**THE ROLE OF SMALL MODULAR REACTORS (SMRS) IN MITIGATING CLIMATE CHANGE AND PROMOTING ECONOMIC GROWTH IN AFRICA:A CASE STUDY OF NIGERIA**

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**Abstract**

 Small Modular Reactors (SMRs) are increasingly viewed as a promising solution to meet the rising energy needs in Africa. They offer cost-effective, financially feasible, and quicker completion options compared to traditional methods. Furthermore, SMRs hold the potential to address critical challenges such as fostering economic development and mitigating climate change. This study investigates the role of SMRs in electricity generation, combat climate change, their potential to spur economic growth. The focus is specifically on Nigeria, serving as a case study. In 2019, Africa accounted for around 4% of global CO2 emissions, with the largest contributors being South Africa, Nigeria, and Egypt due to their significant industrial and energy sectors. Achieving the pace of CO2 emissions reductions in line with the Paris agreement requires large increases in efficiency and renewable investment. Investments in SMRs will contribute to climate change mitigation by reducing reliance on fossil fuels and lowering greenhouse gas emissions associated with electricity generation. SMRs present numerous advantages over conventional large-scale nuclear reactors. These include lower initial costs, improved safety features, and scalability, which are especially beneficial for addressing the challenges posed by poor and inadequate grid systems in Africa. Consequently, by offering a reliable and sustainable source of electricity and will help countries in Africa meet their climate targets under international agreements while promoting the transition to a low-carbon economy. Using Nigeria as a case study, this paper analyzes the potential benefits and addresses challenges of developing and deploying SMRs in the energy mix in Africa. It provides insights into policy implications, financing, operation, and maintenance, as well as recommendations for maximizing the socio-economic and environmental benefits of SMR’s in the region. Overall, SMRs offer a promising pathway towards sustainable development in Africa, with significant implications for energy security, economic prosperity, and environmental sustainability to achieve Net Zero.

## INTRODUCTION

 Africa faces significant challenges in terms of energy access, economic development, and climate change. About Six Hundred million Africans have very limited access to energy, corresponding to an electricity access rate at just over 40 percent, the lowest in the world. Per capita consumption of energy in sub-Saharan Africa (excluding South Africa) is 180 kWh, compared to 13,000 kWh per capita in the United States and 6,500 kWh in Europe [1]. Nigeria, the most populous country in Africa, exemplifies these challenges. Despite its vast natural resources, Nigeria struggles with energy shortages, economic instability, and environmental degradation. The Nigerian government has established three significant and ambitious targets for its electricity sector to be achieved by 2030, considering the current circumstances. These targets focus on increasing access to electricity, developing renewable energy, and reducing emissions. Specifically, the country aims to ensure that 90% of the population, including both rural and urban areas, will have access to electricity [2]. Nuclear power through Small Modular Reactors (SMRs) could play a significant role in this ambition, particularly in reducing carbon emissions.

2. ENERGY LAND SCAPE IN AFRICA: NIGERIA

Energy is essential for economic growth and industrialization, and without sufficient electricity, socioeconomic progress is stunted. In Africa, the gap between electricity demand and generated capacity is significant, impacting the continent’s economic potential. Energy demand in Africa is growing at about 3% annually, the highest rate among continents, but supply has not kept pace, leaving many countries struggling to meet their domestic energy needs. [3]

**2.1** **Energy Access and Demand in Africa**

 Nigeria faces a substantial energy deficit, with a significant portion of its population lacking access to reliable electricity. The country’s energy infrastructure is outdated and insufficient to meet the increasing demand. Frequent power outages and reliance on costly diesel generators are widespread, posing obstacles to economic growth and development [4]. It is significant to note that countries like Egypt, Tunisia, Morocco, and Algeria in the northern parts of Africa have the highest electricity access rates, which are above 95%. Other countries, such as Gabon, Ghana, South Africa, Botswana, Kenya, and Senegal, have electricity access rates above 70% [5]. South Africa, the only African country with a nuclear power plant, has an electricity access rate above 84%. Nigeria, with the largest population and economy in sub-Saharan Africa, faces significant constraints in its power sector that hinder economic growth. Despite being rich in oil, gas, hydro, and solar resources, and having the potential to generate 12,522 MW of electricity from existing plants (excluding off-grid generation), the country often manages to dispatch only around 4,000 MW. This output is inadequate for a nation of over 200 million people [6].

