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FUTURE OF NUCLEAR ENERGY FOR ELECTRICITY GENERATION IN BRAZIL

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ABSTRACT

We discuss in this paper the medium- and long- terms evolution of nuclear power in Brazil considering official governmental studies and reports prepared by research groups. The documents reviewed include the national energy balance (BEN, 2014), the short-term planning (PDEE, 2023) and long-term planning (PNE-2030) documents emitted by EPE, and studies conducted by independent institutions and researchers. The studies consider different scenarios regarding gross national product growth and institutional development for the country and conclude that nuclear power should increase its role in Brazil. The generation matrix should diversity by 2030 and 2040 with hydropower decreasing its share from today's 70 % to values between 47 and 57 %. Nuclear power is considered a viable alternative for baseload electricity generation in Brazil; to reduce generation risks during dry seasons, and to facilitate the operation of the whole power generation system. The share of nuclear power may reach values between 8 % and 15 % by 2040 according to different scenarios. To meet such growth and facilitate new investments, it is necessary to change the legal framework of the sector, and allow private ownership of enterprises to build and operate nuclear power plants in the country.

1. INTRODUCTION

According to EPE official documents and National Energy Balance (BEN-2014) [1-4] the total installed electricity capacity in Brazil in 2013 was 126,743 MW. Comparing with the previous year there was an increase of 5.8 GW, being 30% hydropower, 65% thermal power, and 5% wind power. These figures show nuclear power as a complementary primary source of electricity with a low importance in the energy matrix [1-3]. However, the present crisis in the power sector due to dry seasons, low levels of hydropower plant reservoirs, and persistent increase of electricity consumption (~4 %/year) indicate that the current energy matrix has to diversify in the near future [2].

In fact, in the last two years fossil fuel power plants have generated much more electricity than in previous years because of low levels of the reservoirs from hydropower plants. The current debate about capacity addition includes issues regarding electricity generation reliability during the whole year, and the need to install low fuel cost thermal power plants to generate baseload electricity [2]. Therefore, a debate about what should be the adequate power generation matrix for Brazil in the medium- and long-terms is very pertinent.

In this work, we report the capacity addition plans carried out by EPE [1-4], and studies of independent researchers and institutions [5,6]. We then discuss what could be the contribution of nuclear energy to the power generation sector in Brazil in the medium- and long-terms.

2. AVAILABLE RESOURCES FOR ELECTRICTY GENERATION

Fig. 1 presents the power generation matrix in Brazil for 2013. Renewable sources present the largest share in the Brazilian electricity matrix [1]. Most of the electricity is generated by hydropower, although it is being introduced complementary thermal sources (natural gas and nuclear), and renewable sources (wind, biomass, and solar power). This session describes the reserves and resources of energy, as illustrated in Table 1, with emphasis on the non-renewables.

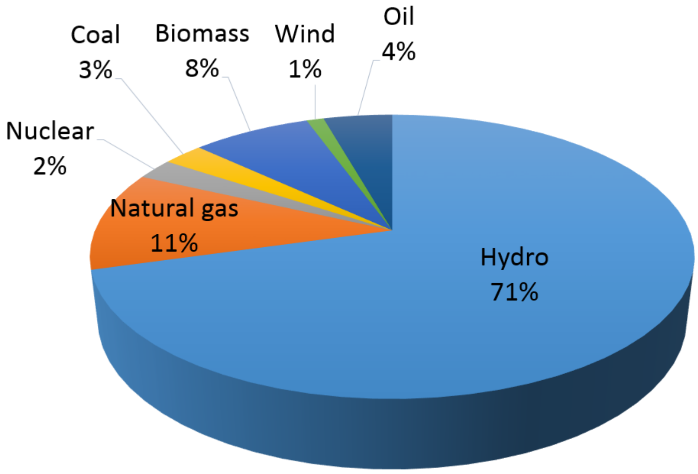

Figure 1: Electricity matrix in Brazil according to the BEN-2014 [1].

Table 1: Brazilian energy reserves and resources in 2013 [1].

