

Reactor Technology Assessment of Small Modular Reactors for Nigeria's Energy Transition

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1. Introduction

Nigeria, which is Africa's most populous nation with over 200 million people, faces severe energy challenges with a grid generating only 4~5 GW against a demand exceeding 20 GW, leading to frequent outages. The current energy status reveals a national grid capacity insufficient to meet demand, with over 40% of the population, especially in rural areas, lacking reliable electricity. The energy mix is dominated by natural gas (approximately 80%) and hydropower (about 18%), with minimal contributions from renewables (less than 2%) due to underdeveloped infrastructure and policy gaps. Total installed capacity has stagnated since 2015, with outages costing the economy an estimated USD 26 billion annually. To achieve its nationally determined contributions (NDCs) for a 47% greenhouse gas (GHG) reduction by 2030 and net-zero by 2060 under the energy transition plan, Nigeria must diversify to low-carbon sources [1]. Small modular reactors (SMRs), with capacities of 50~300 MWe, offer scalable, affordable (USD 1~3 billion per unit), and rapid-deployment (3~5 years) solutions, suited to Nigeria's geography, tropical climate (25~35 °C, high humidity, 1000~2000 mm of annual rainfall), low seismic activity (< 0.1g), coastal flooding in the Niger Delta, and northern water scarcity in the Sahel.

This study aims to identify the best-fitting SMRs for Nigeria by applying the IAEA's Reactor Technology Assessment (RTA) methodology [2]. It is a structured process for evaluating and selecting the most appropriate nuclear reactor technology for a specific country, particularly in the context of near-term deployment. This involves assessing various reactor designs against defined criteria, considering factors like safety, economy, and environmental impact. The goal is to provide decision-makers with the information needed to make informed choices about nuclear power programs. This study began with an initial screening and analysis of eight SMR candidates using the RTA online tool which helped understand the methodology and identify promising options. Based on this screening, the top three candidates of NuScale, SMART and BWRX-300 were selected for a detailed analysis tailored to Nigeria's specific geography (coastal and Sahel regions), tropical climate, water scarcity, grid constraints, and other factors. Data sources include IAEA's advanced reactor information system (ARIS), OECD Nuclear Energy Agency's (NEA) SMR Dashboard [3], Saleh et al. on SMR assessments in emerging markets [4], and Nigeria's energy transition

plan, with insights from a Czech study on coal-to-SMR transitions informing site repurposing options.

2. Method and Results

The RTA methodology utilizes 10 Key Elements (KEs) with assigned weights: KE1 (site and environment, 12%), KE2 (fuel cycle, 10%), KE3 (nuclear safety, 15%), KE4 (nuclear island design and performance, 10%), KE5 (balance of plant design and grid integration, 10%), KE6 (balance of plant design for purposes other than electricity production, 10%), KE7 (safeguards and protection, 10%), KE8 (technology readiness, 8%), KE9 (project delivery, 8%), and KE10 (economics and financing, 7%). Each KE includes key topics with percentages, scored 1~5 based on Nigeria-specific criteria (e.g., desalination for water scarcity, passive safety for grid instability). The initial screening of eight SMRs used the RTA tool for a broad assessment, followed by a detailed evaluation of the top three.

The detailed RTA yielded the following total weighted scores: 4.92 of NuScale, 4.85 of SMART, 4.22 of BWRX-300. NuScale leads due to its exceptional modularity (KE4), robust grid integration (KE5), and favorable financing options (KE10), making it suitable for coastal sites like Lagos. SMART ranks second, excelling in non-electric applications (KE6, e.g., desalination for northern scarcity) and project delivery (KE9) with Korean technological support. BWRX-300 is third, offering strong nuclear safety (KE3) but is limited by higher water requirements (KE1) and costs (KE10), and fitting southern industrial hubs like Port Harcourt. NuScale's 4.92 score reflects its adaptability to Nigeria's unstable grid, SMART's 4.85 highlights its desalination potential for the Sahel region, and BWRX-300's 4.22 underscores its safety in tropical conditions.

