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A SWOT analysis of a Floating Nuclear Power Plant for electricity generation in Brazil

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ABSTRACT

The growing electricity demand, increasing fossil fuel prices, and global warming in Brazil, along with the lack of access to electricity in certain locations in the Northern Region, such as Rondônia, Pará, and Amazonas, are currently seeking solutions. The objective of the present study is to carry out a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the inclusion of a project of a floating nuclear power plant (FNPP) in Brazil to address the lack of electricity in residences and industries located in remote regions. The study results identified several socioeconomic and environmental impacts on these regions. The study concludes that in addition to contributing to the solution to the lack of energy in remote regions, the implementation of this proposal could represent in the future a source of financial resources for the country and international collaboration. This SWOT study will encourage investors, researchers, engineers, and decision-makers to open the debate about the benefit of using an FNPP in Brazil, which, in addition to providing affordable energy rates for the population, would be a profitable business and an international collaboration.

Keywords: **Floating Nuclear Power Plant; Small Modular Reactors; SWOT Analysis.**

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1. INTRODUCTION

Annual Report 2020 from the Institute of Energy and the Environment (IEMA) shows that the three states in Brazil with the highest number of people facing electrical exclusion in the North Region are Rondônia (RO), Pará (PA), and Amazonas (AM) [1]. The objective of the present study is to carry out a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis regarding the inclusion of floating nuclear power plants (FNPP) projects in Brazil to solve the lack of electricity in residences and industries located in remote regions. In Figure 1, we can observe the regions, states, and hydrographic regions (HR) of Brazil, as well as the neighboring countries (Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana, Suriname—and French Guiana).

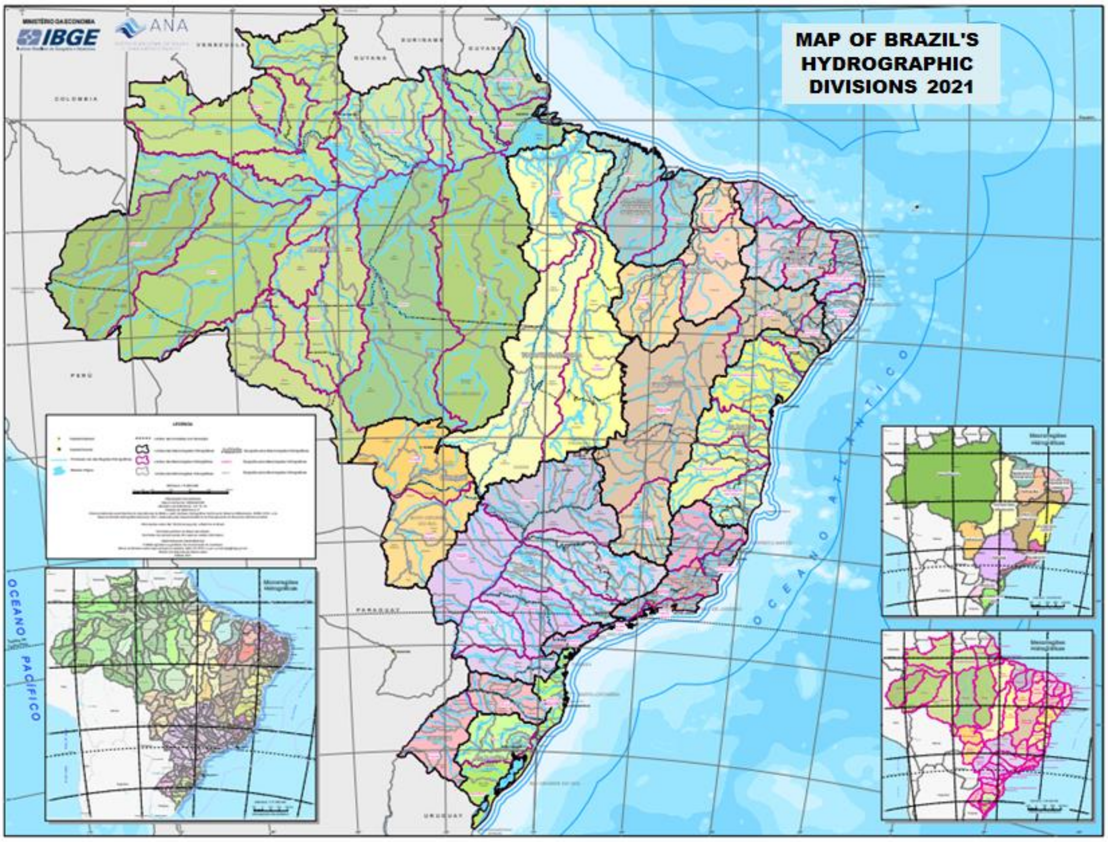
There are a few rivers in Brazil that could be potential candidates for the installation of a FNPP [2]:

