# SMALL MODULAR REACTORS in Brazil:

# A Paradigm Shift in Energy Policy

# for Climate Mitigation

A.R. CARVALHO

Nuclear and Energy Research Institute - IPEN

Sao Paulo, Brazil

Email: amandardcarvalho@usp.br

E.A. RODRIGUES

Environmental Research Institute

Sao Paulo, Brazil

D.A. ANDRADE

Nuclear and Energy Research Institute - IPEN

Sao Paulo, Brazil

J.O.W.V. BUSTILLOS

Nuclear and Energy Research Institute - IPEN

Sao Paulo, Brazil

**Abstract**

Brazil is an important country regarding climate change, both because it is one of the biggest GHG emitters in the world and because it has the means to mitigate these emissions. Brazil has considerable emissions in the energy sector, and power plants that burn either coal or natural gas are increasingly being used to meet energy demand in periods of drought to make up for insufficient hydroelectric production. With the worsening of droughts due to the impacts of climate change, the energy sector is likely to be heavily impacted; in 2023, several regions of Brazil suffered blackouts due to a lack of energy supply. SMRs could represent a viable solution to the problems facing the Brazilian energy sector. The use of a wide variety of energy sources is fundamental to decarbonizing the energy matrix. To decarbonize energy systems efficiently and with the necessary urgency, the sources need to be diversified and climate resilient. When considering the delay and bureaucracy involved in building nuclear power plants in Brazil (the most recent, Angra 3, began construction in 1984 and is still not finished), it’s understandable why Brazilian public policies towards the energy sector have given less importance to nuclear energy. Since their installation is quicker, cheaper, and less bureaucratic, SMRs could be a key to decarbonizing energy production in Brazil, replacing the construction of new coal or natural gas power plants, while being allocated to meet local demands. This study seeks to understand the energy sector in Brazilian and analyze the possibilities for the introduction of SMRs in Brazil.

## INTRODUCTION

Anthropogenic fossil fuel emissions, related to the unsustainable and unequal use of energy and land, have caused the global temperature of the Earth's surface to rise by more than 1 ºC, leading to a wide range of impacts on human societies and the environment. The urgency of implementing mitigation and adaptation measures to reduce these impacts is reinforced by estimates that current emission reduction commitments will not be sufficient to control the temperature increase to below 2 ºC [1].

While the production and use of energy are the biggest sources of greenhouse gas emissions and the cause of global warming worldwide [2-3], electricity generation is one of the main uses of nuclear technology. In a global overview of nuclear energy, 447 nuclear reactors were in operation in 2019, located in 30 countries with a total installed capacity of 398,154 MWe, accounting for 10.4% of the world's electricity production [4]. With COP 28, held in 2023 in Dubai, for the first time nuclear energy was accounted in a significant way by climate stakeholders among the low-carbon technologies that should be used for a quick and deep decarbonization [5], which could mean a future increase in investment in the nuclear energy sector.

Although several countries have demonstrated their intention to reduce their emissions, policies and commitments at the national level differ significantly in terms of scope, specificity and sector. There is a delay in the adoption and development of low GHG emission technologies in developing countries, which is exacerbated in less developed countries [1]. Nuclear energy can also provide solutions to this delay through Small Modular Reactors (SMRs), which are reactors with a power output of less than 300 MW, whose systems and components can be assembled and transported as a unit to the site where they will be used, with a reduction in costs and bureaucracy for their installation compared to ordinary reactors [6].

In Brazil, electricity production is relatively low in CO₂. However, the Brazilian energy matrix is quite carbon intensive. This is because the energy sector includes emissions from freight and passenger transportation - and Brazilian transportation is mostly road-based and fossil fuel-based. In addition, thermoelectric power plants are in increasing use, especially to meet energy demand during periods of drought. In addition, most of Brazil's emissions come from agriculture and LULUCF (Land Use, Land-use Change and Forestry), mainly due to deforestation, fires and the agribusiness. In this context, the aim of this study is to understand Brazilian energy policy and suggest alternatives for the efficient introduction of SMRs in Brazil.

