# INITIATIVES FOR SMRs IN BRAZIL: OPPORTUNITIES

# AND CHALLENGES.

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**Abstract**

The use of renewable sources such as wind and solar energy is growing rapidly around the world and especially in Brazil. On the other hand, nuclear energy has shown a small growth but continues to make a significant contribution to energy supply, energy security and grid stability, and it is one of the few low-carbon energy sources that can generate value across all major energy-intensive sectors. In this sense, disruptive technologies as small modular reactors (SMRs) and micro reactors (MRs) are being designed not only to produce electricity without carbon emissions, but also to provide other clean energy products needed to decarbonize sectors with intensive energy use. This work presents some of the opportunities and challenges that Brazil has to introduce the SMRs and MRs to generate energy and electricity as part of the strategy for the decarbonization commitments. The Integrated Nuclear Infrastructure Review (INIR), made available by the IAEA, is the methodology intended to be applied to assess the capacity of the Brazilian nuclear infrastructure to introduce the SMRs and MRs in the next decades. The first conceptual studies point out that applications of SMRs in Brazil should be for cogeneration with renewable sources (wind and solar), the generation of heat and steam in petrochemical complexes and for low carbon hydrogen production. The use of MRs should support energy generation on offshore oil platforms installed throughout the Brazilian coast.

## INTRODUCTION

Nuclear power is one of the largest global contributors of carbon-free electricity and, although it faces public acceptance challenges in some countries, it has significant potential to contribute to the decarbonization of the global energy sector. Nuclear energy is recognized as a low-carbon energy source and becomes an indispensable option, if implemented quickly and on a large scale, for countries to achieve CO2 neutral generation by 2050 to meet established commitments assumed with the Paris Agreement in 2015 [1].

The commitments of the Paris Agreement also serves to support the strengthening of the nuclear industry. It is important that future energy projects, to be implemented in developed and developing countries, incorporate the concept that nuclear energy is an alternative clean energy source. The expectation is that nuclear energy will provide solutions to the increase in electricity consumption, reducing concerns about air quality, the security of energy supply and contributing to reducing the effects of climate change.

The growing demand for energy and electricity, combined with the need to promote and support sustainable development objectives [2] has forced countries to support and invest in new energy alternatives. Reducing dependence on fossil fuels and coal for energy and electricity generation has become the main priority for the energy security of countries and the climate issue for the planet as a whole.

Data provided by the Energy Research Company (EPE) [3] and presented in Table 1 show that the world has an energy matrix made up mainly of non-renewable sources, where coal, oil and natural gas account for 80.3% of the energy generated. In Brazil, the energy matrix is ​​more diversified and uses more renewable sources than in the rest of the world. In 2022, energy from renewable sources (firewood, charcoal, hydraulics, sugarcane derivatives, wind, solar and other renewable sources) represented 47.1% of the Brazilian energy matrix.

Worldwide electricity generation is also based on fossil fuels such as coal and natural gas. Table 1 shows that 59% of global electricity was generated from the burning of these two energy sources, which is much bigger than the nuclear source (9.8% of total generation). Renewable sources accounted for 28.7% of global electrical production in 2021 and 77.9% of the Brazilian electrical production in 2022.

TABLE 1. Distribution of energy and electrical sources in Brazil (2022) and World (2021) considering renewable and non-renewable type sources.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Type Source | Source | Energy Generation (%) | | | | Electricity Generation (%) | | | |
| Brazil | World | Brazil | World | Brazil | World | Brazil | World |
| Non Renewable | Mineral Coal | 4.6 | 27.2 | 52.9 | 85.3 | 1.2 | 36.0 | 12.1 | 71.3 |
| Natural Gas | 10.5 | 23.6 | 6.1 | 23.0 |
| Oil and Derivatives | 35.7 | 29.5 | 0.9 | 2.5 |
| Nuclear | 1.3 | 5.0 | 2.1 | 9.8 |
| Others | 0.8 | - | 1.8 | - |
| Renewable | Hydro | 12.5 | 2.5 | 47.1 | 14.7 | 63.7 | 15.5 | 77.9 | 28.7 |
| Biomass | - | 9.5 |  | 2.2 |
| Sugar Cane Bagasse | 15.4 | - | 4.7 | - |
| Solar | 3.5 | - | 4.4 | 3.7 |
| Wind | - | 11.8 | 6.5 |
| Charcoal and Wood | 9.0 | - | - | - |
| Others | 7.0 | 2.7 | 0.8 | - |
| Geothermal | - | - | - | 0.3 |
| Waste | - | - | 2.5 | 0.4 |
| Tidal Waves | - | - | - | 0.003 |

