2017 International Nuclear Atlantic Conference - INAC
2017 Belo Horizonte, MG, Brazil, October 22-27, 2017
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6
9 788599 141076

COMPARISON OF THE PERFORMANCE, ADVANTAGES AND DISADVANTAGES OF NUCLEAR POWER GENERATION COMPARED TO OTHER CLEAN SOURCES OF ELECTRICITY

Jônatas F. C. da Mata[1], Amir Z. Mesquita[2] and Rieder O. Neto [3]

[1]Universidade do Estado de Minas Gerais (UEMG) – Campus João Monlevade
Avenida Brasília, nº 1.304, Bairro Baú
35.930–314 João Monlevade, MG
jonatasfmata@yahoo.com.br

[2] Centro de Desenvolvimento da Tecnologia Nuclear (CDTN / CNEN – MG)
Av. Presidente Antônio Carlos, 6.627
31270-901 Belo Horizonte, MG
amir@cdtn.br

[3]Universidade do Estado de Minas Gerais (UEMG) – Campus João Monlevade
Avenida Brasília, nº 1.304, Bairro Baú
35.930–314 João Monlevade, MG
rieder.neto@gmail.com

ABSTRACT

Nowadays, there is an increase in the demand for electricity in emerging countries, such as India, China and Brazil. There are several alternatives to increase energy generation, and each country has followed certain strategies to achieve this goal. For a long time, developed countries, such as the United States, the United Kingdom and Germany, had focused their efforts on the use of thermoelectric generators through the combustion of non-renewable sources such as coal, natural gas and oil. These examples were followed, also, by the emerging countries. However, pollution levels, generated by these sources, have required the breakdown of this paradigm, and the consequent reversal of large investments in clean energy sources, such as hydraulics, solar and wind. Nucleo-electric energy is also considered a clean energy source, since it does not generate polluting gases during the processing of concentrated uranium in nuclear reactors. In addition, all radioactive waste occupying relatively small volumes and being stored in controlled deposits, in aspects of health, environment and safety. The objective of this article is to compare the performance, in economic, environmental and safety aspects, of nuclear power in relation to renewable energy sources. The results show that nuclear energy has become increasingly competitive in all these fields, justifying the growth of investments in new nuclear technologies. Therefore, the coexistence between the use of clean sources of electricity and the thermonuclear matrix will bring, for humanity, truly sustainable systems of energy generation.

1. INTRODUCTION

Since the advent of the Industrial Revolution, in the eighteenth century, until to the present day, there has been a massive use of energy generation through the combustion of non-renewable sources. The main inputs used in this period were mineral coal, oil and natural gas. This movement has brought remarkable advances in humanity's technology, comfort and quality of life. However, several scientific studies have demonstrated increasing environmental damage caused by the use of fossil fuels, such as: a) soil, air and water

pollution; b) greenhouse effect, characterized by the increase of the average temperature of the terrestrial atmosphere; c) respiratory problems for people around industries and reactors; d) abrupt reduction, in the medium and long term, of the reserves of these raw materials. Therefore, there was a need to reformulate investments in clean sources of energy, such as solar, wind and hydroelectric. Nuclear power can also be included as a non-polluting and safe matrix, so this is an interesting way of sustainable energy source [1].

Despite the notable growth in world consumption of electricity, there is a high concentration of consumption in a few developed countries. According to data for 2013, about 1.1 billion people lived without electricity. This energy access deficit is concentrated predominantly in southern and eastern Asia, as well as sub-Saharan Africa. This is reflected in precarious living conditions for its inhabitants, in addition to the blatant economic backwardness of these countries. A comparative analysis between the per capita consumption of electricity and the percentage participation of the world population brings impressive data, such as the fact that 50% of the population consumes less than 60 gigajoules (GJ) per capita (Fig. 1). In addition, an American citizen consumed five times more energy, annually, than a Brazilian citzen, and eleven times more than an Indian [2].

