Small Modular Reactors and the Future of Global Energy Security

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ABSTRACT: As countries seek reliable and low-carbon energy sources to meet growing electricity demand and climate goals, nuclear energy has regained global attention because of its ability to provide stable, clean, and secure power. However, the high cost, long construction time, and large infrastructure requirements of conventional nuclear power plants have limited their wider adoption. In response, Small Modular Reactors (SMRs) have emerged as a promising alternative offering greater flexibility, lower upfront costs, and the potential to improve energy security. This paper examines whether SMRs can realistically strengthen global energy security over the next two to three decades and identifies the conditions that determine whether countries, particularly developing and energy-import-dependent states can benefit from their deployment. This paper analyzes two connected questions. First, to what extent can SMRs plausibly strengthen global energy security over the next two to three decades? Second, what conditions determine whether a given country is likely to capture the energy security benefits of SMRs rather than inherit new vulnerabilities? It concludes with policy recommendations for countries considering SMR deployment.

KEYWORDS: Small Modular Reactors, Energy Security, Nuclear Energy, IAEA, Energy Policy

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Introduction

Energy is the basis of today's civilization. Reliable and secure access to electricity is critical for nearly all aspects of human development. It promotes food production, provision of clean water, provision of health services, education, industrial growth, and digital connectivity. A failure in electricity supply is no laughing matter beyond the mere lack of electricity. During critical medical procedures, hospitals can experience power outages, irrigation systems can fail during the growing season, heating and cooling may turn unreliable in extreme weather, and economic productivity may be lost. These disruptions have the effect of lowering living standards and exacerbating poverty, especially in developing countries.

Even though there has been considerable progress in increasing the generation capacity of electricity, it is one of the greatest challenges in the world today to provide secure and sustainable electricity. Over the past decade, the growth of renewable energy has been swift, particularly in the cases of solar PV and onshore wind energy. The price for solar electricity has dropped by some 89 percent, and onshore wind has dropped by some 70 percent from 2010 to 2023. This has led to renewable power accounting for the majority of the new additions in electricity generation capacity globally, with solar power in 2023 leading the additions in the world (International Energy Agency, 2023).

But the growth of renewables has not put an end to worries about energy security. The need for electricity is growing due to population growth, industrialization, urbanization, and digital transformation. Meanwhile, governments are increasingly being challenged to cut GHGs and provide secure and affordable electricity. Security of energy is thus one of the most prominent policy concerns of the twenty-first century.

It is especially difficult in less developed areas. The IEA (2024) estimates that 775 million people remain without electricity access, mostly in Sub-Saharan Africa and South Asia. Furthermore, almost two billion people have access to electricity but still suffer from unreliable or insufficient supplies of energy, and lack access to affordable energy (Mukherjee Ishani, 2011)

Ensuring access to electricity to meet the electricity demand of these populations, while simultaneously achieving climate goals, is one of the biggest challenges globally.

To meet these challenges, governments and international organizations are now more interested in nuclear energy. Nuclear power is a continuous energy source, unlike intermittent renewable energy, which is not renewable for decades. It additionally minimizes reliance on imported fossil fuel resources and boosts long-lasting energy security (Tuhus-Dubrow, 2025)

But traditional nuclear power plants have suffered from numerous problems, such as long construction periods, high costs, complicated regulatory procedures, security concerns, and issues of nuclear proliferation World Nuclear Association, 2025).

The conventional nuclear reactor is large, producing power of more than 1,000 MW, and has high initial capital cost and needs a broad supporting infrastructure. They also require sizeable, well-integrated electric power grids to efficiently integrate their power supply. They are too complex to be used in many developing countries due to the requirements. Often these construction timeframes are 10 to 20 years, making their quick response to energy shortages and climate commitments difficult (Locatelli et al., 2014).

The constraints have pushed the development of Small Modular Reactors (SMRs). According to the International Atomic Energy Agency (IAEA), SMRs are nuclear reactors with a capacity of up to 300 MW per unit. They are different from conventional reactors in that they are intended to be fabricated in a high proportion in factories and then shipped to the installation site to be assembled (IAEA, 2020). Construction time should be shorter, quality control better, and initial capital costs are expected to be lower due to factory-based production.

