugarcane fermentation, vinasse. However, the Alcohol Program was slowed down in 1985 because oil prices had dropped, and at the same time, the exported sugar price had risen, so that sugarcane manufacturers were now more interested in producing and selling sugar than alcohol. With a large fleet of alcohol-run automobiles, the government suddenly had to import from Europe ethanol made from grapes, and from the USA methanol made from wood, a decision that was highly criticized. The subsidized Alcohol Program for automobiles ended in 2000, as more and more car owners gave up using the fuel. However, with the new generation of flex-fuel motors, running with either gasoline or alcohol, or any mixture of both, and the concern with air pollution, which increased alcohol addition to gasoline to 22%, there came a revival of ethanol at the sugarcane mills and distilleries. Presently the annual production of alcohol is 30 billion liters, mostly processed in the state of São Paulo, and the Alcohol Program has been redirected to biodiesel,

21 Eliana Fernandes, Suani Coelho (orgs.), Perspectivas do álcool combustível no Brasil (São Paulo: USP-Instituto de Energia e Eletrotécnica, 1996).

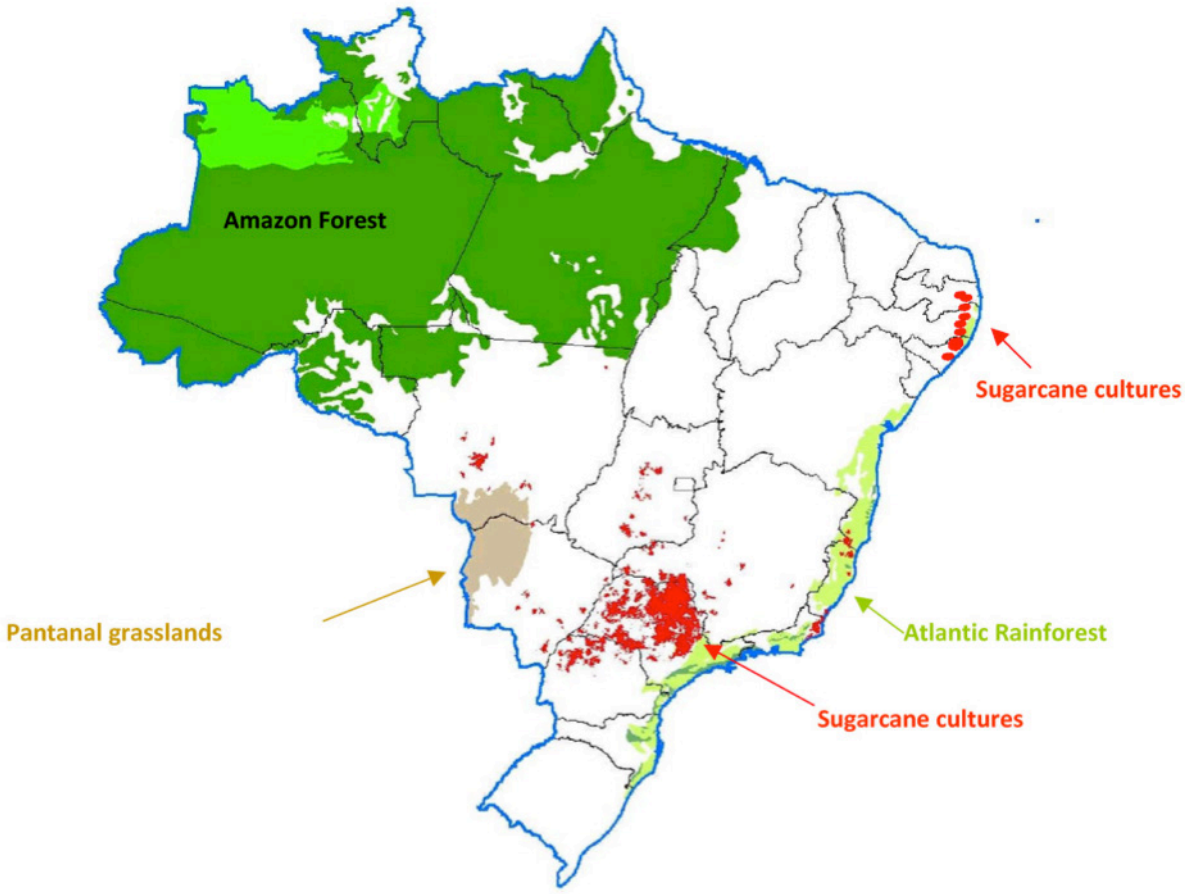

Figure 8: Sugarcane plantations in Brazil (2008). Mills and refineries produce either sugar or ethanol. Food plantations gave way to large extensions of sugarcane monoculture in the Southern State of São Paulo. Source: Wikimedia Commons/ José Goldemberg

a product obtained through a reaction of alcohol and vegetable oil. One more application of the by-products of sugarcane fermentation has been the thermal cogeneration of electricity by burning sugarcane bagasse.

41 The sugarcane harvest still utilizes non-skilled seasonal workers, even though it has become more and more mechanized, and Brazilian agricultural research made it possible to have two annual harvests. The plantation system demands a vast land extension, which has displaced or substituted food products such as corn, rice, cotton and grassland for cattle, and the monoculture landscape consisting of a monotonous "green sea of sugarcane" is also related to a poor vegetal and animal diversity in the country (fig. 8). The sugarcane plantations have contributed to maintain the conflicts with landless poor peasants and to increase the wealth concentration in Brazil, even though it has brought along more circulation of goods. This wealth concentration has extended the sugarcane farm ownership to the alcohol distilleries, as they become ever more the property of the same small number of groups, so that mini-distilleries also end up in the hands of these large groups.[22]

42 Biomass other than sugarcane is still an energy source in Brazil. In spite of being little efficient, and energetically poor, wood is still in use, burned in poor peasant's stoves, or employed to make charcoal as fuel for pig iron metallurgy. Wood can also be gasified, providing methanol, and methane generated by vegetable or animal residues has been used as fuel for urban buses in a few cities.