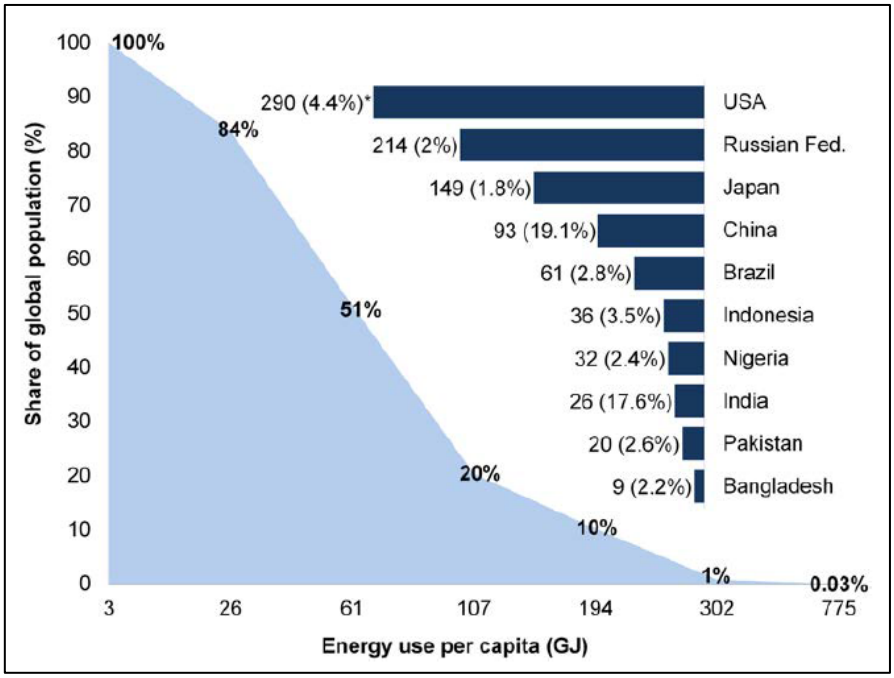

Figure 1: Comparison between the share of global population (%) and the Energy use per capita (GJ).

Therefore, it is necessary to increase the generation of electric energy, in order to reduce the inequalities of supply and, in this way, to enable the economic and social development of the less favored nations. In the meantime, clean energy sources such as hydropower, wind, solar and nuclear should be favored. In the next topics, the advantages and disadvantages of each of these types will be explained, as well as a brief comparison of their performance.

2. HYDRO ELETRICITY

Hydroelectric power is an important type of renewable energy. It comes from the potential energy of rivers, stored in extensive dams. It provides large amounts of power with stability and reliability over time, unlike wind and solar. The countries with the largest installed power plants are: China, with Three Gorges (22.5 GWe) and Xilodu (13.9 GWe); and Brazil, with the Itaipu plant (14 GWe). By 2015, this source accounted for 16% of the world's electricity. It can be seen the great dependence of this type of energy in the following countries: Norway (99% of the country's consumption), Canada (58%), Switzerland (55%) and Sweden (45%) [3].

Another advantage of hydropower is that its turbines can be switched off and reconnected in relatively small times, reaching full power in just ten minutes. However, some disadvantages must be considered: a) it needs storage of water in large reservoirs, which normally causes severe environmental damage to surrounding ecosystems; b) new projects, as required by environmental agencies, have been built with less bulky reservoirs, leading to a reduction in installed capacity; c) in the dry period, the volume of rivers is considerably reduced, leading to the need for rationing of the energy supplied and, therefore, damages to industrial and domestic consumption [3].

3. WIND ENERGY

Wind energy has undergone a remarkable expansion, accounting for annual increases of about 20% in the last 5 years. In the new investments, China's relevant leadership has been noted. In 2016, the world installed capacity in wind energy was 486 GWe, with tens of thousands of turbines installed [3].

