International Journal of Nuclear Security

Volume 9
Number 3 *International Journal of Nuclear Security–Nuclear Security Women 2024 Special Issue*

Article 12

1-2025

# Liberalizing the Nuclear Energy Sector: Small Modular Reactors, Net-Zeros, and Perceptions in India

Hely Desai
*University of Cambridge*



## Recommended Citation

Desai, Hely (2025) "Liberalizing the Nuclear Energy Sector: Small Modular Reactors, Net-Zeros, and Perceptions in India," *International Journal of Nuclear Security*: Vol. 9: No. 3, Article 12.
https://doi.org/10.7290/ijns09347061
Available at: https://trace.tennessee.edu/ijns/vol9/iss3/12

International Journal of Nuclear Security–Nuclear Security Women Special Issue, Vol. 9, No. 3, 2024

# Liberalizing the Nuclear Energy Sector: Small Modular Reactors, Net-Zeros, and Perceptions in India

Hely Desai
University of Cambridge

## Abstract
The experimental small modular reactors (SMRs) have come to gain immense attention and importance given the global quest to quickly achieve net-zero goals. The Indian Government, too, has been pushing for SMRs to aid its industrial decarbonization targets and eventually wield the supply mediation in the race to acquire this novel technology. However, one of the key debates driving SMR discourse in India is the dilemma of allowing the involvement of the private sector into the nuclear energy realm. Although this idea seems to be an exciting solution to India's energy woes, the reevaluation of a 60-year-old energy law comes with a new set of security challenges and financial opportunities for New Delhi regarding the manufacturing and deployment of these new state-of-the-art reactors.

This paper analyzes the efficacy of incorporating SMRs into India's energy mix and if it would be more advantageous to allow private investments into the nuclear energy sector. This research studied India's energy laws and traced its amendments and shortcomings over the years. Although leveraging the private entities may prove to be beneficial in providing cost-effective and smooth grid-adjustment fixes for the nuclear energy sector, the method will face major structural and security challenges and will require an extensively elaborate technology-neutral policy framework with a focus on green taxonomies, as well as a pivot around societal acceptance. There has not been much research conducted on the idea of commencing private involvement in the Indian nuclear energy sector apart from a few NITI Aayog reports and a few trivial opinion pieces in the print media.

DOI: 10.7290/ijns09347061

This study used archival policy reports, government documents, parliamentary discussions, and interviews of officials at the intersection of science and policy as sources to build an elaborate policy report on how beneficial the incorporation of private entities into the nuclear sector would be. Although SMRs have been on the policy lineups for almost a decade now, they have not translated into a practical commercial option. This research tried to investigate if allowing private players would benefit the quick deployment of SMR technology and, in turn, help to fulfill India's commitment to chart its way to becoming net-zero by 2070.

**Keywords:** small modular reactors, energy laws, net-zero, climate, nuclear energy, private investments

# 1. Introduction

Nuclear energy has endured to be the second largest source of low-carbon electricity globally and has historically circumvented the release of almost 70 billion metric tons of carbon monoxide [1]. Although the importance of nuclear as a clean energy source has long been recognized, the high investments, maintenance commitments, and accidental safety and state security concerns that follow have always triggered apprehension about an extensive energy transition to nuclear for countries [2]. But as the world faces a major energy crisis after the COVID-19 pandemic, nuclear energy has witnessed a reawakening of sorts, with a discernible incline in global efforts to push a nuclear-reliant power grid and policies that streamline cutting-edge nuclear innovations. Emerging technologies are being developed, such as microreactors, advanced accident-tolerant fuels, and unconventional reactor manufacturing that are aimed at making nuclear energy more accessible and exploitable for countries [3]. Under the umbrella of such emerging technology, new-wave small modular reactors (SMRs), which are currently in the incipient stage of their design and deployment, are also being endorsed as the in-vogue solution to the global energy quandary. Especially in developing economies such as India, with a large population and a demanding economy that is constantly striving to meet their energy requirements sustainably, SMRs might prove to be a compelling asset to incorporate nuclear power in their energy basket.

This paper analyzes the efficacy of incorporating SMRs into India's energy mix and if it would be more advantageous to allow private investments into the nuclear energy sector. This analysis was done by studying India's energy laws and tracing its amendments and shortcomings over the years. Conducting an in-depth analysis, this work studied whether collaborative efforts within the nuclear energy arena from government and private entities will help the smooth acceptance of SMRs within India's energy grid.

# 2. Unpacking Small Modular Reactors

SMRs are advanced nuclear microreactors that possess a power capacity of up to 300 MW(e) per unit, which is almost one-third of the power-generating capacity of standard nuclear reactors [4]. These fissile reactors designed with modular fabrication technology are said to be faster to construct, more cost-effective, and more smoothly adjustable to varying energy grid requirements [5]. With a small size, modular buildup, and a passive safety system, these reactors can be manufactured in a controlled factory setting and assembled module-by-module, improving their off-shore installation efficacy and, thus, become easier to finance when compared with large plants. Furthermore, inculcating serialization in the manufacturing process of SMRs will help cut costs by aligning plant designs to expedite efficient regulatory compliance and initiate experiential learning vis-à-vis novel serial manufacturing.

