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DISCUSSSIONS AND PROJECTIONS ABOUT THE FUTURE DEMAND FOR NUCLEAR POWER IN BRAZIL

Dr. Fábio Branco Vaz de Oliveira [1] e Dr. Kengo Imakuma [2]

[1] Nuclear and Engineering Center – CEN
Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN – SP)
Avenida Prof. Lineu Prestes, 2242, Cidade Universitária, São Paulo – SP
CEP 05508-900
fabio@ipen.br

[2] Information Technology Development Department - GDP
Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN – SP)
Avenida Prof. Lineu Prestes, 2242, Cidade Universitária, São Paulo – SP
CEP 05508-900
kimakuma@ipen.br

ABSTRACT

This paper aims mainly to discuss the current scenarios of power consumption, nuclear power and conventional and uranium resources and, based on that, present projections about the future demand for power generated through atomic fissions in Brazil, showing that there may be differences in estimates of future projections, depending on the indexes considered: global or domestic. The time horizon for the analysis was studied up to the maximum for the national population, for some of the world and Brazil´s governmental data in terms of population growth, energy consumption and energy consumption per capita. To introduce the importance of the methodology adopted, data and some problems presented about the current world energy and Brazilian scenarios are discussed. Calculations show that the power consumption projections for Brazil**,** when using global indexes, are very high. According to our methodology, power consumption in Brazil is nearly 4.5 times below the estimates presented by the global indexes. The conclusion is that applying global indexes and their extension to domestic scenarios lead to errors of orders of magnitudes, due to the specific particularities of each country, and must be avoided if accurate projections about energy and nuclear scenarios must be considered.

1. INTRODUCTION

Construction of new nuclear power plants is always a subject for debates and speculation. This impacts forecasts of energetic resources consumptions and, therefore, on the uranium resources and their use as energetic source in the future.

However, the shortage of energy resources, mainly those derived from traditional sources such as oil, coal and water; their growing consumption together with the global warming phenomena due to the emission of greenhouse gases, are problems that currently affect us.

For example, climate changes are responsible for the recent formation of tornadoes in the coast of Santa Catarina, the excessive melting of ice caps, etc., which are currently phenomena, but also can be foreshadows of a near future large scale global manifestations of uncontrolled climate changes. Due to the population growth and increasing gap between economical and social classes, it is clear that there is a pressure over all nations to force them to better plan their future, in terms of their real needs of economical and population growth and, mainly, considering what their energy matrix currently provides for their own growing perspectives. Today, alternative sources of energy and probably the nuclear energy, which represents 17% of the total electricity generated in the world, and about 5.43% of the total world energy consumption [1], could be logical candidates to lessen the probability world energy crisis, by increasing its participation in international and national scenarios.

The present work projects the potential need for energy in Brazil in terms of consumption, based on domestic scenarios and data, and using global scenarios [1] for comparison purposes, emphasizing the current nuclear power scenario in our country. After a brief discussion about some advantages and disadvantages of the construction of new nuclear power plants, nuclear power will be contextualized in the current scenario of supply and demand for power in the world.

To show the importance of adopting of domestic scenarios in the projections, graphics are given to show the evolution and compare global and domestic parameters such as population growth, power consumption per capita and total power consumption in some countries.

2. NUCLEAR POWER IN THE GLOBAL AND NATIONAL SCENARIOS

The earthquake followed by tsunami, which damaged the unities I to IV of the Fukushima nuclear central, in Japan, raised some questions regarding the security criteria used in the design of nuclear power plants, mainly in situations of natural catastrophes. The repercussion of the accident made the United States review the current security criteria for the construction of 22 new nuclear power plants in the country. These reactors are based on the AP1000 technology, and are innovative and intrinsically safe.

In spite of having this as its main idea in terms of security, several experts are questioning the AP1000 project, according to Piore [2]. The main reason is that the security factors for the pressure vessel's project is undersized, to avoid excessive costs. Nonetheless, United States is planning to extend the life of their current reactors, and start the construction of 22 new units. The AP1000 reactors use light water as coolant and moderator, and reach a maximum power of 100MW to 300MW. They are modular, and require the fuels to be replaced every 5 to 8 years, reducing the needs for stops and reloads compared to the current PWR´s needs (1.5 to 2 years, for a typical PWR plant such as Angra dos Reis), and minimize the utilization of repositories for spent fuels.

