THE SMALL MODULAR REACTORS: INDIA'S PREDICAMENT TO LIBERALISE NUCLEAR POWER

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ABSTRACT

Small Modular Reactors (SMRs) have the potential to be an important component at present for the worldwide nuclear energy renaissance. SMRs are simpler to build and operate, as well as being suitable for deployment in harsh environmental conditions, while requiring more diluted investment than Large Reactors (LRs). Around the world, a variety of financial and economic models have been developed by the scientific community in order to assess the competitiveness of SMRs. The paper investigates attractiveness of SMRs for India in the present given scenario. India is the second most populated country in the world with rapid economic growth and a huge requirement for energy. There is also good public acceptance, political support, and judicial consciousness for nuclear power in India which are important factors favoring the deployment of SMR's. Further, Government of India's Policy is that Nuclear Power is critical for achieving India's clean energy targets set in COP-26 and India's effort is to achieve net zero emissions by 2070. The G-20 Summit of 2023 paved the way for development of SMR's, though to negate the concerns regarding viability and efficacy around SMR's, the involvement of the private sector remains a key debate within the Policy circle. India has to reconsider the amendment to the Atomic Energy Laws including the licensing and liability regimes that includes the development motive along with economic benefit to pave a path forward and to provide leeway for involvement of the private sector, foreign investment, and startups to provide a reliable low carbon source of electricity that complements intermittent renewals by way of developing the future of SMR's in India.

KEY WORDS: SMR, ENERGY POLICY, PRIVATIZATION, NUCLEAR POWER, ENERGY DEFICIT.

INTRODUCTION

Economic development and population growth are driving the demand for a secure and expanding energy supply, with electricity being the most convenient and reliable form of energy. Nuclear power, known for its stability and minimal dependence on external factors, stands out as a promising solution. While large Nuclear Power Plants (NPPs) have traditionally dominated[1], there's a budding curiosity in smaller units. These Small Modular Reactors (SMRs) offer flexibility and are particularly suited for remote areas and distributed energy systems.

SMRs are gaining traction globally as countries recognize the need to expand their energy production capacities to keep pace with rising energy consumption. For remote regions like northern Alaska or isolated parts of Russia, SMRs provide a reliable source of electricity and potable water. Nations like China are investing heavily in both large NPPs and SMRs to meet diverse energy needs. In the USA, significant support from the Department of Energy (DoE) is accelerating the advancement of light water and next-generation reactor designs.

The concept of SMRs has evolved from small, factory-built reactors that are easy to transport and deploy. The International Atomic Energy Agency (IAEA) now categorizes SMRs as Small and Medium-sized Reactors, producing up to 300 MWe for small reactors and between 300 and 700 MWe for medium reactors.[2] These reactors are particularly advantageous for areas with small power grids or where extending the main power grid is economically unfeasible. An innovative example as observed in the Russian Federation is the floating nuclear power plant design by OKBM Afrikantov, which can deliver energy to various locations as needed.[3]

SMRs are being developed worldwide, including in Argentina, Brazil, Canada, China, France, India, Japan, South Korea, Russia, South Africa, and the USA. This international effort has led to a wide range of reactor designs, with light water reactors (LWRs) being the centre of attention. However, there is growing interest in Liquid Metal Cooled Reactors (LMCRs) and Gas Cooled Reactors (GCRs). Canada remains unique in its pursuit of the Supercritical Water Reactor (SCWR) concept.[4]

The past of atomic power began with the finding of uranium-235 fission by Otto Hahn and Fritz Strassmann in the early 1930s, particularly in 1938. The first self-sustaining atomic chain

[1] https://www.energy.gov/ne/articles/nuclear-power-most-reliable-energy-source-and-its-not-even-close
[2] https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs
[3] https://www.world-nuclear-news.org/Articles/Q-A-The-prospects-for-floating-nuclear-power-plant
[4] Duffey, Romney. (2016). The Development and Future of the Supercritical Water reactor. CNL Nuclear Review. 5. 181. 10.12943/CNR.2016.00040.

reaction was accomplished by Enrico Fermi in December 1942, with the Chicago Pile-1 reactor. Initially used for military purposes, nuclear reactors soon became vital for commercial electricity production. The first commercial NPPs, Obninsk in the Soviet Union and Calder Hall 1 in the UK, were launched in the mid-1950s, leading to a rapid expansion of nuclear energy.

However, the Chernobyl disaster in 1986 significantly decelerated the growth of atomic power. The episode ran into a re-evaluation of nuclear security standards globally. Despite this, the early 2000s saw a revival in atomic energy, with new NPPs being planned and built in the USA and Finland. This period, known as the "nuclear renaissance," included significant global projects and China's construction of numerous reactors. The Fukushima disaster in 2011, however, caused another setback, leading Japan to replace atomic energy and prompting other States to reconsider their nuclear strategies.

Today, SMRs are not only seen as sources of electricity but also as providers of process heat and desalinated water. High-temperature SMRs can produce steam for industrial applications, generate hydrogen gas, and integrate with renewable energy sources like offshore wind farms. Many SMRs are designed for high efficiency and long intervals between refuelling, with some capable of operating for up to 30 years without a shutdown.

Safety is a crucial aspect of SMR design. Modern SMRs incorporate inherent and passive safety systems, adopting a "defense in depth" strategy. Their smaller size simplifies safety measures, as less heat needs to be managed during emergencies. Some designs feature natural convection within the Reactor Pressure Vessel (RPV) through integrated heat exchangers, allowing the reactor to cool without operator intervention in the event of a malfunction. This robust safety approach ensures that SMRs can provide secure, reliable, and sustainable energy solutions for the future.

OBJECTIVES

The main aim of this paper is to examine the contribution of (SMRs) in the power evolution, the current standing of SMR technology advancement, and the readiness of atomic supply chains for their placement. It also explores initiatives to blend SMR regulatory parameters and the global licensing process, as well as preparations for international safeguards, with special reference to India to attract private investment and stakeholders.

SCOPE

This study gathers data from openly accessible, and publications from IAEA, the Nuclear Energy Agency (NEA), and the International Energy Agency (IEA), along with press reports and insights from information associates in this arena in India. The focus of this paper is on the happenings, views, and decisions of energy asset proprietors, technology vendors, controllers, and administrations. It delivers perceptions on how to fully realize the potential of SMRs in the power transition, scrutinizing the opportunities and challenges in India.

EMERGENCE OF SMRS

SMRs have roots in the 1940s-1950s military reactors. Increasing interest from technology developers and customers has led many countries to develop national SMR programs, aiming for deployment by 2035 with extensive global cooperation. SMRs are designed to be manufactured in factories, transported, and installed on-site, reducing installation time and costs. Various SMR designs are grounded on well-known and advanced technologies, primarily aiming to generate emission-free electricity and other clean energy products like hydrogen. SMRs offer flexibility for grid stability and are suitable for small grids, remote locations, and industrial applications. Their rise can strengthen the nuclear sector and contribute to energy transition and resilient infrastructure.

