MINILATERALS FOR SMALL MODULAR REACTORS: Cost Effective and Environmentally Sound Energy Transition Towards Global Net Zero

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Abstract

Small Modular Reactors (SMRs) endorsed as the au courant solution to the dire global energy crisis are still in the incipient stage of its designing and deployment. While developing countries like India have had SMRs on their policy line-ups for a couple of years now, they haven't translated to practical commercial options given the lack of a standardized design, augmented investments and delayed profits, and major security concerns. Minilateral partnerships with like-minded countries to homogenize SMR design structures, regulation and safety approaches, with a shared goal of meeting energy demands and achieving climate goals, will aid in facilitating a conducive environment for SMR deployment by improving capacity-building, proposing shared investment models, and subsequent global design standardization. This paper will make a case for the importance of a 'minilateral approach' towards the deployment of SMRs for developing and poor economies with collaborative endeavours, shared economic burden and reduced financial risks, tech-support from their developed allies to reach a green and sustainable future. SMRs will be key in increasing the nuclear energy share into the global energy grid. This paper analyzing such the advent of minilateral al1liances that will focus on green taxonomies and the incorporation of SMRs into the developing countries' energy agenda, will also shed light on the need for an extensively elaborate technology-neutral policy framework and international harmonization on achieving net-zero.

Keywords: Minilaterals, Net Zero, Design Standardization, Green Taxonomies, Energy Security, Private Investments.

1. INTRODUCTION

Small Modular Reactors (SMRs) have the potential to significantly contribute to both emerging and industrialized economies in supporting sustainable economic development while mitigating the effects of global climate change. The deep decarbonization of power systems is pivotal to global climate efforts, and SMRs could unlock new pathways for the global energy transition. Particularly in emerging economies with smaller energy grids and limited experience working in nuclear energy, SMRs present a promising option for advancing a sustainable energy transition. However, such a transition entails a plethora of intricacies beyond traditional systems, such as regional discrepancies, involvement of stakeholders, public acceptability, and the integration of SMRs into diverse power systems. A coordinated effort among all the relevant stakeholders and partner states is crucial for supporting industrial decarbonization and capitalizing on standardized SMR supply opportunities.

A minilateral approach—characterized by strategic partnerships among select countries—can streamline SMR deployment, facilitate technology transfer, and foster collaborative solutions. By leveraging these targeted alliances, stakeholders can overcome barriers, optimize resource use, and drive the widespread adoption of SMRs, thereby supporting global climate goals and sustainable economic growth.

2. GLOBAL NUCLEAR ENERGY LANDSCAPE, CLIMATE CONCERNS, AND COST-EFFECTIVE SOLUTIONS: WHERE DO SMRs FIT IN?

In the aftermath of the Covid-19 pandemic, debates vis-à-vis economic recovery at the detriment of energy transition progress have garnered considerable attention. States are increasingly shifting towards renewable energy, diversifying their energy grids, and adopting green taxonomies and recovery schemes to balance economic growth with environmental sustainability. Doubling the nuclear share in the global energy mix by 2050—from its current 10 percent—will be vital to achieving ambitious climate goals and addressing large-scale energy crises.

This deliberate shift requires significant changes in energy generation technologies and consumption practices, including greater reliance on low-carbon resources, improved energy efficiency, and the electrification of end-use demand. The transition will depend on the cost, degree, and speed of innovation in advanced nuclear reactor designs and waste management technologies. SMRs have an important role to play here. Consolidating a significant interest from both, the developed and developing world, SMRs with their small size, modular build-up and passive safety system, are manufactured in a controlled factory setting with an improved off-shore installation efficacy and hence, become easier to finance, when compared to large plants. However, the scale of the energy transition needed to support these techno-economic reactors may overwhelm emerging economies, necessitating issue-based partnerships to ensure successful integration into smaller energy grids.

