Examining Pakistan's Potential for Small Modular Reactors to Promote Energy Security and Sustainability

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Abstract

The potential of Small Modular Reactors (SMRs) to meet Pakistan's energy difficulties and improve its energy security and sustainability is examined in this research study. SMRs are appealing choices for decentralised power generation because of their distinctive qualities, which include reduced size, modular design, and improved safety measures. The advantages of SMRs for Pakistan are outlined in the study, including how they can help the country fulfil its increasing energy needs, improve grid stability, lessen its dependency on foreign fuels, and cut down on greenhouse gas emissions. It assesses various SMR designs, taking into account aspects like safety, scalability, and economic viability. These designs include NuScale, Rolls-Royce, GE Hitachi, and CAREM. The adoption and integration of SMRs into Pakistan's energy portfolio is encouraged by suggestions made for policymakers, industry stakeholders, and other pertinent actors. These include creating regulatory frameworks, funding research and development, encouraging public-private partnerships, improving the development of human capital, and involving stakeholders. Pakistan can shift to a more robust and sustainable energy future by utilising the special benefits of SMRs and putting supportive laws and programmes into place.

Abbreviations

Small modular reactors (SMRs), boiling water reactors (BWRs), pressurised water reactors (PWRs).

Introduction

Compared to conventional large-scale nuclear power facilities, Small Modular Reactors (SMRs) are nuclear reactors with reduced size and capacity. Unlike conventional reactors, which may produce energy on the order of gigawatt, they are usually intended to produce tens to hundreds of megawatts. Because of its modular design, SMRs are easy to fabricate in the factory and transport to sites. They may make use of various reactor technologies, such as boiling water reactors (BWRs), pressurised water reactors (PWRs), or sophisticated reactor designs like high-temperature gas-cooled reactors or molten salt reactors, and they frequently integrate cutting-edge safety features. The research will discuss the significance of SMRs in the context of nuclear energy.

This study aims to investigate the potential of small modular reactors (SMRs) to improve Pakistan's energy security and sustainability while solving the nation's energy-related issues. The significance of SMRs in relation to nuclear energy will be discussed in this study, along with some of their special qualities and possible advantages. It is going to specifically investigate whether SMRs are suitable for Pakistan's energy requirements, taking into account things like power demand, grid infrastructure, economic feasibility, and regulatory frameworks. To determine the most promising choices for deployment in Pakistan, the report

will also assess several SMR designs and technologies. Lastly, suggestions for supporting the adoption and integration of SMRs into Pakistan's energy portfolio will be made in this paper for decision-makers, industry participants, and other pertinent parties.

Small Modular reactors

For several reasons, SMRs have the potential to transform the nuclear energy industry drastically. Following are the pertinent aspects:

Enhanced Safety: Passive safety systems and built-in safety measures are included in a lot of SMR designs, which reduces their vulnerability to accidents and makes emergency management simpler.

Flexibility and Scalability: Off-grid applications, dispersed energy generation, and phased expansion per demand are just a few of the versatile deployment possibilities made possible by the modular design of SMRs.

Cost-Effectiveness: SMRs can reduce financial risks through additional investment, accelerated building schedules, and upfront capital expenses linked with nuclear power plants.

System Stability and Resilience: By supplying dependable base load power and lowering reliance on sporadic renewable energy sources, SMRs may promote system stability.

Decarbonisation: Nuclear energy, which includes SMRs, provides a low-carbon substitute for fossil fuels, assisting in the fight against climate change and the achievement of emissions reduction goals.

Significance of Small modular reactor

Smaller Size: SMRs are intended to be substantially smaller than conventional nuclear reactors. Its minimised footprint makes it simpler to site in various settings, such as industrial complexes, distant areas, and cities.

Modular designs: Modular parts produced at a factory and delivered to the assembly location are used to build SMRs. This modular method allows for incremental capacity increase as needed, while also cutting down on building time and costs.

Enhance safety measure: Advanced safety features are incorporated into several SMR designs in order to reduce the risk of nuclear accidents. Passive cooling systems, built-in safety precautions, and reactor designs that are simpler and less likely to experience core meltdown or radiation leakage are a few examples of these characteristics.

Role of SMRs in addressing energy security concerns

Small modular reactors play a significant role in supporting and addressing the energy security concerns. The following points are mentioned below to highlight and explain the relevance of this powerful technology.