*Source: Adapted from Energy Research Company (EPE) [3].*

In Brazil, electrical generation has a very different distribution from the global average profile, since the country has an electrical matrix of predominantly renewable origin, with emphasis on hydro source. The hydro source participated with 63.7%, the wind source participated with 11.8% and solar source participated with 4.4% of the internal supply of electricity in 2022. More recent data indicate that electrical generation through renewable sources reached peaks of up to 92.4% in January 2023 [4]. The relative share of nuclear-based electrical generation has decreased in the last 20 years with the increasing insertion of renewable sources in Brazil. In 2000, nuclear energy represented 3.8% of the total electrical generation produced in the country, while in 2022 it represented only 2.1% of the total electrical generation produced [5].

## importance of nuclear energy in the energy transition scenario

The wind (onshore and offshore) and solar photovoltaic sources are expected to lead efforts to replace fossil fuels and coal in the energy transition process. However, they still need to be complemented by electrical generation sources that can be dispatched at any time of day and season of the year. These two renewable sources are considered intermittent and must be connected to a large set of batteries to maintain stability when being dispatched into the electrical grid.

Nuclear energy is considered the second largest source of energy with low carbon emissions and high dispatch capacity (hydro is considered the first one). The increase of nuclear-based generation, or at least maintenance of nuclear energy's share in global electricity generation, will contribute to guarantee safe, stable and integrated energy systems with renewable energy and low rates of carbon emissions in the Net Zero Emissions (NZE) scenario by 2050 [6].

The nuclear-based generation capacity reached 417 GW in 2022. In the NZE scenario, nuclear energy is expected to double its generation capacity reaching 812 GW and playing a significant role towards a zero-carbon generation in 2050. The “National Energy Plan – PNE 2050”, reported by EPE [7], considers that Angra-1 and Angra-2 nuclear power plants will operate with their life extension approvals, Angra-3 nuclear power plant will be concluded and it is estimated the increasing of another 6 to 8 GW of nuclear energy by 2050 in Brazil. This potential increase in nuclear energy demand could be supported by 6 new large nuclear power plants, or part of this increase being supported by new nuclear generation technologies.

However, the nuclear energy to be considered a source of energy and electricity that effectively will contribute to a low-carbon economy by 2050, it is necessary that nuclear industry and governments establish and adopt some fundamental commitments. According to the IEA [8], these commitments for the nuclear sector are:

* The industry has to deliver projects on time and within budget to fulfil its role;
* New nuclear power plants will require a reduction in construction costs;
* Markets must price system services to reflect their values;
* The governments need to support and finance new investments in technology;
* Nuclear-based electricity may be used to produce hydrogen and heat;
* Nuclear energy source and other dispatchable energy sources must complement renewable energy, providing stability to electrical systems;

All commitments reinforce the need to propose and develop a new disruptive and multifaceted nuclear technology that can transform the use of nuclear reactors not only for electrical generation, but also for other applications that demand the intensive energy use. This new technological route will reinforce the concept that nuclear energy is a clean energy source capable to supporting the energy transition scenarios.