- Amazon River: As the largest river in Brazil and the world, the Amazon River offers significant potential for electricity production. The Amazon Hydrographic Region is located in the Amazon basin but is limited to the Brazilian territory. It encompasses seven states: Acre (AC), Amazonas (AM), Rondônia (RO), Roraima (RR), Amapá (AP), Pará (PA) and Mato Grosso (MT). Its vast size and navigability make it a possible option for the installation of a Floating NPP. However, when considering the feasibility of commercial navigation, it is important to carefully address the social and environmental aspects and the need to protect the unique biodiversity of the Amazon region.
- Madeira River: Known for its substantial water flow and hydroelectric potential, it is one of the main rivers of the Amazon hydrographic region. It flows through the state of Rondônia. The rivers Amazon, Solimões, Trombetas, Madeira, and downstream stretches of the Tapajós (considered lowland rivers) already support various levels of commercial navigation.
- Paraná River: It is the second-longest river in South America and flows through several Brazilian states. The river has a well-established infrastructure for transportation and water management. The Paraguay River Waterway connects the city of Cáceres, in Mato Grosso, to Nueva Palmira, in Uruguay, connecting the Midwest of Brazil to the Atlantic Ocean.

Given its navigational conditions and environmental considerations, the Paraná River could be considered a suitable location for a Floating NPP installation.

- Tocantins River: This river crosses central Brazil and is known for its hydroelectric potential. Its substantial water flow could provide favorable conditions for a Floating NPP. The Tocantins-Araguaia HR encompasses the states of Goiás (GO), Tocantins (TO), Pará (PA), Maranhão (MA), Mato Grosso (MT) and the Federal District (DF).
- São Francisco River: It is one of the longest rivers entirely within Brazil and flows through multiple states. The São Francisco HR span seven Federation Units: Bahia (BA), Minas Gerais (MG), Pernambuco (PE), Alagoas (AL), Sergipe (SE), Goiás (GO), and Distrito Federal (DF). The Northeast Brazil Region (NBR) extensively uses it for hydroelectric production.

Figure 1: *Region, states, and hydrographic regions of Brazil*



Source: IBGE [3]

The aforementioned rivers could be considered as a potential site for a Floating NPP Installation. However, detailed studies would be required to assess the navigability, social and environmental impact, and infrastructure availability for such installations.

Data from the 2019 National Household Sample Survey (PNAD) indicate that more than 141,000 Brazilian households do not have access to electricity. The value is underestimated, as it does not take into account families living in remote regions, such as in the northern part of the country [4].

In Brazil, according to the National Agency for Electric Energy (ANEEL), only 4% of companies report not being affected by power outages. The majority, 44% of industries, claim to have problems with power supply on rare occasions, 34% run out of power occasionally, and 16% of industrial companies claim to have problems with frequent blackouts [5].

The growing lack of electricity in the northern regions, such as Rondônia, Pará, and Amazonas, coupled with the increasing electricity demand in Brazil, brings discussions about potential solutions. This work presents a proposal to supply electricity to communities and industries in remote and isolated regions.

1.1 State of the art of FNPP

Several countries are investing in Small Modular Reactors (SMR) for both offshore and onshore applications, aiming to provide flexible options for electricity generation. These countries include the United States, Russia, Canada, Vietnam, China, and Argentina. Additionally, Estonia, Poland, and Sweden are exploring the possibility of building SMRs [6-8].