These reactors built with a reduced core damage frequency and amplified seismic isolation [6, 7], unlike conventional nuclear power plants, tend to provide more safety in case of accidents. Allowed to operate in and around remote brownfield lands [8] that have been abandoned because of industrial pollution, SMRs are also said to be safe enough to not be constrained by iron-clad zoning prerequisites given their low-pressure operations and decreased reliance on active safety systems.

Built to last 40–60 years, SMRs with varying coolant technologies under different kinds of proposed design classifications include land-based water-cooled SMRs, marine-based water-cooled SMRs, high-temperature gas-cooled SMRs, fast neutron spectrum SMRs, molten salt SMRs, microsized SMRs, and others [9]. With as many as 80 designs for SMRs across almost 17 countries already in various stages of outlining and deployment as of 2020, the global market for SMRs is projected to reach 300 million US dollars by 2040 [10, 11]. Despite the international nuclear power share being as low as 10% [12] when compared with other energy sources, SMRs have managed to garner a significant global interest by addressing most of the safety, cost, and maintenance concerns associated with nuclear power. Especially after the 28th session of the Conference of the Parties Summit acknowledging the crucial role of nuclear energy in reducing the international carbon footprint and propelling definitive initiatives such as “Accelerating SMRs for Net Zero,” which was partnered with the Nuclear Energy Agency, the global momentum for SMRs has reached full throttle [13].

Especially for developing countries with a smaller energy grid and minimal experience working with nuclear power, SMRs could prove to be an ideal alternative for a sustainable energy transition. This advantage is primarily given the relatively abated investments, viability for small-scale power grids, and lesser carbon footprints than that of conventional reactors. 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. But for a state such as India that straddles between the developing and developed, sustaining a demanding economy, massive population, consistently growing energy consumption, and budding tech industry, home-grown SMRs might be the answer to most of New Delhi’s energy dilemmas.

## 3. What is India’s Atomic Energy Act?

The India’s Atomic Energy Act of 1962, drafted by the Atomic Energy Regulatory Board (AERB), has been implied to cater to the development, control, and use of atomic energy in the country for the welfare of people and for other peaceful purposes as well as for matters connected therewith [14]. Since then, with the initiation of agendas that seek to push nuclear power projects in the country, a few amendments to Sections II, III, XI, and XIV of the act were undertaken through the Atomic Energy (Amendment) Bill in 1986, 1987, and 2015, respectively. Section II of the act was amended to redefine the stakes of a government company that may be allowed to be involved in the operational process of nuclear power plants. However, the revised Section III explicitly gives sole authority to the Central Government to manufacture, develop, control, research, or dispose of atomic energy [14]. This amendment further enabled the government to restrict information pertaining to the technology, design, and construction of the prescribed nuclear systems from the public, citing prevention of hazards. After these initial rounds of amendments, the Nuclear Power Corporation of India (NPCIL) was permitted to establish junior joint venture companies with other public sector undertakings to fulfil the surplus capital obligations for the expansion of the nuclear power program while simultaneously employing government regulations over such joint venture companies [15]. The NPCIL currently maintains and controls India's existing cluster of nuclear power plants with a capacity of 7500 MW and has pledged investments for another 1300 MW. However, the act should be further amended in a manner that would allow the private sector to set up SMR manufacturing in India.

In line with recommendations from the NITI Aayog policy report, the Indian Government needs to use an amalgamation of government seed funds and green bonds to attract private investments.[1] However, regardless of new private stakeholders entering the nuclear realm, the entire operational control and surveillance rights must continue to remain with the government. This setup will help assure the safety of the plant and the nuclear establishment, uphold national security protocols, and safeguard nuclear fuel and radioactive waste. The AERB has already prescribed a detailed set of codes and guidelines that define a fastidious process for assessing the safety and security facets of nuclear power projects through manifold evaluations in addition to the regular intermittent inspections [16]. However, with the involvement of private players in the nuclear sector, there also exists the need for the government to further recruit an independent regulatory board that has sufficient expertise to superintend every stage of nuclear power generation cycle, including design sanctioning, location scouting, manufacturing operations, and waste processing, for effective functioning of the nuclear power plants (NPPs). With a reasonable policy push, the private sector might be able to drive a significant amount of the manufacturing and deployment burden of SMRs in the country.

[1] Evidently, the Atomic Energy Department of India had conducted confidential consultations with domestic and global industry players to invite private companies to participate in the atomic and space sectors as late as 2022, but nothing has translated to definitive policy prompts as of yet. (Reported in Deshpande, P. P. *Prospects of Foreign Investment in the Indian Nuclear Industry-A Focus on Pros and Cons. The Times of India*, May 10, 2023. https://timesofindia.indiatimes.com/blogs/truth-lies-and-politics/prospects-of-foreign-investment-in-indias-nuclear-power-industry-a-focus-on-pros-and-cons-part-i/ (accessed 01-03-2024).

