DAWN OF SMALL MODULAR REACTORS IN GREEN INDIA

1. INTRODUCTION

The Indian economy is currently the fifth largest economy in the world calculated on the basis of nominal gross domestic product[1]. As per the projections of the International Monetary Fund[2], if India continues to grow at a rate of more than 7% (seven percent) in the next five years, it will overtake Germany and Japan to become the third largest economy across the globe[3]. Furthermore, in the next few decades it may even be able to catch up with the economical might of China and the United States of America[4]. In order to reach this pinnacle of growth a key pillar which India needs is energy availability and energy security.

India annually consumes more than one gigatonne of oil equivalent[5] of energy, and this demand has continued to grow at a rate of 7% (seven percent) per annum in the recent years[6]. Despite accounting for 17% (seventeen percent) of the global population, India consumes only 6.1% (six point one percent) of global primary energy consumption[7]. In order to increase the standard of living of its population and improve the indices of human development of its population, India needs to ramp up its power generation by at least four times[8]. However, post the Industrial Revolution, ramping up power generation is not as linear as it sounds, as now each quantum of increase in power generation has to be balanced with the increasing ecological costs on the planet and sustainable development. Therefore, development has to balance the scales between,

(i) increasing the living standards of its population and providing them with a sustainable source of energy to keep the economy growing, and

(ii) controlling greenhouse gas emissions produced in the process.

Currently the power mix in India is dominated by coal-based power, which accounts for 46% (forty-six percent) of the entire supply followed by oil (accounting for 24% (twenty-four percent)), biomass (accounting for 20% (twenty percent)), natural gas (accounting for 5% (five percent)) and finally renewable and other sources of energy (hydro, nuclear, solar and wind all cumulatively for 4% (four percent))[9]. India would evidently need to undertake a massive shift in the source of electricity if it vows to go on the green path.

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[1] See https://www.thehindu.com/business/Economy/india-to-become-third-largest-economy-with-gdp-of-5-trillion-in-three-years-finance-ministry/article67788662.ece accessed on May, 22, 2024 at 16:00 (IST)
[2] See https://pib.gov.in/PressReleasePage.aspx?PRID=2001124 accessed on May, 22, 2024 at 16:00 (IST)
[3] See https://www.ey.com/en_in/tax/economy-watch/india-towards-becoming-the-third-largest-economy-in-the-world accessed on May, 22, 2024 at 16:00 (IST)
[4] [*ibid*]
[5] See https://www.enerdata.net/estore/energy-market/india/ accessed on May, 22, 2024 at 16:00 (IST)
[6] See https://www.enerdata.net/estore/energy-market/india/ accessed on May, 22, 2024 at 16:00 (IST)
[7] See https://pib.gov.in/PressReleasePage.aspx?PRID=1809204 accessed on May, 22, 2024 at 16:00 (IST)
[8] See https://pib.gov.in/Pressreleaseshare.aspx?PRID=1577011 accessed on May, 22, 2024 at 16:00 (IST)
[9] See https://www.enerdata.net/estore/energy-market/india/ accessed on May, 22, 2024 at 16:00 (IST)

The country is making strong strides on the front of green development as seen from its aggressive targets pledged in the Nationally Determined Contribution under Paris convention of the United Nations Framework Convention on Climate Change[10]. It has also set ambitious plans for reduction of carbon emission intensity of its gross domestic product by 45% (forty-five percent) by 2030, from 2005 levels and achieve 50% (fifty percent) cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030[11]. Additionally, it has targeted to reach net-zero emissions by 2070. However, these plans and targets which match the prerogative of development with the pledge of clean energy rely heavily on renewable energy sources like solar and wind.

This expectation on renewable energy to carry the mantle of reducing green-house gas emissions and become a sustainable source of clean energy is not practical and sustainable due to two reasons. First, the inherent variable nature of renewable energy prevents it from becoming the sole source of round the clock ("**RTC**") energy, especially in the absence of large scale effective energy storage solutions. Second, there are practical limitations in efficiency of production and storage of renewable energy when compared with fossil fuel based energy which prevents it from completely replacing fossil fuel based energy sources.

In light of these challenges in renewable energy being the sole workhorse for green transition, India needs to find additional sources of clean, green, reliable energy, which not only possesses the lower carbon footprint of renewable energy, but is also vested with the reliable RTC power like that of fossil fuels.