2.1. Developing Countries and SMRs: Why Haven't They Become Practical Commercial Options?

Despite the growing global momentum for SMRs, particularly following initiatives like "Accelerating SMRs for Net Zero" and discussions at forums like COP28, developing countries have struggled to translate the promise of SMRs into viable commercial options[1]. This is largely due to economic constraints, technological limitations, and public acceptance challenges. SMRs require significant capital investment and a robust ecosystem, which can be daunting for countries with smaller power grids and limited technological resources.While state governments also push for a stable financial allowance for the nuclear sector at forums like the G20 and COP28, a feasible tech-led led foreign policy schema would be critical for collaboration on clean energy transition and SMR deployment[2]. With focused policies, quick learning rates and enough production, SMRs have the potential to reach economic conformity with fossil fuels and contest larger nuclear plants before 2050.

Targeted partnerships with like-minded nations could provide emerging economies with the necessary capital security, technology access, and the ability to leverage green taxonomies for energy transitions. When developing SMRs in emerging economies, it is especially important to have a globally harmonized decision-making mechanism in place. By collaborating through minilateral partnerships, these countries can share the economic burden, reduce financial risks, and access technological support from developed allies. Such partnerships would also help in the development of integrated energy systems, where SMRs complement renewable energy sources, and in establishing training programs and regional centers of excellence to build local capacity. On the other hand, a subpar decision-making process may lead to serious economic consequences, including high capital investments and ongoing operating expenses; moreover, issues of public acceptability may become critical overtime. Though, SMRs, with their potential for job creation and low costs, can address these issues effectively. Additionally, the involvement of the private companies can bring substantial investment, advanced technology, and innovative solutions tailored to the unique needs of developing countries[3]. They can play a key role in financing SMR projects, reducing the initial capital burden on national governments. Moreover, private sector engagement can drive innovation in SMR technology and create competitive market conditions that benefit emerging economies. By participating in international consortia, private companies can facilitate technology transfer, provide training, and establish local production capabilities. They can also collaborate with governments to develop favorable regulatory frameworks and streamline licensing processes, making SMR projects more viable. Furthermore, private sector involvement can stimulate job creation and support the development of local infrastructure, which is essential for building the necessary ecosystem around SMR deployment.

While still in the incipient stages of its development, as many as 80 designs for SMRs across almost 17 countries, are already in various stages of outlining and deployment as of 2020 with the global market for SMRs projected to reach 300 (U.S.) dollars by 2040[4]. Despite the multifold advertised benefits of SMRs, and the eventual cost-reductions, emerging economies with smaller power grids and limited technological resources tend to become less favourable towards initiating a large scale nuclear and financial commitment required to build from scratch, a feasible ecosystem for these advanced reactors given the economic intensiveness, lack of technological expertise and public acceptability and hence have not been able to translate into viable commercial options. However, with specific agenda-based small partnerships with like minded-nations, emerging economies will be beneficiary to capital security and technology access, along with the ability to tap at the green taxonomies allotted to energy transitions towards net-zeros.

3. UNPACKING MINILATERALS FOR SMRs: COMBATING COST, CLIMATE, AND HARMONIZATION

3.1. What are Minilaterals?

Minilateral alliances are small groups of like-minded countries with shared interests that form voluntary, informal, non-binding partnerships to focus on specific issues, here SMRs[5]. These alliances are particularly appealing to countries that value strategic independence but are willing to work collaboratively on common goals. Ideologically, it does not restrict a state to a specific directive, but instead allows for adaptability and agility in maintaining complete control to define the future of the coalition and its role in it. In contrast to the broader multilateral frameworks, that often entail politicization of governance issues, minilaterals offer the advantage of informality, selective membership, and a narrow focus, which can lead to more effective and targeted cooperation. Collaborative nuclear technology initiatives with developed countries that are already in the early stages of designing and manufacturing will aid developing states in incorporating SMR technologies into their energy mix.

In the context of SMRs, minilateral partnerships can address the specific needs and circumstances of different countries, including their energy grid sizes, population distribution, and economic sectors to enable clear and customized guidelines for planning, permitting and timelines, regulation and safety. This flexibility allows governments to foster stronger relationships based on mutual stakes, rather than being compelled to operate within the structure of a larger, less cohesive groups. Unlike multilateral partnerships deviated by separate interests, potential overlapping and pushing of a single state's own interests, when collaborating on SMRs, minilaterals will completely be dedicated to mutual goals, i.e., maintaining precision over standardization of designs, developing a stimulating framework by means of seed capital for innovation, stable supply chain, reliable evidences for proof of concept, demand creation and conducive policy environment can help navigate global investor interest. These alliances should particularly include developing states colluding with their developed partners, memorandums with industrial stakeholders, and national and international regulatory bodies to homogenize SMR design structures, regulation and safety approaches, with a shared goal of meeting energy demands and achieving climate goals, will aid in facilitating a conducive environment for SMR deployment by improving capacity-building, proposing shared investment models, and subsequent global design standardization. A 'minilateral approach' has the potential to play a crucial role in the deployment of SMRs for developing and poor economies build collaborative endeavours, with shared economic burden and reduced financial risks, tech-support from their developed allies to reach a green and sustainable future