*DOI: 10.7290/ijns09347061*

# 4. India's Energy Landscape and the Liberalization Conundrum

## a. India's Clean Energy Dilemma

Against the backdrop of an internationally amplified energy demand trend, as the world strives to achieve global net-zero target emissions by the 2045–2070[2] timeframe to delay the irreversible effects of global warming, a conscientious shift by countries toward renewable energy sources is visible [17]. Such a massive energy transition for emerging economies comprises a large-scale procedural transformation and restructuring of energy systems that follow huge investments. This transition poses a much bigger challenge for a highly populous and majorly fossil fuel–reliant India, with colossal developmental aspirations. To cater to its advancing tech, industry, and agricultural endeavors, India requires a multifold increase in its per-capita energy use even as it aims to move toward net-zero greenhouse gas emissions. Confronted with this Janus-type challenge, India also needs to combat the soaring prices of the geopolitically risky fossil fuel and support its emerging transition infrastructure [18]. But given their stochastic nature, merely solar and hydropower would not suffice to reach India's target of achieving 500 GW of renewable energy capacity by 2030, which is almost three times their current capacity of 180 GW [19, 20].

Per India's Nationally Determined Contribution (NDC) under the Paris Agreement as updated in August 2022, the goal to reduce the emissions concentration of its gross domestic product had been increased to 45% by 2030, and the target on the total installed electric power capacity from non-fossil-based resources has been heightened by 50% by 2030 to meet its domestic needs [21]. India's new NDC has been cautiously amended after taking its national circumstances into consideration and envisaging an overall increase in green jobs and government schemes that enable co-benefits and trade-offs through the principle of common but differentiated responsibilities and respective capabilities [22].

However, projected to account for almost 25% of the global energy demand within the next two decades, New Delhi needs rapid deployment of new nuclear energy capacity to fulfil its maximum net growth in energy consumption demands while simultaneously credibly addressing climate concerns at the global level [23]. Failure to accomplish this dual challenge would lead to negotiating on its developmental goals, failing to fulfil the net-zero claims in the said timeframe, or both.

[2] Although Paris set 2050 as the net-zero goal, India at 26th session of the United Nations Framework Convention on Climate Change in November 2021 announced its target to achieve net-zero by 2070. For details, see: Press Information Bureau. *Net Zero Emissions Target*, August 2023. Ministry of Environment, Forest and Climate Change. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1945472#:~:text=India%2C%20at%20the%2026th%20session,achieve%20net%20zero%20by%202070 (accessed 05-2023).

DOI: 10.7290/ijns09347061

### b. Home-Grown Small Modular Reactors and the Private Sector: Is Liberalization the Solution?

With nuclear energy accounting for only 3.15% of India's total electricity generation, emerging technologies such as SMRs could potentially work to facilitate this transformation to nuclear [24]. SMRs have been on Indian policy lineups for almost a decade now but have not yet translated to practical commercial options [25]. This lack of progress is often due to the economic intensiveness, delayed outcome benefits, and tentative safety liabilities of constructing nuclear power reactors (i.e., NPPs) such that some states become less favorable toward initiating a nuclear commitment. However, with a stable financial allowance for the nuclear sector, a potential scope for a global leadership slot in the clean energy transition domain, and a tech-led foreign policy schema at the G20 rostrum and beyond, the Indian Government is once again pushing for SMRs. The efforts to aid industrial decarbonization and, in turn, capitalize on the mediation of the global SMR supply come at a time when two countries—Russia and China—have just entered the operational stages of SMR deployment.[3] This plan also gives New Delhi ample room to delve into the SMR race and gain significant geopolitical bargaining power.

For India to gain a geopolitical upper hand by establishing economic dominance in South Asia and to embark on global energy partnerships, a coherent ecosystem for manufacturing homegrown SMRs needs to be harnessed. To generate a global market interest, the government needs to engage the private sector within the SMR domain by offering carrots in the form of seed capital for innovation, reliable supply chain structures, and demand creation. Opening up India's nuclear energy sector to private financing also fits well within New Delhi's self-reliance agendas of Make in India and *AtmaNirbhar Bharat*, which will help boost indigenous design and deployment of SMRs.[4] According to reports from NITI Aayog,[5] which is a public policy think-tank, an elaborate technology-neutral policy outline that highlights the inclusion of green taxonomy; green bonds;[6] and the importance of societal, governance, and ecological aspects of nuclear acceptance is essential to attract and acquire private investments [26, 27]. The efficient deployment of SMRs will pivot on ardent backing from policymakers and regulators to clout private sector investment [27].

---

[3] As of now, only two SMR projects globally have reached the operational stage: an SMR named Akademik Lomonosov floating power unit in Russia that has two modules of 35 MWe and started commercial operation in May 2020 and the HTR-PM demonstration SMR in China that was grid-connected in December 2021. For details see: Committee on Industry, Research and Energy. *Report on Small Modular Reactors*; A9-0408/2023, 2023/2109(INI); European Parliament: 2023. https://www.europarl.europa.eu/doceo/document/A-9-2023-0408_EN.html (accessed 01-03-2024)

[4] Make in India and *AtmaNirbhar Bharat* are initiatives by the Government of India that aid indigenous production and building a self-reliant nation respectively. *AtmaNirbhar Bharat* translates to "Self-Reliant India."