Other classes of reactors are also being considered, mainly those that enable the extension of the fuel's lifetime (burn up). Globally speaking, 70% of the nuclear power reactors are LWR, which uses ordinary water as moderator and refrigerator. However, the total amount of fuel burned by this kind of reactors is approximately 1% of the total amount loaded at the start of an operational cycle. But this technology has in itself the need to store a large amount of material outside the reactors, which could be used to generate more power once it is inside reactor. Thus, reactors called breeders are being studied, enabling a 60% improvement in fuel utilization. However, several conception details are being taken into consideration regarding efficiency and security, due to the fact that liquid sodium as a refrigerator must be completely isolated from the water in the moderator lines, from the environment and from the steam generator lines, due to the risk of explosion [3].

Those are issues that testify against the use of such technology, instead of the more secure, albeit older, PWR. According to the World Nuclear Association data [4] for the reactors under construction or almost under construction today, most of these reactors still apply old technologies, relegating innovative designs.

Table 01- Nuclear reactors under construction or “almost so”, by design [4].

Reactor design	Quantity
Fast Breeder Reactor	02
Pressurized Water Reactor	61 (China = 30)
Pressurized Heavy Water Reactor	11
Advanced Boiling Water Reactor	08
High Temperature Gas Reactor	01
Total	84

However, despite of the above controversies, to replace the traditional sources of energy by the nuclear, mainly by countries detaining the technology to the design and construction of nuclear power plants, are being considered as the most convenient option.

It is important to observe also that in the long term, in addition to the current 441, more 338 nuclear reactors are planned to be constructed [4], four in our country. On June 1st, 2010, Brazil restarts the construction of the Angra III nuclear power reactor; together with the planned four, our supply of nuclear power will increase in 5,300MW. China, Russia, United States ad Ukraine are planning to build, respectively, 115, 40, 30, 28 and 20 more nuclear power reactors, a total of 223, China with more than one third of the total demand. For the next years, according to the data of the World Nuclear Association [4], electricity generation by atomic fissions will double.

3. THE URANIUM SCENARIO

To see how uranium resources can provide a short term solution to face a possible energy supply crisis, it is convenient to compare the world’s uranium reserves capabilities with those of oil and coal, the most used natural resources in the world.

Generating the current 375GWe (the corresponding electricity generated by nuclear fissions), requires 68,000t of uranium per year. According to Table 02 [5], and ignoring the so called secondary sources of uranium (uranium from nuclear weapons, reprocessing, etc.), if the total estimated amount of uranium metal is 5.5Mt, at the above rate of consumption the uranium reserves will last 80.8 years.

In terms of oil, based on the current consumption rate, 82×10^6 barrels / day, and considering it as constant, a non-realistic hypothesis, its length can be calculated in almost 41 years. United States is the planet’s largest consumer of this resource, with approximately 19×10^6

barrels/day, nearly 25% of the world's consumption, and Brazil appears in seventh place, $2.5x10^6$ barrels/day. Regarding coal, China is in the first place, with $1.31x10^9$ tons/year, followed by the United States, with $1.06x10^9$ tons/year, and together account for 50% of the world´s total consumption, and also for the corresponding greenhouse gas emissions. Brazil appears in 19th place, with $2.3x10^7$ tons/year, almost twice orders of magnitude less than the previous two [6]. In terms of proved coal reserves, considering that there are around 522 billion tons, the current consumption rate of $4.59x10^9$ tons/day [6], and supposing that rate remains constant for the following years, we can estimate the reserves will last 113 years.

In both cases, uranium can be seen as the readiest resource for their possible replacement. For example, as previously mentioned, primary resources of uranium will end, at the current consumption rate, in about 80 years, in the mean value, accounted for the world, not for a particular country figure.