Resilience to disruption

Considering that SMRs may be spread over several sites and deployed in smaller increments than large-scale nuclear reactors, they provide a more robust energy source. The impact of disruptions like natural catastrophes, terrorist attacks, or grid outages is lessened due to this resilience.

Flexibility in Siting

Smaller and off-grid areas are good places to install SMRs because of their modular architecture and reduced size compared to areas with limited access to large-scale infrastructure. By delivering dependable power generation in locations where conventional energy sources could be limited or unstable, this capability improves energy security.

Reduced Dependency on Imports

SMRs can be installed in places like rural or off-grid areas where access to large-scale infrastructure is restricted because to their smaller size and modular architecture. By supplying dependable power generation in locations where conventional energy sources could be limited or unstable, this capability improves energy security.

Flexibility of Small Modular Reactors in deployment

- **Suitable for Remote Areas**: Remote or isolated areas with little access to centralised power infrastructure are ideal locations for SMR implementation. They are simpler to move and install in difficult locations like islands, rural towns, or military posts because of their lower size and modular architecture.

- **Integration with Existing Grids**: SMRs can operate independently or as a component of a distributed energy generation network, and they can be easily included into the current electrical grids. Because of its adaptability, power generation can be optimised to suit changing demand patterns and the current infrastructure may be used more effectively.

- **Adaptability to Changing Energy Needs**: SMRs' modular design allows for flexible capacity growth to accommodate changing energy needs over time. A scalable and affordable method of coping with potential increases in energy consumption is the progressive addition of new modules as required.

All things considered, SMRs have a number of special qualities that set them apart from conventional nuclear reactors and make them an effective option for solving issues related to energy security, especially in areas with poor access to extensive infrastructure. The small modular reactors (SMRs) are a viable solution to address the various energy needs of communities, industries, and countries worldwide because of their reduced size, improved safety measures, modular design, and flexibility in deployment.

Introduction of Nuclear Energy in Pakistan's Energy Portfolio

A vital component of Pakistan's energy mix, nuclear energy promotes economic growth, environmental sustainability, and energy security in the nation. Pakistan is home to multiple nuclear power facilities, such as the Chashma Nuclear Power Plant and the Karachi Nuclear Power Complex, which combined account for a sizeable amount of the nation's electrical producing capacity. By decreasing Pakistan's dependency on imported fossil fuels and lessening the effects of supply disruptions and shortages, nuclear power helps diversify the country's energy mix. Furthermore, Pakistan can satisfy its increasing electrical needs, especially in urban and industrial areas, with the use of nuclear energy, which also helps to lower greenhouse gas emissions and solve air pollution issues.

Small Modular Reactors (SMRs) have the potential to provide economic advantages beyond just producing power. These advantages may include the transfer of technology, the creation of jobs, and the growth of local industries. Below is the explanation of these aforementioned advantages:

- **Job Creation**

SMR deployment initiatives have the potential to generate jobs in a number of industries, including manufacturing, operations, engineering, and construction. SMRs' modular design frequently necessitates on-site assembly and installation, which generates employment opportunities in the surrounding areas.

Research has indicated that nuclear energy initiatives, such as small modular reactors (SMRs), possess the capacity to produce a substantial workforce. For instance, according to a report by the US-based Nuclear Energy Institute (NEI), building and running a single SMR might generate thousands of direct and indirect jobs ("Small Modular Reactors: A Jobs-Creation Platform." , 2021).

In addition, steady job possibilities in fields like plant operations, maintenance, and support services are facilitated by the long-term operation and upkeep of SMRs.

- **Local Industry Development**

- As materials and components for SMRs are frequently manufactured locally or regionally, the deployment of SMRs might encourage the expansion of regional manufacturing and supply chain sectors. Supply chain localization has the potential to advance industrial development and strengthen economic resilience.

- Governments and industry partners can facilitate the growth of local industries by implementing focused legislation, offering incentives, and implementing capacity-building efforts. Partnerships, for instance, between SMR developers and regional manufacturers can promote information sharing and technology transfer, resulting in the creation of specialised competencies (Agency, 2020).

- Through the cultivation of a home grown nuclear sector, nations can lessen their need for foreign machinery and technology, augmenting energy security and advancing economic autonomy.

❖ **Technology Transfer**

The implementation of SMR presents prospects for international technology transfer and knowledge exchange, especially between technology developers and host nations. This knowledge exchange can hasten the creation and application of domestic nuclear energy capacity.