## METHODOLOGY

The development of the study was based on literature reviews, legislation and document analysis. The review was carried out in the scientific databases Web of Science and Scopus. The choice to use them as sources was because of their credibility, interdisciplinary coverage, access to updated and reliable information, and advanced search features, which provide quality and relevance for the information collected for the review. The search aimed to identify publications on the socio-political aspects of SMRs and the role of nuclear technology for climate change.

The results of the search were systematized in a spreadsheet, classified, and analysed. Some were excluded for being duplicated in both databases, for not being relevant for the study or for the full article being unavailable. The 17 resulting articles were subjected to a new complete reading, and technical analysis within the scope of the study.  Additionally, Brazilian legislation and policy, sources accumulated from previous studies, as well as other documents retrieved from the publications available at the IAEA website and the IPCC reports were also analysed.

## RESULTS AND DISCUSSION

The environmental crisis caused by anthropogenic activities threatens the balance of all ecological systems on the planet. Climate change is one of the great challenges of the 21st century; it affects all parts of the planet but, at the same time, has heterogeneous and asymmetrical impacts between regions and socioeconomic groups. Without profound and systemic changes, it is impossible to mitigate the impacts of climate change.

Currently, the largest source of global greenhouse gases (GHG) emissions is the burning of fossil fuels to produce electricity; the energy sector accounts for approximately two thirds of all anthropogenic GHG emissions. Thus, to of reduce GHG emissions it is necessary to replace energy generation from fossil fuels with alternative low-carbon sources such as nuclear, solar and wind. But the reduction in GHG emissions needed to limit the effects of climate change requires considerable investment in decarbonizing the energy sector.

The first commercial nuclear power plants began operating in the decade of 1950. Currently, nuclear power plants are the second largest source of low-carbon energy. More than 50 countries use nuclear energy, but there has been a downward trend in the supply due to the ageing of the installed fleet [4]. This decrease in the use of nuclear energy could lead to delays in meeting climate change targets; to decarbonize energy production efficiently and with the necessary urgency, it is necessary to build diversified and resilient low-carbon energy systems, and nuclear energy is a significant part of these systems, together with other alternative low GHG emission source.

To achieve the mitigation targets, the global electricity production should reach a share of 85% originated from decarbonized sources by 2040. To achieve this, it is estimated that the increase in global nuclear energy production by the same year should be around 80% [4]. Nuclear power is therefore an important low-carbon energy source. Nuclear power plants can also act as low-carbon heat sources for other applications, such as hydrogen production, water desalination and home heating.

Without greater investment in nuclear energy, building a low-carbon energy system will be difficult to achieve and will require a much more significant additional investment. The largest decarbonized energy sources that could replace nuclear energy are wind and solar; and their growth would have to accelerate at unprecedented levels [4]. In the last 20 years, the total growth rate of solar and wind sources has been 580 GW in developed economies, and to make up for the decline in nuclear energy this increase would have to be five times greater. On the other hand, nuclear energy can help reduce the immediate costs of decarbonization and provide greater flexibility for countries' energy systems [4].

Brazil's GHG emissions profile differs from other major emitters [7]. While decarbonizing the energy sector is the biggest challenge for most countries, LULUCF is the most significant sector for Brazilian GHG emissions. Brazil went through a process of reducing the rate of deforestation in the Amazon rainforest between the end of the 2000s and the beginning of the 2010s, which led to a consequent reduction in its GHG emissions in general. However, in the same period, the percentage of emissions from all other sectors increased. This has made emissions from the agricultural and energy sectors even more relevant [8]. Emissions from the energy sector increased by 120.65% between 1990 and 2012, while those from the agricultural sector increased by 46.60% in the same period [7].

Although a large part of Brazil's electricity is produced by decarbonized sources, this percentage has been decreasing for two main reasons: the delay in building new hydroelectric plants, both due to a lack of funding and controversies over their environmental impacts; and the use of run-of-river technology, which requires smaller reservoirs but brings more instability to energy production due to its susceptibility to constant and increasingly frequent periods of drought. Thus, thermoelectric power plants have been introduced as a back-up in the event of insufficient energy production by other means and have been used with increased frequency [7].