3.2. Practical Applications of Minilateral Partnerships for SMRs

In practice, minilateral partnerships can significantly enhance the effectiveness and efficiency of SMR deployment. By pooling resources and expertise, these alliances facilitate accelerated technology transfer, streamline regulatory processes, and enable shared investment in innovation. This collaborative approach not only speeds up the development and deployment of SMR technologies but also fosters the creation of standardized designs that are more easily replicable across different regions. Additionally, minilateral partnerships contribute to building competent supply chains and supporting infrastructure, which are crucial for the widespread adoption and integration of SMRs into diverse energy systems. Such partnerships also promote the exchange of practices and lessons learned, further refining SMR technologies and deployment strategies for optimal performance and sustainability.

3.2.1. Cost and Knowledge Sharing

For fostering effective minilateral partnerships, the allies should support a technology-neutral policy and long-term regulatory framework for small modular reactors (SMRs), consider various clean energy technologies and address nuclear safety and a predictable legal framework to provide investor certainty throughout the lifetime of SMRs. Such an issue-based partnered approach will also help facilitate the initial capital demands, technology and knowledge exchange and improve public acceptance. It is often due to the added economic anxieties, delayed outcome benefits and tentative safety liabilities of constructing nuclear power reactors (NPPs) that some states become less favourable towards initiating a nuclear commitment. Such minilateral collaborations with atleast one technologically capable country and the inclusion of green taxonomies, green bonds to maintain societal and ecological governance, will help the emerging allies in bearing the brunt of the initial costs[6]. The technical costs will eventually decline, once experienced doyens in the private sector and additional international investors are drawn to partake in the manufacturing of SMRs. The technology and knowledge sharing will also benefit the alliance with quick manufacturing of SMRs and abide by the international standardized protocols for designing and deployment.

3.2.2. Public Acceptance

Minilateral agreements also play a significant role in shaping public perceptions and social acceptance of nuclear energy. The reputation of nuclear energy, often marred by historical accidents, misinformation, and safety hazards, has led to widespread skepticism and fear[7]. To counteract this, allied governments, alongside private companies and industries involved in SMR deployment, can launch comprehensive public awareness campaigns that emphasize the safety advancements, environmental benefits, and economic potential of SMRs. Engaging with local communities through transparent and inclusive outreach initiatives is essential to address safety concerns and build trust. Additionally, developing detailed plans for local manufacturing, operation, and maintenance of SMRs not only demonstrates commitment to safety but also creates job opportunities and stimulates local economies. This dual approach of addressing public concerns and promoting local benefits can foster a more positive attitude towards SMRs and facilitate smoother project implementation.

Minilateral agreements can also leverage targeted educational programs and stakeholder engagement to directly address and alleviate public concerns about SMRs. By fostering collaboration between governments, industry experts, and community leaders, these partnerships can effectively dispel myths, highlight the advancements in safety and technology, and ensure that local communities benefit economically and socially from SMR projects.

3.2.3. Harmonization and Standardization

The development of SMRs could serve as an opportunity to establish early international collaboration for the harmonization of licensing frameworks, codes, and standards. Achieving economic benefits through mass production of SMRs would require a large global market for a single design. To realize a global market and reduce the number of designs, multiple levels of regulatory harmonization will be essential. Minilateral alliances will play a constructive role in meeting both regional and international regulatory harmonization standards, thus expediting the commercialization of SMRs. Partnering with emerging economies can provide cheap labor to help with industrial harmonization, accelerating the maturity of designs, reducing construction and installation time, and optimizing overall costs. Minilaterals also enable the harmonization of high-level user requirements through information sharing on national standards and codes, and by accelerating the implementation of a nuclear infrastructure for SMRs[8]. This further declines cost of building and deployment and reduces. Minilateral licensing co-ordination and collaborations along with joint safety evaluations, can also foster design selection and standardization for SMRs.