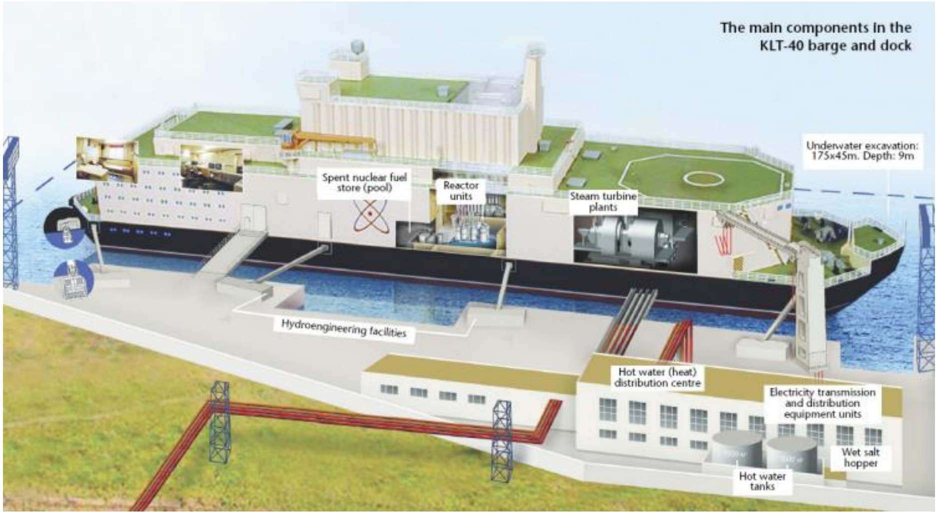
Russia's "Akademik Lomonosov" is the FNPP, as illustrated in Figure 2. It consists of two pressurized water reactor (PWR)-type KLT-40S reactors, each with 35MW of electrical power capability. The Akademik Lomonosov FNPP can provide electricity to remote regions with energy shortages, where it is practically impossible to transport electrical energy by land, such as gas and oil platforms and Arctic ports. The FNPP can supply uninterrupted electricity to coastal regions and existing electrical grids. It started commercial operation in May 2020, offering a capacity of 70 MW and 50 Gcal/h, sufficient to power a city of 100,000 people. The plant is designed for a 40-year lifetime, requiring refueling every 3 years and periodic maintenance in Murmansk, Russia [9, 10].

Safety is a high priority for FNPPs. The design of the Akademik Lomonosov incorporates robust safety measures to withstand natural disasters such as tsunamis and earthquakes. These safety standards adhere to the International Atomic Energy Agency (IAEA) requirements and incorporate lessons learned from the Fukushima nuclear accident. Safety objectives include earthquake and tsunami resistance, prevention of core damage in the event of a loss of the ultimate heat sink (UHS), prevention of radioactivity releases, and confinement of any fuel release or leak within the vessel's hull.

China's ACPR50S is the second FNPP, designed for both electricity generation and desalination purposes. It features a 60 MWe 2-loop PWR-type small modular offshore reactor with passive cooling systems, as shown in Figure 3. According to Chinese engineers, the ACPR50S has been tested and may withstand extreme climate events occurring once every 10,000 years. The design incorporates a passive residual heat removal system, high-pressure safety injection, low-pressure passive safety injection, automatic depressurization system, and long-term circulation system. It also incorporates the control and in-vessel retention of hydrogen and eliminates the possibility of large loss of coolant accidents (LLOCA) and rod ejection accidents [11; 12].

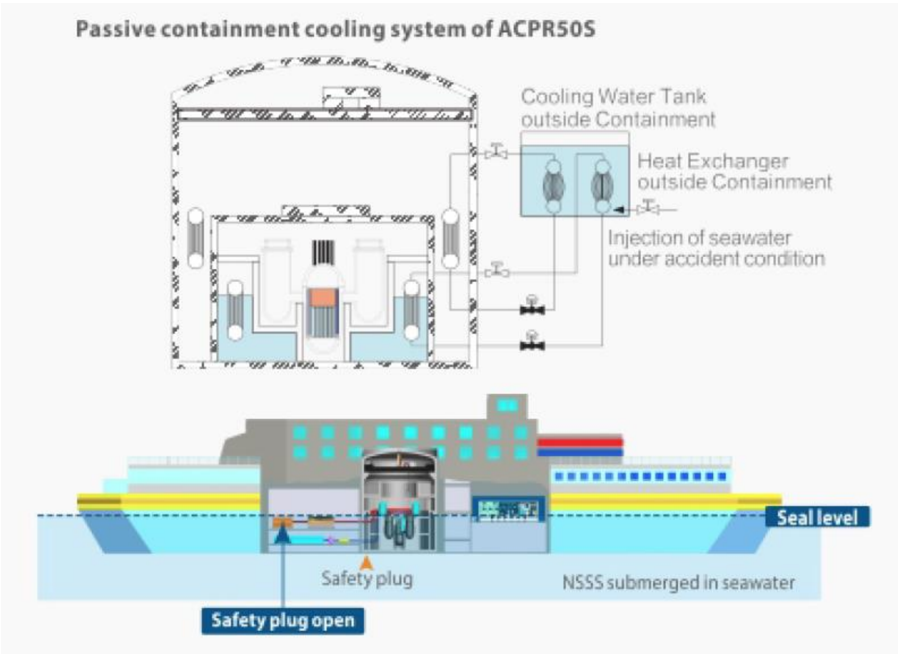
Furthermore, some companies like "Seaborg Technologies" and the Turkish power-floating power plant (FPP) are exploring the concept of equipping ships with SMRs to supply electricity to developing countries. Unlike FNPPs, the Turkish small FPP utilizes a range of electricity generators and fuels, including fuel oil or heavy fuel oil [13; 14].