However, actual generation capacity is compromised by low system utilization (20 to 30%) and intermittent turbine operation. It is known that, according to Betz's law, any open-flow fluid, such as air, can recover a maximum of 59% of the kinetic energy generated. The most efficient wind turbines have reached up to 80% of the limit of Betz's law.

The velocity of the air currents varies according to the time of day, temperature and humidity of the air, latitude of the place and other factors. The power generated is proportional to the wind speed cube, so doubling the speed generates eight times more power. During the operation, the turbines need speeds between 4 and 25 meters per second, obtaining the ideal working power between 12 and 25 m / s. In regions where hydroelectric systems are installed, coexistence of wind turbines is common. They act as a reinforcement of electricity supply, in addition to complementing the energy demand in periods of drought. The economically viable power of commercial wind turbines is about 2 MWe, usually grouped in wind farms of up to 200 MWe. Most turbines operate about 25% of the load factor over a year, with range exceptions of up to 40% [3].

4. SOLAR ENERGY

Solar energy has been widely used to heat water in residences and, increasingly, for electricity generation through Photovoltaic cells (PV). By 2016, there were 296 GWe of installed capacity, 98% of which was from solar PV [3].

The PV system uses sunlight, incident on plates composed of photovoltaic cells, to produce electricity. Such flat plates have been mounted on buildings or special support structures, and are also used for power supply in signaling and communication systems. Sales of photovoltaic modules have increased significantly as efficiency increases and prices are reduced. An important factor to achieve these gains is the granting of financial subsidies for the development and production of photovoltaic cells.

However, the average cost per unit of electricity is still very high, about ten times the cost due to conventional sources of energy. This limits the growth potential of non-subsidized applications such as supplementary facilities in buildings whose maximum supply matches peak demand. Another difficulty, still present, is the low capacity factor, that is, the ratio between the power supplied and the installed capacity. This parameter is influenced by the level of irradiance obtained, which depends on the relative position of the Sun at each time of the year. In Germany, for example, there were 1.5 million photovoltaic installations in 2015, with a combined capacity of 40 GWe. However, the actual delivery of energy was 38.7 TWh, thus consisting of a capacity factor of 11%. Italy, on the other hand, was sunny in 2015. From an installed capacity of 18.9 GWe, there was a delivery of 22.9 TWh, equivalent to a capacity factor of 13.8% [3].

5. NUCLEAR ENERGY

There are more than 440 nuclear power reactors in operating conditions worldwide, covering 31 user countries. The total capacity exceeds 390 GWe, with about 60 reactors under construction. Together, such nuclear units provide about 11.5% of the world's electricity demand. The main advantages of this type of energy matrix are: a) continuous and reliable load, without oscillations; b) it does not generate emissions of greenhouse gases, such as carbon dioxide; c) the waste generated has negligible volumes and, due to radiation risks, is confined and monitored in a way that does not generate pollution to the environment; d) nuclear power plants occupy much smaller areas compared to hydroelectric plants, wind farms and photovoltaic cells [4].

There are a number of controversial points that have contributed to the mistrust of public opinion regarding nuclear energy: a) high investments in reactor construction and auxiliary facilities, as well as high operational safety costs; b) high severity of nuclear accidents, if they occur, with the possibility of radiation emissions to people and the environment; c) time-consuming and expensive licensing process [1].

Countries such as France, the United States and the United Kingdom, thanks to effective partnerships between regulatory agencies, government executive bodies and private companies, have made great progress in addressing these negative points. The improvement of technological research in advanced, efficient and safe reactors, coupled with transparent and rigorous licensing, regulation and inspection laws, has boosted the nuclear programs of these countries with the acceptance of the population. One of the most

important methodologies in this movement is the Probabilistic Safety Assessment (PSA). This tool consists in the careful evaluation of all risks inherent in the following steps: design; construction; operation; and decommissioning. This methodology quantifies the probability of undesirable events and their consequences. In this way, the management of all activities in nuclear power plants is more comprehensive and reliable, considerably reducing the occurrence of accidents [5].