22 Bruce Johnson, "Impactos comunitários do Proálcool" (São Paulo: USP/FEA/IA, 1983). Fernando Melo, Eli Pelin, *As soluções energéticas e a economia brasileira* (São Paulo: Hucitec, 1984). Fernando Safatle, *A economia política do etanol. A democratização da agroenergia e o impacto na mudança do modelo econômico* (São Paulo: Alameda, 2011).

Figure 9: Almirante Álvaro Alberto power station in Angra dos Reis. Finished in 1985, this was the first nuclear unit, named to honor the nationalist admiral who fought for Brazilian independent nuclear research – yet this was built with USA's Westinghouse technology. Source: Eletronuclear

NUCLEAR

43 The Atomic Energy Commission, when created in 1946 by the United Nations, had an active participation of the Brazilian representative, Admiral Álvaro Alberto, who opposed the Baruch Plan of the dominant powers, which posed in fact their control of the world reserves of uranium and thorium. Fears that the superpowers intended to manipulate the nuclear fuels were justified, as demonstrated in 1952, when the USA imported from Brazil in a single commercial transaction all of their two-year uranium quota without the counterpart of nuclear technological transfer for electrical generation, as intended by Álvaro Alberto. Also at that time, the newspapers' headlines showed the scandal of the American trading of Brazilian monazite sand containing thorium for rotten wheat coming from the USA. In face of these difficulties, during the second Vargas government (1951-1954) Álvaro Alberto tried to make deals in Europe involving nuclear technological cooperation. He almost succeeded in secretly embarking ultracentrifuges in Germany for uranium concentration, but the manoeuver was denounced to the USA, who used its authority as occupying force in the defeated country to embargo the shipment in 1954.[23]

44 Nuclear research continued, however, at the Institute of Technological Research (IPT) and the Atomic Energy Institute (IEA), both related to the University of São Paulo, as well as at the "Argonauta", a prototype reactor of the University of Rio de Janeiro, and also in the Thorium Group of the Institute of Radioactive Research in Belo Horizonte (Minas Gerais). In 1959, Brazil successfully inaugurated its first pilot unit for uranium purification.

45 During the military regime implanted in 1964, the Nuclear Energy National Commission, together with a new state company, Nuclebrás, signed a contract with Westinghouse Electric from the USA. This was the origin of the first Brazilian

23 Shozo Motoyama, João Vítor Garcia (orgs.), *O almirante e o novo Prometeu. Álvaro Alberto e a C&T* (São Paulo: UNESP, 1996). Guilherme Camargo, *O fogo dos deuses. Uma história da energia nuclear* (Rio de Janeiro: Contraponto, 2006), 143-224.

nuclear plant, Angra 1 (640 MW), in the state of Rio de Janeiro (fig. 9). The transaction is generally considered a bad example in terms of technology, since it was essentially a "black box" arrangement, without providing for any technological transfer to Brazilians. The second nuclear deal, signed in 1975 by President Geisel with the German company KWU (controlled by Siemens), also failed to help mastering the desired nuclear technology. This Brazil-Germany Nuclear Deal foresaw the building of eight nuclear plants, but effectively only Angra 2 (1,350 MW) was initiated in 1976, but inaugurated only in 2001, due to the increasing internal political opposition, and the diplomatic external pressure reinforced by economic threats of retaliation by the USA. The construction of the following plant Angra 3 (also 1,350 MW) was paralyzed in 1986, and only recently it was continued, and because of constant delays it was rescheduled to be finished in 2018 or even later.

46 Added to the American pressure against Brazilian independent nuclear technology there was a mounting opposition of the civil society after the re-democratization of the country in 1985. This happened also in many parts of the world after the 1986 Chernobyl accident, but in Brazil additionally a dubious association was made between nuclear energy and the military dictatorship. The Brazilian Physics Society and the Brazilian Society for the Advancement of Science manifested their opposition to the uranium enrichment process, which according to them would lead to undesired nuclear weapons. The Carter administration had already prevented Brazil from getting American technology for uranium enrichment. To operate Angra 1, its only nuclear plant, Brazil had to send the locally produced "yellow cake" to Urenco in Europe, for a 3% enrichment. The dismantling of the nuclear effort was considered a victory of the new democratic civil regime, and it was completed during Collor de Mello's term (1990-1992) as President, known for his neoliberal measures and opposition to state participation in the economy.

47 In 1988, the state company Nuclebrás was closed, and the control of nuclear electric generation was passed over to Furnas, one of the companies controlled by the state-owned electricity holding Eletrobrás. The disappointed military, however, secretly maintained a parallel program of nuclear research. The Army intended to build a bomb, considered strategic in relation to the traditional competition with Argentina, but the press uncovered this plot, and the installations were shut down in 1990. However, the Navy continued working to build a nuclear propulsion submarine, together with the University of São Paulo and the Nuclear Energy Research Institute (IPEN, a successor of IEA), strategically located at the University of São Paulo campus. Although the government kept imposing severe cuts to the Navy's budget, the election of President Lula also channeled more attention to remedy the obsolescence that predominated in military equipment, and especially a preoccupation with the military defense of the Amazon region. The Brazil-France Military Cooperation Deal of 2008 is an indication of such nationalist political motivation, coupled with a desire for relative independence from the North American presence across the continent. The Navy enjoyed technological success and called international attention when it announced the development of an innovative uranium enrichment process in 2008, which has been continually perfected since then.[24]

48 Fusion energy research has also been a research target at the Universities of São Paulo and Campinas, although with severe budget restrictions. In terms of nuclear energy application, the country has a long tradition now of medical research for cancer treatment, conducted in São Paulo by IPEN, as well as food irradiation, developed by the internationally well-known Center for Nuclear Energy in Agriculture (CENA), created in 1966 at the University of São Paulo's campus in Piracicaba.

49 At this point it is interesting to compare the recent trends and relative contribution of two primary sources of energy in Brazil, one deriving from agriculture (sugarcane), and another from mining (uranium – U3O8), as in Table 4.

24 Fernanda Correa, *O projeto do submarino nuclear brasileiro. Uma história de ciência, tecnologia e soberania* (Rio de Janeiro: Capax Dei, 2010).