Figure 2: *Floating Nuclear Power Plant "Akademik Lomonosov" (Rússia)*



Source: IAEA [15]

Figure 3: *FNPP CGN*



Source: Lyncean Group of San Diego [16]

2. MATERIALS AND METHODS

The SWOT analysis was first introduced in the 1960s by Albert Humphrey at the Stanford Research Institute (SRI). Humphrey and his team developed the framework as part of a research project aimed at understanding the reasons behind corporate planning failure. The SWOT analysis is a strategic planning tool used to assess an organization, project, or individual. It helps identify internal strengths and weaknesses, as well as external opportunities and threats [17].

SWOT analysis is a valuable tool in various fields, including energy research, because it helps researchers and power companies to determine a strategy plan for planning and decision-making in the electricity supply chain. It aids in efficient resource allocation (such as funding, personnel, and equipment), risk management, and market positioning. In addition, identifying emerging technology as an opportunity may lead to collaborations with tech companies for further R&D, guiding research priorities, and the development of energy solutions.

The SWOT analysis is adopted in this work to identify the positive (strengths and opportunities) and negative aspects (weaknesses and threats) to take into account in the development of the project of an FNPP.

2.1 Challenges associated with entering new markets

In the study by Santiago et al. [18], the different barriers associated with the implementation of SMR in Brazil are discussed. The research reveals that political support remains the main barrier that is present in the FNPP project, encompassing regulatory issues, the licensing process, and economic factors. However, it may add the risk of severe accidents, even with the notion discussed in previous paragraphs that, because they are small reactors, the event would be of low magnitude.

Another challenge is related to the management of radioactive waste, which is present in conventional nuclear power plants. Currently, there is a scientific consensus that deep geological storage, often referred to as the "nuclear tomb", is a viable long-term solution for the management of spent nuclear fuel and radioactive waste from NPP. This solution is considered socially acceptable, technically sound, environmentally responsible, and economically viable to isolate radioactive waste from the biosphere for at least 100,000 years [19; 20].

The FNPP must comply with the safety requirements and principles established in the IAEA safety standards, adopted by the ANSNQ (Autoridade Naval de Segurança Nuclear e Qualidade), and naval engineering standards.

Other important challenges are:

1. Lack of political will due to negative public opinion, which, in turn, is based on a lack of knowledge (groundless fear);
2. A shortage of specialists in the field;
3. Aging of the workforce (most are near to retirement);
4. A lack of an industrial base capable of meeting nuclear requirements;
5. Export restrictions from countries that possess the technology;
6. Risk imbalance (other industries are allowed to undergo large risks and environmental degradation, but nuclear must be safe). A solution could be to adopt a uniform set of rules for all industries, similar to the UK's Health and Safety Executive;
7. Political motivations lead to neglect of economic feasibility;
8. Nuclear power requires an economy of scale to be competitive, but the size of projects (megaprojects) leads to a large number of problems that small projects do not face.

Floating Nuclear Power Plants (FNPPs) are designed to be located in marine environments such as oceans. In theory, it is technically possible to design FNPPs for river use in Brazil as long as the necessary regulatory, safety, and environmental requirements are met. In addition to the challenges already measured above, it is necessary to take into account engineering considerations such as water depth, currents, temperature variations, and localizations of Hydroelectric Power Plants to avoid interference. At the same time, it is necessary to ensure compliance with international agreements and conventions related to nuclear energy, safety, and the use of water.