2. THE NUCLEAR PERSPECTIVE

Nuclear energy in India currently accounts for a mere 2.8% (two point eight percent) of total power generation. This energy is sourced primarily from the Indian nuclear workhorse of 700 (seven hundred) MW[12] Pressurised Heavy Water Reactors[13] ("**PHWR(s)**")[14]. India plans to ramp up this to 9% (nine percent) by 2047[15]. However, considering the current nuclear models there are many hurdles in establishing nuclear energy through PHWRs as a core source of energy. Some of the challenges to establishing traditional nuclear power plants are as follows:

(i) the high cost of setting up (the cost of setting up a PHWR nuclear plant in 2021-22 is upwards of INR 117 million (Indian Rupees One Hundred And Seventeen Million Only) /MW which is going to increase to INR 142 million (Indian Rupees One Hundred And Forty Two Million Only)/MW by 2026-27[16]);

(ii) long construction time;

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[10] Nationally determined Contributions are voluntary commitments made by countries to reduce their greenhouse gas emissions as part of their efforts and measures to achieve the global targets set under the Pariss Framework of the United Nations Framework Convention on Climate Change
See https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs accessed on May, 22, 2024 at 16:00 (IST)

[11] See https://pib.gov.in/PressReleasePage.aspx?PRID=1885731 accessed on May, 22, 2024 at 16:00 (IST)

[12] Megawatt, is a unit of measuring electricity generation and consumption it aggregates to one million watts.

[13] Pressurised Heavy Water Reactors are nuclear reactors which use heavy water (deuterium oxide) as coolant and neutron moderator

[14] See https://www.orfonline.org/expert-speak/indias-targets-for-nuclear-energy-moving-closer accessed on May, 22, 2024 at 16:00 (IST)

[15] See https://economictimes.indiatimes.com/news/india/9-per-cent-of-indias-electricity-to-come-from-nuclear-sources-by-2047-jitendra-singh/articleshow/99361312.cms accessed on May, 22, 2024 at 16:00 (IST)

[16] See https://www.orfonline.org/expert-speak/indias-targets-for-nuclear-energy-moving-closer/ accessed on May, 22, 2024 at 16:00 (IST)

(iii) over runs of cost and time schedule; and

(iv) the ultimate possibility of an adverse political or social environment leading to change in the regulatory landscape.

However, despite the above challenges, it cannot be disputed that nuclear power is vested with low greenhouse gas emissions during its production cycle, and it is a viable alternative to support renewable energy sources during their variable phases to ensure RTC power availability. Hence, advocates and developers of nuclear energy have been on the lookout for an innovative solution to provide a nuclear solution, and increase its percentage in the green energy mix. The result of these efforts and research initiatives has led to the development of the ingenious model for harnessing nuclear energy – the small modular nuclear reactor ("**SMR**").

3. HERALDING THE SMR ERA

The International Energy Agency in its recent report titled *Climate Resilience for Energy Security*[17] has stated that in order to achieve the target of net zero emissions by the year 2050, it is a global imperative that nuclear power capacity is expanded to reach a global capacity of 871 (eight hundred and seventy one) GW[18]. Nuclear power is the second largest source of low carbon electricity generation, wherein along with hydropower it provides for 75% (seventy five percent) of global low carbon energy[19], however owing to an adverse public opinion of nuclear energy the capacity additions have declined by over 3 (three) GW annually instead of expanding with time[20]. Owing to its benefits in providing reliable RTC power as base, and grid balancing, several countries are now focusing on the deployment of SMRs. SMRs are an ingenious variety of nuclear reactors, with power generating capacity which can be less than 30 (thirty) MWe[21] and can go up to 300 (three hundred) MWe. Some features of SMRs are:

(i) **Small** - a typical SMR is only a fraction of the size of a commercial large nuclear plant which range from 540 (five hundred and forty) MWe to around 700 (seven hundred) MWe. The small size provides an advantage to SMRs over traditional nuclear reactors in terms of safety, as seen in nuclear accidents in Chernobyl (*in the year 1986*) and in Fukushima (*in the year 2011*), in which cases the massive size of the nuclear power plants created issues in containment of the disaster. It also requires comparatively less capital and resources compared to traditional large scale nuclear projects[22].