SMRs IN THE INDIAN CONTEXT[5]

The Indian subcontinent is one that is surrounded by the Bay of Bengal on one side and the Arabian Sea on the other, the said seas are met by the eastern and the western ghats as soon as it touches Indian soil. Further, in the north-east of the subcontinent stand the great Indian

[5] *WORKING PAPER 31 – Electric Power Scenario in India: Challenges and Opportunities in Transmission and Distribution Sectors*

Himalayas. India is also blessed to have the Aravalli range ranging from the capital till the western parts of the nation until met with the Great Indian Thar Desert in the state of Rajasthan.[6] The beautiful and diverse terrain of the nation grants it with various beauties of nature, expanding the scope of tourism within the nation. However, the said boons are accompanied by its own set of adversities, the Indian tectonic plate, is exposed to seismic shifts at a noticeable rate, which at time leads to earthquakes in the mountainous regions rendering any major constructive activities, be it of power stations as highly unlikely.[7] The said earthquakes are often responsible for uprooting the electricity transmission lines spread over the region making accessibility to electricity in the mountainous regions a dream for many residents. In lieu of the transmission inefficiencies of electricity and the non-suitability of the contemporary transmission system, one must consider the inefficiencies holistically to advance any possible solution to the problem.

India being the third largest consumer of electric power is ought to produce enough for its needs, the nation meets its needs for power predominantly by coal-based electricity generation requiring the setup of large and hefty thermal power plants. Electricity produced in such plants is then transported using Transmission lines and power grids. However, such transmission of electricity from the thermal power plants to the end consumer is not the simplest procedure for the third largest producer of electricity. It has been observed that India, now considered as a developed nation, still lacks the requisite infrastructure to support the transmission needs of the country and such a lacking is witnessed in the congestion in the transmission lines as a result of the rapidly growing energy demands. The uploading of the infrastructure is not a feasible alternative for its capital-intensive nature, India if desirous of upgrading its present infrastructure of power grids and transmission lines would require more land to setup the infrastructure which often requires acquisition of lands by compensating the owner citizens. If at all, the country is able to pump the requisite capital into the infrastructural expansion of its transmission system, the process is yet not free of legal hurdles that come its way by way of litigation by the citizen owners, the lands of whom is acquired for the purpose of such expansion. One may wonder that whether these shortcomings sum all that would come in way of revamping the transmission lines of the country would such an expansion if made possible be an end to all of India's energy concerns?

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[6] *https://knowindia.india.gov.in/profile/physical-features.php*

[7] *https://timesofindia.indiatimes.com/etimes/trending/shocking-indias-landmass-is-shrinking-every-year-by-2-mm-heres-why/articleshow/107586754.cms*

The answers to the abovementioned questions also lead us to consider the fact that transmission of electricity using electricity lines and power-grids are plagued with high Aggregate Technical and Commercial (AT&C) Losses causing significant losses and financial hardships to the electricity manufacturers and making the field of business far from lucrative. Further, the terrain of the nation is such that it makes last mile connectivity of electricity nearly a distant dream for many a citizen of the nation. Further, the overloading upon the distribution system often leads to uncontrolled voltage and faulty meters and billing further rendering the survival of the electricity manufacturers as difficult in the nation. The transmission issues faced by the Indian electricity system particularly with respect to its transmission, is accompanied by an adverse effect upon the power quality reaching the consumers. Now that the aforementioned highlight the unsuitability of the transmission system of electricity so prevalent in India, one must question as to what is the way forward, what is the path to a sustainable and effective electricity system in India? The short answer to the doubts so raised above is that SMRs will reduce the transmission cost and bring energy generation closer to the consumer, the reasons for which are evaluated extensively in the following paper.

INDIAN ATOMIC ENERGY ACT AND SMRs

A key component of legislation that controls the progress, use, and regulation of atomic energy in India, is the Atomic Energy Act (AEA). The Act, which was promulgated in 1948 and amended in 1962, which delivers a thorough outline for the management of atomic materials and installations and guarantees the benign and protected use of atomic power. The AEA has been instrumental in the expansion of atomic technology by delivering a equilibrium between the advantages of atomic energy and requirement of strict safety regulations and regulatory monitoring. The Atomic Energy Act attempts to safeguard public health and safety, advance national security, and encourage scientific advancement in the arena of atomic energy by establishing guidelines for the management of radioactive materials and the functioning of nuclear reactors.

Regarding SMRs and the Indian legislation is amidst its development with regards to the use of atomic energy. It has always been difficult to test out new technology in a country like India, with its dense population and rich diversity. Addressing the matter, our then Union Minister for

Technology Minister stated in an interview that the government has allowed joint ventures with public sector projects in the nuclear power sector, but not with the private sector.[8]

The 1962 Atomic Energy Act is being re-examined to permit startups and the private sector to participate in the national development of SMR technology. According to the minister, SMR is a potential technology for industrial decarbonization, particularly in situations where a steady and dependable power supply is needed. According to an NITI Aayog research, collaboration amongst the public and private sectors is essential to alleviate associated risks and speed up commercialization because of the technology's young stage and investors' views of business and regulatory risks.

NITI AAYOG'S REPORT ON THE UNIVERSAL ENERGY BLEND, & THE ASSOCIATED PRINCIPAL ENERGY SOURCES

According to the Niti Aayog's report[9], the successor of the planning commission of India, formulated its report in 2023, wherein it stated that conventional power sources equate for approximately 82% of the principal power supply, as illustrated in Table 1.1. Nonetheless, the proportion of renewables in the principal power blend is consistently rising, as depicted in Figure 1.1.

Table 1.1: Principal Energy blend in 2021[10]

Fuel	Consumption (EJ)	Percentage	Combined Percentage
Oil	184.21	30.95	82.28
Natural Gas	145.35	24.42	
Coal	160.10	26.90	
Nuclear Energy	25.31	4.25	17.72
Hydroelectricity	40.26	6.76	
Renewables	39.91	6.71	
Total	**595.14**	**100.00**	**100.00**

[8] https://pib.gov.in/PressReleseDetailm.aspx?PRID=2028578
[9] https://www.niti.gov.in/sites/default/files/2023-05/The-Role-of-Small-Modular-Reactors-in-the-Energy-Transition-05162023.pdf
[10] https://www.niti.gov.in/sites/default/files/2023-05/The-Role-of-Small-Modular-Reactors-in-the-Energy-Transition-05162023.pdf

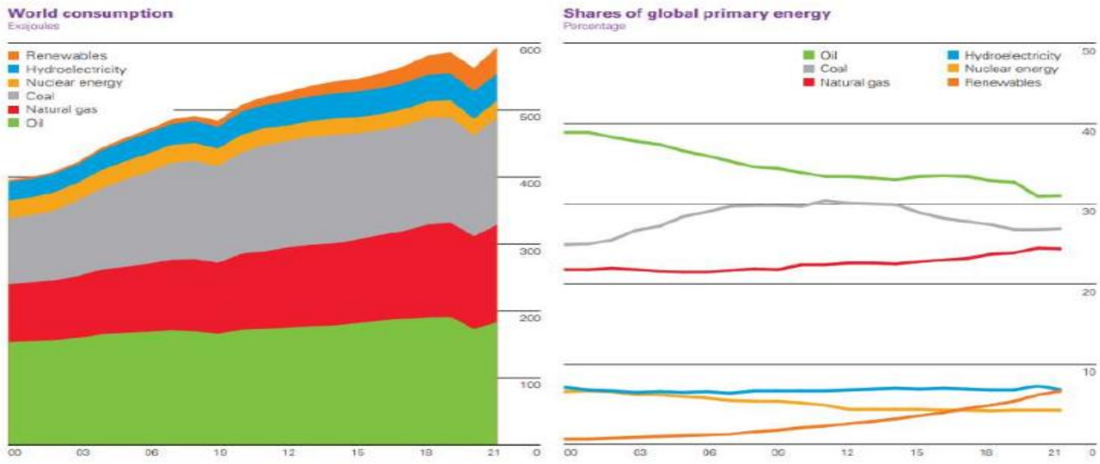

Figure 1.1: Universal Principal Energy Blend (2000-2021)

The energy sector has the potential to decarbonize at a faster rate. Electrifying end-use sectors is critical for reducing emissions across the entire economy. Many economies have set Net-Zero emission goals to be attained by the year 2050, and IEA research indicates that power demand may increase up to two times to reach these targets by 2050. The energy sector, responsible for 40% of worldwide emissions, requires a comprehensive overhaul to meet net-zero desires. Significant capital is needed for the swift enlargement of low-carbon generation capacity and grid infrastructure, in addition to the incorporation of storing and supplementary flexibility measures to ensure grid constancy. The evolution from unrelieved conventional fuels to flexible renewable energy sources poses various technical, societal, and political considerations.

