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# Should Brazil invest in Small Modular Reactor?

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**Abstract**: Brazil exhibits a diversified energy matrix, with 88% coming from renewable sources in 2022, prominently hydroelectricity at 64%. However, climatic vulnerability due to dependence on water for electricity generation poses a challenge during periods of low precipitation. Most consumers are integrated into the National Interconnected System (SIN), while isolated systems, especially in the Amazon region, are managed by the National System Operator (ONS). Over 80% of the country's electricity demand is met by the industrial, residential, and commercial sectors. Despite the modest share of nuclear energy in the national electricity grid, Brazil holds the 8th largest global uranium reserves, suggesting significant potential for expanding this low-carbon option. Small Modular Reactors (SMRs) represent a relevant innovation. With capacities of up to 300 MWe per unit, SMRs are designed to be more economical, secure, and require less refueling compared to conventional reactors. Their modular design allows for factory assembly and simplified transport, making them particularly suitable for remote areas, offering a reliable base load energy source. The ability of SMRs to adjust to electricity demand and operate flexibly positions them as a complementary alternative to renewable sources, which are more susceptible to external climate variations.

**Keywords:** Small Modular Reactors (SMRs), low-carbon, energy, isolated systems.

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# Deveria o Brasil investir em Pequenos Reatores Nucleares?

**Resumo**: O Brasil exibe uma matriz elétrica diversificada, com 88% provenientes de fontes renováveis em 2022, destacando-se a hidroeletricidade com 64%. Entretanto, a vulnerabilidade climática devido à dependência hídrica para geração elétrica é um desafio em períodos de baixas precipitações. A maior parte dos consumidores está integrada ao Sistema Interligado Nacional (SIN), enquanto os sistemas isolados, especialmente na região amazônica, são gerenciados pelo Operador Nacional do Sistema Elétrico (ONS). Mais de 80% da demanda elétrica do país é suprida pelos setores industrial, residencial e comercial. Apesar da modesta participação da energia nuclear na matriz elétrica nacional, o Brasil possui a 8ª maior reserva de urânio global, sugerindo um potencial significativo para expansão dessa fonte como uma opção de baixo carbono. Os reatores nucleares modulares (SMRs) representam uma inovação relevante. Com capacidade de até 300 MWe por unidade, os SMRs são projetados para serem mais econômicos, seguros e exigirem menos reabastecimentos em comparação aos reatores convencionais. Sua modularidade possibilita montagem em fábrica e transporte simplificado, sendo particularmente adequado para áreas remotas, oferecendo uma fonte confiável de energia base. A capacidade dos SMRs de se ajustarem à demanda elétrica e operarem de maneira flexível os posiciona como uma alternativa complementar às fontes renováveis, que são mais vulneráveis às variações climáticas externas.

**Palavras-chave:** SMR, baixo carbono, energia, sistema isolado.

## 1. INTRODUCTION

Brazil has one of the most diverse electrical matrices in the world, with the majority being renewable, representing 88% of the matrix and hydro being 64% in 2022 [1]. The importation of electricity is almost exclusively through the bi-national hydroelectric dam of Itaipu [2]. In 2021, 44,8% of energy in Brazil was renewable compared to 14,7% globally, 84,8% of electricity was renewable compared to 28,1% globally [3]. The reliance on water for electricity can represent a risk for the grid in years of low volumes of rain [4].

Most Brazilian energy consumers are connected to the National Integrated System (SIN), which can be seen as a giant energy "highway" that connects a big part of the territory. Those that aren't connected to the SIN have an Isolated System (IS), mostly in the Amazon region [5]. There are 212 ISs and they represent less than 1% of the electricity consumption of Brazil. Most of their energy comes from diesel oil (ONS, 2024). The National Operator of the Electrical System (ONS) [6] is responsible for the coordination and control of the generation and transmission in the SIN and operational planning of the isolated systems.

More than 80% of electricity demand in Brazil is for the industrial, residential, and commercial sector [7]. The diverse electric matrix, generation and demand are in a precarious situation for the National Integrated System (SIN) due to hydrological risk. Climatic risk can negatively affect hydroelectricity production in years of low precipitation. The Generation Scaling Factor (GSF) is the measurement of this risk [8].

The Department of Economic and Social Affairs of The United Nations has a global action plan called Agenda 2023 with 17 Sustainable Development Goals (SDGs) [9] to eradicate poverty and promote human dignity without compromising the life of this and future generations. Among the SDGs, the seventh is related to clean and affordable energy, that is, countries must ensure access to sustainable, reliable, and modern energy sources for the entire population.