For Brazil, with the growth scenarios for our nuclear matrix estimated by [7], from the current 1.95GW to 3.5 up to 7GW, our reserves will last 120 to 240 years (reserves of uranium considered at a total cost of less than US$ 130 / kg, the criteria for an economical exploration of an uranium mine) and from 200 to 400 years, taking into account also the inferred reserves. A safer estimate, which predicts a maximum percentage of the total electricity generated by the Brazilian nuclear matrix of 5.7%, excluding the estimated by INB [8] inferred reserves of 800,000 tons, the duration of our uranium resources is, in the worst scenario, about 90 years. Taking into account these reserves, together with the 279,000 ton of uranium metal, the estimates are for the operation of 10 nuclear reactors like Angra, for 200 years [9]. The problem is that most of the uranium in the inferred reserves comes from phosphates, and the technique for uranium extraction from phosphates is still uneconomical. The same problem in terms of the costs / economy of extraction is presented with the uranium obtained from sea water, whose amount is estimated in 3.3 ppb [1].

Thorium is another source of fissionable isotope, U^{233}, and thorium reserves are estimated to be 3 times higher than uranium´s. According to Ashley [10], the amount estimated of thorium as a by-product of rare earth processing would be enough to feed 200 nuclear ADTR ("Advanced Thorium Reactor"), without the need to open new mines for exploration and extraction, thus with no initial investments. The other advantages of thorium compared to uranium are its total usage as nuclear fuel as extracted from the mines, instead of the 0,7% relating to the fissile isotope U^{235}, present in an U^{238} matrix. It means that for each 1GW of electric produced only 1 ton of mined thorium is necessary, whereas 200 tons of uranium from the mines or 3.5Mt of coal would be required to produce the same amount of electricity.

Although there are still doubts about the real need for the construction of new nuclear power plants in Brazil, the debate is still open, and the numbers shown in the tables and the scenarios presented above are favorable. Considering the capabilities of the Brazilian nuclear reserves, in the next item we describe some possible scenarios for its utilization in relation to two parameters, among the huge numbers of variables that usually affect a more complete analysis, population growth and energy consumption.

The scenarios for the national analysis were taken from the Plano Nuclear Brasileiro (Brazilian Nuclear Plan 2030) [11], from EPE and Eletronuclear, which are now searching for possible locations for the four planned reactors. A comparison will be made with methodologies found in recent literature [1].

Table 2 – Known recoverable resources of uranium (Reasonably Assured Resources plus Inferred Resources, at US$ 130/kg U, 1/1/09, from OECD NEA & IAEA, *Uranium 2009: Resources, Production and Demand* ("CIA Red Book")).

Country	Tons of uranium	% of world
Australia	1673000	31.0
Kazakhstan	651000	12.0
Canada	485000	9.0
Russian Federation	480000	9.0
South Africa	295000	5.5
Namibia	284000	5.0
Brazil	279000	5.0
Niger	272000	5.0
United States	207000	4.0
China	171000	3.0
Jordan	112000	2.0
Uzbekistan	111000	2.0
Ukraine	105000	2.0
India	80000	1.5
Mongolia	49000	1.0
Other countries	150000	3.0
World total	5404000	100%

4. PROJECTIONS

Since population and the energy consumption growths are the most significant parameters to pressure energy demand, the projections for the Brazilian population growth, presented by the data of IBGE [12] in Figure 1, are firstly analyzed before the estimates of energy needs. Other sources for population growth projections are available, like the CIA fact book [13]. According to IBGE, the maximum in Brazilian population will occur in 2039 (219,124,700 inhabitants). However, between 2020 and 2030, the limits of the proposed energetic planning horizons [11], our population will have a mean of 212 million inhabitants.

The other parameter, energy consumption growth, will give accurate predictions if analyzed for each country, instead of taking estimates based on global means. To put both parameters together, Iceland has the highest index of energy consumption per capita, but its population is below 5 million people, meaning its contribution to the total world energy consumption is low. Countries with the highest energy consumption per capita are China, the United States, Japan, Russia, India, Canada, South Korea, South Africa, Australia, and the European Union. Taking together population growth and absolute population, these countries are not the first ranked ones (in terms of growth rate, East Timor, with 4.5% / year, is in the first place [13]), but pressure the energy consumption by their high number of inhabitants and also by their high energy consumption per capita. The Brazilian energy consumption per capita can be seen in Figure 2. The consumption per capita for the most populated countries is given in Figure 3, to acquaint for the differences mentioned in the introduction.

In terms of world energy consumption, it is important to observe that European and North America countries have lower population growth rates, but their energy consumption is about

1 order of magnitude higher than the mean world energy consumption. This is shown in Figures 4 and 5.