In addition, their compact size is suited for remote areas and countries with smaller electricity distribution systems. Active mechanical systems are not the only safety systems found in many SMR designs; passive physical processes that occur naturally can also be used for safety purposes (Thomas, 2024). Some designs may also be able to use less water or be installed underground for additional flexibility in site selection.

Methodology

This research is qualitative and document-based and deals with the contribution of Small Modular Reactors (SMRs) to the enhancement of global energy security. A qualitative approach is suitable as SMRs are still a new technology. The interest in SMRs has been on the rise in recent years, but only a few projects have progressed to the construction or operating phase. Currently, most designs of SMRs are still in the development or regulatory review phase. Therefore, there is not much operational and quantitative data available, and it is not suitable to make a purely statistical analysis.

The study mainly relies on official reports and publications from the International Atomic Energy Agency (IAEA) and the International Energy Agency (IEA). These include IAEA's Advanced Reactor Information System (ARIS), the 2024 Advances in Small importing countries.

As many studies do in the Strategic Modular Reactor Technology Developments report, the IEA's World Energy Outlook 2024, and other reports on the role of nuclear energy in the global energy transition. These sources include the latest data on SMR technologies, the number of designs in development, and progress in regulation and deployment of SMRs around the world.

Besides the institutional reports, the study has included a literature review of peer-reviewed academic publications on the technical, economic, safety, and policy aspects of SMRs. To provide a balanced analysis, both supporting and critical perspectives are included in the paper. Several studies have noted the benefits of SMRs in terms of enhancing energy security and enabling decarbonisation, but other studies have cast doubt on the economic viability, construction costs and competitiveness of SMRs. The studies of Ramana (2021) and of Friess et al. (2026) are included in particular because they present one of the most complete criticisms of SMR economics. It would be a double-edged sword to consider just one of these and leave the other one out, so you want to take both of these factors into account when assessing the technology.

The analysis is done in three steps. The paper first reviews the status of SMR development around the world based on the information provided by the IAEA and IEA. Second, it summarizes the central arguments for the contribution of SMRs to energy security, and the central challenges and criticisms that have been raised in the literature. Finally, it discusses the circumstances and conditions in which SMRs can best contribute to energy security, especially in developing countries and energy studies and energy policy. This research employs document analysis as a research method to analyze an emerging field with little evidence of operations on a large scale. Many of the conclusions about the cost, performance, and commercial viability of SMRs are based on current research, official projections, and initial demonstration projects. Therefore, the results are preliminary and may vary when more SMRs are in service in the future.

Results

Global Growth of SMRs

Institutional reports have been reviewed, and it is clear that the development of SMRs has picked up considerably in the last five years. The IAEA's report on Advances in Small Modular Reactor Technology Developments (2024) shows that over eighty SMR designs are being developed worldwide, with the number steadily increasing since the 2011 report (IAEA, 2011). Sixty-eight designs have advanced to the stage of measurable technical and/or regulatory progress, suggesting that many projects are past the conceptual phase (IAEA, 2024).

The SMRs currently being developed will be land-based light-water reactors as well as floating light-water reactors, high-temperature gas-cooled reactors, fast-neutron reactors and microreactors for remote and isolated locations. Not only that, but the IAEA reports that there are now almost two-thirds of all SMR designs that do not use water as a coolant, with gas, molten salt or liquid metal used instead. This indicates that innovation is now beyond the traditional reactor technologies (IAEA, 2024).

Growing International Support

The pace of SMRs' growth has also been enhanced by growing interest in international policy and financial support. International financial institutions were not keen on financing nuclear projects for many years. But this is beginning to shift. In 2025, the World Bank agreed to enhance cooperation with the IAEA in the field of nuclear energy financing. The agreement was considered to be a significant step towards introducing nuclear energy in the clean energy investment field, including SMRs (World Economic Forum, 2025).

The IAEA has also raised its forecast for nuclear power generation for the world in its long-term forecasts, which it has done for the past five years. Even as part of the low growth scenario, the global nuclear capacity would be increased by approximately 50 percent by 2050, while under the high growth scenario, it would increase two and a half times compared to the current level (World Economic Forum, 2025).