**2.2** **Nigeria Energy Mix**

 Electricity is produced from various energy sources, including hydro, coal, gas, nuclear, and renewable like wind and solar. Solar and wind are the fastest-growing renewable worldwide due to their low carbon emissions. In combination with nuclear energy, they contribute to the decarbonisation of electricity, advancing a low-carbon energy system. According to a 2021 USAID report, Nigeria has a total installed power generation capacity of 16,384 MW, primarily from gas-fired thermal power plants (11,972 MW) and hydroelectric power plants (2,062 MW). Solar, wind, diesel, and Heavy Fuel Oil (HFO) contribute the remaining 2,350 MW [8]. Nigeria is pursuing its Vision 30:30:30, an ambitious energy plan aiming to generate 30 GW of electricity by 2030, with 30% sourced from renewables such as solar, wind, biomass, and hydroelectric power. This goal is supported by the National Renewable Energy and Energy Efficiency Policy (NREEEP), which emphasizes diversifying the energy mix [8]. The Nigeria Energy Transition Plan (ETP), launched in 2022, outlines a roadmap for achieving net-zero emissions by 2060. Nuclear energy is included as a key component, complementing renewable sources like solar, wind, and hydroelectric power. The plan involves international collaboration with organizations such as the World Bank, UNDP, and the African Development Bank (AfDB) to support funding, capacity building, and regulatory development for nuclear and renewable energy projects [9]. Additionally, the International Atomic Energy Agency (IAEA) and the United States Department of Energy (DOE) assist Nigeria in understanding safety standards and regulatory requirements for Small Modular Reactor (SMR) deployment. Nigeria is also part of the U.S. Government's Foundational Infrastructure for Responsible Use of Small Modular Reactor Technology (FIRST) Program, which supports the safe development of SMRs. Partnerships with countries like Canada and South Korea provide further knowledge sharing, capacity building, and feasibility studies to explore the potential of SMRs for power generation, industrial applications, and desalination [10].

**2.3 Environmental Impact**

 [Nigeria’s energy sector significantly contributes to greenhouse gas emissions, mainly due to its heavy reliance on fossil fuels. The environmental harm caused by oil extraction and consumption has substantial health and ecological consequences. To address these challenges, a crucial step is transitioning to low-carbon energy sources, which can mitigate climate change and enhance public health](https://www.irena.org/Publications/2023/Jan/Renewable-Energy-Roadmap-Nigeria). Nigeria is a signatory to the Paris Agreement, having submitted its Intended Nationally Determined Contributions (INDCs) on November 28, 2015, signed the agreement on September 22, 2016, and ratified it on May 16, 2017. The country developed and validated its NDC Sectoral Action Plan in July 2018, prioritizing five key sectors: agriculture, industry, power, transport, and oil and gas. Nigeria’s greenhouse gas (GHG) emissions are projected to grow by 114% to around 900 million tonnes by 2030. However, its NDC, aligned with the country’s development policy, targets a 20% unconditional and 45% conditional emission reduction below Business as Usual (BAU) levels by 2030 [11]. With the current dependency on fossil fuels and gas-powered stations, Nigeria’s GHG emissions will surpass this projection if the country does not reduce its overdependence on gas for electricity generation. This is exacerbated by the acute shortages of electricity supply across the country, with blackouts lasting several hours a day. Consequently, many households and businesses rely on self-generation of off-grid electricity using diesel and gasoline generators as backup. This situation is unlikely to change soon unless the government invests massively in clean renewable energy. Nuclear power, particularly through Small Modular Reactors (SMRs), could be a game changer in addressing these challenges.