Source	1970	1980	1990	2000	2010	2016
Sugarcane	3601	9301	18451	19895	48852	50658
Uranium	0	0	0	2028	4821	4821

Figure 10: *Table 4 - Gross Domestic Supply (103 TOE)*
Source: *Balanço Energético Nacional* (Rio de Janeiro: MME/EPE, 2017)

ELECTRICITY

50 The first initiatives leading to the systematic use of electricity in Brazil were contemporary of, or arose immediately after, the pioneering use in Europe and the USA at the end of the 19th Century. At this moment, the leading countries were living through the so-called "Second Industrial Revolution", with applications derived from advances in chemistry and electromagnetism, with this new energy applied to create devices, machines and systems in various productive processes. The improvement of electro-mechanical generation and of electric motors, together with more efficient electric light, and regional integration of power transmission and distribution systems opened up horizons for the economic diffusion of electricity.[25] The social and cultural worldwide transformations brought about by electricity, and later by electronics, had just begun, and the fast spreading of electric applications was led by the industrialized nations – foremost Great Britain, USA, Germany and France. The less developed areas of all continents were a sizable market to invest in electricity for the capital accrued by the fast growth of the recent industrialization waves.

51 The public demonstration of Thomas Edison's incandescent lamp occurred in Brazil in 1879, a show promoted by Emperor Peter II at the main railway station of the country's capital, Rio de Janeiro. The first hydroelectric plant (250 kW) was built in 1889 to power a textile mill in Juiz de Fora, in the state of Minas Gerais. Electricity came into the Brazilians' daily life at the decline of the Empire and it sped up during the first years of the Republic (after 1889), marking the association of electricity with the long-aspired modernization symbolized by the Republic. People were at first curious about the electric novelties imported from Europe and North America, such as the telegraph and telephone, and, of course, domestic electric energy. The arrival of electrification sounded the alarm bell for reviving within the new Republican regime an old polemic: the fight around the belated industrialization of the country. The public demand was an incentive to invest in electrification the considerable gains resulting from coffee exports, and Brazilian capitalists related to this activity felt that new "power and light" companies selling electricity as a commodity would mean an opportunity to participate in a market, which was fast becoming an indispensable part of the production system of the contemporary world.

52 From the viewpoint of foreign capital, there had been successive money inflows to Brazil since, in the wake of the Napoleonic wars, the Portuguese crown transferred its administrative center from Lisbon in Europe to Rio de Janeiro in 1808. Given the economic ties of Portugal with Britain, investments continued after the independence, and British capital was applied, directly or indirectly, to interior and external commerce, as well as to mining, agriculture and a few types of manufactures and urban services, including transportation.

53 As the tradition of the national capitalist sector continued to favor investing mostly in land products and cattle, it was not difficult for foreign investors to incorporate many existing local companies that provided public electric

25 Thomas Hughes, *Networks of power. Electrification in Western society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983). David Nye, *Consuming power. A social history of American energies* (Cambridge, Mass.: MIT Press, 1998).

Figure 11: *Coffee blossoms* - Painting by Antonio Ferrigno (1903), showing a São Paulo State landscape, with coffee plantation and women cleaning the ground. In the background, a train passes by the peasant's village. Source: Museu Paulista, University of São Paulo

illumination and distributed electric power to private owners during the first three decades of the 20th century. During the Old Republic (1889-1930), the bulk of economy followed the same pattern as in the monarchy, i.e. massive heavy foreign capital affluence, first English, later on German, and increasingly American after World War 1.[26] The general political direction continued favoring importation of manufactured goods, something that was to be reverted only during Vargas' "New Deal"-style policies.

54 São Paulo Province in the South of Brazil (São Paulo State, after the Republic, not to be confounded with its capital São Paulo City, founded in 1554) remained a forlorn backward region until its fertile soil was recognized as exceptionally good for coffee plantation, during the second half of the 19th Century. The world's continuously growing demand for the black beverage gradually ensured wealth for São Paulo (fig. 11), and contrary to the usual national trend of transferring profits thereof to non-productive goals, they were reinvested in local industries, which increased at a very pronounced rate the state's urbanization.[27]

Electrification spread most conspicuously in 55
Rio de Janeiro, and at the same time in the fast industrializing state of São Paulo, where the largest cities were its capital, São Paulo City, the harbor city of Santos and their surrounding areas, such as Campinas and Sorocaba (fig. 12). São Paulo City adapted soon to the novelty, at first mainly for industrial machines and streetcar traction.[28] Electric light gave an air of modernity by substituting oil lamps in the houses and gas lamps in the streets, and soon electricity

26 Wilson Suzigan, Tamás Szmrecsányi, "Os investimentos estrangeiros no início da industrialização do Brasil", *in* Sergio Silva, Tamás Szmewcsányi (orgs.), *História econômica da Primeira República* (São Paulo: Hucitec/Universidade de São Paulo, 2002), 279-283. José Carlos Pereira, *Formação industrial do Brasil e outros estudos* (São Paulo: Hucitec, 1984). Flávio Versiani, José Roberto Barros, *Formação econômica do Brasil. A experiência da industrialização* (São Paulo: Saraiva, 1977).

27 Sérgio Silva, *Expansão cafeeira e origens da indústria no Brasil* (São Paulo; Alfa-Ômega, 1995).

28 Gildo Magalhães, "Da usina à população na velocidade da luz: fios elétricos e desenvolvimento", *Labor & Engenho*, vol. 9, nº 1, 2015, 6-18.

became an “object of desire” for the entire population. As elsewhere in the world, new working and leisure hours were thereby introduced, and new habits were created.