Source	Unit	Measured	Estimated	Total
Gas	10^6 m^3	433,958	405,523	839,482
Coal	10^6 t	25,750	6,535	32,585
Hydraulic	GW	109	27	135
Nuclear	t U_3O_8	177,500	131,870	309,370

2.1. Hydropower

Brazil is a rich in water, with big hydro potentials such as those located in the Amazon region. The large distance from this potential to the main consumer centers located in the Southeast and South regions has precluded its utilization, and most of hydropower resources from the Paraná basin has been utilized. Presently the important remaining reserves and resources are located in the Amazon region with important environmental and social impacts, namely flooding large rain forest areas and dislocation of native indian populations. Other potentials are small hydropower resources. As shown in Table 1, the hydro available capacity is around 130 GW, with about 90 GW already installed. An additional of ~120 GW mostly in the North and Center-west regions (~50% each) [7].

2.2. Nuclear power

Nuclear power is one of the alternatives to generate baseload electricity in Brazil and increase the power generation reliability during the whole year, especially during dry seasons. Brazil has one of the biggest Uranium reserves in the world as illustrated in Table 1, although with only one third of its territory prospected. The Brazilian company Indústrias Nucleares do Brasil (INB) expects that these reserves increase to 800,000 tons U_3O_8. Despite of these large figures it operates only one mine at Lagoa Real, located in Caiteté, BA, with a production capacity of 400 tons U_3O_8/year [7,9]. This production is not enough to feed the 2 nuclear power plants in operation in the country causing INB to import almost half of what it consumes.

INB conducts almost the complete fuel cycle industrial activities. It operates the uranium mines, converts enriched UF_6 into UO_2, fabricates fuel elements, and is implanting an enrichment facility. All these industrial facilities are located in Resende, RJ.

2.3. Wind power

Brazil has a significant potential for wind power generation [8], although wind parks are presently yet of low importance (1.1%, as show in Fig. 1). Its increasing importance for power generation in the country is discussed in the next section. Presently, wind power plants are built in the Northeast Brazil where the winds are stable and adequate for power generation during the whole year. The electricity production reached 6,579 GWh in 2013, about 30%, and the installed capacity increased to 313 MW. The wind power resources in Brazil is 143.5 GW.

2.4. Solar

Solar generation still does not have a significant contribution in Brazil, despite the average daily solar radiation to vary between 4200 and 6700 kWh/m^2. This figure is greater than most countries from the European Union like Germany (900-1250 kWh/m^2), France (900-1650 kWh/m^2), and Spain (1200-1850 kWh/m^2), where there are strong government support to solar energy [9].

2.5. Biomass

Biomass contributes 7,6 % of the total power generation as illustrated in Fig. 1, mostly through sugar cane bagasse. Today there are more than 200 small power plants burning sugar cane bagasse, mainly by self-producers, with a total around 10 GW of installed capacity. Other biomass resources include black liquor, wood, biogas, and rice [1].

2.6. Natural gas

Natural gas is another candidate to generate baseload electricity in Brazil. As illustrated in Table 1, Brazil has reserves of natural gas and the trend is to increase it given the recent discoveries offshore in Brazil. But the extraction of natural gas in the country may be compromised because of high costs related to the pre-salt explorations and long distance to transport it to the Brazilian coast. Before residences and industrial facilities were the larger consumers of natural gas. Today consumption for electricity generation gained importance; the installed capacity in the country is around 14 GW with about 30 power plants [7,9]. Currently we import from Bolivia an important fraction of the natural gas we utilize in the country. The trend in the near future is the country to become self-sufficient about this energy resource.

2.7. Coal

Coal is an important alternative for baseload electricity generation in the whole world. The Brazilian coal, found mainly in South Brazil, is of low quality. Electricity generation with coal emits greenhouse gases with large environmental impacts related to climate change. As shown in Table 1, the reserves and resources in the country are low, and its contribution to the electricity generation is thus far low too [7,9].

3. EXPANSION PLANS FOR ELECTRICITY GENERATION IN BRAZIL

This section reviews the expansion plans made by EPE [1-4] as well as those made by independent researchers or institutions [5,6]. Expansion plans are strongly dependent on assumed macroeconomics scenarios attempting to reflect possible outcomes in the future. One has to bear in mind that they cannot predict unexpected social, political and economic crises that may occur, and that they are based on opinions of different analysts and decision makers.