3. RESULTS AND DISCUSSION

The results and discussions of the SWOT analysis are described in the following:

3.1 Strengths

1. Energy security: Floating NPPs can contribute to diversifying Brazil's energy mix and reducing dependence on fossil fuels. They can provide a stable (and reliable source of electricity, independent of climate change, helping to enhance energy security.
2. Carbon emission reduction: Floating NPPs contribute to reducing carbon emissions and mitigating climate change.
3. High energy density: Floating NPPs can provide a concentrated power source in areas with limited space for large-scale power plants.
4. Baseload source of electricity: Floating NPPs can provide continuous and baseload power, ensuring a stable electricity supply and supporting the integration of intermittent renewable energy sources.
5. Agricultural development: FNPPs can provide a reliable and consistent source of electricity to support agricultural activities in isolated areas, increasing productivity and supporting the growth of the agricultural sector.
6. Water desalination: FNPPs can also be used to power desalination plants, converting seawater into freshwater. This can be particularly beneficial in arid or isolated areas where access to freshwater is limited. The availability of freshwater can spur agricultural development by enabling irrigation and expanding cultivation in these regions.
7. Economic opportunities: FNPPs can create employment opportunities.
8. Food security: Enhancing agricultural production in isolated areas can contribute to food security by reducing dependence on imported food and ensuring a stable supply of locally produced food. This can strengthen the resilience of the region and enhance its self-sufficiency in terms of food production.
9. Sustainable development: FNPPs can provide a clean and low-carbon energy source.

3.2 Weaknesses

1. Safety concerns: FNPPs come with safety risks. Ensuring stringent safety measures, adherence to international standards, and effective emergency response plans are crucial to mitigate potential accidents or incidents.
2. High initial investment: The construction and deployment of Floating NPPs require significant upfront investment, including research, development, and infrastructure costs. Financing such projects may pose a challenge.
3. Nuclear waste management: Brazil would need to establish robust waste management strategies to ensure the safe handling and storage of radioactive materials. However, this is present in all nuclear power plants.
4. Specialized knowledge and skills: The training and development of personnel to acquire these skills can be time-consuming and challenging.
5. Limited expertise: Developing a qualified workforce with the necessary expertise and experience in operating and maintaining FNPPs.
6. Regulatory compliance: Operating a nuclear power plant involves complying with strict regulatory requirements and safety standards.

3.3 Opportunities

1. Renewable energy integration: Floating NPPs can complement Brazil's existing renewable energy sources, such as wind and solar power. It can be easily connected to any grid and integrated with other clean power sources to build a sustainable energy system.
2. Industrial development: The establishment of a domestic nuclear industry for FNPPs can drive technological advancements, innovation, and job creation.
3. Energy export potential: Brazil could become a leader in floating nuclear technology and export FNPPs in South America to bordering countries.
4. Jobs creation: The generation of employment opportunities can have a positive impact on economic growth and social development.

5. Economic growth: Job creation stimulates economic growth by increasing consumer spending, generating tax revenue, and contributing to overall economic activity. It can improve the quality of life and economic development.
6. Skill development: Job opportunities provide individuals with the chance to acquire new skills, knowledge, professional development, and experience.
7. Reduced unemployment: Job creation helps to reduce unemployment rates, which is a significant social and economic challenge in many regions.
8. Industry development: The creation of jobs can foster the growth and development of specific industries or sectors.
9. Regional development: Job creation in specific regions or communities can lead to regional development and reduce regional disparities.

3.3.1 Threats

1. Public perception and acceptance: nuclear power faces public concerns and resistance due to safety and environmental considerations after the Fukushima accident.
2. Regulatory challenges: Establishing a robust regulatory framework specific to FNPPs and ensuring compliance with international safety standards and regulations.
3. Political and social factors: Political will, stakeholder engagement, and community involvement are crucial factors that can influence the success of FNPP projects.

The results of the qualitative SWOT analysis are given in Table 1.

Table 1: Comparative score of SWOT attributes.

Results of SWOT	**27**	
Strengths	33,3 %	9
Weaknesses	22,2 %	6
Opportunities	33,3 %	9
Threats	11,1%	3

From comparing the attributes of the qualitative SWOT analysis, it is demonstrated that it is favorable to include the strategy of FNPP in the energetic matrix of Brazil.

Job creation was identified as having a positive impact on both society (economic growth) and the individual (development of skills and social well-being).

3.3.2 Advantages associated with the FNPP project

In addition to that previously mentioned, the investment in a FNPP, from an environmental point of view, would reduce greenhouse gas (GHG) emissions, aligning with Brazil's commitments under the Paris Protocol. It's worth noting that when considering GHG emissions from deforestation, Brazil ranks as the fifth-largest emitter globally, following China, the United States, India, and Russia [21].