• Partnerships and international cooperation are essential for enabling technology transfer in the nuclear energy industry. For instance, agreements pertaining to technology licensing, cooperative research and development, and localised employee training may be included in the agreements between SMR developers and host nations.

• By encouraging innovation, standardization, and cost savings, technology transfer helps the nuclear sector worldwide as well as the host nation. The countries may increase energy security and sustainability and hasten the implementation of SMRs by utilizing global best practices and expertise (Association, 2021).

When evaluating Small Modular Reactors (SMRs) for Pakistan's energy requirements, it is important to take into account a number of important factors

- Power Demand: Pakistan's population growth and industrialization are driving up the country's need for electricity. Through the production of dependable and scalable electricity, SMRs could enhance the current power generation infrastructure. SMRs can provide flexibility in addressing fluctuating electricity demand, according to a report by the International Atomic Energy Agency (IAEA), making them appropriate for nations with changing energy needs like Pakistan (IAEA, 2018).

- Grid Infrastructure: Transmission losses, inefficient distribution, and unstable grids are some of the issues Pakistan's grid infrastructure must deal with. By enabling localised power generation, lessening the load on the central grid, and enhancing grid resilience, SMRs could assist in addressing these issues. The Pakistan Atomic Energy Commission (PAEC) conducted a study that demonstrates how SMRs might improve grid resilience and stability (PAEC, 2020).

- Economic Viability: In Pakistan, the economic viability of small-scale gas-fired power plants (SMRs) is contingent upon various factors, including initial investment costs, ongoing operational expenditures, fuel supply, and electricity rates. According to a

World Nuclear Association comparative cost analysis, SMRs could provide a levelized cost of energy (LCOE) that is competitive with traditional large-scale nuclear reactors, particularly in areas with inadequate grid infrastructure (Association., 2021).

- Regulatory Frameworks: Pakistan's nuclear energy regulatory framework includes safety guidelines, authorization processes, and supervision systems. In order to evaluate the viability of SMRs, compliance with international safety standards and conformity with current regulatory frameworks are necessary. Research conducted by the Pakistan Nuclear Regulatory Authority (PNRA) sheds light on the legal requirements for the installation of SMRs in Pakistan ((PNRA), 2019).

- Security and Non-Proliferation Considerations: It is critical to assess the security and non-proliferation implications of SMRs in light of Pakistan's geopolitical situation and worries about nuclear proliferation. To reduce possible dangers related to nuclear technology transfer and proliferation, strong safeguards, physical protection measures, and international collaboration channels are crucial.

- Regional Production and Technology Abilities: Evaluating Pakistan's domestic manufacturing capacity and technological know-how is crucial to determining whether the deployment of SMR is feasible. For SMR construction, operation, and maintenance, utilising local resources, labour skills, and infrastructure could improve knowledge localization, technological transfer, and economic development.

International Case studies of small modular reactors deployment

Although the field of Small Modular Reactors (SMRs) is still in its nascent stages, there are several noteworthy case studies and practical instances where SMRs have been implemented or are being considered for implementation. These illustrations show the wide range of uses and possible advantages of SMRs in different situations. Here listed below are few:

1. **NuScale SMR (United States)**

At the forefront of SMR development is the US-based company NuScale Power. The U.S. Nuclear Regulatory Commission (NRC) has approved their 12-module SMR design, and it has been suggested that the site of Idaho National Laboratory host its implementation. The Carbon-Free Power Project seeks to validate the safety and commercial feasibility of NuScale's SMR technology (Power, 2021).

Furthermore, NuScale has inked contracts with utilities and governments across the US, Canada, and other nations to investigate the use of SMRs for a range of purposes, such as desalination, district heating, and electricity production (Power, Global Projects , 2021).

2. **Rolls-Royce SMR (United Kingdom)**

- Rolls-Royce has been working on an SMR design in the UK to produce electricity that is both affordable and low-emission. The business has suggested building SMR power plants throughout the UK, with the first one anticipated to be online by the early 2030s (Rolls-Royce, 2021).
- The UK government has backed Rolls-Royce's SMR programme with cash and indicated support for the development of SMR technology. The initiative intends to support the nation's goal of having net-zero carbon emissions, generate thousands of employment, and encourage the growth of local industries (Government, 2021).