3.1. The Short Term Expansion Plan (PDEE-2023)

The PDEE-2023 [2] presents a 10 year scenario of power generation expansion considering a balance between the gross national product growth, energy supply with adequate costs under the broad framework of sustainable development [4]. The electricity generation capacity is expected to reach 195.9 GW in 2023 with an increase of 57% compared to 2013. The renewable energy capacity would increase 86%, mostly due to wind power which would go from the present 1,1% to 8.1% share in 2023 (expansion of 20 GW in the period). The plan predicts investments of R$ 1.3 trillion being 23.8 % directed to electricity generation. The large hydropower plants of Jirau (3750 MW) and Santo Antonio (3150 MW), and the Angra 3 nuclear power plant are under construction and foreseen to be in operation in 2016-2018. The Angra 3 will increase nuclear power capacity in the country from 2007 MW to 3412 MW or 75 % [2].

In addition, the plan foresee 19,673 MW of hydropower to be available after 2024. Most of this new capacity is large projects in the Amazon region with controverted environmental impacts.

3.2. The Long Term Expansion Plan (PNE-2030, 2050) and Independent Studies

Officially, EPE makes medium- and long-term plans of energy expansion, being the latest revision issued in 2007 with title PNE-2030 [3]. It is worthwhile to mention that the PNE-2050 is already under study [4]. Besides the official plans, we also review here independent studies [5,6].

The studies developed to prepare the PNE-2030 is structured in four groups: macroeconomic studies; demand studies; energy supply studies; and final studies, which integrate supply and demand taking into account aspects of politics, sustainability, strategy, institutional development and energy supply reliability. The aim is to produce a set of scenarios of supply and demand of electricity.

The international scenarios considered regarding world macroeconomics are [6]:

- ONE WORLD – it assumes a maximum multilateral connectivity (totally globalized), an equilibrium of forces, and international share of macroeconomic politics;
- ARCHIPELAGO – it assumes partial connectivity and economic blocks with a shared hegemony of the European Union and United States, recovery of the American economy, and localized conflicts worldwide;
- ISLAND – it assumes economic protectionism, major participation of the Asian blocks, disruption of the commercial relations between China and USA, and a weak economy recovery. In addition, it assumes pronounced divergences among different countries.

The national scenarios considered natural resources, poor infrastructure, and social differences [3]:

- Scenario A (on the crest of the wave) - this scenario is associated with the optimist international scenario of the ONE WORLD. In short, it assumes that there will be a significant improvement in infrastructure and in the income disparities. It also assumes increasing competitiveness with a high productivity for the Brazilian economy;
- Scenario B1 (surfing the wake) - this scenario assumes that infrastructure bottlenecks have partially reduced, relevant income disparities, and moderate competitiveness with medium productivity for the Brazilian economy;
- Scenario B2 (paddle boat) - this scenario assumes a small reduction in the infrastructure bottleneck, small reduction in the income disparities, and low gains in the competitiveness;
- Scenario C (shipwreck) - this scenario is associated with the pessimist international scenario (ISLAND). It assumes scarce improvements in infrastructure and social differences, and reduced competitiveness and low productivity in economics.

Fig. 2 shows projected growths for the gross national product for the different scenarios. Fig. 3 presents the scenarios for electricity generation projected until 2030. The projections from medium- and long-term planning projected 1246 TWh for scenario A and 847 TWh for scenario C in 2030. Other scenarios present intermediate figures.

Table 2 illustrates the general balance of electricity considered in the PNE-2030 [3]. In addition, scenarios for the expansion of the installed capacity per source were considered. In Case 1 a high utilization of hydroelectricity was assumed, while in Case 2, the restrictions were admitted. In addition, in Case 1 the nuclear generation was limited to 6000 MW, in Case 2, to 8000 MW, and renewables were projected to be the same. Table 3 presents the alternatives considered for capacity addition.