[5] NITI Aayog is the apex public policy think tank of the Government of India and a nodal agency that is tasked with catalyzing economic development and fostering cooperative federalism.

[6] *Green bonds* are fixed income financial instruments in which the money raised from investors is to be used exclusively for financing projects that have a positive environmental impact. For details see: Henry, P.; North, M. *What are Green Bonds and why is this market growing so fast?*, 2023. World Economic Forum. https://www.weforum.org/agenda/2023/11/what-are-green-bonds-climate-change/ (accessed 01-03-2024).

DOI: 10.7290/ijns09347061

In doing so, the Department of Atomic Energy of India (DAE), the state-run company NPCIL, and the AERB should join to formulate a touchstone licensing process for SMRs and articulate regulation protocols for inviting private investments. A stimulating framework by means of seed capital for innovation, stable supply chain, reliable evidence for proof of concept, demand creation, and a conducive policy environment can help navigate global investor interest [26]. The technical costs will eventually decline once experienced doyens in the private sector and international investors are drawn to partake in the manufacturing of SMRs. The Indian Government is now ostensibly looking to invite private funds worth approximately 26 million dollars into the nuclear energy sector. Allegedly for the first time, Indian private industry moguls such as Reliance Industries, Tata Power, Adani Power, and Vedanta are being examined to deliberate plans of investment and invite proposals for SMR developments [28, 29].

These private firms, under an elaborate funding plan, are proposed to acquire land and water and undertake construction in areas outside the reactor complex of the plants [30]. The stakeholder companies will then be able to earn revenue from the plant's electricity sales with the fuel and station management rights still solely held by the NPCIL. A further collaborative venture between government bodies such as NPCIL, the Bhabha Atomic Research Centre, National Thermal Power Corporation, and Bharat Heavy Electricals Limited that have significant experience in running NPPs with capital investments from private industry patrons and maximum operational rights with the government will work as an ideal solution for a conducive SMR environment. This setup allows a zero-carbon nuclear power plant to expand by drawing green finance from the Green Climate Fund and international investors without unduly burdening the government exchequer. The funding would facilitate India's ability to achieve its target of possessing non-fossil fuel–generated electric capacity by 2030, up from 42% now [31]. However, to allow the involvement of such private entities in the nuclear energy sector, it is crucial to make the needed amendments in India's 60-year-old Atomic Energy Act that enable private investments.

## 5. Encouraging Private and International Investments

Only a hampered private interest remains in the nuclear energy sector because of ambiguity around initial SMR costs. This lack of interest may fundamentally be because of the limited benefits and slower paybacks—at least on the preliminary prototypes of the reactors. Private participation here can be encouraged through multiple incentives from the government, including implementing technical training programs, garnering substantial political support for the SMR initiative, building a conducive SMR regulatory framework led by national regulators, creating schemes that help induce social acceptability of nuclear power, and building a mature nuclear supply chain and confidence-building measures for smooth international collaborations.

Technical training and capacity-building workshops must be undertaken to streamline manufacturing processes and boost investor confidence. Despite gradually upscaling its reactor size in recent times from fairly petite 220 MWe reactors to 700 MWe pressurized heavy-water reactors, New Delhi definitively holds expertise in producing small reactors [32], which are a much more efficient replacement for countries with mid-sized grids for decentralized operations [33]. Political support in the form of seed funds to sponsor the first units and create a market that enables the development of specific SMR licensing processes will initially help in attracting private interest. A successful proof of concept may further help drive investor confidence. Derisking potential investment opportunities is the key to financing. This goal may be achieved by floating policies that promote legally binding contracts with defined roles and responsibilities to establish an opportune investor–vendor partnership framework [26]. Public policy and meticulous regulatory measures remain the cornerstones for the establishment of an industrial ecosystem. To encourage private involvement, the harmonization of regulations, codes, and standards for emerging technologies that have global value chains must be taken up and fast-tracked.

# 6. Fostering International Collaboration

International endeavors such as the Nuclear Harmonization and Standardization Initiatives[7] (NHSI) have been put in place by the International Atomic Energy Agency (IAEA) to boost regulatory collaborations among states, evade duplication, and improve efficacy without compromising on nuclear safety and national sovereignty [34]. In doing so, NHSI through its Regulatory Track helps make crucial strides in global harmonization by building on its previous regulatory activities. Additionally, the NHSI Industry Track aids in cultivating a more homogenized industrial approach for SMR deployment, manufacturing, and operations [34]. Instituting common standards endorses standardized reduced licensing timelines, costs, and deployment times for SMRs.

Washington and Paris hosted summits for the advancement and investment in SMR ventures. The G20 summit in September 2023 witnessed India and the US joining forces on the development of SMRs, among many other sustainability technologies [35]. New Delhi's G20 Sherpa Amitabh Kant demanded unfettered Indian access to US technology to join forces for SMR development under the India–US civil nuclear cooperation pact [36]. Incorporating the SMR agenda under bilateral strategic and clean energy initiatives such as the Renewable Energy Technology Action Platform will also help to further pilot and test such technologies [37]. France and India have also overtly asserted their intent to expand bilateral cooperation and forge a partnership for codeveloping SMR and advanced modular reactor technologies by enhancing their tech exchanges to add to its continued civil nuclear alliances on the Jaitapur nuclear plant project and the Jules Horowitz Research Reactor.