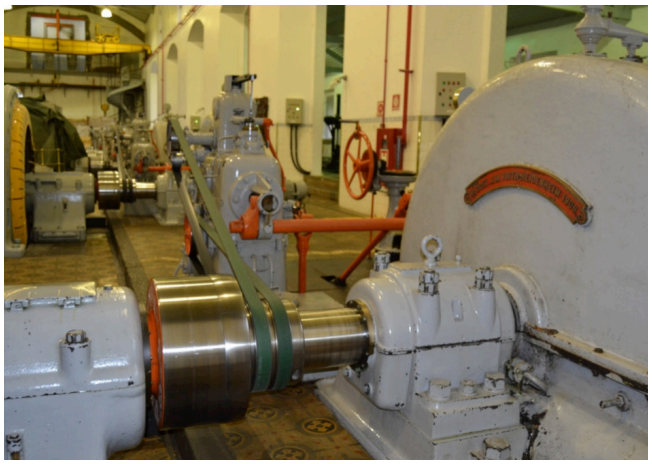

Figure 12: Itatinga power plant. Inaugurated in 1910, this plant was built to electrify the coffee-exporting harbor of Santos, and it still runs with the original equipment and buildings. Source; Electromemory Archive, University of São Paulo

With the coffee plantations’ steady boom during the early 20th Century, São Paulo State’s urban frontier moved westwards from São Paulo City and the cities near the coast. Until the 1920’s and 1930’s the Western area, comprising about half the state’s territory, remained mostly uninhabited, poorly geographically charted, and largely covered with the relatively mild (subtropical) Atlantic forests. Little touched by modern civilization, this was a land with areas still inhabited by hostile native Indians, while jaguars and snakes were not uncommon around the scattered villages. 56

On the other hand, scientific expeditions, led by São Paulo State’s Geographical and Geological Commission, had braved these areas from the 1890’s to the 1910’s, surveying their natural resources, including river courses and waterfalls (fig. 13). Those experts dutifully estimated a vast hydroelectric potential in the major rivers, and 57

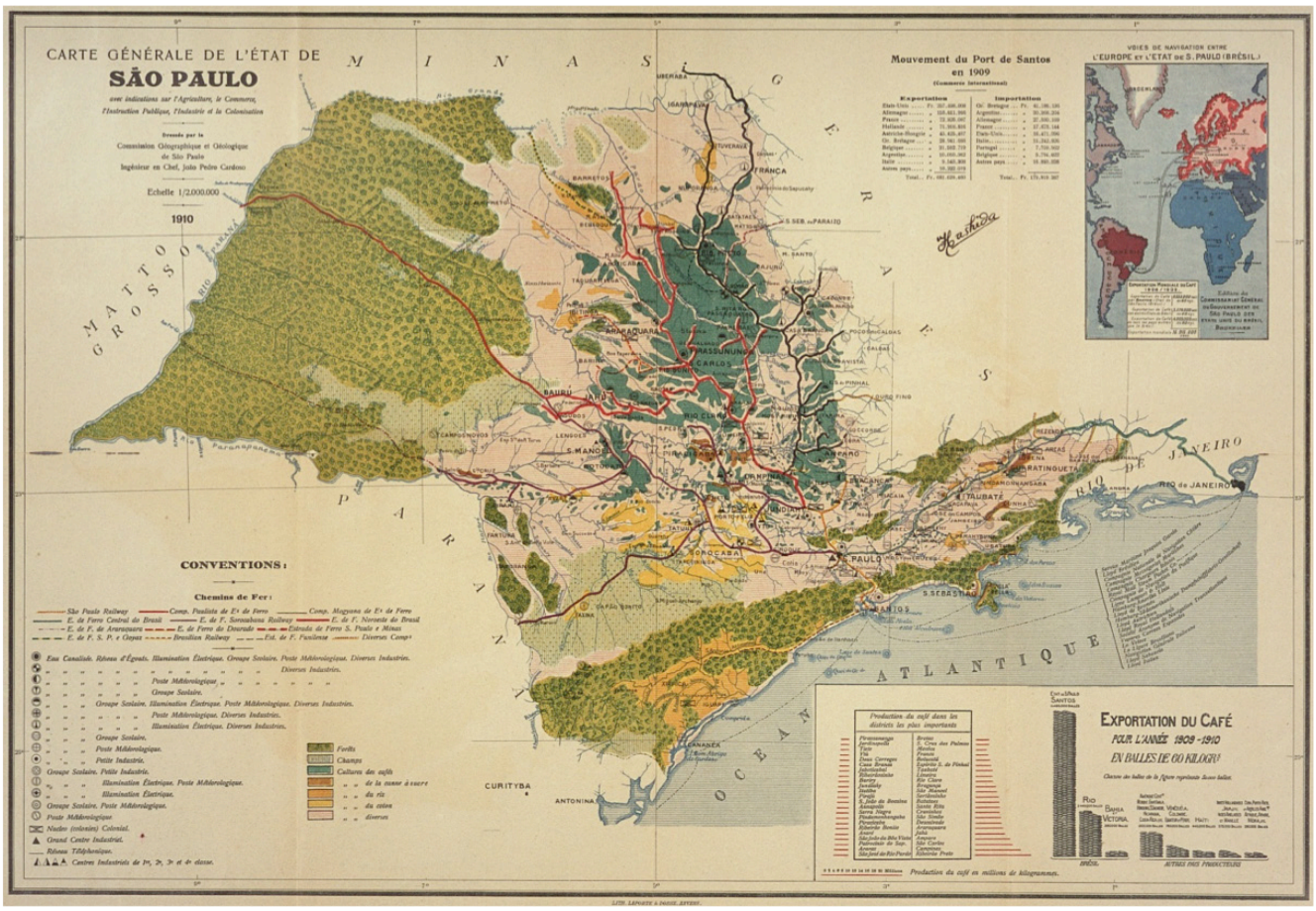

Figure 13: General chart (1910), São Paulo State Geological and Geographical Commission. This institution was responsible for surveying mineral and hydrological resources. Also depicted is the annual coffee exportation, Brazil’s main product, responsible for the first industrialization and electrification impulse. Source: Electromemory Archive, University of São Paulo

showed that the state had immense corresponding reserves of "white coal". At the time, this widely-used expression stressed that the three longest rivers in the state, Grande, Tietê and Paranapanema (which run contrary to the usual pattern from inland to the sea, and instead flow westwards from the high mountain ranges along the Eastern coastline towards the fertile plain lands limited by Paraná River basin) could indeed be used for massive electric power generation. This was quite convenient, given the expensive price of imported coal, and Brazil's small coal reserves. Due to these coal cost factors, before hydroelectric generation imposed itself, electricity was generated by burning cheaper wood after the devastation of nearby forests.