In this context of decreasing conventional electricity volume and swiftly increasing flexible clean energy, atomic based generation of energy guarantees power supply security and grid constancy. Atomic power can significantly contribute to the energy transition by providing baseload capacity, continuous 24/7 availability, and the flexibility to balance variable clean sources of generation. Crucial strategies for achieving flexible functioning in an atomic plant comprise bolstering fundamental power through control manoeuvres, reducing passage through the turbine (via steam venting or rerouting to alternative users in unified systems), and utilizing energy storage for demand response options.

According to the IEA's Net-Zero by 2050 report, atomic energy is a crucial basis for the power shift. The power supply from atomic is expected to increase by 40% by 2030, and by 2050, it is projected to more than double compared to 2020 levels, as illustrated in Figure 1.2.

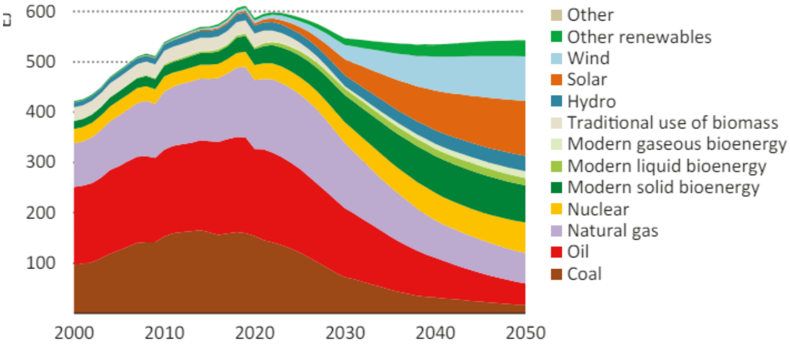

Figure 1.2: Total Energy Supply in Net-zero by 2050 Scenario of IEA

Currently, atomic energy contributes more than 25% to the entire low-carbon energy generation. Beyond electricity, atomic energy can be utilized for non-electric uses as hydrogen manufacturing, desalination, and district heating. Worldwide, atomic energy reactors generate nearly 2.3 TWh of energy corresponding to power for procedures like desalination and district heating, which accounts for less than 1% of their entire energy yield. This highlights the potential for atomic energy to enlarge its use in non-electrical uses as part of upcoming decarbonization strategies.

INDIA AND ITS NUCLEAR REGULATORY FRAMEWORK

India is a participant to only one global convention that is Convention on Supplementary Compensation for Nuclear Damage (1997) and has its own national legislations and policies laying down the framework of the Nuclear Energy in India. The national legislations include Atomic Energy Act, 1962 and residue of the environmental aspects being governed by the Environment Protection Act, 1986.

G20 Summit 2023 and the Role of SMRs[11]

The G20 Summit of 2023, convened in New Delhi, India, was a landmark event that underscored the growing importance of (SMRs) in the international power landscape. Bringing together the leaders of the planet's prime economies, the summit focused on the critical issues of energy security and sustainable development. Among the key highlights was the recognition of SMRs as a vital component in the quest for sustainable energy solutions and in combating the global challenge of climate change.

[11] https://www.g20.in/en/media-resources/press-releases/july-2023/etwgm-concludes.html

SMRs were spotlighted for their potential to revolutionize the nuclear energy sector by offering scalable and flexible energy solutions. Unlike traditional large reactors, SMRs can be constructed and deployed incrementally, which provides a significant advantage for countries with varying energy needs and financial capabilities. This scalability allows nations to enlarge their atomic energy ability as required, without the need for massive initial capital investments typically associated with large reactors. For many developing economies represented at the summit, this feature of SMRs presents an attractive option for diversifying their energy portfolios and meeting growing energy demands in a cost-effective manner.

Another crucial aspect of the discussion was the role of SMRs in supporting renewable energy sources. As G20 nations increasingly turn to renewables like wind and solar power to meet their climate goals, the intermittency of these energy sources poses a challenge for preserving a steady and dependable energy supply. SMRs can serve as a dependable backup, providing continuous baseload power that complements the flexible nature of renewable power. This synergy between SMRs and renewables is essential for creating robust and sustainable power systems that can familiarize to fluctuating power demands and alleviate the effects of climate alteration.

The summit also emphasized the environmental benefits of SMRs, particularly their low carbon emissions. With the G20's commitment to reducing global greenhouse gas emissions and achieving the objectives established by the Paris Agreement, the integration of SMRs into the energy blend represents a significant step forward. By generating electricity with minimal carbon footprint, SMRs contribute directly to the decarbonization of the energy sector, supporting global exertions to curb climate alteration and guard the environment.

A key theme of the G20 Summit was the need for international collaboration in the expansion and deployment of SMRs. Identifying the complexities and challenges involved in advancing nuclear technology, G20 leaders called for enhanced cooperation among member countries. This includes sharing best practices, technical expertise, and regulatory frameworks to streamline the adoption of SMRs worldwide. Nations with recognized atomic capabilities, such as the USA, Canada, and France, pledged to support other countries in developing their SMR programs by providing access to their knowledge and experiences.

Joint research and development initiatives were identified as crucial to accelerating the advancement of SMR technologies. Collaborative efforts in R&D can lead to innovations in reactor design, improve safety protocols, and reduce overall costs, making SMRs more reachable and viable for a wider range of countries. The G20 summit also proposed the creation of standardized regulations and certification processes to facilitate the global market development of SMRs. Harmonizing these regulations would lower the barriers to international trade and investment, fostering a more competitive and dynamic market for SMR technology.

Economic considerations were a central focus of the summit discussions. The leaders acknowledged the need to assess the economic competitiveness of SMRs against large reactors. While SMRs have the advantage of lower initial capital investment, their long-term economic viability depends on operational efficiency, market demand, and regulatory costs. The involvement of the private sector was highlighted as critical for driving innovation, reducing costs, and accelerating the deployment of SMRs. Encouraging private capital infusion and public-private partnerships can render a substantial role in bringing SMR projects to fruition.

Policy reforms were identified as necessary to support the integration of SMRs into national energy policies. Countries were urged to amend their nuclear energy laws to accommodate the unique features of SMRs, such as their licensing, construction, and operational requirements. Streamlined regulatory processes are essential to reduce bureaucratic hurdles and expedite the deployment of SMRs. The G20 summit set a clear path forward, advocating for joint ventures, regulatory harmonization, and innovative approaches to guarantee that SMRs owes its share to a sustainable and resilient global energy future.