Such bilateral partnerships, in addition to helping battle climate crisis, will provide India with access to cutting-edge American and French technology and avail foreign direct investments (FDIs) while granting the investors access to India's cheap labor and economically attractive supply chains for SMRs. Furthermore, initiating confidence-

[7] The NHSI is a complementary initiative that aims to advance the harmonization and standardization of SMR design, construction, regulatory, and industrial approaches. The initiative comprises two separate but complementary tracks: the NHSI Regulatory Track and the NHSI Industry Track. IAEA. *The SMR Platform and Nuclear Harmonization and Standardization Initiative (NHSI).* https://www.iaea.org/services/key-programmes/smr-platforms-nhsi (accessed 01-03-2024).

DOI: 10.7290/ijns09347061

building measures with partner states that facilitate harmonization for a smooth tech exchange, strengthening international safeguards, and upholding sovereign security measures are essential to exploit the available FDIs for manufacturing and supply change management and to attract supplementary private investments.

Currently, the atomic energy sector of India lies among the list of prohibited branches for foreign direct investment per the consolidated FDI policy of India [38]. However, there remains no cap on FDIs in equipment manufacturing and additional supply provision within the nuclear sector [39]. A number of international companies such as Rosatom, Westinghouse Electric, General Electric Hitachi, and Electricite de France, among others, have already demonstrated substantial interest in partaking in India's SMR ventures in the capacity of technology partners, suppliers, contractors, and service providers. International collaborations and forging alliances within the nuclear energy arena from the government, global partners, and private entities through policies that cultivate political support, confidence-building measures, and government seed funds will also factor into the private and social compliance of nuclear energy by working toward smooth acceptance of SMRs. However, international collaborations with foreign allies and the entry of private players may also add to the safety and security conundrums that come with dealing with nuclear materials.

## 7. Challenges

### a. Security and Safeguards

Although the involvement of private overseas entities is deemed to bring in foreign capital, the subsequent off-site operations that are due to follow may raise safety and national security concerns. Bilateral or multilateral "tech and security agreements" underlined with the prerequisite of addressing security concerns must be set up to avoid such threats. SMR technologies, when manufactured and shared, explicitly require the application of international safeguards that comprise the establishment of novel or customized technical measures. This verification process also demands time and resources, making the potential collaboration with the relevant government and industry crucial [26]. Particularly when the design approval for reactors happens in one country and the product manufacturing and installation is carried out in another, often leading to structural oversights, it becomes extremely essential to develop and promote a global nuclear safety culture. Such regulation discrepancies between countries also increase licensing and liability issues in the development of any new technology, which can possibly lead to heightened manufacturing costs, making the whole purpose of building SMRs redundant [32]. Opening up nuclear projects to the private sector may also cause complications in the radioactive waste management systems and may lead to proliferation hazards. Therefore, despite the subsequent entry of private entities within the nuclear domain, the safety and security around SMRs must exclusively stay with the government [7].

### b. Licensing Challenges

The novel and emerging SMR technologies may not fit well into the current licensing processes given nuclear safety regulatory organizations' lack of experience with

DOI: 10.7290/ijns09347061

working with modern and dynamic designs. This inexperience poses a substantial problem in analyzing and authorizing the safety standards. Once streamlined, the SMR supply chain may also require further solidification to make the most of the economies of scale production with a push from the private sector. Furthermore, some design and implementation concerns may also be present given that new designs of SMRs may contain additional technological facets that do not exist in contemporary designs for large-scale light-water reactor designs. The safety and licensing of such prototypes may pose demonstration challenges because they have never been tested before. Global harmonization over design and operations, along with sole government control on the sanctioning of these designs, may help aid this quandary.

### c. Public Acceptability

Radioactive waste produced from SMRs will also require further financing to set up spent fuel storage and disposal facilities, which may initially lead to sociopolitical resistance. Privatization will play a critical role in influencing public perceptions and fostering social acceptance of nuclear energy, the understanding of which has been obscured by accidents, lack of public awareness, and safety hazards [40]. Especially after the Fukushima nuclear disaster, the global public acceptance of nuclear energy has evidently declined [41, 42]. Nuclear energy has often been mistaken to be substitutivity used with nuclear weapons by the unaware masses and thus tends to be associated with all things catastrophic. Awareness campaigns from the government, in collaboration with renowned private companies that have stakes in SMR deployment, could work toward softening the attitudes of the public toward nuclear energy [7]. Outreach programs that acknowledge the safety concerns of the surrounding local communities will help with an affable transition toward the public approval of SMRs. The Indian Government has now started work in its initial phases toward listing emergency planning zones and public acceptance of SMRs [43].

