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# Must Nuclear Energy be Increased on Brazilian Energy Mix in a Post-COVID-19 World?

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## 1. Introduction

Modern civilization is possible because people have learned how to change energy from one form to another and then work. In this context, the energy and energy matrix could understand as measurable and calculable values, which enable the achievement of the most diverse goals of society, facilitating human work, economic growth, and enabling poverty reduction [1] [2].

The energy used daily to meet energy needs (demand), whether of an individual, a city, a country, or the world, using the different types of energy sources available, in different proportions, depending on the case, form what is defined commonly as an energy matrix [1] [3].

To achieve sustainability in energy, human society must face the challenger of initiating a significant transformation of the energy matrix due to the possible catastrophic effects of climate change. Their increasingly perceived consequence leave little time for effective implementation [4].

Alternative clean energy generation technologies, such as solar photovoltaic (PV) and wind, are currently the flagship in implementing energy mix changes, both with a growing percentage on the national energy mix in Brazil. However, these alternatives need further development to reduce the effects of intermittency, increasing the capacity factor to make them truly attractive for replacing the baseload of the national system, which currently relies on hydropower, an alternative highly dependent on climate conditions [5]. Another challenging aspect of solar PV and wind energies is their supply dependence - solar panels and magnets based on rare earth, from producing countries such as China, the United States, and others, are still a problem to be overcome, in addition to its need for large areas for high energy production demanded by cities and agriculture [6].

The COVID-19 pandemic brought a new context in which an economic crisis that, on the one hand, reduced the energy demand for industrial and commercial applications and resulted in the scarcity of global supplies, owing to several factors such as logistics difficulties, reduced manufacturing capabilities and political issues [7].

Amid this challenging context, this paper aims to contribute to the discussion on the convenience and feasibility of increasing nuclear energy participation in the Brazilian energy mix, considering climate change, scarcity of natural resources necessary to base energy generation, mainly hydropower. As also to discuss a possible restart and expansion of the Brazilian nuclear program, at the same time, the population still suffers socio-economic impacts resulting from the COVID-19 pandemic and the pre-pandemic economic crisis.

## 2. Methodology

To answer the question: should nuclear energy increase its participation in the Brazilian energy matrix? The work proposes four analysis axes: environmental factors, economic, safety/legislation and technological aspects, and through bibliographic research in scientific articles published in journals, theses, laws, regulations, and international recommendations. In terms of environmental aspects, the paper argues the emissions of greenhouse gases generated by nuclear energy, considering the technology used here, Uranium-based Generation II and Generation II+, to other energy alternatives if it increases the country's need to achieve the goals of international agreements to reduce $CO_2$ from burning fossil fuels.

Regarding economic aspects, costs of building, operation and decommissioning compare during the life cycle of the different energy sources. In terms of safety and legislation, regulatory regimes are compared mainly in terms of safety and security requirements.

The abundant natural resources deserve special attention, as Brazil has one of the most significant U, Th, and Li minerals reserves. In technological aspects, in addition to knowledge and mastery of the nuclear fuel cycle, considering that its beginning was in the 40s with the pioneers of ORQUIMA, through the interaction of Universities with various institutes from CNEN, the Brazilian Navy and other sectors of industry. Figure 1 shows a flowchart of the study:

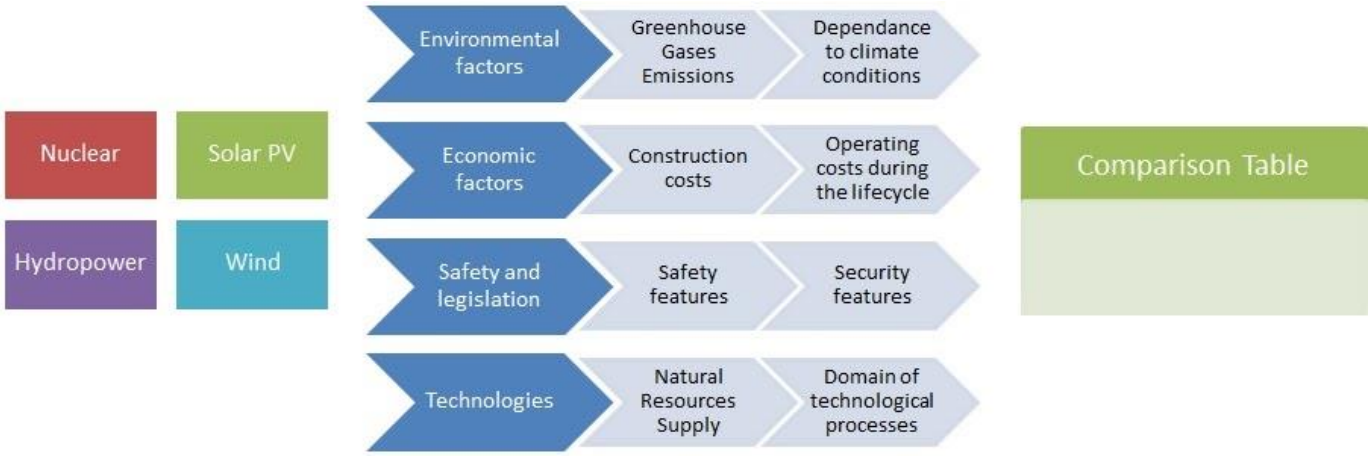


Figure 1. Structure of methodology steps for this study.

## 3. Results and Discussion

The elaboration of the results was based on the studies carried out with Energy Security, climate change, evaluation of modular nuclear reactors and the main associated legislation as follows:

### 3.1 Brazilian energy security

Energy, from the economic interpretation, becomes a good, which in general is poorly distributed, expensive, and subject to price fluctuations. From the oil crisis of the 1970s, this vision made energy become a national security issue, depending on geographic location, amount of natural resources, international relations, political system, economic and ideological arrangements. [8].

This new question added the physical definition of the energy matrix to the evaluation component called energy security, which has numerous definitions, the International Energy Agency (IEA) defines energy security as "*the uninterrupted availability of energy sources at an affordable price*", the Asia-

Pacific Energy Research Centre (APERC) defines it as "*the ability of an economy to ensure the availability of the supply of energy resources in a sustainable and timely manner with the price of energy at a level that will not adversely affect the economic performance of the economy*", there are several others in the literature, but that do not stray too far from these positions [9-11].

Analysing the description and values of the energy matrix in Brazil (Tables 1), in the period 2019 and 2020, and additional information obtained from the National Energy Balance (BEN), we can obtain some data for analysis [6].

Table 1: Total energy supply 2019 – 2020 – Brazil

| Source (Mtep) | 2019 | 2020 | Δ20/19 |
|---|---|---|---|
| **Renewables** | **135,6** | **139,1** | **2,5** |
| Sugarcane biomass | 52,8 | 54,9 | 3,8 |
| Hydraulic Power (1) | 36,4 | 36,2 | -0,6 |
| Vegetable firewood and charcoal | 25,7 | 25,7 | 0,0 |
| Bleach and Other Renewables | 20,7 | 22,2 | 6,8 |
| **Not renovable** | **158,3** | **148,5** | **-6,6** |
| Petroleum and derivatives | 100,9 | 95,2 | -6,0 |
| Natural gas | 35,9 | 33,8 | -6,2 |
| Mineral coal | 15,4 | 14 | -10,0 |
| Uranium (U3O8) | 4,3 | 3,7 | -16,2 |
| Other Non-renewable | 1,8 | 1,7 | -5,9 |

1 - Includes import of electricity from a hydraulic source

### 3.1.1 Brazilian risks in the energy area until 2050

As of 2010, the generation of electric energy through thermoelectric plants stabilizes the supply but creates pressure that raises the costs of the economy. It is essential to highlight that the values of the total electric power generation did not grow due to the recession and the consequent low growth of the Brazilian economy from 2014. However, if we analyse the period until 2050, worrying problems are foreseeable:

i. Brazil will only be able to grow economically if there is an energy supply, in a proactive way, if it increases its energy matrix, more specifically the production of electric energy.