58 The ensuing urbanizing effort followed closely the advancing frontier of the coffee plantations, and together with the "white coal" available helped establish São Paulo's role as the leading Brazilian industrial center. It was also during the Old Republic that two engineering faculties were founded in São Paulo City: Polytechnic School (1894), state funded, public (free), and later (1934) incorporated to the first Brazilian university, the University of São Paulo; and Mackenzie School of Engineering (1896), privately-owned (founded by American Presbyterian missionaries), later part of Mackenzie University.

59 Both schools established electro-mechanical engineering courses in the early 1910's, and their graduates became part of São Paulo State's industrialization take-off.[29] Those engineers participated in the political life of the nation, including public debates in São Paulo's Institute of Engineering, and they took several initiatives, such as:

- Defense of national products versus imported ones.
- Suggestion of integrated use of energy resources (coal, hydro, oil, sugarcane alcohol), while emphasizing hydroelectric power as the best suited for the country.
- Promotion of professional schools for intermediate level technicians.
- Application of electric furnaces to steel production.
- Electric rail transportation (mass and freight).

60 An important spin-off of the Polytechnic School, and key to the industrialization effort was the Machine and Electrotechnic Laboratory (presently Institute of Energy and Environment, at the University of São Paulo), which in 1926 became the first national laboratory to conduct tests to standardize and to certify electric equipment for the local industries.[30]

61 With the happy conjugation of the factors of capital surplus (generated by coffee exports), expansion of labor force brought about by immigration, and technological support provided by the newly educated cadres, São Paulo State was able to reach the stage of the Industrial Revolution. This was, however, a belated achievement, in relation to the USA and the main European economies. In the beginning, all electric equipment was imported, but in 1923 electric cables began to be locally manufactured. Competition between foreign and fledgling national products appeared in several electrical applications. At first local inventors and their products displayed lower quality and higher prices, but they became increasingly better and cheaper.

62 Notwithstanding the improvement, several Brazilian electrical inventions did not materialize into products, a reflex of the lack of interest of local capitalists, and still a consequence of a traditional mistrust in the country's capacity as a manufacturer. A few relevant examples of this trend of lack of confidence during the Old Republic were: electric furnaces for metal processing (a Brazilian patent was relayed to a Belgian industry, after unsuccessful pledges of funding to the government); electrolytic

29 Gildo Magalhães, *Força e luz. Eletricidade e modernização na República Velha* (São Paulo: UNESP, 2000).

30 Only much later (in 1974) an important nationwide electric research institution was established by Eletrobrás in the state of Rio de Janeiro, the Center for Research in Electric Energy (CEPEL). See Renato Dias (coord.), *História do Centro de Pesquisas de Energia Elétrica – CEPEL* (Rio de Janeiro: Memória da Eletricidade, 1991).

transformers (the patent was sold to a French industry, which later exported them back to Brazil); submarine light-weight batteries, soon abandoned.[31] Consequently, the industrialization effort did not complete itself – a shortcoming which was felt not only in electrical innovations, but overall in Brazilian industry.

63 A further hindrance to expand the electric systems was the lack of standardization, in terms of voltages and frequencies. While the states that suffered more influence from American companies tended to adopt the frequency of 60 Hz and 110 V as final consumer voltage, the Southern states had considerable German influence, and they adopted 50 Hz and 220 V; elsewhere there were other slight variations. The 127 V value became more common after the 1960's and the frequency was standardized at 60Hz in the 1970's. This was also the period when the federal government succeeded in creating nationally integrated systems, which could efficiently and centrally dispatch electricity, in order to better distribute the load and share their electric availability. A larger integration has been more difficult to achieve with immediate Latin American neighbors.

64 The story of electrification becomes more complex when regarding the electric power companies. From 1888 onwards, small private companies in Brazil started operating thermoelectric generators using mainly wood as fuel for the steam turbines, and at the beginning they provided electricity principally to commercial houses and industries. The demand for electric energy in the state of São Paulo was also spurred by the fast diffusion of public illumination services, including small towns and villages. In the medium-sized Brazilian cities and in the larger State capitals, besides street illumination, the streetcar service also helped the electric market grow. Even though these predecessor companies did not last long, they showed that Brazil was a promising sizable market, which was in need of electricity for its economic development. Two types of companies marketed electric power from the end of the 19th century up to the 1930's. The greater number corresponded to the already-cited smaller companies, which were either municipal or operated regionally, and were organized by local landowners or businessmen. They used thermoelectric generation or small hydroelectric generation units, in some cases this latter type was an *in situ* adaptation of existing textile or lumber factories with waterwheels that supplied mechanical power to their production line.

65 The second group was far stronger in their investment capacity, and comprised foreign companies with roots in the international finance system. The foreign capital had the capacity to answer faster in this moment to the rapid growth of electricity demand by industrial and commercial consumers. They were also keener to take advantage of the other factor that benefited states like São Paulo: the large hydroelectric potential. Many small companies, unable to raise capital to build bigger dams and import generation equipment, were eventually bought up by the international groups, a movement which led power production to become concentrated in powerful and geographically expanding corporations, gaining more government-awarded concession areas. Two of the best known such foreign corporations were "Light" and "Amforp", as described in what follows.

66 In 1899, a group of British-Canadian investors established the "São Paulo Tramway, Light and Power Company", with the permit duly signed by Queen Victoria.[32] The initial investment amounted to US$ 6 million, which allowed the company (whose name was shortened by Brazilians simply to "Light") to incorporate a great deal of its competitors in the state of São Paulo in a short time, and also to expand in the direction of the neighbor state of Rio de Janeiro. As a matter of fact, Light was part of an international group of companies including interests in Belgium, Portugal,

31 Magalhães (2000), op. cit. More recently, products have had partial success, including electric motors, turbines, small or medium sized generators, and transformers.

32 Edgard Souza, *História da Light. Primeiros 50 anos* (São Paulo: Eletropaulo, 1982). Antônio Faria *et al.*, *Energia e desenvolvimento. 70 anos da Companhia Paulista de Força e Luz* (Campinas: CPFL, 1982).