Brazil is also a country with great energy inefficiency and high levels of energy waste. In addition, fossil fuels are widely used in a transportation system that is mostly road-based. This system is also highly inefficient, with diesel as the main fuel for cargo transportation. The Brazilian automotive industry, especially with the lobbying of US and European companies, accepts only vague labels regarding the energy efficiency of its vehicles and most of the population only considers the short-term financial costs when buying cars [7].

Although nuclear energy accounted for only 2.5% of Brazilian electricity production in 2017 and 2018, the country's energy scenario and the water crises that have negatively impacted its energy production in recent years show that it is essential for the country's energy security to discuss its energy planning, including all the sources currently used, in depth and over the long term [9-10]. Regarding nuclear energy, Brazil currently has two nuclear power plants in operation (Angra 1 and Angra 2) with a total installed capacity of 1,990 MWe; and one nuclear power plant under construction (Angra 3), with 1,405 MWe of installed capacity [9].

Even though the decarbonized energy sources are intermittent and suffer from seasonal variations with a tendency to worsen, the National Strategic Energy Plan-2050 did not consider the susceptibility of these sources to climate change and doesn’t analyse that role of nuclear power plants in depth [11].

Together with the efforts to extend the licenses for Angra 1 and Angra 2 and the implementation of Angra 3, the installation and operation of SMRs in Brazil could directly reduce the costs of nuclear power generation [12]. In the case of Brazil, another factor besides the costs impacts nuclear sector; the development of nuclear power seems conditioned to a conservative strategy for safety and to the negative opinion of the population regarding nuclear energy in general [13].

More than 80 different designs for SMRs are under development and offer better operational flexibility, economics, safety, as well as a wider range of plant sizes and the ability to meet emerging needs for sustainable energy systems [14-15]. SMRs have characteristics that meet the Brazilian reality, especially due to their wide applicability. However, to be competitive, their expansion requires an evaluation of current Brazilian nuclear policies and regulations, with a view to a new positioning of the national nuclear industry [12].

Considering the sensitivity of the nuclear industry to public opinion, the structuring of well-designed and continuous marketing strategies for the presentation and development of SMR projects and new approaches for the involvement of scientists, companies, regulators and decision-makers are also essential for the implementation of SMRs. Transparency and clear communication with the population, as well as consistent education campaigns regarding the different applications of nuclear technology could be an important strategy for improving public opinion.

Although SMRs constitute a new form of nuclear technology development on a smaller scale and with different costs, location and management requirements, they probably have the same public and stakeholder perception of risk and operational safety associated with larger nuclear facilities [9]. These external factors linked to the acceptance of the local community, impacts on the well-being of the population and historical and political aspects of the project's life cycle are less controllable by investors due to their qualitative and subjective nature, but they strongly influence operations and are capable of strongly affecting the attractiveness of the investment.

The development and maintenance of a highly competent and independent national regulatory system, complemented and supported by a strengthened international nuclear safety regime are also important aspects in determining whether nuclear power can be successfully and safely deployed [14]. However, the literature on SMRs is largely strategic, with important knowledge gaps in relation to social, political and cultural aspects.

According to the Brazilian Federal Constitution [16] the rights to all nuclear energy generation belongs to the Federal Government. This doesn’t exclude other sectors from participating the production of nuclear energy, though, which can be done through concessions or partnerships with the strict supervision of the federal government [17].

The Brazilian nuclear policy is established by the act nº 4.118, from August 27, 1962 [18]. The legislation also establishes the creation of the National Nuclear Energy Commission (Comissão Nacional de Energia Nuclear – CNEN, a federal agency linked to the Ministry of Science, Technology and Innovation. It has administrative and financial autonomy, and its main purpose is to collaborate in the formulation of the National Nuclear Energy Policy; to carry out research, development, promotion and service provision activities in nuclear technology and its applications for peaceful purposes; and to regulate, license, authorize, control and supervise this use [19]. The Brazilian nuclear policy has been updated and changed constantly through the years, with the most recent and comprehensive update occurring on 29 December 2022, with the act nº 14.514 [20].