6. COMPARISON OF HISTORICAL EVOLUTION AND PERFORMANCE

Comparing the capacity of electricity in 2012 and that projected for 2050, there is a tendency to double the electricity generation (Fig. 2). This growth will occur mainly in countries such as China, India, Sub-Saharan Africa and Southeast Asia due to economic and population growth. However, there will still be heavy dependence on the energy generated by the burning of fossil fuels, such as oil, coal and natural gas. Growth in sustainable sources of energy such as wind, hydro, solar and nuclear can be seen, but in amounts not yet significant enough to minimize the sources that generate the greenhouse effect [2]. The medium-term challenge, therefore, is to leverage investments in renewable sources in order to maximize such sources and minimize reliance on electricity generation from fossil fuels.

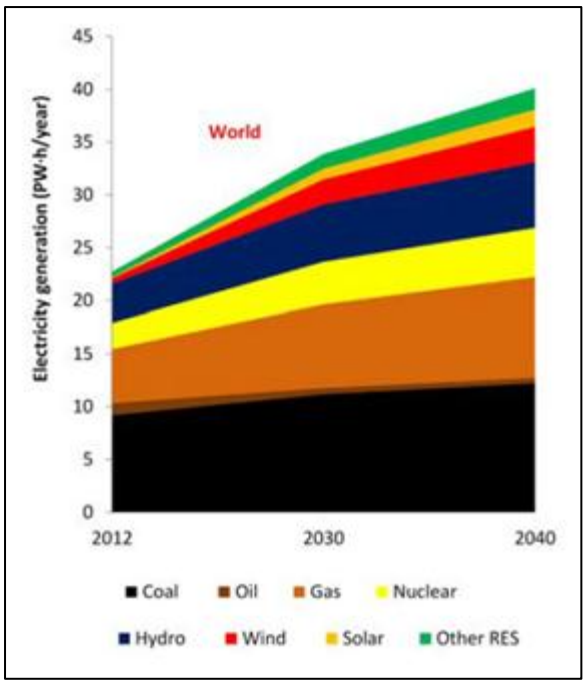

Figure 2: Historical evolution of electricity generation by source - 2012 to 2050.

With respect to the return of capital invested in the facilities required for the generation of energy, a comparative analysis can be carried out between the different sources through the parameter Energy Returned by the Energy Invested (EROEI). This variable measures how much energy is obtained in a given energy production process compared to the amount of energy expended in this process (Figure 3). Some types of energy have a distinct EROEI for situations where energy is not buffered and in cases where such energy is buffered for later use [2].

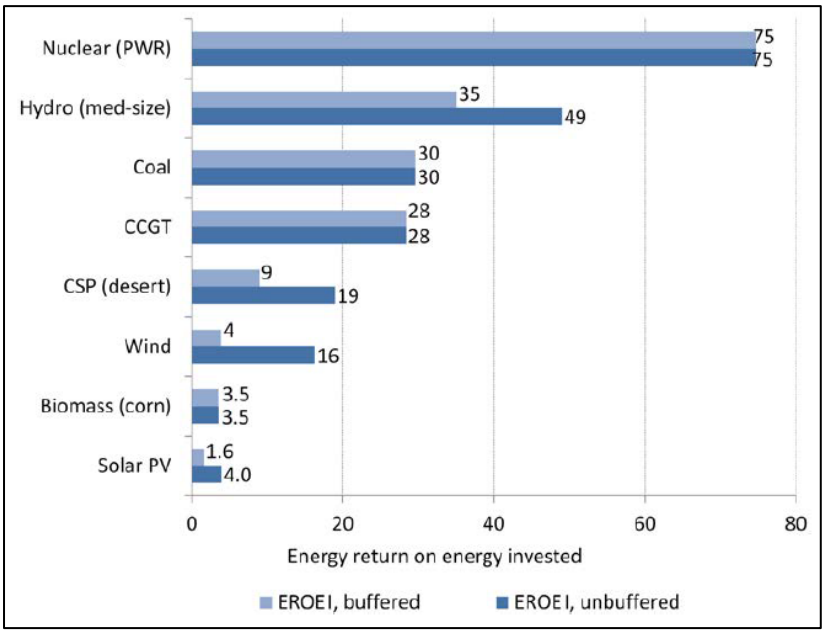

Figure 3: Energy return on energy invested.