(ii) **Modular -** Contrary to the traditional method of constructing nuclear power plants, SMRs are constructed through assembly of movable parts which can be transported to the location and assembled at the relevant site or disassembled at one site and reassembled at another, along with

[17] Climate Resilience for Energy Security
See https://iea.blob.core.windows.net/assets/10229b31-fd82-4371-b92c-a554f95369ea/ClimateResilienceforEnergySecurity.pdf accessed on May, 22, 2024 at 16:00 (IST)
[18] Gigawatt, is a unit for measuring electricity generation and consumption it aggregates to one billion watts
[19] See https://www.iea.org/reports/nuclear-power-in-a-clean-energy-system accessed on May, 22, 2024 at 16:00 (IST)
[20] Climate Resilience for Energy Security, Chapter 3: Climate Change impacts on energy supply See https://iea.blob.core.windows.net/assets/10229b31-fd82-4371-b92c-a554f95369ea/ClimateResilienceforEnergySecurity.pdf accessed on May, 22, 2024 at 16:00 (IST)
[21] Megawatt electric, is a unit to measure the electrical output of a generating station
[22] See https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs accessed on May, 22, 2024 at 16:00 (IST)

potential for retrofitting. This benefit lends the SMR models convenience, portability and cost advantages compared to the traditional nuclear reactors.

(iii) **Reactors -** Reactors utilise nuclear fission for the generation of heat to produce electricity or any other ancillary application like hydrogen production, desalinisation, or industrial heating. They have an advantage over fossil fuel energy systems due to their low carbon footprint and they can overcome the limitation of renewable energy sources to provide reliable power in adverse weather conditions and can be a source of reliable RTC power as backup.

Based on available prototypes, SMRs are currently grouped under the following categories according to their designs, fuel types and energy production capacity:

(i) **Land based water-cooled SMRs** - These are SMR versions of the configuration of traditional pressurized light water reactors ("**PWR**")[23] and PHWRs. These designs utilise the traditional industrial knowledge due to which these projects have advanced beyond the design stages and are very close to deployment on field. Success of deployment of land based water cooled SMRs can be seen in the under-construction CAREM project in Argentina[24], which is planned to commence operations in 2027 and the ACP100 project in China[25] which is slated to commence its operations in 2026.

(ii) **Marine based water cooled SMRs** - These SMR designs of traditional PWRs are aimed for deployment in marine ecosystems and the deployment is usually in the form of floating units, which are attached on ships or barges. This design is the most successful amongst the current available SMR designs, as it is the first SMR to be connected to the grid as seen from the model KLT-40S in Pevek, Russia[26], which was connected to the grid in 2019 and is currently deployed on Akademik Lomonosov - a first of its kind floating nuclear power plant[27]. In fact, the popularity and ease of construction of the PWRs have incentivised Russia to not only start construction of another project, but they have planned a whole line of marine SMRs[28] .

(iii) **High temperature gas-cooled SMRs ("HTGRs") -** HTGRs' design focuses on achieving high temperatures and can be ideal for providing ancillary industrial applications due to their high efficiency in heat and power generation capabilities. HTGRs have also been technologically operationalised as seen in the HTR-PM project in China[29], having a capacity of 210 (two hundred and ten) MWe, which achieved first criticality in September 2021 and achieved commercial operations in December 2023.[30]. Due to its use of helium, instead of water[31] as coolant, and due to the high energy efficiency coupled with high heat generating potential, HTGRs can be deployed in

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[23] Pressurized Water Reactors are traditional nuclear reactors which use water at high pressure as coolant.
[24] See https://www.world-nuclear-news.org/Articles/Argentina-s-SMR-CNEA-and-Nucleoelectrica-sign-agre accessed on May, 22, 2024 at 16:00 (IST)
[25] See https://world-nuclear-news.org/Articles/Core-module-installed-at-Chinese-SMR accessed on May, 22, 2024 at 16:00 (IST)
[26] See https://aris.iaea.org/PDF/KLT-40S.pdf accessed on May, 22, 2024 at 16:00 (IST)
[27] See https://www.worldnuclearreport.org/A-Closer-Look-at-Two-Operational-Small-Modular-Reactor-Designs.html accessed on May, 22, 2024 at 16:00 (IST)
[28] See https://world-nuclear-news.org/Articles/Construction-starts-on-Russia-s-next-floating-nucl accessed on May, 22, 2024 at 16:00 (IST)
[29] See https://world-nuclear-news.org/Articles/China-s-demonstration-HTR-PM-reaches-full-power accessed on May, 22, 2024 at 16:00 (IST)
[30] See https://www.worldnuclearreport.org/A-Closer-Look-at-Two-Operational-Small-Modular-Reactor-Designs.html accessed on May, 22, 2024 at 16:00 (IST)
[31] See https://www.jaea.go.jp/04/o-arai/nhc/en/faq/ accessed on May, 22, 2024 at 16:00 (IST)