3. THE POTENTIAL OF NUCLEAR: SMALL MODULAR REACTORS (SMRS)

 Nuclear, power is an important low-emission source of electricity; it provides nearly 10% of global electricity generation in the world, its complements other renewable energy sources in reducing power sector emissions while also contributing to electricity security as power source [12]. It’s a dependable option for generating low- emission heat and hydrogen .Nuclear energy can reduce the reliance on fossil fuel, which is a major contributor to green gas emission, with around 413 Gigawatts (GW) of capacity operating in 32 countries, it contributes to both goals by avoiding 1.5 Gigatonnes (Gt) of global emissions and 180 billion cubic metres (bcm) of global gas demand a year [12]. Nigeria can also leverage on this in solving its energy shortages. SMRs represent a promising solution to these intertwined issues, offering a sustainable, reliable, and flexible energy source. It offers a much easier alternative , it will help achieve most if not all the goals of building a Nuclear power Plant with less challenges and also achieving the aims of generating electricity for industrial development and sustainability while mitigating climate change through clean energy because Modular Reactor are: less expensive, this can reduce the cost and burden of financing , It is also safer due to its coherent safety ,It is compactable and can easily be moved around to areas where there is grid .It requires less water, it can be deployed in any part of Nigeria particularly in the North to spur development and industrialization and Job creation [13] .It also has less preparation time to build, compared to a conventional PWR which could help actualize Nigeria’s vision 2030 ambition targets for its improved electricity for industrial development .

**3.1 Effects of climate change on Africa**

 **Africa has started to experience more severe climate change than most other parts of the world, despite bearing the least responsibility for the problem, with** nearly one-fifth of the world’s population today, Africa accounts for less than 3% of the world’s energy-related carbon dioxide (CO2) emissions to date and has the lowest emissions per capita of any region  **such experiences are not limited to** higher temperatures, drought, changing rainfall patterns, increased climate variability, floods, reduced food production, lower economic growth and prosperity these can also be connected to the issues of mass illegal migration and risks of frequent desperate journey to Europe by crossing the Mediterranean sea were hundreds of life’s are lost daily.

4. NUCLEAR ENERGY FOR INDUSTRIAL AND SUSTAINABE ECONOMIC DEVELOPMENT

 Nuclear power can play a significant role in the generation of electricity for industrial and economic development while promoting sustainability and mitigating climate change in Africa. It has some advantages; it is reliable and consistent source of electricity, capable of supplying base load power. It offers Energy Security any country with significant nuclear power capacity can reduce their reliance on imported fossil fuels and enhance their energy security, It provides sustainable energy because it produces low gas emissions, which is vital for addressing climate change and achieving sustainable development goals, it also provides long-term sustainability due to its long operational life spans, typically exceeding 40 to 60 years, It assures stable and enduring source of electricity for industrial development and economic growth in the region, and job creation and skill development. The establishment and operation of nuclear power plants will lead to the creation of high-quality jobs and drive skill development in the host country, technology transfer, capacity building, and development of indigenous expertise and capabilities, which will boost Africa's technological advancement. By adopting nuclear power, African countries can improve air quality and public health, and water conservation.

**4.1. Nuclear Power Plant Development**

 The Nigerian government, through the Nigeria Atomic Energy Commission (NAEC), is pursuing nuclear power as a long-term solution to diversify its energy mix and meet the growing electricity demand. As part of its Strategic Plan for Energy Security, Nigeria aims to generate 4,000 MW of electricity from nuclear power by 2035. The adoption of Small Modular Reactors (SMRs) offers a practical pathway to achieving this target. By deploying approximately 14 SMR units, each with a capacity of 300 MW, Nigeria can incrementally build its nuclear capacity. Starting with a few SMR units will allow the country to overcome initial grid limitations and resource constraints while gradually scaling up to meet its 4,000 MW goal. To support these efforts, Nigeria has signed an agreement with the Russian State Nuclear Corporation (ROSATOM) to provide technical expertise and support for the development of nuclear power technology. ROSATOM's assistance will cover key areas such as site selection, conducting feasibility studies, and human resource development, all of which are critical for the successful implementation of the project [14].