COP26 and Climate Action[12]

The 26th Conference of the Parties to the United Nations Framework Convention on Climate Change, known as COP26, held in Glasgow in 2021, was a defining moment in the worldwide effort to address climate alteration. The conference gathered nearly 200 countries to reaffirm their vow to the Paris Agreement and to take concrete steps towards restricting global warming to 1.5°C over pre-industry level. This determined goal requires substantial decreases in greenhouse gas releases and a transition to sustainable energy systems.

COP26 was instrumental in strengthening the resolve of nations to enhance their Nationally Determined Contributions (NDCs), which are individual country plans for reducing emissions and adapting to climate impacts. Countries were encouraged to set more ambitious targets and to outline clear strategies for achieving them. A major focus of the conference was on the need to phase out coal and reduce dependency on fossil fuels, which are major sources of carbon

[12] https://www.oecd-nea.org/jcms/pl_61714/nea-at-cop26

emissions. In this context, nuclear energy, and specifically SMRs, were recognized as crucial elements in the shift to a low-carbon energy future.

SMRs were highlighted for their ability to render a crucial role in the clean energy shift. As low-carbon power sources, SMRs can generate reliable electricity with minimal greenhouse gas emissions, rendering them an lucrative alternative for countries in quest to decarbonize their energy sectors. The versatility of SMRs extends beyond electricity generation; they can also be used for industrial applications such as providing process heat and desalinated water, further contributing to sustainable development goals.

In addition to their environmental benefits, SMRs enhance energy security and resilience. Their modular and flexible design allows for deployment in various settings, including remote and off-grid locations where large reactors would be impractical. This capability is particularly valuable for improving energy access in underserved regions and for supporting decentralized energy systems. By providing a steady and unceasing energy supply, SMRs can help to mitigate the risks associated with energy intermittency from renewable sources and ensure a reliable energy supply in the face of growing demand.

The success of SMRs in contributing to climate action depends on supportive policy and regulatory frameworks. COP26 underscored the need for countries to streamline licensing and approval processes for SMRs to facilitate their rapid deployment. Simplified regulatory frameworks can reduce the time and cost associated with bringing new reactors online, making it easier for countries to integrate SMRs into their energy strategies. Furthermore, providing financial inducements, including but not limited to tax breaks, grants, and subsidies, can boost investment in SMR projects and stimulate the growth of the nuclear energy sector.

International standards and cooperation are essential for the successful deployment of SMRs. Establishing common standards for SMR design, construction, and operation can facilitate international collaboration and trade, making SMRs more accessible to a wider range of countries. COP26 emphasized the importance of continued global cooperation to share knowledge, resources, and best practices, and to foster partnerships that can advance the development of SMR technology.

Looking ahead, the outcomes of COP26 set the stage for a robust and coordinated approach to deploying SMRs as part of the broader strategy to combat climate change. Nations are encouraged to implement stronger climate policies and to translate their commitments into concrete actions. This includes setting ambitious targets for clean energy adoption and carbon reduction and supporting technological innovation in the nuclear sector. Investment in research and development is critical for progressing SMR technology, making it more cost-effective, efficient, and adaptable to diverse energy needs.

Continued global partnership will be vital to the successful integration of SMRs into global energy systems. By fostering global partnerships, harmonizing regulations, and investing in innovative technologies, countries can unlock the full potential of SMRs and make significant progress toward achieving their climate and energy goals. The leadership demonstrated at COP26 provides a hopeful vision for a future where SMRs contribute to a sustainable, resilient, and low-carbon global energy landscape.

Adoption of SMRs In India

Having analysed the benefits that come along with SMRs, and, the suitability that it can pose in India, it becomes necessary for India to consider adopting of the requisite technological know-how along with the necessary infrastructure to facilitate energy production originating from SMRs in India. It is also intrinsic to mention that Union Minister of State (Independent Charge) Science & Technology; MoS PMO, Personnel, Public Grievances, Pensions, Atomic Energy and Space, recently termed nuclear power as a potential clean energy option for power generation and further announced that Small Nuclear Reactors are being researched by the government to shift to clean energy.

The benefits of the SMRs are known to India by virtue of the aforementioned discussions and the perusal of the results rendered around the globe. However, it is equally intrinsic to consider the suitability of the SMRs in the Indian Scenario, the consideration being done before such technology is researched, crafted and adopted as a matter of practice to satiate the Indian energy needs.

STATE-WISE POWER CRISIS AND ROLE OF SMRs

Recently, the Secretary, Department of Energy of one of the larger States in the eastern part of India informed[13] that the sudden rise in consumption has left the State with a 200–300 Mega Watt (MW) daily electricity shortage. The state uses about 6,000 MW of power each day, while there are only 5,000 to 5,200 MW of power available from various sources. But nearly every

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[13] https://www.businesstoday.in/latest/story/power-crisis-in-india-these-states-facing-electricity-problems-full-list-332105-2022-05-02

day, the state purchase about 600 MW of power from the exchange for our state's consumers at higher prices.

Some of the most populous states in India, have long struggled to provide its citizens with dependable energy. The state's quality of life and economic growth are impacted by the poor and irregular electrical supply, even with recent improvements. The use of (SMRs) is one viable remedy for this enduring problem. The capacity of several Indian States to generate power is far less than the demand for it. Due to the state's heavy reliance on electricity imports from the national grid, load distribution and frequent power outages are common. The state's inadequate infrastructure for producing electricity, which consists of a combination of thermal, hydro, and renewable energy sources, causes this dependence.

Electricity problems in Northern India

To address the soaring electricity demand and ensure sufficient power supply amid the intense summer, the Ministry of Power has initiated several measures to meet an unprecedented highest requirement of 250 GW. The Northern Region of India had experienced severe heatwave since May 17, 2024, causing a spike in power consumption. Despite these conditions, a record highest requirement of 89 GW was efficaciously fulfilled on June 17, 2024, by bring in 25-30% of the region's energy needs from other regional grids.[14]

Utilities have been instructed to support high-alert and reduce forced equipment fallouts. Under Section 11 of the Electricity Act, 2003, Imported Coal Based (ICB) Stations are mandated to continue generating energy during this period of high demand. Generating units have minimised planned maintenance, and increased efforts to reduce fractional and forced fallouts to extend generation ability to its fullest potential.

Generating companies, under these conditions, were urged to ensure their stations operate at full capacity. Coal-based thermal stations are maintaining adequate coal stocks, while hydro stations are conserving water throughout solar hours and maximising generation throughout non-solar hours.

Surplus power from generating stations is being made available in the marketplace as per the Electricity (Late Payment Surcharge and Related Matters) Rules, 2022, allowing states to

[14] https://www.thehindubusinessline.com/economy/power-ministry-reviews-electricity-demand-supply-situation-as-intense-heat-waves-bake-north-india/article68304086.ece

procure additional power. States can also arrange power via the PUShP portal. The Ministry of Power directed utilities to remain highly alert and reduce forced equipment outages due to the increased electricity demand from the ongoing heatwave, especially in the northern region awaiting the monsoon.

Although the installed capacity exceeds the demand, not all plants run continuously at optimal capacity, and immediate power transmission is not always possible. As States in Northern India continue to endure heatwaves, in another incident, there was a power outage at Delhi Airport which halted operations for nearly 30 minutes.

The India Meteorological Department predicts no major relief, as the monsoon was expected to reach the northern states by the end of June.