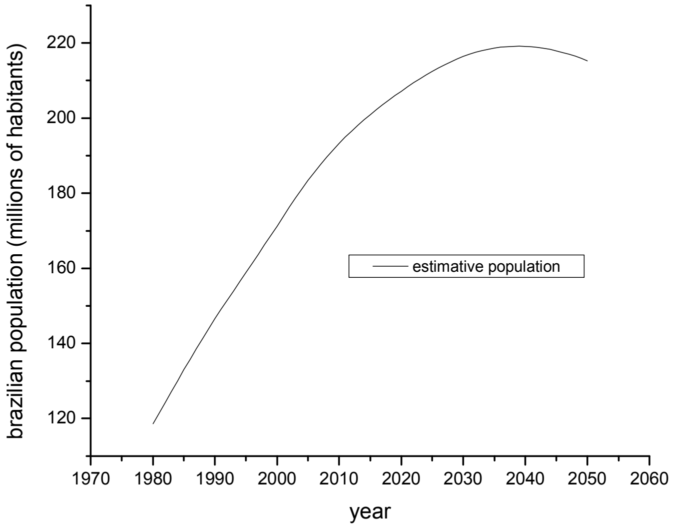

Figure 1 – Brazilian population growth projection, up to 2050[7].

In terms of projections, in a recent paper from Tomabechi [1], it was estimated that when the world population reaches $\mathbf{N_{hm}}$ = 10 billion inhabitants, around the next 30 to 50 years, according to the current global population growth of 81 million / year, the energy needs will be $\mathbf{C_m}$ = 2 ZJ / year (where 1 Z = 10^{21}). This number was defined based on data about the energy resource consumption of developed countries, extended to all the countries of the world. Thus, the mean energy world consumption per inhabitant ("per capita"), $\mathbf{C_{pc}}$, at the time of $\mathbf{N_{hm}}$, would be:

$$\mathbf{C_{pc} = C_m / N_{hm}} =$$

$$= [2 \times 10^{21}\ (\text{ZJ / year}) / 10^{10}\ (\text{inhabitants})] = \mathbf{200\ BJ / (inhabitant\ .\ year)} \qquad (1)$$

where BJ = 10^9J = billion Joules, in an unrealistic scenario which predicts equality for the future energy consumption and, thus, for the quality of life of the world's population. It is shown in the following graphs that developed countries are in general the largest energy consumers, and sometimes have the highest rates of energy consumption per capita, just to confirm that global indexes clearly do not represent local realities.

According to the indexes of the table 01 of Tomabechi´s paper [1], to start the projections of $\mathbf{N_{hm}}$, since nuclear power accounts for approximately 5.4% of the total energy consumption in the world [1], the demand for this resource would be:

$$\mathbf{C_{pcnuke}} = 10.8\ \text{BJ / (inhabitant year)} \qquad (1').$$

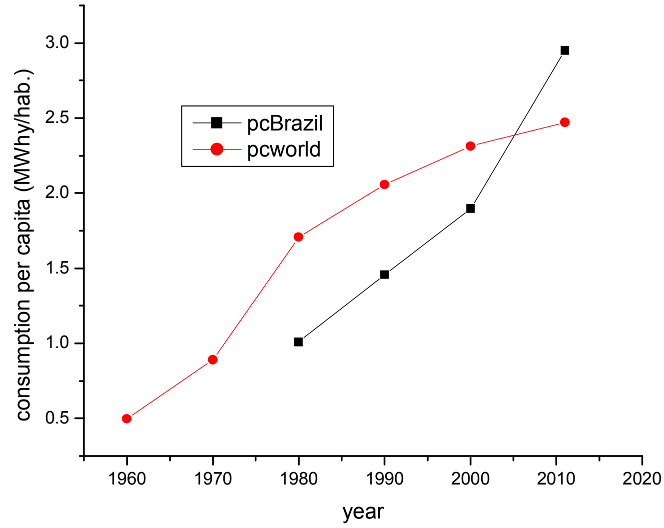

Figure 2 – Consumption per capita, Brazil.