The Brazilian nuclear program started after World War 2 with United States president Dwight D. Eisenhower's support, under the "Atoms for Peace" program. In the 70s [10], Brazil made a deal with West Germany to construct nuclear reactors, including the technology transfer to enrich uranium. The first nuclear power plant, Angra 1, started building in 1972 and commercial operation in 1985. The second, Angra 2, started building in 1976 and commercial operation in 2000 [11]. Brazil has the 8th biggest uranium reserve in the world [12]. Nuclear represents only a small part of Brazil's electrical matrix and has the potential to be a bigger low carbon alternative [13].

The nuclear sector is developing new technologies, including the Small Modular Reactor (SMR). The SMR has a capacity of up to 300 MWe per unit. It represents up to one third of the capacity of traditional nuclear reactors. Many advantages of SMRs are in their design, small and modular. It's small compared to a traditional reactor and modular as it is assembled in a factory and transported as a unit to the installation point. They offer better cost/benefit compared to a traditional reactor due to lower upfront costs and construction time. They can be used in remote regions and are primarily based on energy. SMRs also need less fuel, so they are refueled less frequently, every 3 to 7 years, compared to 1 to 2 years of a traditional nuclear plant. Some SMRs are even projected to operate for up to 30 years without refueling. A big challenge of remote areas' access to electricity is the infrastructure cost to connect them to the grid [14].

The management of SMRs is simpler. The security process is more passive, with no human intervention needed to shut down the system. This means significantly less chance of radioactive emission in the environment and for the population. SMRs, like all nuclear power plants, have unique traits in efficiency, economy and flexibility. Nuclear reactors are among dispatchable energy sources, meaning they can adapt production to the demand, contrary to some renewables such as wind and solar, that depend on external factors [14].

To assess the applicability of Small Modular Reactors (SMRs) and evaluate their potential adoption in Brazil, it is essential to first analyze the technological profile of these smaller reactors and review key aspects related to their development and commercialization, including their advantages and disadvantages. Relevant research on the costs and economic feasibility of SMRs is examined in detail to identify the critical challenges to their deployment. A comparison with other energy sources is also provided. Finally, the central question proposed by this study is addressed.

## 2. METHODS

This research is classified as exploratory in terms of its objectives, and in terms of its methods, it is substantially a bibliographic and documentary work.

For the elaboration of bibliographic and documentary research, the systematization was done with a search string to organize the national and international reference databases of subjects that are published in books, journal articles, events, and theses, namely: IAEA, EPE, Google Scholar, ANEEL, ONS, and others.

## 3. RESULTS AND DISCUSSIONS

According to Adriano Pires, PhD., climatic conditions can make Brazil's electric matrix very vulnerable and the demonization of thermic generation in favor of renewables is irresponsible. He thinks that Brazil's electric matrix needs to be diversified to be reliable. 64% of electricity generated in Brazil is hydro [15]. One alternative to lower this dependency on rain is SMRs.

Despite not being a consolidated technology yet, lacking validation and economies of scale, there are already cost estimates that can be comparable or even lower than those of the large existing reactors [16]. In Table 1 is a comparative overview of SMRs and other electricity generation sources in isolated systems [17] [18] [19].

**Table 1:** Comparative overview of SMRs and the other electricity generation sources in isolated systems

| Source | Fuel | $CO_2$ Emission | Dispatchability | Suitability for Remote Areas | Cost per MWh (US$) |
|---|---|---|---|---|---|
| Diesel | Oil | High | High | High | ~250-400 |
| Hydroelectric | Water | Very Low | Medium | Low (needs river basin) | ~30-70 |
| Solar + Battery | Sun + Lithium | Very Low | Low | Medium | ~100-300 |
| Wind | Wind | Very Low | Low | Low (needs wind corridors) | ~50-150 |
| SMRs | Uranium | Very Low | High | High | ~60-120(est.) |

Source: [17] [18] [19], adapted by the authors.

According to the IAEA and Idaho National Laboratory (INL) estimates, the levelized cost of electricity (LCOE) for SMRs ranges between USD 60 and 120/MWh, depending on design, location, and regulatory conditions. Although still higher than large-scale nuclear plants due to lack of economies of scale, SMRs may become cost competitive as manufacturing process mature and series deployment increases. Compared to diesel, commonly used in isolated systems (USD 250-400/MWh), SMRs represent a significantly cheaper and cleaner alternative in the long term [20] [21] [22].

Due to the increase in renewable sources, adjusting the demand with the supply is becoming more complicated for the operator. SMRs have the potential to balance the irregular energy supply from wind and solar [23]. Today this is done with polluting thermals that are also activated in periods of drought [24].