Spain, Cuba; in Brazil it was under control of the holding "Brazilian Traction, Light and Power".[33] Light installed the streetcars' rails along main avenues in the city of São Paulo, while it simultaneously provided illumination and domestic electricity. In 1912 Light bought the English "The San Paulo Gas Company", responsible for the city's street illumination. By the way, as Light had the monopoly of electricity in São Paulo and Rio de Janeiro, the company opted for keeping liquefied gas for cooking, and not electricity, which is the predominant situation even nowadays, since cooking gas (natural or liquefied petroleum gas) prices are kept much lower than electricity for the household consumer.[34] The only Brazilian company that tried to oppose the economic interests of the foreign capital represented by Light, but was defeated in a series of political manoeuvers, was the industrial group "Companhia Brasileira de Energia Elétrica" (CBEE), headed by Eduardo Guinle.[35]

67 In the 1920's the Brazilian census confirmed that large areas of São Paulo State were rapidly becoming industrialized, and electrification represented an important role to achieve this result.[36] Light inaugurated large hydroelectric power plants, like Parnaíba (2MW in 1903, augmented to 16 MW in 1912), Ribeirão das Lajes (12 MW in 1908), and Cubatão (70.6 MW in 1927, 469 MW in 1949). This expansion attracted another major investor and competitor, the American & Foreign Power Co. (AMFORP), a branch of General Electric in the USA, which started operating in 1927, in the Midwest of São Paulo State. This company reached a kind of *entente* with Light, which kept for itself the axis São Paulo-Rio de Janeiro, while AMFORP bought up several smaller local businesses in the rest of the state of São Paulo, while it also reached to the neighbor state of Minas Gerais, and later to other states. By the end (1930) of the Old Republic, São Paulo had 166 power plants – 13.5 MW of thermal and 318 MW of hydroelectric generation, over 50% of Brazil's capacity concentrated in just one of the nation's 20 states, and mostly in the hands of those two foreign companies, which could also dictate the utility prices.

Soon the two foreign companies owned 80% 68
of the power concessions in Brazil, a situation that they maintained until 1960. Light and AMFORP were uninterested in improving their service quality, complaining that the government had limited their profits. Moreover, by then their installations had long ago become obsolete, and because of lack of proper maintenance, blackouts and power consuming restrictions had scratched the companies' reputation. At the same time, the automobile industry had established itself in the metropolitan area of São Paulo City, and more industry and urbanization implied a continuously growing electric demand.

The Brazilian electric sector history in mid- 69
20th Century was marked not only by this supply crisis faced by consumers, but also by the rekindling of ideological and cultural questions aroused by nationalist ideas, at this moment defended by several social sectors, with different hues. The publication of the federal Water Code in 1934 represented the first decisive state intervention act in the electric area. At the end of the 1940's the Inspectorate of Public Works was created in the State of São Paulo, subordinated to its Secretary of Roadways and Public Works. By this time, the federal government decided not only to increase its regulatory capacity, but also to start investing heavily in its own new hydroelectric plants. In the beginning of the 1950's, when engineer Lucas Garcez (a professor at the Polytechnic School) took over the office as São Paulo's Governor, the first state-owned power companies were created, and then they began the construction of higher-capacity power plants that became the largest hydroelectric generation complex in the country.[37]

33 Duncan McDowall, *The Light. Brazilian Traction, Light and Power Company Limited, 1899-1945* (Toronto: University of Toronto Press, 1988).

34 João Luiz Silva, *Cozinha modelo. O impacto do gás e da eletricidade na casa paulistana, 1870-1930* (São Paulo: EDUSP, 2008).

35 Alexandre Saes, *Conflitos do capital. Light versus CBEE na formação do capitalismo brasileiro, 1898-1927* (Bauru: EDUSC, 2010).

36 Helena Lorenzo, Wilma Costa, *A década de 1920 e as origens do Brasil moderno* (São Paulo: UNESP, 1997).

37 Catullo Branco, *Energia elétrica e capital estrangeiro no Brasil* (São Paulo: Alfa-Ômega, 1975).

Figure 14: Jupiá. Built on Paraná River (1974), this large hydroelectric was also a landmark, as it was the first power plant totally designed by national engineering. The dam is 5,495 m long, and the reservoir has an area of 330 km2. Source: CESP

70 The year 1950, besides representing a paramount crisis of electric energy, which entailed dramatic electric energy shortage in the following years, signaled also the beginning of the engineering studies for Barra Bonita hydroelectric plant, on the Tietê River in São Paulo, which came to conclusion in January, 1956. From this point on, São Paulo State's intervention and participation increased, first with the creation in 1951 of the Water and Energy Department, and subsequently, several state power companies were formed in the state. Among these were: "Paranapanema River Basin Electric Plants" (*USELPA*), in 1953; "Pardo River Hydroelectric Corporation" (*CHERP*), in 1955; and finally, "São Paulo Electric Plants" (*CESP*), in 1966, which incorporated the previous ones, as well as a large number of smaller private companies.

71 After a series of public debates, which emphasized the evident lack of interest from the part of the private companies in providing electric energy for the new cycle of economic development, public opinion pressed the government to cancel their concession.[38] The foreign companies were either expropriated or bought by the government, and so ex-AMFORP (in 1975) and ex-Light (in 1979) also became part of the state's public energy grid, which could then provide the whole chain of electric generation, transmission, and distribution, so that electricity became a "vertical" utility. Their common ownership facilitated planning and constructing the backbone of São Paulo state's electric generation: the hydroelectric plants of Bariri, Ibitinga, Caconde, Euclides da Cunha, Limoeiro, Barra Bonita, Jupiá (fig. 14), Ilha Solteira, Porto Primavera, Promissão, Avanhandava, Água Vermelha, Taquaruçu, Rosana, Capivara, Canoas 1 and Canoas 2, Chavantes, Jurumirim, Paraibuna, and Jaguari (a total of 11,094 MW).