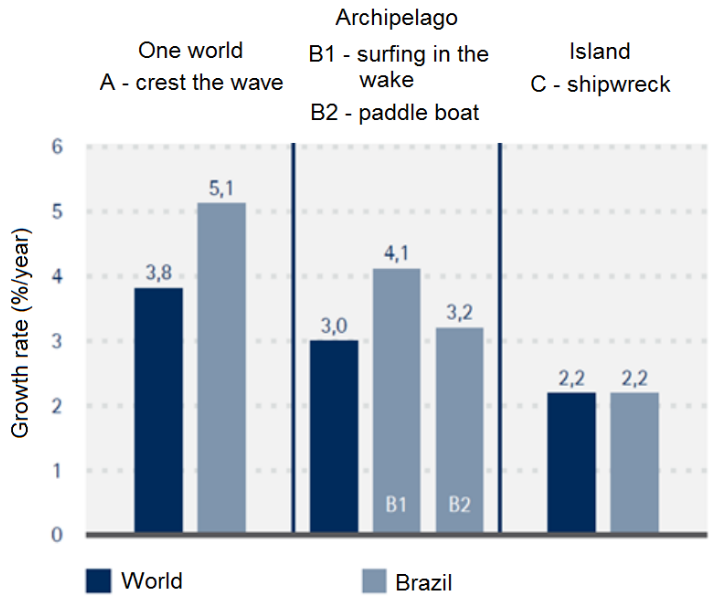

Figure 2: Macroeconomic scenarios used in PNE-2030 [3].

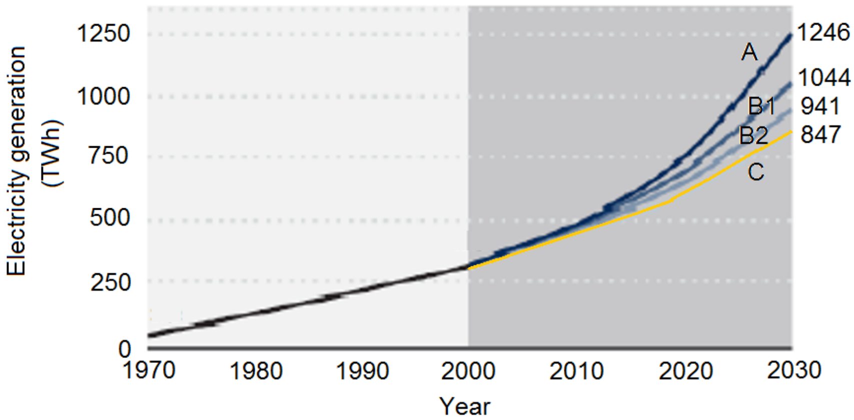

Figure 3: Electricity generation projection used in PNE-2030 [3].

Table 2: Balance of electricity (TWh) [3].

	2005	2010	2020	2030
Internal supply	442	575	829	1198
Production	403	536	785	1154
Net import	39	39	44	44
Total consumption	375	489	709	1033

Table 3: Alternatives for electricity expansion for period 2015-2030 (MW) [3].

Source	Case 1 (without restrictions)	Case 2 (with restrictions)
Large hydropower	73.4	69.9
Total thermal power	35	37
Natural gas	35	37
Nuclear	6	8
Coal	9	9
Total renewables except hydropower	17.3	17.3
Small hydropower	8	8
Wind power	3.3	3.3
Sugar cane bagasse	4.7	4.7
Urban waste	1.3	1.3
Total	125.7	124.2

The long-term official expansion (PNE-2050) is still in elaboration, and only 3 documents had already being made, the reference term, the economic scenario, and the energy demand for 2050 [4].

Besides the official expansion plans, some work had been done by independent Brazilian researchers, such as a recent work of Mafra et al [5]. In this work global energy demand scenarios are constructed encompassing medium- (2020), long- (2035) and very long- (2060) terms. They evaluated the share of different primary energy sources for electricity generation and their availability in the country. The macroeconomics scenarios assumed were:

- Basic scenario – it is an extension of the official PNE-2030 up to 2060;
- Developed Brazil scenario – it assumes that in 2060, Brazil will achieve the same level of development of OECD countries.