Solutions to improve these problems

The Ministry has reported that to meet the rising power demands, they were keeping power plants dependent on imported coal operational and limiting maintenance shutdowns to the bare minimum. Power generation companies have been recommended to support their plants in optimal condition, while hydropower stations are conserving water during the day and maximising power output at night. Gas-fired power plants are also being used to support the increased demand.

India's power generation relies heavily on thermal power, which makes up about 55% of installed capacity, with coal accounting for 90% and gas for the remaining 10% of thermal capacity. Wind and solar power make up about 30% of installed capacity, but their output is variable due to natural factors, limiting their reliability for on-demand power.

Several strategies can help alleviate the impact of severe power cuts. Improving power sector efficiency through investments in modern technology and infrastructure—such as upgrading power plants, transmission lines, and distribution networks—can reduce losses and enhance reliability. Promoting clean energy sources like solar and wind, which are progressively pocket friendly, is another solution. Encouraging the usage of power-efficient systems, such as home solar setups, can also manage demand and reduce consumption.

Solar energy, a sustainable and renewable resource, offers a reliable electricity supply even during power outages when combined with battery storage. The decreasing cost of solar panels in India makes this an attractive choice. Solar power has significant advantages, including cost-effectiveness, minimal maintenance, and zero greenhouse gas release.

However, the sustainability of the energy sector requires addressing production costs and subsidies. India faces crucial decisions to secure its power future, including the establishment of diverse power production plants while managing environmental impacts. Ignoring certain energy sources, such as nuclear power, due to political reasons would be unwise.

A diversified energy portfolio, including wind and solar power, is essential. Southern India, particularly Tamil Nadu, has untapped potential for wind and solar energy due to its geographic location. Resolving issues like government payment obligations, which have led to the shutdown of wind farms, can unlock significant power potential. Large-scale solar thermal systems could also be implemented in arid regions.

Urbanisation and increased consumption will drive up electricity demand, needing efficiency improvements. Innovative cooling methods that do not rely on electricity should be promoted, like rainwater harvesting initiatives.

A national grid and uniform distribution system for power production are essential for effective policy and load management. Surplus power from high-production states can be distributed to areas in need. A unified grid ensures fair power distribution and reduces regional disparities.

Incentivising households to adopt off-grid solar panels can provide independence from the grid and allow excess power to be fed back into it, offering vast potential for energy generation and stability.

How SMRs will help in overcoming electricity shortage in India

SMRs would have two vital characteristics– small and modular. These fission reactors tend to have an output of about 300 MWe or less. Their modular design enables for centralized manufacturing in a facility, making them mobile to the intended spot for setup and installation. Unlike typical atomic stations that are built on-site, SMRs may be brought, installed, and begin producing electricity much like an appliance. Furthermore, multiple reactors can be installed as needed. SMRs can be deployed on land, on vessels for offshore operations (also referred to as floating nuclear-powered stations), or even in below-ground or underwater locations. Currently, over 70 SMR concepts are being researched worldwide, ranging from minimally modified old reactors to wholly contemporary technologies. To keep up with the rapid pace of progress and creativity in this field, the (IAEA) organized the SMR Regulators' Forum. This forum allows for the exchange of information about shared topics among countries. In 2021, the IAEA issued a Technology Roadmap for Small Modular Reactor Deployment, which tracks and evaluates SMR technologies and fosters collaboration and knowledge exchange amongst innovation creators, stakeholders in the industry, users, and regulatory organizations.

(SMRs) signify a groundbreaking progression in power generation. Imagine a university campus or an industrial hub like NTPC, BHEL, or Jamshedpur, powered by a discreet yet robust nuclear plant delivering clean, reliable electricity—this is the promise of SMRs.

On a global scale, SMRs have the potential to revolutionise energy production. These compact nuclear power plants, designed to produce between 30 MW and 300 MW, are ideal for efficiently powering small communities and industrial sites. SMRs offer several advantages over larger reactors, including the ability to be discreetly installed almost anywhere with proper safety measures. Decommissioned thermal plant sites are particularly suitable, as they already possess essential infrastructure such as power evacuation systems, water access, and storage facilities.

Another innovative application is mounting SMRs on maritime barges, which allows for flexible transport to coastal areas. An example of this concept is the 200 MW Taneer Bhavi plant, formerly owned by the GMR group, which demonstrated the feasibility of barge-mounted power plants.

The modularity and standardisation of SMRs are significant strengths. Standardised designs enable mass production, making deployment more cost-effective. The maritime sector has already demonstrated the effectiveness of small nuclear plants, as seen with India's INS Arihant, which houses an 83 MW nuclear reactor.

INDIA: THE PATH AHEAD WITH SMRS

India operates 23 atomic reactors, most with a capacity of 220 MWe, and has also constructed an 85 MWe facility for its atomic submarine, demonstrating its ability to design, build, and operate small reactors. Although India hasn't yet utilised modular factory processes, the nuclear equipment manufacturing industry could adapt if the nuclear establishment priorities such reactors.

Recognising SMRs' potential, India's Department of Energy is developing this technology. K N Vyas, former Secretary of the Department of Atomic Energy (DAE) and Chairman of the Atomic Energy Commission, stated in 2019 that designing and refining reactor systems is an ongoing process, but technology development for SMRs needs to fill current gaps before continuing seriously.

While the DAE monitors SMR advancements, its current focus is on enhancing existing reactors. Progressing from 220 MWe to 540 MWe and 700 MWe, India aims to rapidly expand nuclear electricity generation. The Indo-US nuclear cooperation agreement sought to enable larger reactor imports, although these have faced price and liability issues. Meanwhile, India has successfully developed 700 MWe reactors indigenously.

For a country with growing electricity demand, large reactors are clearly justified. However, SMRs could be useful in specific scenarios, such as replacing decommissioned coal plants. Shrikumar Banerjee, another former Chairman of the Atomic Energy Commission, suggested that some decommissioning coal power plants could be replaced with SMRs, helping to combat air pollution and meet Paris Agreement goals. SMRs could also supplement renewable energy by providing a reliable baseload power source and serve remote areas or islands.

Despite the promising outlook, it remains uncertain whether SMRs will deliver the transformative impact they promise. The urgency for low-carbon electricity has generated significant interest, presenting a major investment occasion for the atomic industry. India must explore options, particularly through private sector involvement. The DAE/Nuclear Power Corporation of India (NPCIL) could support private players in building such reactors once a design is proven. The government could further incentives this through production-linked incentive schemes. Recent atomic collaboration agreements with republics like France, the USA, South Korea, and Russia also include potential collaborations on SMRs.

However, given India's electricity needs, SMRs should be given as much priority by the DAE, as larger nuclear reactors. Developed countries pursuing SMRs are often dealing with stable or stagnant electricity demand and population growth. For them, SMRs represent a way to keep the nuclear industry active and promote new nuclear builds in regions with stalled reactor construction or potential for exports. Diverting significant resources towards SMRs would detract from the focus on quickly constructing planned larger reactors to boost India's power supply in an eco-friendly manner. Long-term policy support is crucial to achieve the timely completion of these larger reactor projects.

Atomic energy can play a significant role in clean power shifts

Atomic power plays a crucial role in energy manufacturing, providing 10% of the worldwide energy supply in 2018. In progressive economies, it books for 18% of production and is the leading low-carbon electricity source. However, its share of global energy supply has been decreasing, mainly due to ageing nuclear fleets in advanced economies, the slow addition of new capacity, and the retirement of reactors constructed in the 70s and 80s of the previous century. This decline has hindered progress in the direction of a clean energy system. Notwithstanding significant progress in solar and wind energy, the complete portion of green power in the entire energy supply in 2018 remained at 36%, equivalent to the past two decades, because of the reduction in atomic power. Reversing this trend is essential to accelerating the decarbonisation of energy supply.