ii. The Brazilian government, through the defunct Secretariat for Strategic Studies (SAE), in the Brazil 2040 Study, was already aware of the risks in the generation of electricity via hydroelectric plants, caused by climate change. Studies showed that depending on the variation in the temperature increase on the planet, certain basins could lose up to 40% of their flow, more catastrophic forecasts pointed to a 70% reduction [12-14].

iii. Studies developed within the scope of Universities and in the IPCC 2021 report corroborate and expand the vision of the forecasts [15-17].

iv. These forecasts also alert to the situation of variation in the rhythms and potentials of the wind system and the level of insolation in different regions of Brazil [18-21]

v. There is also a concern that very heavy rainfall regimes also create problems in controlling the plants.

vi. Thermal plants in Brazil have been showing an operating cost pressure generated by the increase in the cost of gas, resulting from the greater demand for this fuel by developed countries, which seek to reduce the carbon footprint of the electricity used by them, generated originally and preferably, from burning coal, which is extremely polluting.

vii. There is a limitation to the development of energy solutions via thermonuclear plants, as the National Energy Plan 2050 of the Ministry of Mines and Energy in conjunction with the Energy Research Company [22, 23], states: "*However, it should be noted that the time required for licensing and construction of a new plant, the national fuel supply capacity and the scale of the supply industry*

*are factors that end up defining thermonuclear expansion, in addition to Angra complex, at 10 GW in the horizon of the PNE 2050*."

viii. Brazil needs to clearly determine how much and from what sources the country seeks to cover each, energy needs to maintain a compatible growth rate, something like 4% per year (undetermined value, depending on the type of companies), and the amount of energy which will have to be added to the current capacity to compensate for the foreseeable losses in the generation of the current hydroelectric plants (this is talking about something like 80 GWh).

ix. Emphasize that the water storage capacity must grow and be used to maintain the necessities of life (agriculture and livestock, sanitation, and human consumption).

x. Paying attention to the fact that biomass is also directly dependent on water and may suffer reductions in productivity with the increase in the planet's temperature, energy via biomass in Brazil is responsible for 57.9% of the total used of renewable energy.

### 3.2 Environmental Aspects - Climate Change

Data from the Brazilian Panel on Climate Change (a scientific body created by the Ministries of Science and Technology and the Environment) indicate that Brazil could lose around 11 million hectares of arable land due to climate change by 2030. According to estimates in a report of the IPCC released in 2014, the combination of the increase in the average temperature and the scarcity of water resources would considerably reduce the cultivation of food [24]. As there is in Brazil a direct relationship between the water problem and the supply of electricity, due to its percentage of 65.2% in electricity generation by hydroelectricity [25], all issues that affect the economy, due to a reduction in energy supply, must be considered for the Post-COVID-19 world, when it is established that the Brazilian energy matrix must maintain the same percentage of electricity from hydroelectricity.

### 3.3 Energy Solutions for Brazil – Small and Medium Nuclear Reactors

The existence of the domain of uranium and thorium fuel cycle technology in Brazil allows us to realize the importance of small and medium-sized nuclear reactors in meeting energy needs. The International Atomic Energy Agency (IAEA) defines 'small' as less than 300 MWe, and up to around 700 MWe as 'medium' - including many 20th century operating units. Together, they have been called by the IAEA Small and Medium Reactors (SMRs). However, the term "SMR" is commonly used as an acronym for "small modular reactor", designed for construction in series and collectively to comprise a large nuclear power plant. [26,27].