Electricity demand is also forecast to nearly double by 2050, driven by economic growth, the increasing electrification of transport and the dramatic growth of data centres, according to the International Energy Agency (IEA). The IEA believes that nuclear (including SMRs) will be a growing part of the mix to satisfy this demand and help phase out fossil fuel use. The Agency also notes, however, that this will not be enough to secure the necessary investment for future nuclear expansion, which will be massive, as this will require private investment (IEA, 2024).

SMRs will be especially significant in terms of their importance. The importance of SMRs will be particularly relevant. The scholarly sources list some of the reasons why SMRs are increasingly considered as an instrument to enhance energy security. Several reasons are mentioned in the literature to explain the perception of SMRs as an instrument to increase energy security.

Firstly, they are smaller in size, so they can be utilized in countries with relatively small electricity grids, remote areas, or where large conventional reactors are not viable. This is especially appealing to many developing nations, of which SMRs are a growing part.

Second, SMRs are meant to be factories, and reactor modules are built at the installation site. The strategy will cut down on construction time, quality assurance, and the problems of cost overruns on numerous large-scale nuclear initiatives.

Thirdly, 3rd generation SMRs can contribute to diversifying national energy systems. SMRs can help countries with high dependency on imported coal, oil or natural gas to boost the domestic production of electricity from a trusted and low-carbon fuel. This can involve minimizing exposure to fluctuations in fuel prices and help to improve long-term energy security.

Economic Challenges

While these benefits may be realised, there are a number of key challenges to note from the academic literature. The most prevalent concern is the economics of SMRs. It is not that smaller reactors are automatically cheaper, since that would be the case, argues Ramana (2021). Construction costs are also not directly proportional to the reactor size, leading to SMRs having higher costs per unit of electricity than large nuclear reactors. This is a drawback that can be overcome only if SMRs can be manufactured in a factory-based scale of 1000's, which has not yet been done, said Ramana.

This concern is also justified based on history. Little reactors constructed in the United States in the 1950s and 1960s were shut down due to their inability to compete economically with the end of government subsidies (Ramana, 2021). The NuScale-UAMPS project in the USA was cancelled more recently due to significant increases in estimated project expenses. For the first-of-a-kind SMR projects, as in the case at hand, financial uncertainty exists, even in countries with robust nuclear industries, as explained by Ramana (2024).

These concerns are especially significant for developing countries. According to Friess et al. (2026), many developing country policymakers believe that SMRs will be a source of affordable electricity, an already proven technology, and domestic production. But the authors say that those hopes might be misplaced, as few designs for SMRs are actually operating. This implies that there is a mismatch between the expectations about SMRs and their commercial maturity. There are regulatory and security issues to be addressed. Regulatory and security issues have to be dealt with.

Apart from the economic issues, the literature also encompasses a number of regulatory and security issues. A variety of SMR designs are based on technologies that are very different from traditional nuclear power plants. Thus, traditional regulatory systems are not necessarily applicable to these new systems. To reflect the unique features of SMRs, the IAEA has therefore started to review and revise international safety standards (IAEA, n.d.-a).

Security is a consideration as well. Some SMR designs are to be used in remote locations, to operate without any operator, or to be part of high-end fuel cycles, which poses new security and safeguarding challenges. To address these concerns, IAEA has created a dedicated Nuclear Security Working Group and is creating technical guidance for SMRs (IAEA, 2024).

New challenges are also being posed to the national regulatory institutions. As SMR programmes proceed, it is likely that regulators will be increasingly faced with the challenge of speeding up licensing processes, as proposed by Ramana and Blaise (2024). This pressure may impact the independence of safety reviews, unless there is appropriate regulatory capacity built up along with reactor deployment.

Overall, the results indicate that SMRs have a significant potential, but their contribution to energy security will rely not just on technological advancements, but also on robust regulatory institutions, good governance and realistic economic planning.

Regional Perspective

The results of this study are of relevance to South Asia as the region experiences high growth of electricity demand while a number of the countries continue to struggle with energy security problems. The region continues to be highly reliant on imported fossil fuels, with several countries facing increased electricity prices, shortages, and power sector financial challenges. These conditions have stimulated interest in alternative supplies of reliable, low-carbon electricity.