A variety of innovations, notably atomic electricity, will be necessary for worldwide sustainable power transitions. As the worldwide power system grows progressively power-based, the key for greening power systems is to change the power sector from the most significant CO2 emitter into a low-carbon source that cuts fossil fuel emanations in conveyance, heating, and industrial use. While green sources will continue to lead, nuclear power, combined with fossil fuels using carbon capture, utilization, and storing, can also play an important role. Countries planning to integrate nuclear technology in their future power mix account for majority of the world demand for energy and CO2 emissions. To line with sustainability aims and international environmental objectives, the spread of renewable energy must be three times quicker than it is now, needing 85% of worldwide energy to originate from renewable sources by 2040, in contrast to 36% today. This would need significant expenditures in efficiencies and renewables, coupled with an 80% rise in worldwide nuclear power generation by 2040.

Nuclear power facilities boost electrical security in numerous ways. They assist stabilise power grids and can modify their procedures to fit requirements and supply changes. As the share of renewable energy sources like wind and solar photovoltaics (PV) increases, the necessity for such services will expand. Atomic reactors can offset the effects of seasonal variations in renewable output and boost power safety by lowering reliance on imported fuels, especially in India, which experiences varied temperatures and weather conditions throughout the year.

Lifetime extensions of atomic reactors are vital to bring the energy shift back on track

Policy and regulatory choices are grave for the replacement of old reactors in prosperous nations, where the average age of an atomic fleet is 35 years. The European Union and the United States have the oldest and biggest atomic fleets, both surpassing 100 gigawatts, with median age of reactors between 35 and 39 years, respectively. Most reactors were initially built for a 40-year service lifespan. By 2025, around one-fourth of present-day nuclear capacity in industrialized economies will be heading for a shutdown, mostly due to regulations aimed at diminishing nuclear energy's role. The eventual utilization of the residual capacity rests on choices concerning lifetime renewals in the years that follow. In the US, around 90 reactors have 60-year licenses to operate, however seven were deactivated early, and several more are facing the risk of shutting down. In Europe, Japan, and other industrialized economies, opportunities for extending plant lifespan are equally questionable.

Economic variables play a crucial effect as well. Prolonging the lifespan of current reactors is considerably less expensive than constructing new ones and affordable with other energy generation methods, notably new wind and solar projects. However, major expenditure is still necessary to repair and renovate crucial components to ensure continuing safe operation. Low wholesale power and carbon prices, coupled with new limitations on water use for chilling reactors, render certain plants in the United States commercially unfeasible. Furthermore, markets and regulatory institutions sometimes penalize atomic power by disregarding its worth as an environmentally friendly power source and its involvement in electrical security. Therefore, most atomic power stations in industrialized economies are at danger of untimely closure.

SELECTIVE PRIVATIZATION OF (SMRS) IN INDIA: A STRATEGIC APPROACH TO BALANCING ENERGY DEMAND, SUSTAINABILITY, AND SECURITY

India's energy sector stands at a crucial juncture where balancing increasing demand with sustainability and security is imperative. Amidst this challenge, Small Modular Reactors (SMRs) present an innovative solution that warrants selective privatization within the nuclear sector. Unlike traditional large-scale reactors, SMRs offer several advantages, including reduced capital costs, shorter construction timelines, and enhanced safety features, making them particularly suitable for private sector involvement. India has lofty plans to become a leading power in harnessing electricity from SMRs. This was evident by the revelation by India’s Finance Minister, Ms. Nirmala Sitharaman in her Budget Speech in July of this year, of plans to take the route of Private-Public Partnerships to develop 220-megawatt SMR’s called “Bharat Small Reactor”. Following her speech, the Tata Group announced that it would be collaborating with the Department of Atomic Energy to set up 40 – 50 BSRs in the coming decade.

Privatizing the entire nuclear sector is neither necessary nor advisable given the strategic and security implications associated with nuclear technology. However, selectively allowing private companies to invest in and develop SMRs could significantly benefit India's energy landscape.

SMRs are designed to be modular and factory-built, which not only reduces construction costs but also ensures a consistent and scalable approach to expanding nuclear capacity. This modularity also allows for flexible deployment in various locations, including remote areas, thereby enhancing energy access and grid stability.

The involvement of the private sector can drive technological innovation and operational efficiency in the development of SMRs. Private companies, driven by competitive market forces, are likely to invest in advanced research and development to improve reactor designs, enhance safety measures, and lower operational costs. This can lead to the rapid commercialization of SMR technology, making nuclear energy more accessible and cost-effective.

Moreover, private sector participation can attract substantial investment, both domestic and international. Such investments are crucial for overcoming the financial limitations of government-funded projects and accelerating the deployment of SMRs. By fostering a robust supply chain and industrial base for nuclear components and services, private sector involvement can also create high-skill jobs and spur economic growth.

To facilitate this selective privatization, it is vital to create a clear and supportive regulatory framework. This framework should differentiate SMRs from traditional nuclear reactors, addressing specific licensing, safety, and liability issues. Streamlined regulatory processes can reduce bureaucratic hurdles and provide clarity and assurance to private investors. Additionally, policies that promote public-private partnerships, offering inducements such as tax breaks, subsidies, and grants, can further inspire private sector participation.

Public perception and acceptance are vital for the success of nuclear projects. Therefore, extensive awareness campaigns are necessary to highlight the safety features and environmental benefits of SMRs. Transparent communication and community engagement can help address fears and misconceptions about nuclear energy. Demonstrating the reliability and safety of SMRs through pilot projects can build public trust and pave the way for broader acceptance of privatized nuclear initiatives.

Going by media reports, elaborate discussions are on-going at the highest levels to evaluate the effectiveness of SMRs. The Prime Minister of India, on his recent visit to the USA met with the promoter of Holtec International – considered to be one of the largest exporters of capital nuclear components. Holtec, a small privately held company has proposed a private-public partnership to deploy "its proposed SMR-based projects and the possibility of joint manufacturing at some point in the future". This has come as the first tangible beacon of light in a two-decade long tunnel of time since India and the US had their civil nuclear agreement.[15]

Regulatory Framework for Small Modular Reactors (SMRs) in India: Drawing Parallels with Digital Economy Regulations to Enhance Energy Security and Sustainability

India's evolving energy landscape necessitates the implementation of regulations for Small Modular Reactors (SMRs) similar to how the country has approached regulation in other critical sectors. The strategic deployment of SMRs can significantly enhance India's energy security, reduce carbon emissions, and address the growing demand for electricity. However, just as with other advanced technologies, the integration of SMRs requires a robust regulatory framework to ensure safety, efficiency, and public confidence.

The need for regulation of SMRs can be likened to previous regulatory milestones in India, such as the regulation of the digital economy through the Information Technology (Intermediary Guidelines and Digital Media Ethics Code) Rules, 2021, and the regulatory oversight established by the Data Protection Bill. These regulations were implemented to address new challenges posed by technological advancements and to protect the interests of users and stakeholders. Similarly, the landmark case of *Internet and Mobile Association of India vs. RBI* underscores the necessity of creating clear and supportive regulatory environments for emerging sectors to foster growth while safeguarding public and national interests.