### 3.4 Legal aspects of nuclear safety

About the legal and regulatory aspects of nuclear safety and nuclear physical safety, it should be noted that the peaceful character of the Brazilian nuclear program is expressly guided by the Constitution, which clearly advocates the state monopoly of the nuclear sector and the strictly peaceful purpose of use of nuclear technology in the country, only in the forms authorized by the National Congress [28]. Critical nuclear infrastructure is heavily regulated, with currently 59 nuclear standards and 12 regulatory positions in place [29].

Preliminary results of the study indicate that nuclear energy, despite being less cost-effective when compared to other energy sources, especially in the construction phase of a power reactor, which normally takes a long time and consumes much financial resources, is a true competitive alternative to energy mix, due to the abundance of natural resources, low greenhouse gases emissions, independence to climate conditions and a highly regulated regime in force that assures safety and security of nuclear materials and facilities, as well as the management of nuclear waste.

## 4. Conclusions

From the results obtained from the study, it was possible to draw an optimistic panorama of the future use of nuclear energy in Brazil. The country has several unique characteristics (resources, technology, legislation) that make the sustainable use of nuclear energy possible. This alternative must be seriously considered for the expansion of the national energy matrix.

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## Referencies:

[1] EPE - Empresa de Pesquisa Energética. Matriz Energética e Elétrica. (2021) Available at: < https://www.epe.gov.br/pt/abcdenergia/matriz-energetica-e-eletrica >. Last access on Oct.17th, 2021.

[2] Le, Thai-Ha and Nguyen, C.P. Is energy security a driver for economic growth? Evidence from a global sample. Energy Policy 129 (2019) 436–451. Available at:<https://doi.org/10.1016/j.enpol.2019.02.038>. Last access on Oct. 18th, 2021

[3] LA FONDATION d'entreprise TOTAL. Planête Énergies - What Is the Energy Mix?. last update Jul. 2020. Available at: <https://www.planete-energies.com/en/medias/close/what-energy-mix>. Last access on Oct.17th, 2021.

[4] Intergovernmental Panel on Climate Change. AR6 Synthesis Report: Climate Change 2021. Available at: <https://www.ipcc.ch/report/sixth-assessment-report-cycle/>. Last access on Oct. 19th, 2021

[5] Webinar: Água e Mudanças climáticas: principais impactos na região Sudeste do Brasil e possíveis caminhos para endereçar esse desafio. Available at: <https://ceowatermandate.org/wp-content/uploads/2017/11/Brazil_LN_Presentation_Notes_Portuguese.pdf>. Last access on Oct. 19th, 2021

[6] EPE- Empresa de Pesquisa Energética. Balanço Energético Nacional- Relatório Síntese 2021, ano Base 2020. Available at: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-601/topico-588/BEN_S%C3%ADntese_2020_PT.pdf>. Last access on July 30th, 2021

[7] Vogel, J. et al. Socio-economic conditions for satisfying human needs at low energy use: An international analysis of social provisioning. Global Environmental Change Volume 69, July 2021, 102287. Available at: <https://doi.org/10.1016/j.gloenvcha.2021.102287>.

[8] Paravantis, J.A. et al. A Geopolitical Review of Definitions and Indicators of Energy Security. 2018 9th International Conference on Information Intelligence, Systems and Applications (USA). Available at: < hppts://researchgate.net/publications/330879521 >. Last access on Oct. 19th, 2021.

[9] IEA - International Energy Agency. Energy security. (2019). https://www.iea.org/areas-of-work/ensuring-energy-security

[10] APERC - Asia Pacific Energy Research Centre. A QUEST FOR ENERGY SECURITY IN THE 21st CENTURY. (2007). https://aperc.or.jp/file/2010/9/26/APERC_2007_A_Quest_for_Energy_Security.pdf

[11] Khatib, H. (leader author) et al. Chapter 4 – Energy Security. World Energy Assessment: Energy and the Challenge of Sustainability (UNDP). (2015). https://www.undp.org/publications/world-energy-assessment-energy-and-challenge-sustainability

[12] IPCC – Intergovernmental Panel on Climate Change 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

[13] SAE - Presidência da República – Secretária de Assuntos Estratégicos . BRASIL 2040: RESUMO EXECUTIVO. (2015). http://www.agroicone.com.br/$res/arquivos/pdf/160727143013_BRASIL-2040-Resumo-Executivo.pdf

[14] Jong, P. Barreto, T.B. et al. Estimating the impact of climate change on wind and solar energy in Brazil using a South American regional climate model.