38 Eletropaulo, "Departamento de Patrimônio Histórico, Estatização x privatização", *História & Energia*, vol. 7, 1997.

72 In the federal plan, Eletrobrás, a federal holding company, was created in 1962, after a long struggle against privatization interests, and with it the planning of the electric energy sector, which used to be regional, began to be nationwide and more rationalized. Centralized load dispatching was introduced, so that technical integration among the various state and regional systems was enhanced, resulting in their joint dispatch operation and supervision.[39] The new cycle of development of electricity and of the economy as a whole coincided with the military regime (1964-1985), when only a few electric concessions remained in private hands.[40] The subsidiaries of Eletrobrás were regrouped in four major regional companies: CHESF, a state company, already created by President Vargas in 1945, destined to exploit the hydroelectric potential of São Francisco River in the Northeast of Brazil; Furnas, active mostly in the Midwestern states; Eletrosul, for the Southernmost states; and Eletronorte, for the vast Amazon region.[41] During the military regime a treaty signed between Brazil and Paraguay allowed the construction of Itaipu, a major hydroelectric generation plant, with a maximum capacity of 14 million MW in the state of Paraná, inaugurated in 1984 (the last unit became operational in 2007). The energy generated at Itaipu is carried through high voltage (600 kV) direct current transmission lines (810 km long), as Brazil buys the excess energy generated at the Paraguayan side at 50 Hz, converting it to direct current and then reconverting it to 60 Hz for distribution, nearby São Paulo City.

73 An important aspect of the process was the simultaneous improvement of the national engineering capacity for designing hydroelectric works, a basis for the future Brazilian consulting and design companies that gradually substituted foreign experts, who had traditionally been in charge of this service before. A distinctive feature of Itaipu is exactly that this great project was designed by a group of Brazilian engineering companies, a fact considered as a "coming of age certificate" for local technology. Those companies later became large national consulting groups, and contributed to the country's economic development also in the petrochemical and industrial projects in general.

74 The great hydroelectric projects of the period, like Itaipu in Paraná State and Ilha Solteira (3.444 million MW) in São Paulo, were constructed with external financing. National and international political decisions resulted in very heavy debt services, while the government's National Economic and Social Development Bank (BNDES) imposed rules that practically turned electric investments prohibitive for the state-owned companies later on. After the military left power in 1985, the "New Republic" aligned itself with the so-called Washington Consensus, decidedly enforcing neoliberal reforms. The decision to privatize the electric sector state companies (fig. 15) was taken by President Fernando Henrique, which privatized also the telecommunications sector, state banks, iron mining, and railroad companies.[42]

75 In terms of electric supply, the effects of deregulation were more immediately and acutely felt in the state of São Paulo. The result was twofold: the sale of the state companies over to private initiative, and secondly the denationalization of the sector, as the biddings were won by foreign investors, mainly American and, later, resold to Chinese. The previous pattern, of almost total control of the electric sector policies by state companies, gave way to another model, one where the vertical business of generation,

39 José Luiz Lima, *Políticas de governo e desenvolvimento do setor de energia elétrica: do Código de Águas à crise dos anos 80* (Rio de Janeiro: Memória da Eletricidade, 1995). Marcelo Silva, *Energia elétrica, Estatização e desenvolvimento, 1956-1967* (São Paulo: Alameda, 2011).

40 Anon. *A energia elétrica no Brasil* (Rio de Janeiro: Biblioteca do Exército, 1977). Francisco de Assis Gomes, "A eletrificação no Brasil", *História & Energia*, vol. 2, 1986. Renato Dias, *Panorama do setor de energia elétrica no Brasil* (Rio de Janeiro: Centro de Memória da Eletricidade, 1988), 198-215.

41 Renato Dias (coord.), *A Eletrobrás e a história do setor de energia elétrica no Brasil* (Rio de Janeiro: Centro de Memória da Eletricidade, 1995). John Cotrim, *A história de Furnas. Das origens à fundação da empresa* (Rio de Janeiro: Furnas Centrais Elétricas, 1994).

42 Lindolfo Paixão, *Memórias do \projeto RE-SEB* (São Paulo: Massao Ohno/ENRON, 2000).

Figure 15: Privatization struck São Paulo State more heavily than the rest of Brazil. These 24 largest hydroelectric power stations in São Paulo State were built by the public sector along 4 major rivers in the second half of the 20th Century, and sold to foreign investors starting in 1998. Source: Electromemory Archive.

transmission, and distribution, previously provided by the same authority, was subdivided and mostly horizontally transferred to different private hands. The price of electric energy, which used to be calculated by a method of historic production costs, became instead a function of market auctions, where energy batches constitute merely a merchandise, and are also subject to the effects of the speculative action of future markets.[43]

76 Table 5 shows the chronological evolution of the 20 largest-capacity hydroelectric stations in Brazil in the last five decades.

77 The average annual electricity consumed by Brazilians is presently 2,578 kWh/inhabitant, a low number even among Latin American countries.[44] The correlation between energy consumed and wealth concentration is well established, and there has been a strong concentration of the use of electricity in the upper layers of society.[45]

78 It is evident that the electricity per capita availability would have to be increased to cope with population growth and a better wealth distribution. However, a new political factor has slowed down the development of hydroelectricity: radical environmentalism mobilization against hydroelectric plants, using even physical violence, by burning construction sites, inciting Indian use

43 Ildo Sauer, "Energia elétrica no Brasil contemporâneo: a reestruturação do setor, questões e alternativas", *in* Adriano Branco (org.), *Política energética e crise de desenvolvimento* (Rio de Janeiro: Paz e Terra, 2002). José Paulo Vieira, *Antivalor. Um estudo da energia elétrica: construída como antimercadoria e reformada pelo mercado nos anos 1990* (Rio de Janeiro: Paz e Terra, 2007).