Here, licensing SMRs presents a new opportunity for standardization, in the nuclear energy realm. There remains a status quo barrier bolstered by the existing licensing regimes making it difficult to propose renewed standardization practices. Minilateral alliances with a mutually agreed upon and periodically updated standardized licensing framework will enable smooth manufacturing of SMRs and provide streamlined opportunities for knowledge and experience sharing among partner states. By instituting common standards it endorses standardized reduced licencing timelines, costs and deployment times for SMRs.

International initiatives such as the Nuclear Harmonization and Standardization Initiatives (NHSI) have been established by the IAEA to enhance regulatory cooperation among countries, avoid duplication, and improve efficiency without compromising on nuclear safety and national sovereignty. The NHSI Regulatory Track makes important strides in global harmonization by building on its previous regulatory activities, while the NHSI Industry Track helps to develop a more standardized industrial approach for SMR deployment, manufacturing, and operations[9].

3.2.4. Interplay with Renewable Energy Sources

Minilateral cooperation on SMRs should also explore synergies with renewable energy sources to create more resilient and efficient energy systems. Countries could collaborate on developing hybrid energy systems where SMRs provide reliable baseload power, balancing the intermittency of renewable sources like solar and wind. This cooperation can be extended to include joint research on advanced energy storage technologies that store excess energy generated from renewables, as well as innovations in grid integration and smart grid development. By optimizing the use of both nuclear and renewable energy, these integrated systems can enhance overall energy security, improve grid stability, and accelerate the transition to a low-carbon economy. This approach not only supports a more stable and reliable energy supply but also maximizes the environmental benefits of clean energy technologies.

3.2.5. Global Governance and Non-Proliferation

Minilateral agreements must emphasize strict adherence to non-proliferation standards and security protocols. These partnerships should include provisions for shared responsibility in ensuring that SMR technology does not contribute to nuclear proliferation. Effective non-proliferation measures are critical to preventing the misuse of nuclear materials and technology, thereby avoiding potential threats to global security. Collaboration with international organizations like the IAEA is essential to align with global nuclear governance norms and maintain high standards of safety and security. Regular audits, transparent reporting, and joint security assessments should be integrated into these agreements to monitor compliance and address any potential risks. Furthermore, engaging with the broader international community to share best practices and lessons learned will enhance the overall effectiveness of non-proliferation efforts and support the sustainable development of SMRs

3.2.6. Scalability and Long-Term Viability

To ensure the long-term scalability and economic viability of SMRs, minilateral partnerships should focus on creating economies of scale by standardizing SMR designs across multiple countries. This approach can significantly reduce unit costs, streamline manufacturing processes, and foster a competitive market for SMRs. By harmonizing design specifications and production standards, these alliances can lower costs and facilitate more efficient production and deployment. Additionally, minilateral partnerships can explore joint ventures in manufacturing and supply chain management, optimizing resource use and accelerating delivery timelines. This collaborative effort can attract investment, stimulate innovation, and ensure that SMRs remain a viable and economically attractive option for energy transition in the coming decades. Emphasizing shared infrastructure and bulk procurement strategies will further enhance cost efficiency and market stability, supporting widespread adoption and integration of SMRs into diverse energy systems.

4. CHALLENGES

Despite the potential benefits of minilateral partnerships for SMRs, several significant challenges must be addressed to ensure successful deployment and integration. These challenges encompass a range of technical, economic, regulatory, and social issues that can impact the effectiveness and feasibility of SMR projects. Technical difficulties include maintaining high safety standards and ensuring operational reliability, while economic challenges involve managing substantial upfront costs and securing long-term funding. Regulatory hurdles necessitate harmonizing diverse licensing processes and safety standards, and social issues revolve around gaining public acceptance and addressing community concerns. Addressing these obstacles requires a concerted effort from all stakeholders to develop effective solutions and strategies, fostering collaboration and innovation to overcome barriers and achieve successful integration.