The IT Rules (2021) were introduced to regulate digital content, curb misinformation, and protect user data, reflecting the government's proactive stance in adapting to the digital age. These regulations provided much-needed clarity and guidelines for intermediaries and digital media, ensuring accountability and transparency. This approach is crucial for SMRs, where clear regulations can address safety standards, operational protocols, and emergency response measures, thereby mitigating risks associated with nuclear technology.

In the context of the Data Protection Bill, the emphasis on safeguarding personal data and ensuring privacy parallels the necessity for stringent safety and security measures in the atomic

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[15] https://indianexpress.com/article/business/20-years-after-nuclear-deal-new-jersey-firms-proposal-for-small-reactor-opens-a-door-9607315/; 7th October 2024

sector. Just as the Data Protection Bill aims to protect individual privacy and foster trust in digital services, SMR regulations would aim to protect public health and safety, build public trust in nuclear energy, and promote environmental sustainability. Comprehensive regulations would encompass site selection, design approval, construction standards, operational safety, waste management, and decommissioning procedures.

The precedent set by the *Internet and Mobile Association of India vs. RBI* case highlights the importance of creating enabling regulatory frameworks that do not stifle innovation. In this case, the Apex Court struck down the RBI's blanket ban on cryptocurrency transactions, emphasizing the need for balanced regulation that fosters innovation while addressing potential risks. Similarly, regulations for SMRs should be designed to encourage technological innovation and private sector participation without imposing overly restrictive barriers. By fostering a conducive environment for SMR development, India can attract investments, both domestic and international, and accelerate the deployment of this clean energy technology.

The Digital Personal Data Protection Act (DPDP) underscores the importance of safeguarding public interest while embracing technological advancements. Regulations for SMRs would similarly need to prioritize public safety and environmental protection while enabling the deployment of advanced nuclear technologies. This balanced approach would ensure that the benefits of SMRs, such as lower carbon emissions and reliable power supply, are realized without compromising safety or public trust.

Evolving India's Legal Framework: Drawing Constitutional Parallels for Regulating Small Modular Reactors (SMRs) India's legal framework is dynamic, evolving to meet new challenges and opportunities.

This adaptability is enshrined in the Indian Constitution, which allows for amendments to address the changing needs of society. The regulatory landscape for Small Modular Reactors (SMRs) can be shaped by this same flexibility, ensuring that the deployment of this innovative technology is both safe and efficient. Several landmark cases illustrate how the Indian Constitution has evolved over time to reflect contemporary realities, which support the argument for the establishment of a regulatory framework for SMRs.

One of the most significant cases demonstrating the Constitution's flexibility is **Kesavananda Bharati v. State of Kerala (1973)**. This case recognized the doctrine of the basic structure, which states that while the Constitution can be amended, its fundamental framework cannot be altered. This decision underscored the importance of a balance between change and stability, allowing for progressive amendments while preserving core principles. The doctrine established by the Supreme Court of India, has enabled numerous amendments that have progressively modernized India's legal and regulatory environment, paving the way for new policies and frameworks that address emerging technologies like SMRs.

Similarly, the case of **Minerva Mills Ltd. v. Union of India (1980)** reinforced the idea that the Constitution's amendments should not destroy its essential features, but allowed for necessary changes to facilitate the nation's progress. This case highlighted the need for a responsive legal system that can adapt to new developments, which is crucial for integrating advanced nuclear technologies. By drawing on this precedent, India can develop specific regulations for SMRs that align with modern safety and environmental standards while upholding constitutional principles.

The **S. R. Bommai v. Union of India (1994)** case further exemplifies the Constitution's adaptability. This ruling clarified the scope of federalism in India, showing that the Constitution could accommodate changes in the political and administrative structures to better serve the nation's needs. Similarly, regulating SMRs will require a collaborative approach between the central and state governments to guarantee that these reactors are deployed in a manner that maximizes their benefits while minimizing risks.

The introduction of the **Goods and Services Tax (GST) in 2017** is a contemporary example of significant constitutional change to address economic needs. The 101st Amendment Act unified the taxation system across the country, demonstrating the Constitution's ability to adapt to economic and administrative requirements. This precedent supports the argument for amending regulatory frameworks to accommodate SMRs, ensuring that India's energy policies are as modern and efficient as its economic policies.

IMPACT ON INDIA AFTER ADOPTING SMRS

The adoption of (SMRs) in India has the potential to significantly impact the country's economy, presenting both opportunities and challenges. By diversifying the energy mix, SMRs can improve energy security and decrease dependency on imported traditional fuels. This diversification minimizes risks associated with supply disruptions and volatile international energy prices, contributing to a more stable economic environment. Furthermore, SMRs provide a reliable source of electricity, essential for continuous industrial operations and economic activities. This reliability can help mitigate power outages that currently hinder productivity and economic growth.

The development and deployment of SMRs can also stimulate the domestic manufacturing sector. India has the potential to become a hub for SMR production, creating jobs and fostering technological advancements. Additionally, the modular nature of SMRs allows for deployment in remote and underserved regions, promoting regional development and reducing urban-rural economic disparities. This regional development can lead to a more balanced economic growth across the country.

The growth of the SMR sector can create numerous high-skilled jobs in engineering, construction, operation, and maintenance. The demand for a highly skilled workforce in the nuclear industry will likely lead to increased investment in training and education, enhancing the overall skill level of the workforce and creating long-term human capital benefits. This investment in human capital is crucial for sustaining the growth and development of the nuclear sector.

Adopting SMRs can also bring significant environmental and health benefits. By replacing coal and other fossil fuels with nuclear power, SMRs can substantially reduce air pollution, leading to healthier population and decreased healthcare costs. Additionally, the low carbon footprint of nuclear energy can help India meet its climate change goals, avoiding economic damages associated with climate change impacts. This dual benefit of improving public health and mitigating climate change is essential for sustainable economic development.

The economic impact of SMRs is further amplified by their potential to attract both domestic and international investments. The advanced nuclear technologies embodied in SMRs can foster economic growth by drawing investments into infrastructure, services, and supply chains. This investment can lead to positive multiplier effects across the economy, creating new business opportunities and stimulating economic activity.

However, the adoption of SMRs also presents significant challenges and costs. The initial investment required for SMR development and deployment is high, and financing these projects could strain public finances or necessitate substantial private investment. Ensuring robust regulatory frameworks and safety standards for SMRs is essential but can be complex and time-consuming, potentially delaying economic benefits. Effective management of nuclear waste remains a critical challenge that requires long-term solutions, incurring additional costs.

The adoption of SMRs can spur innovation and technological advancement in nuclear technology and related fields, positioning India as a leader in atomic research and development. By advancing in SMR technology, India can enhance its global competitiveness in the energy sector, potentially exporting SMR technology and expertise to other countries. This global competitiveness can open up new markets and create additional economic opportunities.

In summary, the adoption of SMRs in India presents a transformative opportunity with the potential for significant economic benefits, including enhanced energy security, job creation, regional development, and environmental improvements. However, these benefits must be weighed against the challenges of high initial costs, regulatory hurdles, and waste management. Strategic planning and investment will be crucial to maximizing the positive economic impact of SMRs on India's economy.

Impact On Treasury of India After Adopting SMRs;

The adoption of Small Modular Reactors (SMRs) in India is poised to impact the country's treasury across various dimensions, encompassing both expenditures and potential revenue streams. Initially, substantial investments would be required for infrastructure development, including the construction of nuclear power plants and associated grid integration. Moreover, research and development efforts aimed at adapting SMR technology, enhancing safety standards, and ensuring regulatory compliance would necessitate significant financial allocations. Establishing robust regulatory frameworks would also incur costs related to licensing, inspections, and monitoring activities.