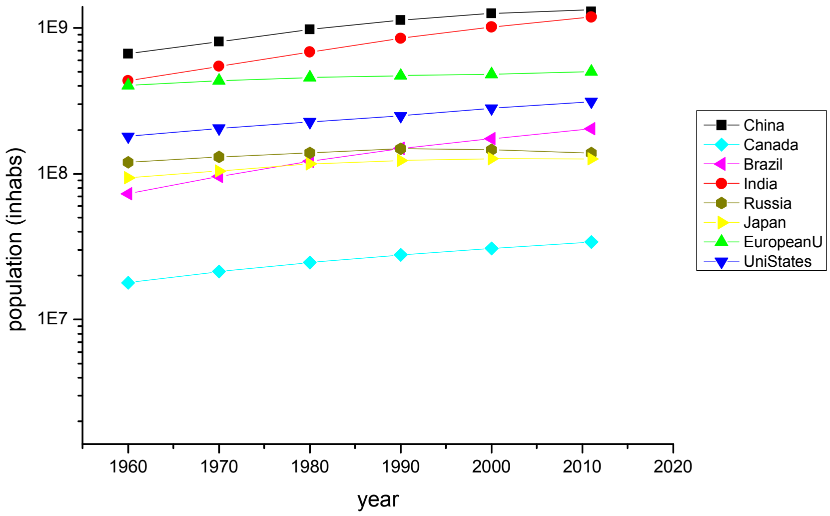

Figure 3 – Population growth of the most populated countries [6].

According to the IBGE [12] data, in 28 years, the Brazilian population $\mathbf{N_{hBr}}$ will reach its maximum at 219 M inhabitants (Figure 1, where 1M = 10^6), at about the same time the world population is estimated to reach $\mathbf{N_{hm}}$. It can be predicted that, taking into account the above hypothesis, the Brazilian energy consumption per year, C_{Br} , will be:

$$\mathbf{C_{Br} = C_{pc} \; . \; N_{hBr}} =$$

$$= 200 \times 10^9 \text{ (J / inhabitant. year) . } 219 \times 10^6 \text{ (inhabitant)} = \mathbf{0.0438 \ ZJ / year} \qquad (2),$$

corresponding to 2,19% of the global energy needs.

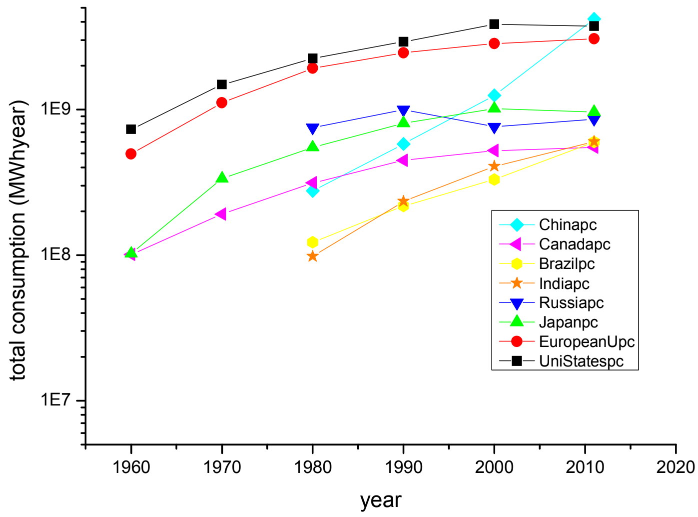

Figure 4 – For the same countries of figure 3, total energy consumption [6].

According to data of the 2005 Brazilian National Energy Balance ("Balanço Energético Nacional 2005") presented in an EPE publication[14], assuming a constant growth rate of 0.67% per year in relation to the total energy consumption, and 0.64% relating to the electricity consumption, some estimates can be carried for the total energy consumption per inhabitant in Brazil, $\mathbf{C_{pcBrtotal}}$.

First, for the total energy consumption, the result is, for 2030:

$$\mathbf{C_{pcBrtotal}} = [9.518\text{x}10^{-3} \text{ (ZJ / year) / 216,010,430 (inhabitants)}] =$$

$$= 44.1 \text{ (BJ / inhabitant year)} \qquad (3)$$

and for 2039:

$$\mathbf{C_{pcBrtotal}} = [1.0175\text{x}10^{-2} \text{ (ZJ / year) / 219,124,700 (inhabitants)}] =$$

$$= 46.4 \text{ BJ / (inhabitant year)} \qquad (4),$$

both results nearly 4.5 times lower than the value of $\mathbf{C_{pc}}$, predicted according to of Tomabechi´s methodology [1], and to the equation (2). This result shows that the differences can be very high if the estimates are taken from global indexes, which are means, justifying the use of domestic indexes for the following estimates.