areas with scarce fresh water resources for nuclear power as well as for powering desalinisation plants.

(iv) **Liquid metal cooled fast neutron spectrum SMRs ("LMFRs") -** In LMFRs, the primary coolant is a liquid element such as sodium or lead, which provides LMFRs with high thermal conductivity, efficiency in heat and power generation. This model is under development stage in Russia under the project BREST-OD-300, with its projected commencement of operations from 2026[32].

(v) **Microreactors (MRs) -** MRs include a wide variety of designs as this broad head covers all nuclear reactors which generate power only up to 10 (ten) MWe. MRs include various kinds of coolants like light water, helium, as well as liquid metal[33]. These are under development in Canada where Global First Power has proposed building a microreactor and has procured the relevant approvals from the Canadian Nuclear Safety Commission[34]. MRs are aimed to be used as backup generators and aimed to be deployed in off-grid areas and disaster-stricken areas for quick relief actions, or for medical supply aid[35].

SMRs are novel innovations which can transform the potential for deployment of nuclear energy as a primary source of clean energy. They provide the benefits of nuclear energy and come at only a fraction of operational and input costs. However, there are certain technological and regulatory challenges that inhibit the wide scale deployment of SMRs. In order to understand and overcome these challenges, the current regulatory landscape for nuclear energy needs to be analysed, which will enable us to incorporate modifications for development of SMR industry in India in a safe, secure and prudent manner.

4. CURRENT NUCLEAR REGULATORY LANDSCAPE

Most nuclear energy regulations are composed of primarily two limbs – (a) first are the laws governing control of construction, development, commissioning, and operation of nuclear plants in a safe and secure manner, and (b) second are the laws providing liability in the event of nuclear irradiation.

In India the aspects of use, development and control of nuclear energy is governed under the aegis of Atomic Energy Act, 1962 ("**Atomic Energy Act**")[36] which provides the Union Government with powers for controlling, governing and use of nuclear energy as well as disposal of nuclear products. The statute governing the liability for nuclear accidents in India is the Civil Liability for Nuclear Damage Act, 2010 ("**Civil Liability Act**") which lays down provisions for affixing liability in the event of nuclear accidents or disasters, and specifies the procedures for compensation of victims.

In India, the function of regulation and monitoring of nuclear power plants is performed by the Atomic Energy Regulatory Board ("**AERB**") which derives its power from Section 27 of the Atomic Energy Act. AERB is the nodal regulatory agency for nuclear power plants, and provides licenses for the development, construction, and commissioning of nuclear power plants. It is also responsible for carrying out periodical safety inspections and ensuring that there are no lapses in the safety and security protocols in the

[32] See https://world-nuclear-news.org/Articles/Production-under-way-of-prototype-pump-unit-for-le accessed on May, 22, 2024 at 16:00 (IST)
[33] See https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs accessed on May, 22, 2024 at 16:00 (IST)
[34] See https://nuclearsafety.gc.ca/eng/reactors/research-reactors/nuclear-facilities/chalk-river/global-first-micro-modular-reactor-project.cfm accessed on May, 22, 2024 at 16:00 (IST)
[35] See https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs accessed on May, 22, 2024 at 16:00 (IST)
[36] See https://www.aerb.gov.in/images/PDF/Atomic-Energy-Act-1962.pdf accessed on May, 22, 2024 at 16:00 (IST)

commissioned nuclear power plants. AERB is responsible for ensuring the safety of the nuclear plants and ensuring the safety of the workers engaged in nuclear power plants, along with the health of general public and the environment from any adverse effects from ionizing radiation and nuclear energy.