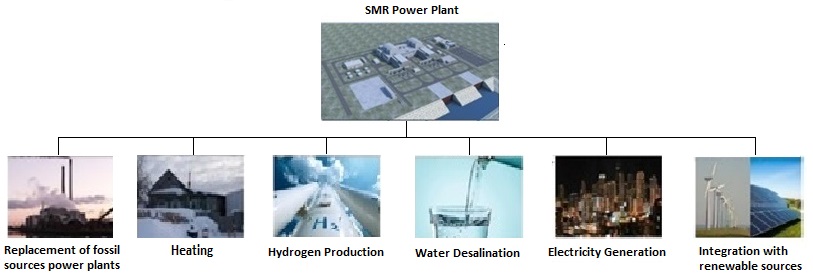
### 2.1 The Insertion of Small Modular Reactors (SMRs)

The electrical generation represents less than 25% of the final use of energy sources. Almost two-thirds of this value is generated from coal and fossil fuels, meaning these two energy sources provide the majority of electrical energy for residential and urban lighting, industrial manufacturing, transportation and heat generation.

The need to seek new disruptive technologies so that nuclear energy continues to support the energy transition in the NZE scenario by 2050, has made it possible to recover the concept of small modular reactors (SMRs) and micro reactors (MRs). Currently, SMRs are being introduced into the international market as an innovative approach to the use of nuclear energy, offering advantages in terms of size, financing, deployment flexibility and use in several other applications in addition to electrical generation.

The design features of SMRs projects meet the commitments proposed by the IEA [8] to strengthen the use of nuclear energy. Furthermore, the use of SMRs is a market attempt to differentiate them from large conventional nuclear reactors. The great expectation is that SMRs and MRs represent the next nuclear innovation and play a critical role for neutral carbon emissions.

The main driving force behind the development of an SMR project is to satisfy the need for flexible energy generation for a wide range of users and applications, replacing obsolete units that burn fossil fuels and coal. With smaller dimensions and passive safety criteria inherent to the project, the SMRs promise to provide flexibility in location and choice of new nuclear sites making it possible to be used in many electrical grids configuration or close to industrial clusters providing heat cogeneration and low carbon hydrogen production, support for seawater desalination, as well as enabling hybrid nuclear energy systems coupled with renewable sources. The main proposed applications of the SMRs is presented in the Fig. 1.

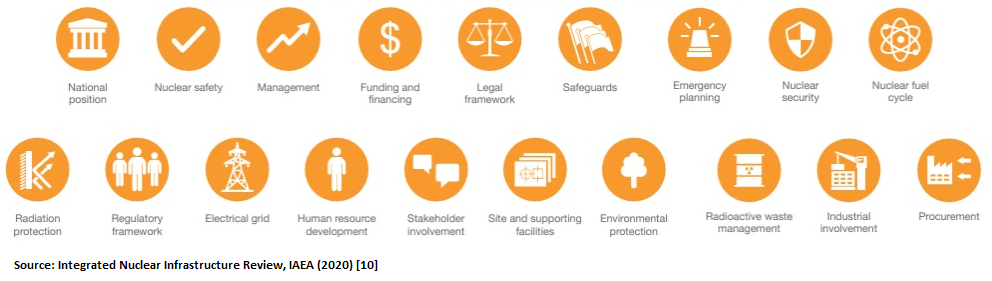


*FIG. 1. Proposed applications using Small Modular Reactors (SMRs).*

### Infrastructure Required to Implement an SMR Program

The implementation of a new nuclear technology is an important commitment that requires careful planning, preparation, financial investment, human resources development. The compliance with international standards, legal instruments, internationally accepted nuclear safety standards, safety guidelines and safeguards requirements are also essential to establishing, maintaining and expanding a responsible nuclear energy program.

The IAEA [9] defines a set of 19 infrastructure issues to address the capacity of a country's infrastructure to support the beginning or expansion of a nuclear energy program, and all infrastructure issues must be considered to achieve each infrastructure milestone. The Fig. 2 shows the 19 infrastructure issues needed to evaluate national capacity to support or expand a nuclear energy program or implement a new subprogram, e.g., for SMRs [10].