Figs. 4 and 5 illustrate the results for these scenarios. These predictions were based mostly in the analysis of greenhouse gases environmental impacts which favored nuclear power generation.

A recent study made by Getulio Vargas Foundation [6] presents projections for electricity generation up to 2040 based on different scenarios. These scenarios consider different conditions of social development for the Brazilian society in 2040. The study also considered three different internal rates of return (IRR) for the capital cost of different power plants to get insight about cost variations that may occur in the period. Table 4 presents the scenarios in which are considered three different market conditions:

- Competition regime;
- Regulated scheme with 7%/year of IRR;
- Regulated scheme with 10%/year of IRR.

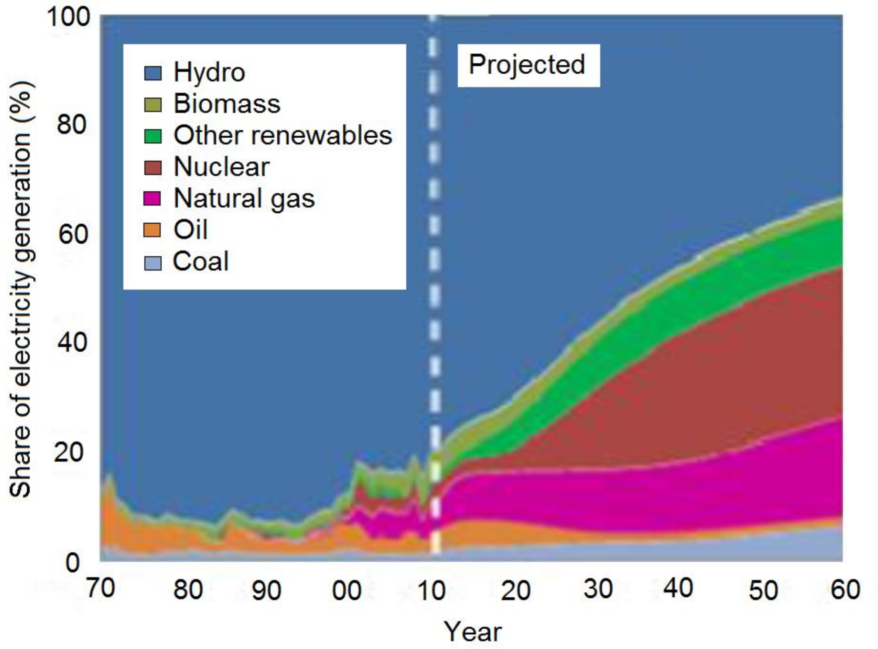

Figure 4: Projections of share of electricity generation for the basic scenario [5].

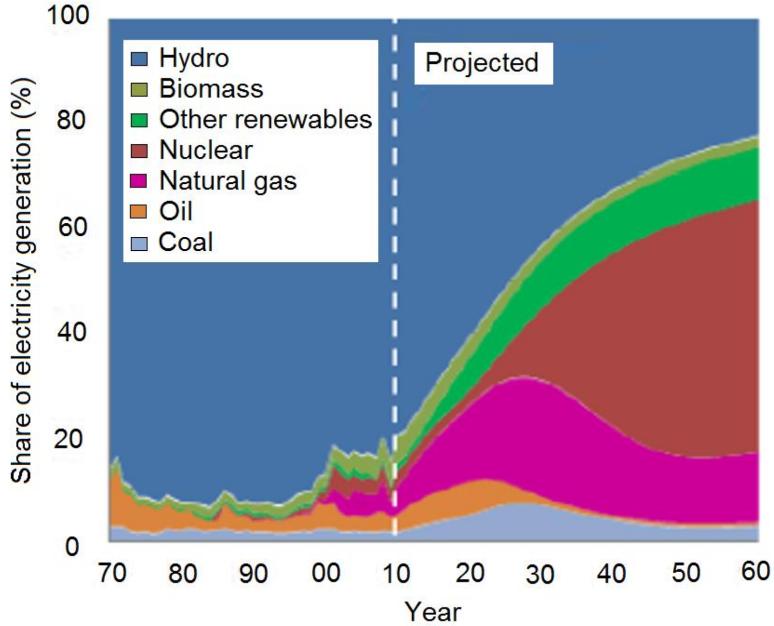

Figure 5: Projections of share of electricity generation for the developed Brazil scenario [5].