The responsibility to ensure that the nuclear power plants are designed, constructed, and operated safely rests with the entities operating the nuclear power plants. In India, generation of nuclear power is controlled by the Union Government and every activity is licensed. Currently, there are only two organizations responsible for the design, construction, and operation of nuclear power plants i.e. Nuclear Power Corporation of India Limited[37] and Bharatiya Nabhikya Vidyut Nigam[38]. These organisations follow the safety rules and protocols notified by the AERB.

The AERB has notified the following rules under the Atomic Energy Act and the Civil Liability Act for the safety and security of nuclear power plants:

(i) **Atomic Energy Mines and Minerals Prescribed Substances Rules 1984**[39] - provides for the rules governing provision of license for any nuclear ore or mineral, along with the terms and conditions of handling nuclear substances.

(ii) **Atomic Energy Safe Disposal of Radioactive Waste Rules 1987**[40] - deals with the rules for issuance of license for disposal and management of radioactive waste. The licensed entities under these rules are the only ones empowered to process, treat, and dispose of radioactive waste.

(iii) **Atomic Energy Factories Rules 1996**[41] - lays down the terms governing the welfare, safety and health of personnel working factories owned by the Union Government for undertaking functions under the Atomic Energy Act 1962.

(iv) **Atomic Energy Radiation Protection Rules 2004**[42] - provides the terms and conditions for surveillance of sources of radiation and measures to ensure adequate protection from such sources of radiation.

(v) **Civil Liability for Nuclear Damage Rules 2011**[43]- specifies the procedure for adjudication of claims and award of compensation upon any nuclear accidents.

The AERB is mandated to perform a plethora of functions with respect to various facets of nuclear energy generation. It is tasked with the development of safety regulations as well as ensuring the technical compliances during the construction, commissioning and decommissioning of nuclear power plants. As the nodal regulatory agency governing nuclear energy in India the AERB inspects, regulates, and licenses all activities from design, operation, commissioning and decommissioning to the end impact assessment

[37] See https://www.npcil.nic.in/content/328_1_AboutNPCIL.aspx accessed on May, 22, 2024 at 16:00 (IST)
[38] See https://bhavini.nic.in/Userpages/CompanyView.aspx accessed on May, 22, 2024 at 16:00 (IST)
[39] See https://aerb.gov.in/images/PDF/1.24-Atomic_Energy_Mines_Minerals_Prescribed_Substance_Rules-1984-PB.pdf accessed on May, 22, 2024 at 16:00 (IST)
[40] See https://aerb.gov.in/images/PDF/1.24-Atomic_Energy_Safe_Disposal_of_Radioactive_Waste_Rules-1987-PB.pdf accessed on May, 22, 2024 at 16:00 (IST)
[41] See https://aerb.gov.in/images/PDF/1.24-Atomic-Energy-Factories_Rules-1996-PB.pdf accessed on May, 22, 2024 at 16:00 (IST)
[42] See https://aerb.gov.in/images/PDF/1.24-Radiation_Protection_Rules-2004-PB.pdf accessed on May, 22, 2024 at 16:00 (IST)
[43] See https://aerb.gov.in/images/PDF/1.24-Civil_Liability_for_Nuclear_Damage_Rules-2011-PB.pdf accessed on May, 22, 2024 at 16:00 (IST)

of the nuclear plant on the surrounding population. Besides the above stated rules, AERB has over the years published numerous regulatory documents and guides relating to construction, design, operation, radioactive waste management, emergency responsiveness and planning involved in setting up and operating a nuclear installation[44].

5. The SMR Regulations - Deviations and Propositions

Owing to the unique structure, technology, designs, fuel types and novel applications, SMR(s) are completely different from the traditional nuclear reactors. Due to this disparity with the traditional models of PWR(s) and PHWR(s), SMR(s) would be unable to fit in the current regulatory model. To effectively govern and manage SMR(s) the current regulations and facets of nuclear law in India would require a significant overhaul.

Key elements which would need to be deliberated and analysed for the purposes of framing appropriate regulations for the SMR industry are elaborated as follows:

(i) Technical and Operational Aspects

(a) **Construction, Site Selection**

The technical and safety norms notified by AERB would require modification to lay down new guidelines for construction and site selection for SMR(s). Since the capacity of SMRs are smaller compared to traditional nuclear reactors there is possibility of establishing multiple SMR units in the same site. SMRs can also have common shared infrastructure like civil structures, electrical systems, compressed air systems pools, transmission infrastructure, security and emergency arrangements between them.