However, apart from safety concerns, the anticipation of the displacement of the local population further influences public hostility toward nuclear technology. Ordinarily, the erection of larger, traditional nuclear power plants has led to the government seizing vast public lands and creating exclusionary zones by restricting local movements for operations and driving people away from their homelands. This action has historically led to land disputes and protests. Given such umbrages, the locals do not consent to the usually forceful construction of nuclear facilities in and around their vicinities [44]. A comprehensive public-friendly outline for SMR deployment, emphasizing its modular and compact nature, that does not call for local displacement and creates awareness about the benefits and safety features of nuclear energy will aid in public acceptance. Communicating the advantages of nuclear energy to the locals by publicizing the public-friendly features of SMRs and by educating people about potential job opportunities that will arise with the local manufacturing and operation of SMRs will also help create an inclusive and amenable public attitude toward SMRs and nuclear energy [7].

## 8. Policy Recommendations

SMRs have the potential to develop as a viable emerging technology to combat the climate crisis, provide clean energy, and help cut down on costs diverted toward the

DOI: 10.7290/ijns09347061

generation and supply of electricity. Immediate vigilance vis-à-vis SMR designs generated from initial illustrative plants can help diminish the intensity of risk perception and in turn stimulate supply chain formation and attract investments [26]. To play an eloquent part in the energy transition realm, the first-of-a-kind units of SMRs need to be deployed as early as the 2030s with assistance from the private sector. To achieve a lucrative and efficient SMR ecosystem, private sector investments must be leveraged [26]. Necessary amendments to India's Atomic Energy Act to allow for private sector participation, but keeping operational rights with the government must be executed. A multifold national strategy for a quick rescaling of nuclear energy is essential. States should forge treaties and minilateral alliances to enable collaboration of global investors interested in the development of SMRs and facilitate its streamlined deployment. Private and international allies and stakeholders must establish a partnership to share cutting-edge scientific findings, design faux pas, execution practices, and directive expertise to accelerate the manufacturing process. All the relevant stakeholders must abide by the harmonization and operational guidelines of the IAEA. These guidelines must be revised and renewed intermittently. An intricate technology-neutral policy framework must be implemented for securing private investment. To further incentivize private interests, an intermingling of government seed funds and green finances will be key to derisking SMR projects [26].

Additionally, to improve the social perception of nuclear power in the country, the DAE must work to publicize both job creation around SMRs and exhaustive statistics pertaining to environmental and public health around civil nuclear reactors that function under international safeguards in India [26]. Communicating the advantages of nuclear energy to the people by advertising public-friendly features of SMRs will help cultivate sociopolitical support for SMRs. Competent public policy and international codes of practice remain the nucleus of building an effective SMR ecosystem.

# 9. Conclusion

Without nuclear energy reaching its full potential, India may not be able to achieve its goal of committing to net-zero by 2070 and simultaneously achieving a developed status. To reach this goal, SMRs have surfaced as the favored alternative when compared with large reactors. New Delhi needs to channel its own distinctive energy and security policy without being guided by external stakeholders. The path ahead wholly depends on the government's revisions to the Atomic Energy Act to allow investments from the private sector and foreign stakeholders. Although SMRs have been on New Delhi's policy priority for quite some time, what changes now is the push for these SMRs to turn mainstream. Collaborative efforts within the nuclear energy arena from the government and private entities aid the social compliance of nuclear energy by working toward smooth acceptance of SMRs.

# 10. References

1. International Atomic Energy Agency. *Nuclear Energy and Climate Change: Questions and Answers on Progress, Challenges and Opportunities*; International Atomic Energy Agency: Vienna, Austria, 2023. https://www-pub.iaea.org/MTCD/publications/PDF/PAT-002_web.pdf.