4.1. Cost Fluctuations and Economic Viability

While SMRs offer a potentially cost-effective solution in the long run, initial capital investments are substantial. Variability in construction costs and economic uncertainties can deter investors and hinder project development. Addressing these concerns involves developing financial models that distribute risks and costs effectively among partner countries. Harmonizing financial incentives, creating joint funding mechanisms, and leveraging green taxonomies and green bonds can help stabilize costs and attract investment. Additionally, addressing the potential for cost overruns and delays is crucial to maintaining economic viability.

4.2. Licensing and Regulatory Barriers

Navigating the diverse regulatory frameworks of different countries poses a significant challenge. Variations in licensing processes, safety standards, and regulatory requirements can create delays and increase costs, making it difficult for SMR projects to progress efficiently. Minilateral partnerships need to focus on harmonizing licensing procedures and developing standardized regulatory frameworks to streamline the approval and deployment of SMRs. This requires coordinated efforts to align national regulations with international best practices, ensuring consistency in safety and operational standards across all participating countries.

Licensing issues, including differing national standards and the complexity of obtaining approvals, can significantly impact the timely deployment of SMRs. Disparate regulatory approaches can lead to prolonged review times and increased compliance costs, which may deter investment and slow down the adoption of SMR technology. Therefore, effective minilateral partnerships must work towards creating a unified regulatory environment that simplifies and accelerates the licensing process while maintaining high safety and operational standards. This collaborative approach will help mitigate delays and enhance the overall efficiency of SMR deployment globally.

4.3. Intellectual Property and Technology Transfer

The transfer of SMR technology raises concerns regarding intellectual property (IP) rights and protection. Disagreements over IP ownership, technology sharing, and licensing agreements can create obstacles in collaborative projects. Minilateral partnerships must establish clear agreements on IP management and ensure that technology transfer does not undermine proprietary innovations[10]. Developing frameworks for IP protection, addressing concerns about technological theft or misuse, and fostering transparent technology-sharing agreements are crucial for building trust and encouraging international collaboration.

Effective deployment of SMRs requires the integration of new technologies into existing energy systems and the development of local capacity. Emerging economies may face challenges in adopting advanced nuclear technologies and building the necessary infrastructure. Minilateral partnerships should focus on technology transfer, capacity building, and training programs to ensure that all partner countries can manage and maintain SMRs independently. Collaborative research and development efforts can address technological gaps and accelerate innovation, ensuring that local expertise is developed alongside technological advancement.

4.4. Geopolitical and Strategic Interests

Minilateral partnerships may encounter challenges related to geopolitical and strategic interests, as differing national priorities, political considerations, and strategic objectives can complicate collaboration and decision-making. To navigate these complexities, it is crucial to establish clear governance structures and mechanisms for conflict resolution within minilateral frameworks. This includes creating formal processes for addressing disputes, aligning on mutual objectives, and ensuring transparent communication. Additionally, fostering a shared vision and understanding among partner countries can help in harmonizing divergent interests and priorities. By implementing these strategies, minilateral partnerships can mitigate geopolitical risks and enhance the effectiveness of collaborative efforts. Through strategic planning, coordinated actions, and credible frameworks, these alliances can not only overcome potential obstacles but also strengthen the viability and success of SMR projects. This approach will be instrumental in achieving a more sustainable and secure energy future, benefiting all partner nations involved.

5. CONCLUSION

Achieving a successful and efficient SMR ecosystem demands a strategic focus on private sector investments and international cooperation. Countries must forge treaties and minilateral alliances to drive collaboration among global investors and stakeholders in SMR development. These partnerships should facilitate the exchange of cutting-edge scientific knowledge, best practices in design and execution, and regulatory expertise to fast-track manufacturing and deployment. Adhering to IAEA guidelines is essential for ensuring safety and consistency. The integration of SMRs is not just about technological advancement but also about meeting ambitious climate goals. Without realizing the full potential of nuclear energy, countries may fall short of their 2050 net zero emissions targets. SMRs, with their scalability and efficiency, are poised as a critical alternative to large reactors, offering a dynamic solution to both energy and environmental challenges. Success in developing a robust SMR ecosystem will also hinge on overcoming economic and regulatory hurdles through coordinated international efforts. By harnessing collective expertise and resources, minilateral partnerships can accelerate the deployment of SMRs, ensuring that they contribute effectively to global decarbonization goals and energy security.

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