(b) **Commissioning**

SMR(s) can be constructed and commissioned remotely in factories and assembly plants. The current regulations do not envisage such a scenario, and have a provision for construction and commissioning tests on site only. These regulations would thus need to be modified to provide for adequate safety checks for remote testing and commissioning of operational SMR(s). The prospect of remote commissioning would also increase the risks posed for factories and assembly lines, thus safety and health regulations for workers would also require a massive overhaul.

(ii) Safety and Liability

(a) Transportation

Unlike traditional nuclear power plants where only raw material was being transported for construction on site, in SMR(s) fully constructed nuclear power plants can be

[44] See https://www.researchgate.net/publication/222907654_Regulatory_practices_for_nuclear_power_plants_in_India accessed on May, 22, 2024 at 16:00 (IST)

transported along with fuel. Additionally, there are SMR models where the entire plant is commissioned off-site and is transported along with a fuel for connection on site.

Having fuels and commissioned nuclear reactors being transported increases risks. Regulations would require to be framed for determining liability in the events of accidents or lapses in transportation. Regulators will need to provide for clear demarcation of liability in various phases of packing, loading, unloading, transportation, and methods of transportation. There may even be provision of compulsory insurance and security particularly in instances where the transborder movement of modules or fuel is happening.

(b) Decommissioning

Similar to the new horizons opened by SMR(s) in commissioning and operation, it has introduced new aspects in decommissioning as well. When SMR(s) are being decommissioned, particularly in a facility where there is a multi-module system in place, regulators will need to take into account situations like management of working nuclear plants while decommissioning activities are being performed for some other plants. Lifecycle management and fuel management and disposal plans need to be framed and be updated on a regular basis.

(c) Retrofitting, Recycling of Parts

SMR(s) due to their modular construction can be refurbished and re-assembled. Such SMR(s) which would have their parts retrofitted, would need to be inspected in terms of safety, longevity, and resilience. Regulators will need to create separate safety and technical manuals for decommissioning works, retrofitting of SMR(s) and put in place protocols for fuel management, refurbishment and management of active power plants.

(iii) **Private Participation, De-licensing and Beyond**

Section 3 of the Atomic Energy Act provides that the Union Government shall have the power of production, development, use and disposal of atomic energy by itself, through any authority or through a government company[45].

The current regulations pertaining to nuclear energy, its development and use do not provide for any private participation or for that matter foreign participation. The extant Foreign Direct Investment Policy issued on October 15, 2020 by the Department for Promotion of Industry and Internal Trade, Ministry of Corporate and Industry[46], prohibits any form of foreign investment in

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[45] Section 2(bb) of the Atomic Energy Act defines a government company as a company in which
(i) not less than 51% (fifty percent) of the paid up share capital is held by the central government. Or

(ii) the whole of the paid-up share capital is held by one or more of the companies specified in sub-clause (i) and which, by its articles of association, empowers the Central Government to constitute and reconstitute its Board of Directors;

[46] See https://dpiit.gov.in/sites/default/files/FDI-PolicyCircular-2020-29October2020_0.pdf accessed on May, 22, 2024 at 16:00 (IST)

the atomic energy sector. However, the Union Government is keen to open up ancillary areas in the field of atomic energy particularly with regards to equipment manufacturing and supply[47].

Furthermore, India is looking to examine the provisions of Atomic Energy Act to de-license activities and increase private participation particularly for the development of SMR(s)[48].

This policy decision can be a boon for the sector as de-licensing and entry of private participation in the sector will not only lead to influx of technology and best practices but there would be a massive upsurge in the amount of capital invested. However, from the perspective of regulation, AERB would need to examine the issue in a holistic fashion. Some of the areas to be deliberated upon before opening the sector for private participation are discussed below:

(a) **Form and extent of private participation -** Nuclear energy cannot be simply equated with renewable or thermal energy, thus the liberalization of electricity generation done by the Electricity Act 2003 cannot be emulated for nuclear energy completely. The Union Government would need to formulate models for extent of private participation based on the risk posed to national security, nuclear disaster etc. Considering that generation of nuclear energy and management of nuclear installations have an inherent security and national security risk, it would be prudent to have a prominent government role in this industry. Therefore, the Union Government should explore the concept of joint ventures for future cooperation efforts. Joint ventures with industry bodies both international and domestic can provide the industry with technology as well as capital and along with it we shall be secure in areas of national security, safety and control.