2. Goldemberg, J. Nuclear Energy in Developing Countries. *Daedalus* **2009**, *138* (4), 71–80. DOI: 10.1162/daed.2009.138.4.71.
3. Office of Nuclear Energy. *3 Innovations transforming the Nuclear Industry*, 2018. US Department of Energy. https://www.energy.gov/ne/articles/3-innovations-transforming-nuclear-industry (accessed 01-03-2024).
4. Liou, J. *What are Small Modular Reactors (SMRs)?*, 2023. International Atomic Energy Agency. https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs (accessed 01-03-2024).
5. World Nuclear Association. *Small Nuclear Power Reactors*, 2024. World Nuclear Association Information Library. https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx (accessed 01-03-2024).
6. Srikanth, R. Can Small Modular Reactors Help India Achieve Net-Zero? *The Hindu*, August 10, 2023. https://www.thehindu.com/sci-tech/science/small-modular-reactors-india-nuclear-power-net-zero/article67175626.ece (accessed 01-03-2024).
7. Desai, H. Small Modular Reactors: India's Quandary to Liberalize the Nuclear Energy Arena. *South Asian Voices*, November 8, 2023. https://southasianvoices.org/smrs-and-perceptions-india/ (accessed 01-03-2024).
8. Hansen, J.; Jenson, W.; Wrobel, A.; Stauff, N.; Biegel, K.; Kim, T.; Belles, R.; Omitaomu, F. *Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants*; INL/RPT-67964-Rev000; Idaho National Laboratory: Idaho Falls, Idaho, 2022. DOI: 10.2172/1886660.
9. International Atomic Energy Agency. *Advances in Small Modular Reactor Technology Developments—A Supplement to: IAEA Advanced Reactors Information System (ARIS)*; International Atomic Energy Agency: Vienna, Austria, 2020. https://aris.iaea.org/Publications/SMR_Book_2020.pdf.
10. Deign, J.; GreenTech Media. Nuclear: These Countries Are Investing in Small Modular Reactors. *World Economic Forum*, January 13, 2021. https://www.weforum.org/agenda/2021/01/buoyant-global-outlook-for-small-modular-reactors-2021/ (accessed 01-03-2024).
11. Mohan, P. Nuclear Power: The Case for Small Modular Reactors. *Observer Research Foundation*, January 15, 2022. https://www.orfonline.org/expert-speak/nuclear-power-the-case-for-small-modular-reactors (accessed 02-03-2024).
12. World Nuclear Association. *Nuclear Power in the World Today*, 2024. World Nuclear Association. https://world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx (accessed 01-03-2024).
13. Nuclear Energy Agency. *Ongoing Report: Accelerating SMRs for Net Zero*, 2023. Nuclear Energy Agency. https://www.oecd-nea.org/jcms/pl_88539/accelerating-smrs-for-net-zero (accessed 01-03-2024).
14. Atomic Energy Regulatory Board, The Atomic Energy Act, 1962; No. 33 of 1962; Government of India: India, 1962. https://www.aerb.gov.in/images/PDF/Atomic-Energy-Act-1962.pdf; Ministry of Law and Justice, The Atomic Energy (Amendment) Act, 2015; No.5 of 2016; The Gazette of India. January 2016. New Delhi. https://www.barc.gov.in/about/ae_amend_2015_0116.pdf.

15. Press Information Bureau. Amendment in Atomic Energy Act; Department of Atomic Energy, Government of India, 2016. https://pib.gov.in/newsite/PrintRelease.aspx?relid=136697.
16. Atomic Energy Regulatory Board. Nuclear Power Plant Operation; Code No. AERB/NPP/SC/O; Government of India, 2008. https://www.aerb.gov.in/images/PDF/CodesGuides/NuclearFacility/NPPOperation/2.pdf.
17. Kakodkar, A. India Needs to Go Nuclear. *The Indian Express*, October 12, 2023. https://indianexpress.com/article/opinion/india-needs-to-go-nuclear-8978909/ (accessed on 01-03-2024).
18. Kamal, N. India Faces Clean Energy Challenges as Energy Demand Soars, Global Fossil Fuel Subsidies Rise. *Times of India*, March 12, 2024. https://timesofindia.indiatimes.com/city/chandigarh/india-faces-clean-energy-challenges-as-energy-demand-soars-global-fossil-fuel-subsidies-rise/articleshow/108441953.cms (accessed 01-03-2024).
19. Wang, J.; et al. Inherent Spatiotemporal Uncertainty of Renewable Power in China. *Nature Communications* **2023**, *14*. DOI: 10.1038/s41467-023-40670-7.
20. Ministry of New and Renewable Energy. *Government Declares Plan to Add 50 GW of Renewable Energy Capacity Annually for Next 5 Years to Achieve the Target of 500 GW by 2030*, 2023. Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1913789 (accessed 01-03-2024).
21. Press Information Bureau. *Cabinet Approves India's Updated Nationally Determined Contribution to be Communicated to the United Nations Framework Convention on Climate Change*, 2022. Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812 (accessed 10-05-2024).
22. Vishwanathan, S.; Fragkos, P.; Fragkiadakis, K.; Garg, A. Assessing Enhanced NDC and Climate Compatible Development Pathways for India. *Energy Strategy Reviews* **2023**, 49, 101–152. DOI: 10.1016/j.esr.2023.101152.
23. Press Information Bureau Delhi. *India's Energy Demand Will Continue to Provide Fuel for Future Economic Growth and is Bound to Grow Exponentially in Coming Years: Petroleum Minister Hardeep S Puri Inaugurates 26th Energy Technology Meet*, 2023. Ministry of Petroleum and Natural Gas, Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1966227#:~:text=India%20is%20likely%20to%20account,200%20bn%20dollars%20very%20shortly (accessed 03-03-2024).
24. Tewari, S. M.; Department of Atomic Energy, Government of India. *Lok Sabha Unstarred Question No. 660 To Be Answered On 20.07.2022: India's Nuclear/Atomic Energy*, 2022. Sansad India Archives. https://sansad.in/getFile/loksabhaquestions/annex/179/AU660.pdf?source=pqals#:~:text=JITENDRA%20SINGH)%3A,power%20reactors%20at%20rated%20capacity (accessed 01-03-2023).
25. Ramana, M.; Berzak, L.; Hopkins, A. Licensing Small Modular Reactors. *Energy* 2013, 61, 555–564. DOI: 10.1016/j.energy.2013.09.010.