However, significant challenges remain, particularly concerning Africa's grid limitations]. The International Atomic Energy Agency (IAEA) recommends that a country's grid capacity should be at least ten times the output of a nuclear power plant. In Nigeria, despite an installed national grid capacity of 6,500 MW, the transmission infrastructure can handle only a maximum of 4,500 MW. This reflects broader challenges across Africa, where infrastructure constraints and political barriers limit grid expansion, restricting access to electricity in rural areas and centralizing supply in major cities [15]. SMRs could help mitigate these grid issues by being built closer to areas of need, reducing the dependence on extensive transmission infrastructure and addressing some of the challenges associated with poor or inefficient grids [16].

**4.2 Economic Growth and Development**

 Nigeria's inconsistent power supply and the high costs of captive generation adversely affect the economy, impacting both residential and industrial sectors. Households and small and medium-sized enterprises spend two to three times more on kerosene, diesel, and petrol than on grid electricity[8] . This leads to higher business costs, hindering economic growth, discouraging local production, and making importation more attractive. Consequently, manufacturing companies collapse or relocate, resulting in increased unemployment. Deploying Small Modular Reactors (SMRs) in Nigeria can guarantee energy security by providing reliable energy access, a cornerstone of economic development. SMRs can offer consistent and affordable electricity, reducing reliance on costly and polluting diesel generators, thereby spurring industrial growth, improving productivity, and attracting foreign investment [17]. The implementation and operation of SMRs can generate numerous employment opportunities across various fields, including construction, engineering, manufacturing, and maintenance. Additionally, establishing a local nuclear industry can stimulate growth in related sectors and contribute to skill development. This type of development is essential for Nigeria and Africa, helping to employ youth and graduates, prevent crime, and reduce the risks associated with mass illegal migration and dangerous journeys across the Mediterranean Sea, where hundreds of lives are lost daily.

**4.2 Challenges and Considerations**

 Adopting nuclear energy, particularly Small Modular Reactors (SMRs), presents several challenges due to the evolving nature of the technology and limited global operational experience. For Nigeria, a major consideration is financing, which is constrained by scarce resources and competing priorities. While nuclear power projects involve high initial costs, SMRs offer a more affordable alternative than traditional Pressurized Water Reactors (PWRs), requiring less time and fewer resources to build. SMRs provide an opportunity for quicker completion, fostering development, job creation, and faster returns on investment for both governments and financiers.

5. WAY FORWARD

 Nigeria's electricity supply system faces major challenges, including inadequate financing, high investment risks, and policy uncertainty. Specific issues include limited generation capacity, weak transmission and distribution infrastructure, gas supply shortages, seasonal water fluctuations, and governance problems. Recent policies, like feed-in tariffs for renewable energy and new metering regulations, aim to mitigate these setbacks. However, adopting nuclear energy, including Small Modular Reactors (SMRs), also poses financing challenges due to the significant investment required. Achieving reliable power supply and improved electricity access will demand substantial investment in Nigeria's power sector, estimated at USD 34.5 billion by 2030, presenting opportunities for SMR development to address many of these challenges.

6.0. RECOMMENDATIONS

 Nigeria can effectively adopt SMRs, fostering economic growth, creating employment opportunities, and mitigating climate change by taking the following steps:

* Establishing a Robust Regulatory Framework: Develop comprehensive nuclear policies and strengthen the Nigerian Nuclear Regulatory Authority (NNRA) to ensure safe and secure SMR deployment, building public trust and compliance with international standards.
* Securing Financing and Investment: Explore innovative funding mechanisms, such as public-private partnerships and international grants, and provide government support through subsidies and tax incentives to attract private investors and secure capital for SMR projects.
* Investing in Infrastructure and Grid Modernization: Upgrade and expand the national grid to support SMR integration and improve electricity distribution, and develop necessary infrastructure, including transportation networks for nuclear materials.
* Strategic Planning for Economic Growth and Climate Mitigation: Integrate SMRs into Nigeria’s long-term energy strategy to complement renewable energy sources, reduce fossil fuel reliance, meet emissions reduction targets under the Paris Agreement, stimulate economic growth, create jobs, and attract foreign investment.

7.0 CONCLUSSION

 Deploying Small Modular Reactors (SMRs) in Nigeria offers a significant opportunity to mitigate climate change and promote economic growth. SMRs offer numerous benefits for industrial, economic, and sustainable development. By providing consistent and affordable electricity

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