Pakistan is a good example in this regard. The nation is one of the oldest civilian nuclear programmes of developing countries. It started with the Karachi Nuclear Power Plant (KANUPP) under the Atoms for Peace programme and was extended with the other reactors at Chashma and Karachi. This has enabled Pakistan to build up the technical expertise, regulatory institutions and operational capacity which other countries that are looking to deploy SMRs for the first time are not yet equipped with.

Despite this experience, Pakistan still faces serious problems in its energy sector. High electricity cost, circular debt and reliance on imported fuels are still a concern. Thus, the future deployment of SMRs will rely on their technical performance as well as on their financial affordability and economic viability.

To address this, the IAEA has stepped up its interactions with developing countries that are interested in SMRs. In 2024, the IAEA's SMR Platform held deployment workshops for countries such as Jordan, Mongolia, Myanmar, Indonesia, and Thailand, to assist in planning, regulatory development, and capacity building. (IAEA, 2024) These efforts illustrate that SMRs are more than just a reactor technology. Countries must also have good institutions, human resources with the skills, regulatory frameworks, and long-term planning.

The impact of SMRs on energy security in import-dependent countries like Pakistan will thus rely on multiple factors. These include availability of low-cost financing, technology transfer arrangements, long-term fuel supply, and building of regulatory and institutional capacity. The potential energy security benefits of SMRs could be challenging if these supporting conditions are not met.

Discussion

A more complex relationship between SMRs and energy security is indicated by the findings above, as both proponents and opponents of SMRs are often over-optimistic. The development of SMRs is not an off-the-radar or purely experimental initiative, but rather a part of the current design pipeline, the participation of key international institutions, and a change in the financing posture of institutions such as the World Bank (IAEA, 2024; World Economic Forum, 2025). Concurrently, the literature reviewed here indicates that the economic arguments presented for SMRs are still not commercially scalable and that early experiences of the deployment of this technology, including the cancellation of prominent projects, should temper expectations of the speed and cost at which this technology can be deployed (Ramana, 2021, 2024).

This tension can be seen in the multi-dimensional notion of energy security that was introduced in this paper earlier. With a domestic energy source that is low-carbon, low-dependency, and not as susceptible as imported gas or coal to fluctuations in international fuel markets, SMRs could be used to support the availability and diversity aspects of energy security, potentially. There is the potential that SMRs can contribute to energy security through the diversity and availability dimensions – specifically by providing a domestic, low-carbon energy source, and not dependent on volatile international fuel markets in the same way as imported gas or coal.

They may, however, simultaneously have a negative impact on the affordability and resilience aspects of energy security, especially in the case of countries with limited fiscal space, if they are more costly than alternatives or if they rely heavily on foreign vendors for design, fuel, components and/or long-term technical support. So, SMRs are not necessarily a panacea for energy security; they just add to the nature of the risk which a country carries, and move it from fuel supply risk to financing risk, dependence on technology, and regulatory risk.

This risk distribution is important to developing and import-dependent economies, such as Pakistan, which suffer from chronic energy shortages and limited public funding. The results of Friess et al. (2026) suggest that expectations among officials in developing nations for low costs, proven technology, and local manufacturing prospects from SMRs are not yet substantiated.

While SMRs could certainly be a technically viable route to low-carbon baseload in a nation like Pakistan, which already has a long-established civilian nuclear programme with the Karachi Nuclear Power Plant under the Atoms for Peace initiative, it may still be a technically viable option for smaller and less developed parts of the grid. But the results of this paper seem to indicate that in order to realize this potential, one must be realistic about the financing costs, have a regulatory body with enough technical expertise and independence to supervise new and unproven designs, and have a realistic idea of how dependent the country will be on foreign vendors for fuel and technical support during the lifetime of the reactors.