Table 4: FGV scenarios for electricity projection up to 2040 [6].

	Market Control	**Economic Rationality**	**Institutional Advancement**
Gross national product growth (%/year)	4 % (short-term) 3 % (long-term)	2.5 % (short-term) 4 % (long-term)	2.5 % (short-term) 5 % (long-term)
Electricity demand	small growth in energy demand and reduced consumption in the industrial sector	intermediate demand growth requiring increasing the installed capacity and consumption (kWh/hab)	large demand growth and expansion of private investments

Figs 6, 7 and 8 present some of the results. Considering all scenarios the minimum and maximum electricity consumption in 2040 are 1259 and 1522 TWh. For the competition regime and market control conditions the electricity matrix would diversify less, keeping a share of hydropower generation as high as 57 % as shown in Fig. 6. In this scenario, the next important source would be natural gas with 17 % and nuclear power with 8 % share of the total electricity generated. For larger diversification of the electricity matrix, the best scenario would be competition regime and institutional advancement shown in Fig. 7. In this scenario, the hydropower share of the total generation would decrease to 47 % followed by nuclear power and natural gas with 15 % each [6].

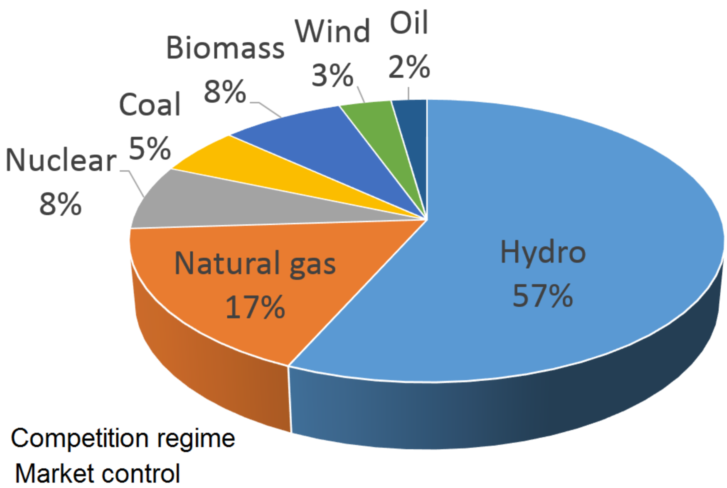

Figure 6: Electricity generation matrix in 2040 for the competition regime and market control conditions. Total electricity generated is 1278 TWh [6].

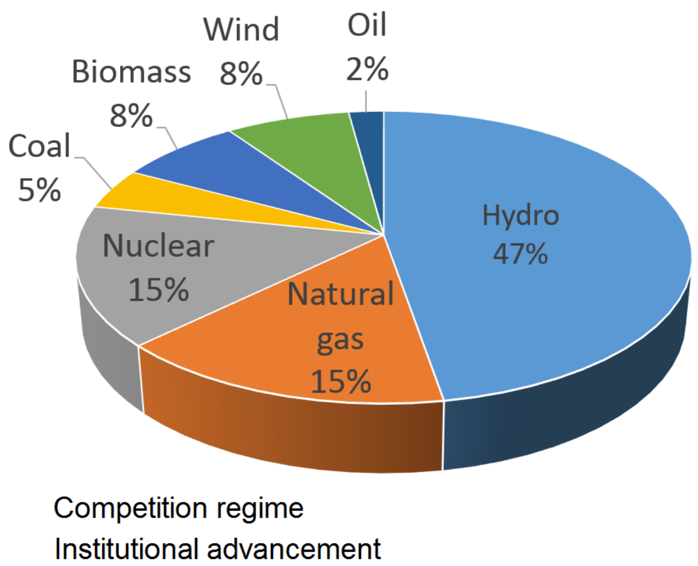

Figure 7: Electricity generation matrix in 2040 for the competition regime and institutional advancement. Total electricity generated is 1473 TWh [6].