It is possible to notice that nuclear energy has a very advantageous EROEI (75), due to its high stability and multiplicative capacity of this type of energy. In a relatively small mass of enriched uranium, it is possible to generate a large amount of thermal energy in the form of steam, which drives the turbines that generate electricity. And that financial return to the nuclear power matrix has increased significantly as the process of enriching uranium by gas diffusion is changed to centrifugal enrichment, which is equivalent to 35 times more efficiency of energy. For nuclear energy, there is not the formation of energy buffer, because the uranium decay occurs at a constant rate.

The second source with the greatest financial return is the hydroelectric power plant, which has an EROEI of 35, considering the real-time transformation of hydroelectric energy into electricity, and 49, considering the energy buffering in the dam, allowing greater stability of electrical power in the face of peak times and falling demand. Thermal energy generated through coal and combined cycle gas turbines (CCGT) performs similarly, and there is not the buffering of energy. Concentrated solar power (CSP) and wind power have a lower performance, which improves considerably considering the mechanisms of buffering of generated energy. Solar Photoelectric Energy (Solar PV) presents the lowest EROEI of the sources studied.

Figure 4 shows a comparison of levelized costs of energy (LCOE) for each source of electricity. In the meantime, three discount rates are considered: 3% (corresponding to the social cost of capital), 7% (corresponding to the market rate in deregulated markets) and 10% (related to expected returns on investment in high risk environments). The higher discount rates are applied to more expensive and higher risk technologies, that is, they need more initial investment. This is the case of nuclear energy, which involves high expenditure on structure and security, but on the other hand has low production costs. It should also be noted that the large cost ranges reflect the large regional differences, influenced by the structure of the market, internal policies and resources [2].