There isn’t legislation specific for SMRs in Brazil, although a good part of the current legislation is applicable. On the other hand, creating specific, robust and clear legislation for SMRs will allow tackling the challenges and issues that their implementation could create, as well as ensuring that all parties adhere to safety and security measures, while allowing for innovation and for the development of SMRs as a solution for the low-carbon energy issues that are growing in Brazil. The inclusion of the private sector in nuclear energy generation is also a challenge for the implementation of SMRs in Brazil, but there’s precedent in the similarities with the inclusion of the private sector in the mining of uranium through Public-Private Partnerships [19].

According to the Brazilian Association for the Development of Nuclear Activities, legislation for this purpose would need to: establish a clear objective and scope for the partnerships; delimitate the types of activities that could be subject to the partnership; stablish the standards for safety and security; define the specific responsibilities of the state and the private entities in the partnership; create a robust licensing system; create an institution with capability for regulate and monitor the operations; delimitate the decision-making processes and supervision mechanisms for the state; define finance structures allowed; establish transparency mechanisms for energy costs, as well as for all of the stages of the partnership and for the safety and security of the operations; include dispositions for environmental protection, impact evaluations, resources and waste management; promote the development and use of the safest and least impactful technology; ensure consultation and communication with local communities; and establish social and economic benefits for the communities impacted by the facilities [17].

Proponents of SMR technologies should recognize that, in the contemporary environment, community consultation, public education and policy co-production are central elements in both technology production and sustainable transitions and that more work is needed that addresses socio-political, environmental and energy transition issues for this type of energy. The resurgence of the nuclear energy industry, especially with SMRs, has promoted changes in regulatory requirements that open new opportunities while requiring a holistic understanding of plant technology, operations, construction, licensing, public opinion and the political atmosphere [21].

Public and stakeholder opinion on the impacts of energy generation projects appears as an important theme in the literature, especially wind, solar and hydroelectric, but is absent in the literature on SMRs, with evidence of a significant knowledge gap regarding the social, political and cultural impacts of this technology [22]. Without social acceptance, SMR technologies will have great difficulties in becoming a widespread application. Thus, successful implementation of SRMs requires policy development and dissemination and new approaches based on a strong understanding of the social aspects of technological innovation that can potentially accelerate the movement of technologies from the laboratory to the field [21].

## CONCLUSIONS

The analysis of the literature provides a solid basis for future research and public policy development for smt. Its findings highlight that the references on the subject are multidisciplinary in nature but still incipient and range from technical and development issues to environmental, political and management considerations. The evidence shows a significant gap in research that directly investigates socio-cultural and political aspects of SMR. To overcome the challenges of public acceptance, it is essential to promote greater engagement and develop effective communication strategies that highlight the benefits and mitigate the concerns associated with SMRs and nuclear technology, in a holistic approach to technical and social aspects. In addition, international collaboration and continued investment in research are key to the advancement and successful implementation of this promising technology.

For SMRs to become a viable solution for decarbonization and energy security, a coordinated effort is needed to engage the public, educate about the benefits of the technology and develop regulatory policies that support its implementation. New and innovative research also needs to be developed beyond the technical issues of SMRs, addressing the socio-political and cultural issues of SMRs to contribute to the development of more balanced and informed approaches to the implementation strategies for SMR.

The discussion on the implementation of nuclear power plants, which includes the introduction of SMR, highlights the need for specific legislation for SMRs in Brazil's nuclear policies and regulations. Although Brazil has abundant natural resources and a robust nuclear infrastructure, it is essential to review existing policies and regulations to fully exploit the potential of nuclear energy as part of the national energy matrix. Finally, since nuclear energy in Brazil is exclusive to the state, without governmental action and incentive it’s not possible to increase the generation of nuclear energy. With the proper incentive, nuclear energy has a great potential to make a significant contribution to the decarbonization of the energy matrix and to Brazil's energy security.