(b) **Affixing liability, dispute resolution and setting up specialized tribunals -** Upon provision of private participation and large scale industrial activity in nuclear energy, there would be requirement to set up specialized courts for adjudicating on disputes as well. Furthermore, with concepts like SMR which allow for micro plants to be set up and being commissioned remotely, the liability regime would need to be detailed to a wide extent. The Union Government and AERB would need to recalibrate their adjudicatory and regulatory powers to deal with the spurt in the production activity.

(c) **Planning, development and financing institutions -** Taking an example from the rise of renewable energy, if private participation in nuclear energy grows in a similar manner, the Union Government would also need to consider setting up development institutions. These development institutions may be similar to Solar Energy Corporation of India Limited or they can be financing institutions similar to Indian Renewable Energy Development Agency Limited (IREDA), REC Limited and Power Finance Corporation. These development and financing institutions would provide crucial support in the standardization and scaling of sector. They would provide technical support and subsidized debt along the lines of Union Government policies and regulations.

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[47] See https://www.pib.gov.in/PressReleasePage.aspx?PRID=1655136 accessed on May, 22, 2024 at 16:00 (IST)
[48] See https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1945029 accessed on May, 22, 2024 at 16:00 (IST)

The Union Government should create subcommittees for the creation of these development and financing institutions. The key area of focus for these subcommittees should be the creation of a conducive regulatory environment keeping in mind the challenges that the nuclear energy sector in general and the SMR sector in particular is facing.

In the next section we discuss some of these challenges faced by the sector and look for the hope provided by this avenue of clean energy.

6. CHALLENGES FOR SMR(S): HURDLES AND HOPE

SMRs are a pioneering piece of technology and can potentially be a crucial element in achieving low carbon energy security; however, the path to their large scale deployment is beset with hurdles ranging from financial uncertainty, competition from cheaper energy sources, regulatory ambiguity and the most uncertain of all - public perception.

If SMRs have to be deployed on a large commercial scale, then for the bankability of such projects, practical and reasonable solutions need to be found to overcome the challenges faced by the industry. Major challenges and impediments that inhibit the development of this industry are:

(i) **Lack of Viability –** Currently, the market of SMRs is filled with multiple options in the field of technology, fuel, design. However, there is no one stop solution and no real producer who can offer commercially viable solutions. The SMR designs available in the market are also not fully developed and the products are still in a nascent stage to determine which technology can be financially profitable and adoptable on a large scale basis.

(ii) **Supply Chain Problems[49] -** Despite having an inherent design benefit over traditional nuclear reactors in terms of assembly, the supply chain issues for SMRs are still not resolved. SMRs by their inherent design will have more manufactured products being transported and assembled instead of civil construction. The assembly lines are not fully developed to handle the novel models being proposed by the industry and there are no large-scale manufacturing operations currently in place for these models. Additionally, unlike a traditional nuclear reactor where the civil construction occurs on site and then the fuel is transported for commissioning, SMRs can have the entire reactor constructed and commissioned offsite, which may increase the risk posed in transportation. This vacuum of supply chain preparedness has an impact on the cost as well as availability of fuel and reactors.

(iii) **Legal and Regulatory Issues -** As discussed in above sections, production of nuclear energy in India is a licensed activity with requirement for procurement of registration with various agencies and ministries. Considering the inherent risk and hazardous nature of activity involved, licensing for all forms of nuclear energy production is advocated to stay in place. However, considering that SMR industry is presently in its initial stages, it would need to undertake experiments and perform modifications in real time environment in order to assess the viability of the enterprise. Licensing and regulatory environment will need to accommodate for the same by bringing in adequate safety

[49] See https://world-nuclear-news.org/Articles/Panellists-address-SMR-supply-chain-challenges accessed on May, 22, 2024 at 16:00 (IST)

and control regulations which will harbour innovation and not compromise on safety of the general masses. This also provides opportunities for international collaboration for development of licensing frameworks in order to ensure streamlined development of the industry on a global level. However, at this stage, the required regulatory support through research and development, incentives, subsidies and relief from procurement of licenses, as compared to large scale nuclear power projects, for SMRs is not available and may not be available till SMRs become a proven technology that benefits commercial concerns of the industry.