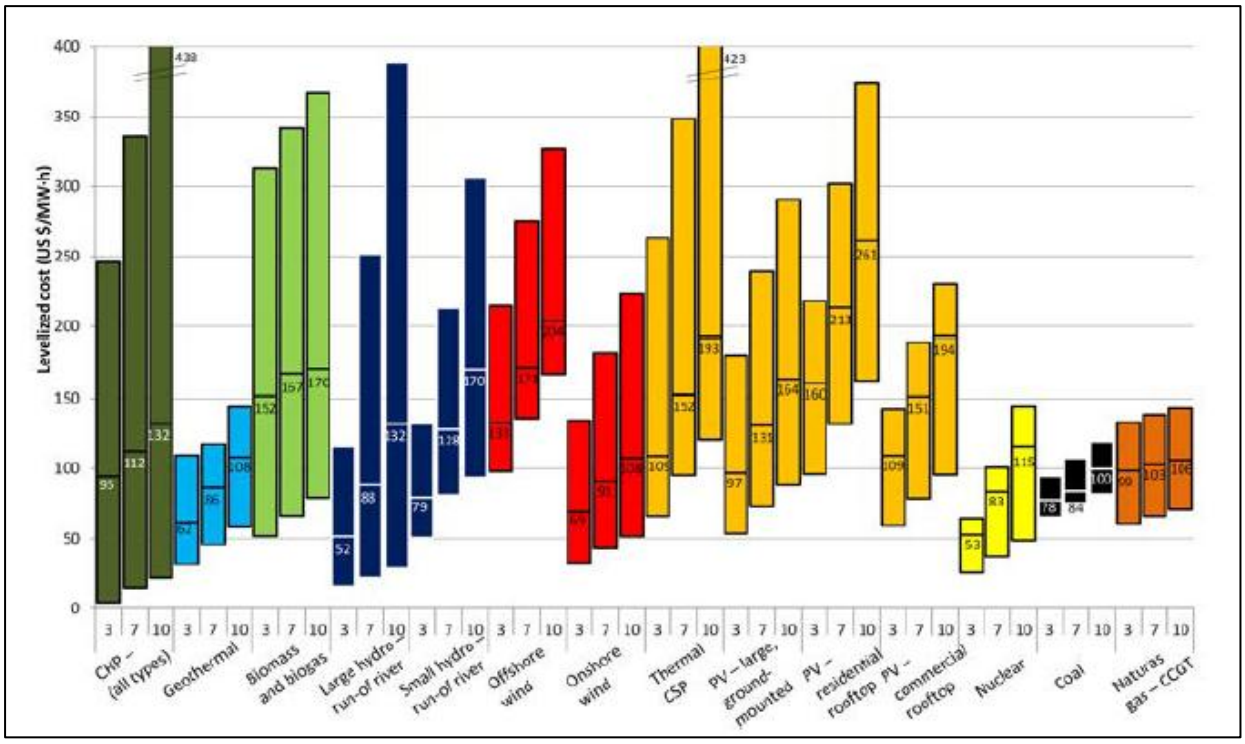

Figure 4: Levelized costs of electricity generation associated with new construction.

7. CONCLUSIONS

It can be seen from the data studied in this paper that there is still a long way to go in order for sustainable energy sources to be able to meet world demand for electricity. Dependence on fossil fuels is a reality that should last for years to come, but this can be mitigated through massive investments in technology improvement and regulation of new projects in the renewable energy sources.

Nuclear energy is very competitive compared to other clean energy sources, in terms of financial returns, generation of large electric power, absence of polluting gases and low operating costs. This type of energy demands high investments in technology and operational safety, as well as in the search of convincing the population that the benefits of nuclear power plants are sustainable.

In the medium term, the planning to be adopted is to work on a mix of clean energy sources. In this way, the potential of wind, solar, hydroelectric and nuclear generation in each region can be harnessed in a balanced way. Thus, the ultimate goal of reducing the use of fossil fuels will be achieved without detriment to people's progress and well-being.

ACKNOWLEDGMENTS

The following institutions supported this work: University of State of Minas Gerais (UEMG), Nuclear Technology Development Center (CDTN), Brazilian Nuclear Energy Commission (CNEN), Research Support Foundation of the State of Minas Gerais (Fapemig) and Brazilian Council for Scientific and Technological Development (CNPq).

REFERENCES

1. B. W. Brook; A. Alonso; D. A. Meneley; J. Misak; T. Blees; J. B. van Erp, "Why nuclear energy is sustainable and has to be part of the energy mix", *ScienceDirect,* **Sustainable Materials and Technologies 1-2,** pp. 8-16, Ed. Elsevier (2014).
2. IAEA – International Atomic Energy Agency, *Nuclear Power and Sustainable Development*; IAEA; Vienna, Austria (2016).
3. "Renewable Energy and Electricity", http://www.world-nuclear.org/information-library/energy-and-the-environment/renewable-energy-and-electricity.aspx (2017).
4. "Nuclear Power in the World Today", http://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx(2017).
5. J. F. C. Mata; V. Vasconcelos; A. Z. Mesquita, "Análise Comparativa da Utilização de Análise Probabilística de Segurança no Licenciamento de Centrais Nucleares em Âmbito Nacional e Mundial", *Terceira Semana de Engenharia Nuclear e Ciências das Radiações - SENCIR 2016,* Universidade Federal de Minas Gerais, Belo Horizonte, 4 a 6 de outubro de 2016, Vol. 1, pp.1-6 (2016).