ACKNOWLEDGEMENTS

The authors would like to thank CAPES for the financial support, and the graduate program in Nuclear Technology from Instituto de Pesquisas Energeticas e Nucleares (IPEN).

References

1. IPCC. “Climate Change 2023: Synthesis Report”, Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva (2023).
2. Mathew, M. D. (2022). Nuclear energy: A pathway towards mitigation of global warming. Progress in Nuclear Energy, 143, 104080. https://doi.org/10.1016/j.pnucene.2021.104080
3. Vujić, J., Bergmann, R. M., Škoda, R., & Miletić, M. (2012). Small modular reactors: Simpler, safer, cheaper?. Energy, 45(1), 288-295. https://doi.org/10.1016/j.energy.2012.01.078
4. ELETRONUCLEAR, 2020, Energia nuclear no mundo,
https://www.eletronuclear.gov.br/Sociedade-e-Meio-Ambiente/Espaco-do-Conhecimento/Paginas/Energia-nuclear-no-mundo.aspx.
5. UNFCCC, 2024. United Nations Convention on Climate Change. https://unfccc.int/.
6. INTERNATIONAL ENERGY AGENCY - IEA. Nuclear Power in a Clean Energy System. International Energy Agency, 2019.
7. VIOLA, Eduardo; BASSO, Larissa. Wandering decarbonization: the BRIC countries as conservative climate powers. Revista Brasileira de Política Internacional, v. 59, 2016.
8. BASSO, Larissa. Brazilian energy-related climate (in) action and the challenge of deep decarbonization. Revista Brasileira de Política Internacional, v. 62, 2019.
9. ESTANISLAU F. B.; COSTA A. L.; VELASQUEZ C. E.; PEREIRA C. Integrated analysis of the Brazilian nuclear energy system. International Journal of Energy Research. V. 45, n. 8, p. 11526-37, 2021.
10. FERRARI, L A, AYOUB J M, TAVARES R L, SILVA A L, SENEDA J A, Must nuclear energy be increased on Brazilian energy mix in a Post-COVID-19 world? Brazilian Journal of Radiation Sciences. V. 10, S. 3A, p. 01-20, 2022.
11. MINISTRY OF MINES AND ENERGY, Plano Nacional de Energia-2050, 2020.
12. SILVA et al., 2021
13. YULING and DONG 2023.
14. MATHEW, M D, 2022, Nuclear energy: A pathway towards mitigation of global warming. Progress in Nuclear Energy, 143, 104080.
15. MICHAELSON, D, JIANG, J, 2021, Review of integration of small modular reactors in renewable energy microgrids, Renewable and Sustainable Energy Reviews, Volume 152, 2021, 111638.
16. BRASIL, Constituição, 1988. Constitution of the Federative Republic of Brazil of 1988, Article 21, item XXIII.
17. BRAZILIAN ASSOCIATION FOR THE DEVELOPMENT OF NUCLEAR ACTIVITIES, Reflexões Sobre A Inserção de SMR no Sistema Elétrico Brasileiro, 2024,
https://abdan.org.br/2024/04/29/reflexoes-sobre-a-insercao-de-smr-no-sistema-eletrico-brasileiro/
18. BRASIL. Lei nº 4.118, August 27, 1962.
19. MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION. Comissão Nacional de Energia Nuclear, Competencias, 2021,

https://www.gov.br/cnen/pt-br/acesso-a-informacao/institucional/competencias

1. BRASIL. Lei nº 14.514, December 29, 2022.
2. BUDNITZ, R. J., ROGNER, H. H., SHIHAB-ELDIN, A. (2018). Expansion of nuclear power technology to new countries–SMRs, safety culture issues, and the need for an improved international safety regime. Energy policy, 119, 535-544.
3. IAKOVLEVA, M., RAYNER, J., COATES, K. (2021). Breaking Out of a Niche: Lessons for SMRs from Sustainability Transitions Studies. Nuclear Technology, 207(9), 1351-1365.