*FIG. 2. The 19 Nuclear Infrastructure Issues of the IAEA Milestones Approach [10].*

IAEA has developed the Integrated Nuclear Infrastructure Review (INIR) methodology [11] to assist a country in assessing the stages of the national infrastructure level. The INIR methodology allows to develop in-depth discussions on national and international experiences to implement national infrastructure. An approach using the INIR methodology also allows the country to complete a self-assessment of the 19 infrastructure items included in the IAEA milestone approach [9].

## innitiatives for smrs in brazil

Several civil organizations body have expressed interest in knowing, prospecting or publicizing the technological capabilities and the various applications that should be made available with the insertion of SMRs in the country's energy and electrical generation market. However, based on the statements presented for the activities carried out by the Government of Brazil, it is verified that there is still no set of alignments of actions and investment plans for the SMRs.

The CNEN Regulatory Board (DRS/CNEN) has participated in the IAEA Regulation Forums (e.g., NHSI Agenda [12]) and initiating a revision of Brazilian guides and standards for nuclear power reactors to introduce the first requirements that must be observed by SMR projects that will be proposed in the country. The CNEN Research and Developing Board (DPD?CNEN) has published an initial study in 2021 analysing the feasibility of using SMRs in the country using SWOT analysis [13] and since 2022 has participated in several IAEA technical events on SMRs and structured a working group with representatives from its research institutes. The EPE and Idaho National Laboratory (INL) published in 2023 a joint study for a preliminary assessment of opportunities and challenges for Small Modular Reactors in Brazil [14].

Among class entities in the Brazilian nuclear sector, only the dissemination of the positive and multifaceted characteristics of SMR technology is verified. Mainly to support the revitalization of the Brazilian nuclear industry, to provide a source of electricity to compete with fossil power plants where industrial activities require intensive use of energy or to support energy transition actions.

Brazilian universities and research institutes demonstrate more interest in carrying out numerical simulations of SMRs characteristics (mechanical, neutronic and thermohydraulic) and safety analysis scenarios, as well as studies about the importance of SMRs to support the energy transition in the country.

It should be noted, however, that all positive propaganda and partnership agreements established to develop and implement SMRs and MMRs projects in Brazil will be effectively implemented if the government, the stakeholders and the nuclear regulatory body can demonstrate the existence of a national infrastructure capable of supporting and meeting all 19 infrastructure issues to implement the first SMRs installation in the country.

In this sense, DPD/CNEN started a research project in 2024 with the purpose of evaluating the infrastructure and regulatory requirements for the implementation of SMRs in Brazil based on the integrated review of nuclear infrastructure methodology [15].

### Challenges

The main challenges facing the insertion of SMRs in the country include the following:

* Evaluate and characterize the Brazilian energy and electricity generation market and the main energy transition actions that can be adopted using SMRs to achieve the objectives and targets established by the Paris Protocol by 2050;
* Evaluate and justify the need to introduce SMRs and MRs in the Brazilian energy and electricity generation market since the capacity to generate renewable energy has grown much faster and at lower costs;
* Propose and justify the need for a Nuclear Energy Infrastructure Development Plan to assess the capacity of national infrastructure to support and deploy SMRs and MRs in the country;
* Revision of nuclear guides and standards, regulation and licensing issues that must be implemented to allow the safe insertion of SMRs and MRs. Even considering that DRS/CNEN and Brazilian Navy Regulatory Board does not have a definition of which technologies the SMR projects will be using in a short future and considering different continental or maritime environments for operation.

### Opportunities

The main opportunities facing the insertion of SMRs in the country include the following:

* Propose a roadmap so that Brazil can include SMRs and MRs in the next revisions of the National Energy Plan by EPE;
* Identify the main actions that should be proposed so that the 19 items of national infrastructure may be individually analysed and, subsequently, integrated within the general framework for the preparation of PHASE I of the country's infrastructure development plan;
* Prepare the integrated nuclear infrastructure review (needs met or that should be met) for PHASE I and assess whether it is already possible to identify the completion of MILESTONE I [9].

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