Once operational, SMRs would entail ongoing costs for maintenance, fuel procurement, and waste management, necessitating continued financial support from the treasury. However, the electricity generated by SMRs would provide a steady revenue stream through its sale to the national grid. Additionally, India could capitalize on export opportunities by leveraging its expertise in SMR technology, thereby generating substantial revenue and bolstering economic growth.

The deployment of SMRs is expected to excite economic activity and create employment occasions across various sectors, leading to increased tax revenues for the government. Indirect taxation, such as goods and services tax (GST) and excise duties, would also see an uptick due to heightened consumption and business activity.

In conclusion, while the adoption of SMRs in India would necessitate significant upfront investments and ongoing operational costs, it also presents promising opportunities for revenue generation, economic expansion, and technological advancement. Effective financial planning, strategic investments, and regulatory frameworks will be critical to optimizing the positive impact of SMRs on India's treasury and overall economy.

Impact On Energy Sector of India After Adopting SMRs;

The adoption of (SMRs) in India holds the promise of a transformative shift in the nation's energy sector, touching upon various dimensions from energy generation to environmental sustainability and energy security. By integrating SMRs into the energy mix, India can diversify its energy sources, dropping dependance on traditional fuels and bolstering energy security. These reactors offer reliable base load power, complementing intermittent renewables like solar and wind energy, ensuring a stable electricity supply to meet rising demand. Additionally, SMRs enable capacity expansion, contributing to overall electricity generation and meeting the energy demands of a rapidly developing economy.

In terms of environmental impact, SMRs provide a low-carbon energy alternative, aiding India's efforts to decrease its carbon footprint and battle climate change. By displacing coal-fired power plants, SMRs can significantly mitigate greenhouse gas emissions and improve air quality by decreasing pollutants like sulphur dioxide and nitrogen oxides, benefiting public health and environmental quality.

The adoption of SMRs would stimulate innovation and research in nuclear technology, fostering advancements in reactor design, safety features, and operational efficiency. This could position India as a leader in nuclear technology development and offer opportunities for skill development and capacity building in the nuclear energy sector, enhancing the expertise of Indian scientists, engineers, and technicians.

Moreover, SMRs could play a crucial role in rural electrification efforts, providing clean and reliable electricity to remote and off-grid areas where conventional grid infrastructure is inadequate. While the initial investment in SMRs may be substantial, the long-term operational costs could be competitive compared to other energy sources, contributing to energy affordability and reducing the financial burden on consumers.

In terms of energy security, SMRs offer the potential to reduce India's dependency on imported conventional fuels, bolstering energy security and decreasing vulnerability to geopolitical risks associated with energy imports. These reactors can also bolster grid steadiness by offering a steady and continuous energy supply, thereby reducing the risk of blackouts and ensuring reliable electricity supply for industrial and commercial activities.

Overall, the adoption of SMRs in India represents a significant opportunity to revolutionize the country's energy sector, offering a sustainable, reliable, and low-carbon energy solution that addresses key challenges such as climate change, energy access, and energy security. Effective policy support, investment in infrastructure, and collaboration with international partners will be crucial for comprehending the full potential of SMRs in India's energy shift journey.

Impact On Environment of India After Adopting SMRs;

The adoption of (SMRs) in India is poised to have a substantial impact on the environment, offering both benefits and challenges in the context of sustainability and ecological preservation. One of the prime environmental benefits of SMRs is their ability to produce electricity with minimal carbon emissions. Unlike traditional conventional fuel-based power facilities, which produce great quantities of carbon dioxide (CO_2) and other pollutants which are left into the atmosphere, SMRs generate electricity through nuclear fission, emitting virtually no greenhouse gases during operation. This reduction in carbon emissions can contribute significantly to India's pains to battle climate change and diminish its overall carbon footprint. By replacing coal-fired power plants with SMRs, India can recover air quality and alleviate the harmful effects of air pollution on public health and the environment. Coal combustion releases various pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM), which contribute to respiratory diseases, smog formation, and environmental degradation. SMRs offer a cleaner alternative, producing electricity without emitting these harmful pollutants, thus promoting better air quality and environmental well-being. SMRs also require significantly less land and water resources compared to traditional fossil fuel-based power plants. Coal mining and natural gas extraction, which are integral to conventional power generation, often entail habitat destruction, water pollution, and ecosystem disruption. In contrast, SMRs operate within a compact footprint and do not rely on large-scale resource extraction, thereby minimizing their environmental impact and conserving precious natural resources. While SMRs produce radioactive waste as a byproduct of nuclear fission, advancements in nuclear technology have enabled more efficient and safer waste management practices. Proper disposal and storage of nuclear waste are essential to avert environmental contamination and safeguard public health. India would need to develop robust waste management substructure and regulatory outlines to guarantee the safe treatment and long-term storage of radioactive materials generated by SMRs. Despite their environmental benefits, SMRs also pose certain environmental risks, particularly related to nuclear accidents and radioactive contamination. While modern SMR designs incorporate progressive safety features to minimalize the likelihood of accidents, the potential consequences of a nuclear incident could be catastrophic for the environment and human health. India must prioritize stringent safety standards, regulatory oversight, and emergency preparedness measures to mitigate these risks and ensure the safe operation of SMRs. Overall, the adoption of SMRs in India has the ability to substantially diminish carbon emissions, recover air quality, and conserve natural resources, thereby giving a share to a more sustainable and environment-friendly energy landscape. However, it is imperative for India to address the environmental challenges associated with nuclear energy, implement stringent safety measures, and invest in sustainable waste management practices to maximize the environmental benefits of SMRs while minimizing their potential risks.

NUCLEAR AUDIT AUTHORITY; A STEP TOWARDS WELCOMING SMRS

Recently, the Government of India has also advanced a step towards welcoming SMRs in India by announcing to setup a Nuclear Audit Committee which is ought to be bestowed with the responsibility to promote Bharat Small Reactors by working hands in gloves with the IAEA. At the same time, the government is further planning to bring in key and significant developments in the Civil Liability pertaining to and arising out of The Civil Liability for Nuclear Damage Act, 2010 paving way for attracting investments in SMRs in India.

THE WAY FORWARD

SMRs have the potential to offer clean electricity, hydrogen, and process heat, making them versatile solutions for various energy needs. They can provide stable baseload electricity while also supporting the incorporation of renewable energy sources into the grid. Additionally, SMRs can aid non-electric utilisations like desalination and district heating, and micro SMRs can supply both energy and heat to remote populations. While SMR technologies like PWR and PHWR have reached a mature stage, others such as HTGR, LMFR, and MSR are still in the research and development phase. Safety standards and legal frameworks have been established for some reactor types, but others require further development. Challenges may arise during the deployment of innovative SMR designs, necessitating adjustments to legal, regulatory, and safeguards outlines. Initial demonstration of SMR plants can mitigate risk perception, attract investment, and stabilize the industry. Harmonization of licensing and regulatory approaches, along with government support, is vital for the evolution of the global SMR market under net-zero emissions initiatives. To render a worthy role in climate change extenuation, first-of-a-kind SMR units should be deployed by the early 2030s. Successful deployment of SMRs requires leveraging private sector investment and establishing a technology-neutral policy framework that considers factors like taxonomies and environmental, social, and governance criteria.

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