3. **CAREM SMR (Argentina)**

Argentina is the developer of the Central Argentina de Elementos Modulares (CAREM) SMR, a pressurised water reactor (PWR) with an approximate 25 megawatt power output. Together with assistance from the International Atomic Energy Agency (IAEA), the Argentine government and regional industrial partners are working on the CAREM project (Atómica, 2021)

The CAREM SMR is made to assist industrial uses like desalination and process heat while also supplying electricity to rural and remote areas. The project's objectives are to show that Argentina's native SMR technology is feasible and profitable, and it may even export SMR technology to neighbouring nations (Agency, CAREM, 2021).

These case studies illustrate the various ways in which SMRs are being used to address energy-related issues, foster economic growth, and mitigate climate change. They additionally demonstrate the advancement and promise of SMR deployment in various nations.

In Case of Pakistan's specific requirements here are few small modular reactors to be considered

A thorough evaluation of SMRs' suitability for Pakistan's energy demands can be carried out by looking at these variables and citing reliable sources that come from government agencies, international organizations, and scholarly publications.

To assess potential Small Modular Reactor (SMR) designs and technologies for implementation in Pakistan, it is imperative to take into account multiple criteria, including safety attributes, scalability, affordability, and appropriateness for regional conditions. An overview of a few small modular reactor designs and technologies is provided below,

1. **NuScale SMR**: One scalable module in NuScale's SMR architecture can generate 60 megawatts of electricity. Because of its modular design and passive safety features, it may be used in Pakistan's energy sector. Because of its scalability, Pakistan can fulfil its fluctuating energy needs with a variety of deployment options. The NuScale reduces the danger of accidents and enhances safety by including modern safety measures like passive cooling systems and underground containment structures. Further the modular construction element of NuScale's SMR is manufactured in a factory and then

transported to the assembly site, which may have advantages for project management, construction schedules, and cost effectiveness if used in Pakistan. Subsequently, as the advanced technology the NuScale's SMR makes use of sophisticated reactor technology and has advanced significantly in the commercialization process, giving assurances on its viability and deployment readiness. Lastly the NuScale's safety features have drawn a lot of attention, and the company is getting closer to going commercial (Agency, Nuclear Safety and Security Framework, 2021).

2. **Rolls-Royce SMR**:

3. An SMR design being developed by Rolls-Royce is intended to produce 440 megawatts of electricity. Their design places a strong emphasis on dependability, simplicity, and quick construction. Rolls-Royce has engaged with regional partners to investigate the suitability of its SMR design for various markets, and the company has suggested its deployment in a number of countries (Rolls-Royce, Rolls-Royce SMR, 2021). This increased output for Pakistan might be appropriate for locations with higher energy use or grid systems. The simplified Rolls-Royce's SMR design places a strong emphasis on dependability, simplicity, and a shorter building period. These features may have benefits for project schedules and cost-effectiveness. Moreover, the advanced safety elements of building on its experience in nuclear reactor technology and safety, Rolls-Royce have integrated advanced safety elements into the design of its SMR.

4. **GE Hitachi SMR**: The BWRX-300 SMR, a project being developed by GE Hitachi, is intended to produce 300 megawatts of electricity. The design contains cutting-edge safety features and builds on the company's experience with boiling water reactor (BWR) technology. GE Hitachi has evaluated whether its SMR design is ready for commercial deployment by conducting feasibility studies and interacting with regulators (BWRX-300, 2021). All things considered, the power output, safety features, ease of design and construction, fuel flexibility, and global support provided by the GE Hitachi BWRX-300 SMR may make it an appealing choice for meeting Pakistan's energy needs.

5. **CAREM (Central Argentina de Elementos Modulares)**: A pressurised water reactor (PWR) with a power output of about 25 megawatts is a feature of the indigenous CAREM SMR design from Argentina making it suitable for smaller grid systems or remote areas in Pakistan. The Small size, passive safety measures, and the possibility of local manufacturing are highlighted. CAREM features a modular design that allows for incremental capacity expansion and simplified construction, potentially reducing costs and project timelines. CAREM has been tested and evaluated in Argentina and

may be used as a template for the implementation of SMR in other nations (Atómica, 2021).