In the strategic studies context, the security aspect of SMR deployment needs to be highlighted as well. It is clear from the IAEA's progress report that the security architecture for SMRs is still in the process of catching up to the rapid technological advances (IAEA, 2024), and concerns have arisen regarding remote or autonomous operation as well as non-traditional siting. This not only affects the physical security of nuclear material but also the securitisation of the energy sector as a policy field, where the planning and decision-making of energy policy are increasingly interwoven with questions of national security and/or questions of regulatory sovereignty, as well as questions of technological dependence on foreign suppliers.

It is also important to mention one caveat of the term used in the context of SMRs: 'energy security '. Most institutional sources (like the IAEA and IEA) consider energy security mostly in terms of supply adequacy and decarbonization compatibility, mostly from a large, technologically advanced economy with a well-established regulatory system.

Most institutional actors (e.g., IAEA, IEA) focus primarily on the available supply and its compatibility with the decarbonization process from a technologically advanced large economy with a well-developed regulatory system. In contrast to critical academic literature, though, costs are accentuated, and technical maturity and the modesty of expectations are more prominent, sometimes in a broader, global, comparative context (Ramana, 2021; Friess et al., 2026). Framing or content alone is not everything. An alternative approach and one consistent with the multidimensional energy security literature (Cherp & Jewell, 2014) is to examine SMR deployment country-by-country and determine whether SMRs would benefit or worsen the energy security situation of a country based on their own particular mix of import dependency, fiscal capacity, regulatory maturity, and country strategy.

All in all, these results indicate that SMRs are not a panacea for energy insecurity, but rather an option that needs to be deployed in a given institutional setting. States that have sufficient funding, enforce credible regulation, and have realistic expectations of the cost and timeline are more likely to reap meaningful energy security advantages from SMRs. If states are already in a position to adopt SMRs, they are doing so because of a set of underlying conditions, but if they deploy SMRs without tackling these underlying conditions, they are taking one form of energy insecurity for another.

Conclusion

In this paper, it was analyzed whether Small Modular Reactors (SMRs) can contribute to global energy security and what conditions must be met to gain from SMRs in a country. The results indicate SMRs have progressed from a theoretical technology. Over eighty designs are being developed around the world and are gaining growing recognition from international institutions like the IAEA, IEA, and the World Bank. This emerging momentum suggests SMRs will continue to be a major consideration in the future of energy systems that are clean and reliable.

The study also highlights that the potential benefits of SMRs need to be looked at alongside their challenges. The economic competitiveness of SMRs is not yet clear, as many designs are not yet in commercial operation. Tremendous concerns remain about high costs, limited operating experience, regulatory requirements, and reliance on specialized technology suppliers that continue to affect their future prospects. The role that SMRs can play in energy security will thus be influenced by technological progress, as well as financial, institutional and regulatory factors in countries implementing SMRs.

They should be regarded as a supplement to the energy security strategy and not as a panacea for energy issues. Their potential to enhance energy security will depend on individual country circumstances, including energy demand, financial resources, regulatory readiness and long-term energy planning. SMRs can offer a possibility for developing and energy-import-dependent countries such as Pakistan to increase their supply of reliable low-carbon electricity generation, if only their deployment can be backed with realistic planning and strong institutional capacity

Way forward:

First, the governments should do a detailed economic assessment prior to the SMR projects, and should not only take optimistic calculations into consideration. It is crucial that the financial aspects of construction, financing, and long-term operating costs are transparent.

Second, countries interested in SMRs should build up their regulatory institutions and technical background. Many designs have been developed for SMRs, which are new technologies, and regulators need to possess adequate independence and capacity to provide effective safety and security oversight.

Third, SMRs must be part of broader energy policies—not an alternative to other energy options. A balanced approach of nuclear energy, renewable energy development, grid improvement and energy efficiency will yield more energy security benefits.

Lastly, deployment of SMR needs to be part of a strategic overview. Energy independence, technology access, fuel security and national resilience are also high on the agenda for nuclear energy decisions alongside technical and economic considerations. In countries like Pakistan, a crucial aspect of the successful rollout of SMRs will be the negotiations around financing, technology transfer, fuel supply arrangements, and long-term partnerships with international SMR developers.

There is a need for comparative case studies as more SMRs become operational. Much of the existing data are only projections or preliminary projects, so only a handful of operating SMRs will be able to indicate whether they can provide the promised benefits in terms of energy security.

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