Fig. 8 presents the levelized cost of electricity per MWh for each source considering the scenarios of Table 9. The maximum and minimum values for each generation source are presented. Hydropower, natural gas and coal present the lowest levelized costs, nuclear, wind and biomass present intermediate values competing with the high values of hydropower, natural gas and coal. Oil presents the highest levelized costs [6].

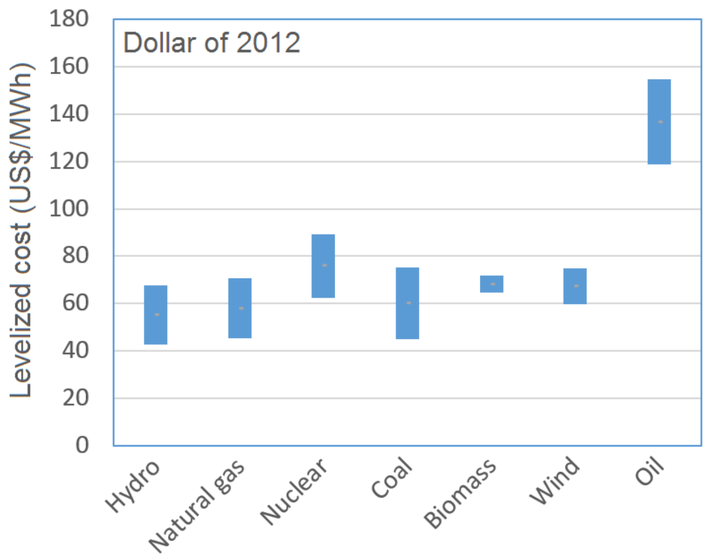

Figure 8: Range of variation for levelized cost of electricity for various sources. according to the several scenarios [6].

For baseload power generation, natural gas and coal power plants present the lowest levelized cost, but coal present large restrictions regarding environmental impacts. Nuclear power appears competitive with high cost natural gas power plants, presents the advantages of low cost fuel, fuel availability in the country, and low environmental impact. The main disadvantage is related to the negative views of the public regarding nuclear power.

4. CONCLUSIONS

Brazil has a mixed electricity matrix with an important share of renewables (hydropower), and important reserves of non-renewable resources such as uranium and natural gas. The matrix present increasing diversification with wind power and natural gas electricity generation. We observe that hydropower is still the main resource but with declining importance in the medium- and long-terms. The current share of hydropower electricity generation of 71 % should decrease to values ranging from 57 % to 47 %, according to different scenarios.

Nuclear power currently presents a low contribution for the electricity with ~ 2000 MW of installed capacity. A third power plant, Angra 3, is under construction. Recently the federal government approved actions for site selection for at least more two new nuclear power plants with capacity around 1000 MW, The first studies indicate that a possible location is in the São Francisco basin in the Northeast region. Due to the Fukushima accident, the public opinion and government officials still debate about construction of new nuclear power plants in the country.

In the short term, most of the important projects have been defined as in 2015. The large projects include hydropower plants (Jirau, Santo Antonio and Belo Monte) and the Angra 3 nuclear power plant. With the completion of Angra 3, the nuclear power capacity in the country will increase to 3412 MW. Beside these large projects, several auctions for power generation have been conducted with increasing presence of wind power, small hydropower plants and biomass power plants.

The FGV study predicted important increase in electricity generation through nuclear. For long-term scenarios (up to 2040), it expects for nuclear power between 6000 MW and 8000 MW of installed capacity. For renewables, it expects mainly wind power, hydropower and biomass power plants. For medium-term scenarios, nuclear power is considered as a viable alternative for baseload electricity generation in Brazil; reduce generation risks during dry seasons, and to facilitate the operation of the whole power generation sector in Brazil.

Nuclear power has a future in Brazil even without taking into account innovations such as fast breeder reactors, Thorium fuel cycles in PWRs, and closed fuel cycles. Technological developments such as electric cars, and utilization of Hydrogen as energy source should increase substantially the electricity demand. In this case, nuclear power presents the advantage of producing large amounts of electricity per plant.

To facilitate investments in nuclear power, the government should alter its present legal framework to allow private firms to build and operate nuclear power plants.

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