Thus, taking into account a Brazilian scenario provided by EPE / Eletronuclear [7] about the future participation of the nuclear power in the energy matrix in Brazil, and the INB [8] projections for the Brazilian uranium supplies, its future contribution in the energy needs can be projected, and the result compared to (02).

In the first scenario [7], called the minimum growth, nuclear energy participation, in the national electricity demand, would grow from the current 2.5% (from a current national total of 78GW) to 2.7%. Thus, there will be a need of one more nuclear power station with capacity of 100 to 300MW, and nuclear matrix will growth from 1950MW to a maximum of 3550MW, considering also the construction of Angra III, which started on June 1st of 2010. At a scenario of simple development [7], the participation would be 4.2%, comprising the construction of one more nuclear power station with 1300MW power, (together with Angra III) and two other nuclear power stations of 300MW each, adding 3200MW to the current 1950MW, and making up a total of 5150MW. At a scenario of self-sustained development [7], which is more interesting to assure the future supply of energy for the next generations, an increase of 5.7% would be supported by the construction of two new nuclear power plants with 1300MW power each (together with Angra III), and four more new modular stations with 300MW power each. The electricity generation capacity via nuclear power would grow from the current 1950MW to 6950MW.

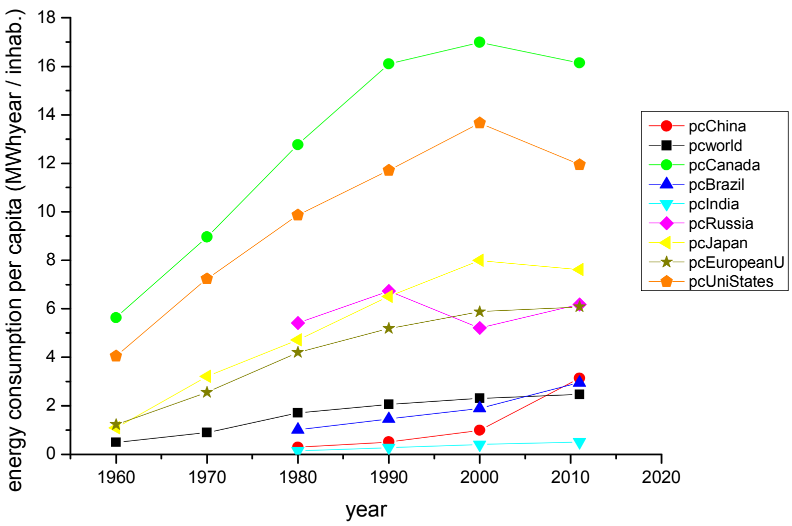

Figure 5 – For the same countries, energy consumption per capita.

Thus, the participation in the energy consumption in Brazil per inhabitant in relation to nuclear energy, can be estimated according to those three scenarios, and the results are shown in Table 3, where MJ is equivalent to millions of joules. Using the assumptions described above for the consumption rates for the total energy and for the energy from electricity, and the values obtained in equations (03) and (04), we can obtain the electricity consumption values projected for 2030 (16,04%) and 2039 (15,88%). Thus, for 2030, the result of the Brazilian projected electricity consumption needs, $\mathbf{C_{pcBrel}}$ would be:

$$\mathbf{C_{pcBrel}} = [9.518\text{x}10^{-3} \text{ (ZJ / year) / 216,010,430 (inhabitants)] x } 0.1604 =$$

$$= 7.07 \text{ (BJ / inhabitant year)} \quad (5)$$

and for 2039:

$$\mathbf{C_{pcBrel}} = [1.0175\text{x}10^{-2} \text{ (ZJ / year) / 219,124,700 (inhabitants)] x } 0.1588 =$$

$$= 7.37 \text{ BJ / (inhabitant year)} \quad (6).$$

Considering the self-sustained scenario, electricity generation via nuclear power in the years of 2030 and 2039 in Brazil would be near of $9x10^{-5}$ ZJ / year, corresponding to approximately 7.1GW of projected power. Since for each installed MW it is necessary 178kg of U_3O_8, it would be necessary 1.02Mt of metal. This amount is very close to the estimated by INB in terms of our uranium resources.