26. NITI Aayog, Department of Atomic Energy, Government of India. *A Report on the Role of Small Modular Reactors in the Energy Transition*; NITI: India, 2023. https://www.niti.gov.in/sites/default/files/2023-05/The-Role-of-Small-Modular-Reactors-in-the-Energy-Transition-05162023.pdf (accessed 01-03-2024).
27. International Energy Agency. *Nuclear Power and Secure Energy Transitions*; International Energy Agency: Paris, France, 2022. https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions (accessed 03-03-2024).
28. World Nuclear News. India to Seek Nuclear Investors as Kakrapar Units Inaugurated. *World Nuclear News*, February 23, 2024. https://world-nuclear-news.org/Articles/India-to-seek-nuclear-investors-as-Kakrapar-plants (accessed 01-03-2024).
29. Singh, S. C. India Seeks $26 Billion of Private Nuclear Power Investments. *Reuters*, February 21, 2024. https://www.reuters.com/business/energy/india-seeks-26-bln-private-nuclear-power-investments-sources-say-2024-02-20/ (accessed 01-03-2024).
30. Ksheerasagar, A. As India Expands Its Nuclear Power Capacity, Reliance, Tata Power, Adani Power, Vedanta Are at the Forefront. *Mint*, February 26, 2024. https://www.livemint.com/market/stock-market-news/as-india-expands-its-nuclear-power-capacity-reliance-tata-power-adani-power-vedanta-are-at-the-forefront-11708915562167.html# (accessed 03-03-2024).
31. Press Trust of India. India Seeks $26 bln of Private Nuclear Power Investments, Sources Say. *The Hindu*, February 20, 2024. https://www.thehindu.com/business/india-seeks-26-bln-of-private-nuclear-power-investments-sources-say/article67866922.ece (accessed 30-03-2024).
32. Sethi, M. *Assessing the Promise Of Small Modular Reactors From An Indian Perspective*, 2022. Asia Pacific Leadership Network. https://www.apln.network/news/member_activities/assessing-the-promise-of-small-modular-reactors-from-an-indian-perspective (accessed 01-03-2024).
33. Sasi, A. Why Small is Now the New Big as India Opens Up Two Strategic Sectors to Private Participation. *The Indian Express*, September 11, 2023. https://indianexpress.com/article/explained/explained-economics/nuclear-power-space-india-strategic-sectors-private-8930052/ (accessed 01-03-2024).
34. International Atomic Energy Agency. *The SMR Platform and Nuclear Harmonization and Standardization Initiative (NHSI)*. https://www.iaea.org/services/key-programmes/smr-platforms-nhsi (accessed 01-03-2024).
35. Tembhekar, C. G20: US Keen On Sharing Advanced SMR Technology in Nuclear Power with India. *Times of India*, May 18, 2023. https://timesofindia.indiatimes.com/india/g20-us-keen-on-sharing-advanced-smr-technology-in-nuclear-power-with-india/articleshow/100312458.cms?from=mdr (accessed 01-03-2024).
36. Press Trust of India. Kant Calls for Unfettered Access to US Nuclear Technology to Build Small Modular Reactors. *The Economic Times*, May 16, 2023. https://economictimes.indiatimes.com/news/science/kant-calls-for-unfettered-

access-to-us-nuclear-technology-to-build-small-modular-reactors/articleshow/100279732.cms?from=mdr (accessed 31-03-2024).

37. Press Information Bureau Delhi, Ministry of New and Renewable Energy. *Renewable Energy Technology Action Platform Under US–India Strategic Clean Energy Partnership*, 2023. https://pib.gov.in/PressReleasePage.aspx?PRID=1953550 (accessed 01-03-2024).
38. Press Information Bureau, Department of Atomic Energy, Government of India. *Investment in Atomic Energy*, 2020. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1655136 (accessed 01-03-2024).
39. Tripathi, S. S.; Department of Atomic Energy, Government of India. *Lok Sabha Unstarred Question No. 573 To Be Answered on 06.02.2019: Investment in Atomic Energy.* Sansad India Archives. https://sansad.in/getFile/loksabhaquestions/annex/17/AU573.pdf?source=pqals (accessed on 2024-03-01)
40. Seigrist, M.; Visschers, V. Acceptance of Nuclear Power: The Fukushima Effect. *Energy Policy* **2013**, *59*, 112–119. DOI: 10.1016/j.enpol.2012.07.051.
41. Kim, Y.; Kim, K.; Kim, W. Effect of Fukushima Nuclear Disaster on the Global Public Acceptance of Nuclear Energy. *Energy Policy* **2013**, *61*, 822–828. DOI: 10.2139/ssrn.2322394.
42. Ramana, M. V.; Mian, Z. One Size Doesn't Fit All: Social Priorities and Technical Conflicts for Small Modular Reactors. *Energy Research and Social Science* **2014**, *2*, 115–124. DOI: 10.1016/j.erss.2014.04.015.
43. Press Information Bureau, Department of Atomic Energy, Government of India. *Government is Working on New Technologies Such as Small Nuclear Reactors to Make Clean Energy Transition*, 2023. https://pib.gov.in/PressReleasePage.aspx?PRID=1982958 (accessed 01-03-2024).
44. Bidwai, P. *People vs. Nuclear Power in Jaitapur, Maharashtra*. Economic and Political Weekly **2011**, *46* (8), 10–14. http://www.jstor.org/stable/41151784.