FNPPs have the advantage of supplying a stable and reliable source of electricity that can operate 24/7, regardless of climatic change. This makes them well-suited for supplying electricity to remote or hard-to-reach locations where traditional land-based power sources may not be practical. They also have a much higher energy density compared to floating wind and solar power systems, allowing them to generate more electricity per unit of area.

Another point to consider supporting the FNPP installation is that the NBR suffers from recurrent prolonged droughts, which directly affect food production and energy security.

It is important to note that the FNPPs could replace isolated systems that use diesel generators (DG) in regions of Brazil, mitigating negative impacts such as noise pollution, logistics challenges associated with obtaining diesel, and environmental impact, among others.

In previous studies by Brazilian researchers [22], an economic feasibility analysis of small-scale mobile nuclear power plants was developed based on a system engineering methodology. The research explored the use of these reactors to supply electricity to a wide range of national customers, including merchant ships, armed forces, the agricultural sector, industries, businesses, and homes. Our study extends the use of FNPP to supply electricity locally and to neighboring countries.

After evaluating the advantages mentioned throughout this work and in the previous one, we can consider that the FNPP is an alternative to be considered by the Empresa de Pesquisa

Energética (EPE). This would open the debate on FNPP as a local energy source and their potential to export electricity, which could help reduce electricity costs for Brazilian consumers.

Further analysis will be conducted to determine the number and power capacity of reactors needed. This analysis should consider the electricity demand by regions and states that currently lack access to electricity, as well as housing centers near navigable stretches of the Amazon basin in the remote region of Brazil.

3.3.3 Technologies

For navigation and river use of FNPPs, several technologies can be considered, including floating platforms (boats or ships). These platforms should be engineered to withstand river currents, waves, and other environmental conditions.

3.3.3.1 Potential obstacles

The adoption of FNPPs in Brazil can face several potential obstacles, including political mindset, political support, public perception, and environmental concerns. These obstacles to adopting FNPPs can be overcome by first changing the political mind and, subsequently, addressing the concerns of the population.

3.3.3.2 Risks due to non-adoption of FNPP in Brazil:

- Energy security: If Brazil fails to diversify its energy sources, it may become overly reliant on traditional energy resources like fossil fuels. This dependence can leave the country vulnerable to supply disruptions and price fluctuations in the global energy market.
- Environmental impact: Depending on the energy mix, increased reliance on fossil fuels can contribute to air pollution, GHG emissions, and climate change. Transitioning to cleaner energy sources, such as nuclear power, could help mitigate these environmental risks.

- Competitiveness: As other countries adopt nuclear power, Brazil may lag in terms of competitiveness and technological advancement. Nuclear power can provide a stable and reliable source of energy, which is crucial for industrial growth and economic development.
- Grid reliability: Nuclear power plants offer a consistent and baseload power supply, contributing to grid stability. Without such a reliable energy source, Brazil may face challenges in maintaining a stable power grid, which can impact various sectors of the economy.

4. CONCLUSIONS

In conclusion, this work presents a compelling proposal for the integration of Floating Nuclear Power Plants (FNPPs) into Brazil's energy mix through the PNE 2050 initiative. Our aim is to reach decision-makers in both the public and private sectors, emphasizing the transformative potential of this endeavor.

The primary objective is to transport the small modular reactors on a floating ship to supply clean and efficient electricity to remote and isolated communities in Brazil. These communities currently lack access to the electrical grid and rely on isolated diesel-powered systems that have high generation costs, low efficiency, and high maintenance requirements, in addition to emitting GHG that severely contaminates the environment. FNPPs present a promising alternative to replace these systems.

Moreover, the SWOT analysis revealed that, despite various challenges, FNPP offers numerous benefits for Brazil. These benefits encompass a substantial reduction in electricity production costs, a marked decrease in greenhouse gas emissions, and the facilitation of economic development and agricultural expansion in remote and isolated regions. Additionally, FNPPs serve as a valuable complement to other energy sources that may exhibit intermittency, such as hydroelectric, wind, and solar power.

Upon successful implementation, FNPPs hold the potential to export electricity to nations grappling with energy shortages. This exportation not only generates significant financial resources for Brazil but also fosters international. Ultimately, this proposal opens a national debate in Brazil, one that explores the myriad social and economic benefits of implementing floating nuclear power plants.

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