(iv) **Unchartered waters -** The SMR technology along with the equipment and machinery created under its umbrella are novel initiatives. The risks and hazards associated with these said innovations are also unknown, until adequate demonstrations are made for proving the viability, safety, efficiency, and sustainability of the experiment. It would be difficult to scale the experiment to a level where it makes a vital impact on the goals envisaged.

(v) **Public Perception** – One of the gravest challenges which faces the nuclear energy use in general and the SMR sector in particular is the public perception, particularly after the nuclear accident in Fukushima Daichi, Japan in 2011[50]. The public perception for nuclear power has become significantly averse due to which it is difficult to not face public outcry at the mere mention of such SMRs. This delineates investors, hampers research and development efforts and development in the sector and affects the financial viability of a project.

To successfully implement the commitments made by India in the Nationally Determined Contribution, Paris convention of the United Nations Framework Convention on Climate Change and to sustainably drive the cause of energy security and address climate change, nuclear energy will be a key sector, the development of which will enable India to realise its dream of cheap and sustainable clean energy. India currently holds the largest reserves of thorium, which can be leveraged for development of self-reliant energy and for export of energy as well[51]. However, in order to develop a strong small nuclear energy industry, India will need to build a sustainable SMR ecosystem.

Some key steps which can be adopted to develop the SMR industry in India are:

(i) **Political Support** - for the development of SMR ecosystem, the first and foremost requirement is political support backed by expeditious goals and belief to promote and include SMRs as a viable source of power in India. Unless the legislators shaping the political environment in India accept SMRs and nuclear energy as fundamental to achieving the energy security goals, long term development of the SMR industry will remain at a nascent stage and the potential of this industry will not be realised. Political attitude, turbulences and hindrances not only hamper the ease of doing business but also discourage involvement of the financing institutions hindering the chances of fundraising for industry participants.

(ii) **Regulatory Framework -** In addition to positive political support**,** development of a robust and conducive regulatory framework is the bedrock for the development of any sector, particularly for

[50] See https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident.aspx accessed on May, 22, 2024 at 16:00 (IST)
[51] See https://www.thehindubusinessline.com/business-tech/this-new-nuclear-fuel-can-guarantee-indias-green-energy-transition/article67716078.ece accessed on May, 22, 2024 at 16:00 (IST)

an industry which is a licensed activity. The regulations in favour of SMRs need to be flexible and should be developed by taking into account the views and opinions of all stakeholders, to address the feasibility, economic and safety risks adequately.

(iii) **Incubation facilities for the industry -** Grand challenges, hackathons need to be organised on a countrywide scale to solve the existing issues and challenges faced by the sector. The Union Government and industry bodies should collectively develop institutional framework, incubation centres which provide seed funding and assist in the development of practical models. These incubation centres should provide impetus on practical, successful, and safe proof of concepts/demonstrations. Successful, practical proof of concepts and models will also build public confidence in the technology and convince the masses about the benefits of nuclear energy as a clean source of power.

(iv) **An inclusive energy policy framework -** India needs to develop and inclusive and effective policy framework which incentivises development of clean sources of energy. This will ensure that the development of models for SMR technology are provided support and subsidies.

In India, the SMR and small nuclear energy industry is at a very nascent stage. This sector is currently in need of encouragement, support and robust incentivisation particularly from the investment, legislative, research and regulatory prisms. Once a conducive environment for the sector is allowed to function similar to the one facilitated for renewable energy over the recent years, the SMR ecosystem can channel massive private participation and realise its immense potential to grow. India can leverage international joint cooperation efforts for the development of SMR(s) along the lines of its programme with France[52] . These joint efforts would not only lead to influx of foreign investment and assist India in meeting its Nationally Determined Contribution under the United Nations Framework Convention it would also help forge avenues of international cooperation, create avenues for skill arbitrage as well as lead to development of Indian industry in a field still relegated to oblivion.

The SMR industry if provided with a safe harbour, can be a crucial lever to catapult the country to its rightful status of a global superpower. It can make the nation self-sufficient to meet its energy needs and steady the country's journey to a clean, safe and green future.

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[52] See https://www.deccanherald.com/india/india-france-in-talks-for-financing-mechanism-localisation-for-jaitapur-n-project-2866501 accessed on May, 22, 2024 at 16:00 (IST)

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