Cost estimates are NuScale at USD 1.8 billion, SMART at USD 2 billion, and BWRX-300 at USD 2.2 billion. NuScale (77 MWe per module) could add 231 MWe with three units, meeting (4.6% of current demand (5 GW)). SMART (100 MWe) offers 300 MWe with three units (6% of demand), including 500,000 m³/day desalination for Mambilla and Jigawa. BWRX-300 (300 MWe) provides 600 MWe with two units (12% of demand), ideal for Port Harcourt's industrial load. NuScale reduces CO₂ emissions by 1.2 millions ton/year (231 MWe), SMART by 1.5 (with desalination offset), and BWRX-300 by 3.0 millions ton/year (per 600 MWe), supporting 47% GHG reduction target. Water use is lowest for NuScale (3 m³/MWh) versus

BWRX-300 (6 m³/MWh), critical for the Sahel. Lagos scores 4.5/5 (NuScale) for grid access, Mambilla 4.3/5 (SMART) for water needs, Jigawa 4.0/5 (SMART) for secondary desalination, Port Harcourt 4.2/5 (BWRX-300) for industry, and Kainji 4.4/5 (hybrid) for hydro synergy, weighted by KE1 and KE5. The three SMRs are paired complementarily: NuScale for urban grid support, SMART for rural water-energy nexus, and BWRX-300 for baseload reliability. Challenges include fuel supply logistics (KE2) for a nuclear newcomer and external hazards (KE1) like flooding. Fig. 1 depicts the comparative performance and pairing of the three best-fitting SMRs (NuScale, SMART and BWRX-300) optimized for Nigeria's diverse energy needs, including geography, tropical climate, and water scarcity. Fig. 2 details two selected geographic locations and specific suitability of potential deployment sites across the country.

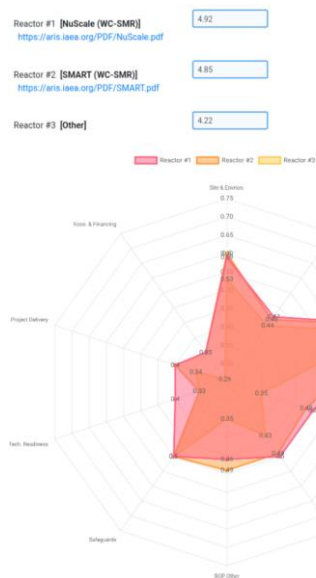


Fig. 1. Radar chart illustrating the performance and pairing of NuScale, SMART and BWRX-300

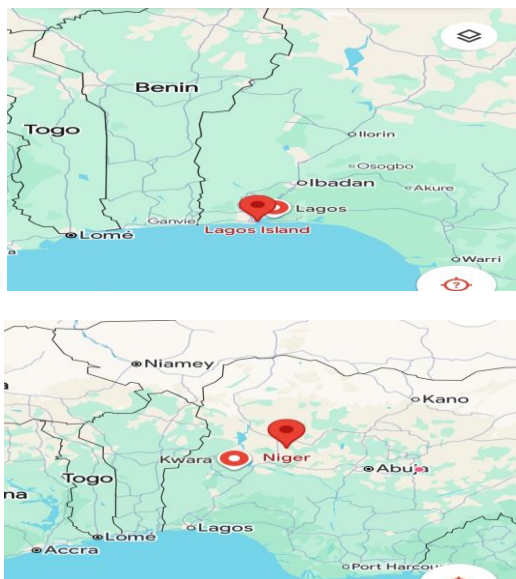


Fig. 2. Potential SMR deployment sites of Lagos and Niger

3. Conclusions

SMRs are considered as a potential technology to support Nigeria's energy transition, offering a pathway to a cleaner, more reliable, diversified energy supply. SMRs, with their modular design, potential for factory-based construction, and suitability for smaller grids, present a compelling option for Nigeria seeking to reduce reliance on fossil fuels and expand its energy infrastructure. NuScale, SMART, and BWRX-300 are the best-fitting SMRs for Nigeria, with NuScale leading for its modularity and cost-effectiveness. The study, grounded in the RTA online tool and detailed analysis, supports Nigeria's 2035~2040 nuclear deployment to achieve sustainable energy security and GHG reduction targets. Further research should address local manufacturing and financing to maximize benefits.

Acknowledgment

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