Policymakers and stakeholders in Pakistan can make well-informed decisions about the most promising solutions for deployment in the nation's energy sector by assessing various SMR designs and technologies based on their technical attributes, safety features, and commercial readiness. To further improve the evaluation process, experts' advice and feasibility studies tailored to Pakistan's needs should be undertaken.
In order to facilitate the adoption and integration of Small Modular Reactors (SMRs) into Pakistan's energy portfolio, suggestions for policymakers, industry stakeholders, and other pertinent players must take a holistic approach that takes into account technical, regulatory, economic, and social factors. The following suggestions are listed below:

1) **Provide a Clear Regulatory Framework**

    a. Pakistan has to create a regulatory framework that is specific to SMRs in order to preserve the environment, ensure safety, and encourage investment and innovation. To make it easier to deploy SMRs, this framework should make details like safety requirements, licensing processes, and supervision systems clear. Enhancing credibility and regulatory harmonization can be achieved by cooperation with international regulatory bodies and peer review procedures (Agency, Nuclear Safety and Security Framework, 2021).

2) **Invest in Research and Development**: Research and development (R&D) projects centred on SMR technologies, such as materials science, innovative manufacturing methods, fuel cycle innovation, and design optimization, should receive funding from Pakistan. Enhancing local expertise and accelerating technical developments can be achieved through academic institution collaboration and public-private collaborations.

3) **Facilitate Public-Private Partnerships**: Pakistan should promote cooperation in the financing, development, and implementation of SMRs amongst government agencies, businesses in the private sector, and foreign partners. Public-private partnerships have the potential to overcome finance constraints and expedite project deadlines by using resources, knowledge, and risk-sharing mechanisms. To encourage private investment in SMR projects, incentive mechanisms like tax breaks, loan guarantees, and regulatory support might be established (Group, 2020) .

4) **Promote Human Capital Development:** To create a workforce with the necessary skills for developing, running, and maintaining SMRs, Pakistan should make investments in training and capacity-building initiatives. This covers specialist instruction in project management, safety analysis, nuclear engineering, and regulatory compliance. Skill development and technology transfer can be facilitated through cooperation with foreign organisations and knowledge transfer initiatives ((IAEA), 2021).

5) **Encourage Public Knowledge and Stakeholder Engagement:** To foster trust, address concerns, and raise public understanding of the advantages and hazards of SMRs, Pakistan should interact with stakeholders, such as nearby communities, civil society organisations, and environmental groups. Open dialogue, public hearings, and platforms for including stakeholders can help make decisions more informed and help SMR initiatives get support. SMR deployment can garner political and popular support by emphasising the possible socioeconomic benefits, such as job creation, energy availability, and industrial development (Agency, Stakeholder Involvement, 2021).

By putting these suggestions into practice, Pakistan may foster an atmosphere that will make it easier for SMRs to be adopted and integrated into its energy mix, improving energy security, fostering economic growth, and slowing down global warming.

Recommendations for overcoming the challenges and barriers to SMR adoption in Pakistan include: To further improve the feasibility and efficacy of SMRs in Pakistan, the following areas warrant more study and improvement in the future.

The following are some suggestions for removing the obstacles and hurdles to SMR adoption in Pakistan:

- The concerned authorities need to create a transparent and unambiguous legal framework that is adapted to the unique features of SMRs.
- Further there should be improving stakeholder consultations, open communication, and educational initiatives to raise public knowledge and engagement.
- Government should form public-private partnerships to use global resources and knowledge to finance, develops, and deploys small modular reactors.
- Hence, investing in research and development will modernize SMR technology, improve effectiveness and safety, and reduce costs.
- Fostering collaboration among governmental agencies, commercial associates, educational establishments, and overseas collaborators to expedite the implementation of SMR and technology transfer.

SMRs, offer a viable way forward for Pakistan's energy future that will lead to economic growth, environmental sustainability, and energy security. Pakistan may realise the complete potential of SMRs and meet its energy objectives by tackling the obstacles and hurdles to SMR adoption and allocating resources towards research, development, and cooperation.

Conclusion

To sum up, there is a great deal of promise in Small Modular Reactors (SMRs) to help Pakistan overcome its energy problems and shape its energy destiny. SMRs are able to generate power in a dependable, adaptable, and sustainable manner because of their distinctive features, which

include their lower size, modular design, and improved safety features. SMRs provide Pakistan several advantages, including as improved grid stability, decreased reliance on foreign fuels, energy mix diversification, and greenhouse gas emission reduction. However, there are a number of obstacles and challenges to the deployment of SMRs in Pakistan, such as lack of funding, public acceptance, technological preparedness, and regulatory obstacles. Policymakers, industry stakeholders, and other pertinent actors must work together to create clear legislative frameworks, encourage public awareness and involvement, enable funding methods, and invest in order to overcome these obstacles and realise the full potential of SMRs.

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