44 International Energy Agency, Key World Energy Statistics 2016 (data from 2014), access on April 24, 2017, at www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf

45 Antônio Carlos Boa Nova, *Energia e classes sociais no Brasil* (São Paulo: Loyola, 1985).

Plant	Power (MW)	Start
Ilha Solteira	3,444	1973
Jupiá	1,551	1974
Foz do Areia	2,511	1976
Marimbondo	1,814	1977
São Simão	1,710	1978
Paulo Afonso IV	2,850	1979
Água Vermelha	1,380	1979
Salto Santiago	1,420	1980
Itumbiara	2,082	1981
Itaipu	12,600	1982
Tucuruí	8,360	1984
Itaparica (Luiz Gonzaga)	1,480	1988
Xingó	3,162	1994
Serra da Mesa	1,275	1998
Itá	1,450	2000
Porto Primavera	1,430	2000
Santo Antônio	3,568	2012
Jirau	3,300	2012
Teles Pires	1,820	2015
Belo Monte	11, 187	2016

Figure 16: *Table 5 – Chronology of larger capacity hydro-power stations in Brazil*
Source: Data compiled by author (2018)

Source	1966	2016
Hydraulic	73	64.0
Thermal (gas, biomass, oil, coal)	27	30.2
Thermal (nuclear)	0	2.4
Eolic	0	3.4

Figure 17: *Table 6 – Evolution of electric generation sources in Brazil (%)*
Source: EPE – Ministry of Mines and Energy, *National Energetic Balance* (Rio de Janeiro, 2017)

of weapons against engineers and workers, etc. The starting point for this occurred in 1998 during the "Indigenous Peoples' Meeting" of Altamira, in the Amazon region, sponsored by the "Forest Alliance", jointly organized by the World Bank and World Wildlife Foundation, with the support of the World Council of Churches and several Non-Governmental Organizations.[46] This movement was endorsed by President Fernando Henrique Cardoso and by the governments that followed his own, which strongly backed up a position against the construction of new hydroelectric plants, initially in the Amazon region, but they succeeded in barring other initiatives around the country, as well. This reaction created a political mood which defined hydroelectric plants as anti-ecological, and as enemies of local inhabitants, Indians or not, an outlook that has continually weighed on public opinion.[47]

79 These attacks succeeded in delaying or even cancelling already approved projects. Among the plants that suffered significant delays due to this effect, one may cite Tucuruí (8,360 million MW) on the Tocantins River, and the hydroelectric plants on Madeira River: Belo Monte (11,197 million MW), Santo Antônio (3,568 million MW), and Jirau (3,300 million MW). A compromise was reached for some plants, which had to lower their dam height, reducing the projected power capacity, and at the same time to diminish the flooded area corresponding to the artificial lake, thereby affecting the produced energy during the dry seasons.

80 A consequence of those conflicts and the standstill regarding hydraulic power was the decision to generate electricity by means of sources other than water. Wind turbines, besides thermal generation employing gas, especially in the Amazon region, biofuels and coal have all been replacing hydroelectric generation. Taxes on electric bills were imposed to the normal consumer to compensate for the higher cost of thermal plant operation, adding on to the already higher prices that resulted from privatization.

The evolution of electric sources is seen Table 6, 81
which shows a fifty-year interval, indicating the displacement of hydraulic generation by thermal and wind generation.

FINAL REMARKS

The history of energy in Brazil, as in other coun- 82
tries, has also been a history of the battle to become a developed nation. Major cycles of economic development occurred in three distinct phases, and all of them were connected with energetic questions. After preliminary efforts beginning in the second half of the 19th Century, the impacts of World War I contributed to an industrialization wave in São Paulo during the 1920's, which was enhanced and politically used during the 15 year-long first Vargas administration. The main question addressed in this period was electrification and the progressive dominance of hydraulic generation, and a second issue was the existence of oil reserves in Brazil. A nationalist sentiment was solidified, as noted in the discussions about oil prospection and steel production in the country.

The end of World War II also represented an 83
opportunity for an economic impulse, which was signaled by the creation of state companies related to electricity and oil. The petrochemical industry and the automobile plants installed by multinationals in São Paulo challenged the existing foreign electricity concessionaries to produce more energy, and their negative reply made the State gradually enter the electric sector. The military regime made good use of the resulting available infrastructure, and many imported manufactured goods were substituted by nationally produced equivalent products, thus increasing the industrialization in the country. The threat posed by the oil shocks was attenuated by the introduction of ethanol derived from sugarcane as a substitute.

46 Lorenzo Carrasco *et al.*, *Ambientalismo, novo colonialismo* (Rio de Janeiro: Capax Dei, 2005).

47 Lygia Cabral (coord.), *O meio ambiente e o setor de energia elétrica brasileira* (Rio de Janeiro: Memória da Eletricidade, 2009). Carlos Locatelli (org.), *Barragens imaginárias. A construção de hidrelétricas pela comunicação* (Florianópolis: Insular, 2015).

84 The political re-democratization in 1985 also concurred to the adhesion to the neoliberal ideology, which favored the skyrocketing of interest rates and the domination of the economy by speculative financial capital. The privatization of many sectors included the public auctioning of electric generation and transmission lines, and the local distribution networks, as well as significant parts of the oil industry. A shorter economic boom was manifest during President Lula's administration, with the discovery of huge oil and gas deposits in the continental platform under the sea. The electric supply, however, did not follow this trend, radical environmentalism prevented the expansion of hydroelectric and nuclear power plants, and the deregulation of this electric market signified a real increase of rates far above the inflation. The forceful use of thermal electric generation only complicated the situation, with the end of the economic development effort, and the subsequent stagnation, deindustrialization, and high unemployment verified in the country. Social and political tension increased, income concentration returned to previous high levels, and this setback made the country again highly dependent on imported technology.

85 During the energy crises, ideological disputes have questioned whether there is a correlation between energy consuming and economic development. Neo-Malthusian currents have denied such a dependence, arguing for a population control, the curbing of industrialization, and a "greening" of energy sources. However, a truly sustainable economy should provide not only for a necessary control of the quality of air and water, as well as avoiding wastes, but to plan for coming generations the necessary production of enough food, transportation, and public health – all of which demand a growing energetic input. Brazil has sometimes been looked at as a model for these discussions, given national initiatives such as its biofuel policies, and also because it is a large territory comprising the vast reserve of the Amazon forest. All of this suggests a closer attention to how the country's history of energy has developed so far.

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