[15] Owusu, P.A., and Sarkodie, S.A. A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Engineering (2016), 3: 1167990. https://doi.org/10.1080/23311916.2016.1167990

[16] Vogel, J. et al. Socio-economic conditions for satisfying human needs at low energy use: An international analysis of social provisioning**.** Global Environmental Change Volume 69, July 2021, 102287. https://doi.org/10.1016/j.gloenvcha.2021.102287.

[17] Dias, V.S. et al. An Overview of Hydropower Reservoirs in Brazil: Current Situation, Future Perspectives and Impacts of Climate Change. Water 2018, 10(5), 592 https://doi.org/10.3390/w10050592

[18] Pryor, S.C., Barthelmie, R.J., Bukovsky, M.S. et al. Climate change impacts on wind power generation. Nat Rev Earth Environ 1, 627–643 (2020). https://doi.org/10.1038/s43017-020-0101-7

[19] Almazroui, M., Ashfaq, M., Islam, M.N. et al. Assessment of CMIP6 Performance and Projected Temperature and Precipitation Changes Over South America. Earth Syst Environ 5, 155–183 (2021). https://doi.org/10.1007/s41748-021-00233-6

[20] Penmetsa, V. and Holbert, K.E. Climate Change Effects on Solar, Wind and Hydro Power Generation. 2019 North American Power Symposium (NAPS), 2019, pp. 1-6. DOI: 10.1109 / NAPS46351.2019.9000213

[21] Solaun, K. and Cerdá, E. Climate change impacts on renewable energy generation. A review of quantitative projections. Renewable and Sustainable Energy Reviews Volume 116, December 2019, 109415. https://doi.org/10.1016/j.rser.2019.109415

[22] MME – Ministério de Minas e Energia e EPE - Empresa de Pesquisa Energética. Plano Nacional de Energia 2050. (2020). https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-227/topico-563/Relatorio%20Final%20do%20PNE%202050.pdf

[23] MME – Ministério de Minas e Energia e EPE - Empresa de Pesquisa Energética. NOTA TÉCNICA PR 04/18 Potencial dos Recursos Energéticos no Horizonte 2050. (2020) https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-227/topico-

416/03.%20Potencial%20de%20Recursos%20Energ%C3%A9ticos%20no%20Horizonte%202050%20(NT%20PR%2004-18).pdf

[24] Guldberg, O.H., Impacts of 1.5°C of Global Warming on Natural and Human Systems -

IPCC, 2019, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Chapter3_Low_Res.pdf

[25] Balanço Energético Nacional- Relatório Síntese 2021, ano Base 2020.EPE, 2021. Acesso em 30/07/21 https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-601/topico-588/BEN_S%C3%ADntese_2020_PT.pdf

[26] IAEA (2020), Advances in Small Modular Reactor Technology Developments, A supplement to: IAEA Advances Reactors Information System (ARIS), 2020 Edition, IAEA, Vienna https://aris.iaea.org/Publications/SMR_Book_2020.pdf.

[27] IEA (2020), Tracking Clean Energy Progress: Nuclear Power, OECD Publishing, Paris,

www.iea.org/reports/nuclear-power.

[28] BRASIL. Constituição da República Federativa do Brasil. Disponível em: <http://www.planalto.gov.br/ccivil_03/constituicao/constituicao.htm>.

[29] CNEN – COMISSÃO NACIONAL DE ENERGIA NUCLEAR. Normas. Disponível em: <http://appasp.cnen.gov.br/seguranca/normas/normas.asp>.