Table 3 – Estimated consumption of electricity generated via nuclear power, per inhabitant per year, according to the scenarios of the PNB 2030 and using the estimates equation (02).

Growth scenarios	2030 [MJ/(inhab.year)]	2040 [MJ/(inhab.year)]
Minimum (2.7%)	190.89	200.34
Development (4.2%)	296.94	311.64
Self-sustainable (5.7%)	402.99	422.94

Percentages are given taking into account the participation in the electricity demand [6]. It can be observed that, according to the predictions of our work, one more nuclear plant will be needed to supply the remaining 200MW power, the difference between ours and the published predictions [7].

5. CONCLUSIONS

Taking into consideration the current indexes for the world electricity consumption, pushed up mainly by the developed and highly industrialized countries, and assuming that they are the same for the developing countries, by the time world´s population reaches 10^{10} inhabitants, the results for Brazil would be 4.5 times higher than the obtained by the data from the national energy balance data.

Thus, for our case as well as for other countries in the world, accurate results can be obtained when the analysis is considered individually for each country. This fact is supported by Figure 5, where the comparison is made with global indexes, for each country.

Result obtained by the methodology adopted in this work agreed with the published in literature [7], the difference are only about 200MW. It is important to note that, according to our estimates, the energy demand (for nuclear, total and electricity) is low compared with Tomabechi [1]. Since 84% of the energy generated in Brazil is from hydropower, and since our water resources are now limited due to considerations of preservation and other environmental aspects [9], to reduce this restraint in terms of space, nuclear expansion in terms of the self-sustained scenario would be helpful.

In the Brazilian case, the recent discovered pre-salt oil deposits offer a possibility of a different solution for a possible energy crisis, when compared, for example, to the United States. Together which China and the European Union, they are responsible for almost 65% of the world´s energy consumption, having also combined factors like large population and large energy consumption per capita. Both factors lead to high levels of emissions and to the fast depletion of the current natural resources.

However, despite the great potential of our reserves of uranium, water, oil, etc., clean energies must be prioritized in the future. For a non-emission source, nuclear is the most available candidate, even with the use of old technologies, such as PWR.

7. REFERENCES

1. Tomabechi, K., Energy Resources in the Future, ***energies***, 2010, v.3, pp.686-695.

2. Piore, A., Planejando o Cisne Negro, ***Scientific American Brasil***, Especial Energia Nuclear, Junho 2011, pp. 07-11.

3. Cochran, T.B., Feiveson, H.A., Mian, Z., Ramana, M.V., Schneider, M., von Hippel, F.N., It´s time to give up on breeder reactors, ***Bulletin of Atomic Scientists***, 2010, pp. 50-56.

4. World Nuclear Association, WNA, current status in June / 14 / 2011, at http://www.world-nuclear.org/info/reactors.html.

5. Kidd, S., Uranium Supply for the Nuclear Future, ***Energy and Environment***, v.22, no. 1 and 2, 2011, pp.61-66.

6. Data to graphics and tables extracted from http://www.nationmaster.com.

7. Boletim da Empresa de Pesquisa Energética EPE nº. 20080512-7, ***Geração Termonuclear***, Ministério de Minas e Energia, Secretaria de Planejamento Estratégico, Maio de 2008.

8. Data and more information available at http://www.inb.gov.br.

9. Gonçalves, O.D., Brasil Ainda Hesita na Área Nuclear, ***Scientific American Brasil***, Especial Energia Nuclear, Junho 2011, pp. 35-39.

10. Ashley, V., ET AL., The Commercially Viable ADTR™ Power Station, ***Nuclear Future***, vol.7, issue 3, pp.41-45, 2010.

11. Data presented at www.epe.gov.br/PNE/20070625_09.pdf.

12. Séries Estatísticas do Instituto Brasileiro de Geografia e Estatística (IBGE), em http://www.ibge.gov.br/series_estatisticas/exibedados.php?idnivel=BR&idserie=POP300 .

13. Data available at http://www.cia.gov/library/publications/the-world-factbook.

14. Boletim da Empresa de Pesquisa Energética EPE nº. 20080512-1, ***Análise Retrospectiva***, Ministério de Minas e Energia, Secretaria de Planejamento Estratégico, Maio de 2008.