Likewise, SMRs can be used to balance intermittent power supply, they can serve as base load power or both. This reduces vulnerability to weather conditions, water, sun and wind, and gives more control to the National System Operator (ONS). By increasing the participation of the nuclear source with the SMRs, the CO2 reduction target is also met. Furthermore, SMRs can be built closer to consumer centers, which reduces large investments in transmission. Moreover, SMRs have an economic characteristic like renewables: high initial investment and low operational cost.

Several SMR designs are under development, each with different cooling methods, fuels, and applications. For instance, NuScale Power Module (USA) is a Pressurized Water Reactor (PWR) design, producing up 77 Mwe per module with passive safety systems and underground placement. The CAREM reactor (Argentina) is a prototype PWR of 32 Mwe, aiming at local manufacturing capability and modular deployment. Both designs emphasize passive safety, reduce the need for human intervention, and adaptability to isolated or decentralized grids. These reactors are in advanced stages of licensing or prototype construction, with expected commercial readiness by the end of this decade [19] [25] [26]. In table 2 compare technical characteristics of selected SMR designs [25].

**Table 1:** technical characteristics of selected SMR designs

| Reactor | Country | Type | Power Output (Mwe) | Cooling Method | Refueling Interval | Stage |
|---|---|---|---|---|---|---|
| NuScale | USA | PWR | 77 | Water | 2 years | Licensing |
| CAREM | Argentina | PWR | 32 | Water | 3-5 years | Prototype |
| SMART | South Korea | PWR | 100 | Water | 3 years | Licensing |
| BWRX-300 | USA | BWR | 300 | Water | 1-2 years | Desing |
| ACP100 | China | PWR | 125 | Water | 2 years | Under construction |
| Akademik Lomonosov | Russia | PWR | 2x35 | Water | 3 years | Operation |

Source: [25], adapted by the authors.

Currently, according to the IAEA [27], more than 80 commercial SMR projects are under development, aiming at various results and applications, such as: electricity, hybrid energy systems, heating, water desalination, and steam for industrial applications. The Akademik Lomonosov, from Russia, was the world's first floating nuclear power plant, generating energy from two 35 MWe SMRs and started commercial operation in 2020. Other SMRs are in the licensing phase in South Korea, China, the United States, Argentina, and Canada.

Small Modular Reactors (SMRs) are a category of nuclear energy systems designed with reduced capacities, suitable for a variety of energy applications ranging from isolated scenarios to integration into smaller and distributed networks. Developed specifically to generate low-carbon electricity, SMRs are particularly effective in smaller-scale contexts, facilitating efficient integration with renewable sources through mini-grids and micro-grids [28]. Moreover, they represent a viable option to replace fossil fuels in cogeneration systems and other similar applications [28].

According to the International Atomic Energy Agency (IAEA), it is likely that the first prototypes of Small Modular Reactors (SMRs) will use low-enriched uranium fuel [29].

Brazil, as one of the few countries with know-how in nuclear technology, should focus its efforts on opening the market for investment in the nuclear area.

In regions like the North of Brazil, where there is a lack of transmission network or the transmission networks have restricted capacity, SMRs can be installed on an existing network or off the grid, directly on the load, due to their low energy production, providing energy with low greenhouse gas content, both for industry and for the population.

Finally, achieving the goal of universal access to energy, SDG 7, even though the country has a renewable energy matrix and an efficient interconnected system, gaps still prevail, especially in remote and difficult-to-access regions.

## 4. CONCLUSIONS

The reliability of nuclear energy supply, throughout the year, regardless of the season, as well as being able to be generated in any territory, large-scale production, in addition to being a source with low carbon emission, places it with a fundamental role in sustainability and energy security. The energy supplied by SMRs can be classified as clean, reliable, and affordable energy. Furthermore, SMRs can serve as a backup energy source in emergency situations, replacing coal or diesel power generators.

A hindrance to current regulatory assessments is the limited availability of operational data. Innovative equipment that has not been previously manufactured or used in the nuclear industry will also require new codes and standards for performance, qualifications, and testing requirements. Changes in supply chain and decommissioning require new or enhanced regulatory and institutional frameworks.

Questions have been raised about new regulations and institutional capacities related to technological and fuel characteristics, as well as associated processes and their applications. One objective of this document is to highlight known aspects of the technology and areas under development. Design choices have significant regulatory implications depending on the direction taken in preliminary design. Therefore, it is important to identify regulatory elements crucial for decision-making within this context.

This paper suggests as a recommendation for future studies the applicability of SMRs in isolated systems.

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## CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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