Article

Small Modular Reactors in India's Energy Transition

R. Srikanth

Abstract

Energy Security, Energy Access, and Energy Affordability are key factors for economic development. Deep decarbonisation with clean and firm Nuclear Power Plants (NPPs) that can supply zero-carbon and reliable energy on a 24x7 basis is key for India to reach Net Zero by 2070 with energy security and reliability. The Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act enacted in December 2025, allows private and public sector companies to set up NPPs. As part of National Institute of Advanced Studies (NIAS's) ongoing work with several companies interested to contribute to India's Nuclear Energy Mission (NEM), site selection reports have been prepared for 39 candidate sites for NPPs. However, the ultimate suitability of each site for a NPP is subject to the confirmation of the seismotectonic features and the geotechnical aspects of the site, the availability of adequate land and water from the State Government, and public acceptance. Therefore, the Central Government should involve the State Governments and also advise Department of Atomic Energy (DAE) and Atomic Energy Regulatory Board (AERB) to publicise the results of the environmental and health surveys around various NPPs in India. Further, the development of indigenous Small Modular Reactors (SMRs) by Bhabha Atomic Research Centre (BARC) should be expedited to repurpose the land and infrastructural facilities in Thermal Power Plants (TPPs) that can be progressively retired between 2030 and 2050 to install SMRs.

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The opinions expressed in this article are the author's own and do not reflect the journal's policy.

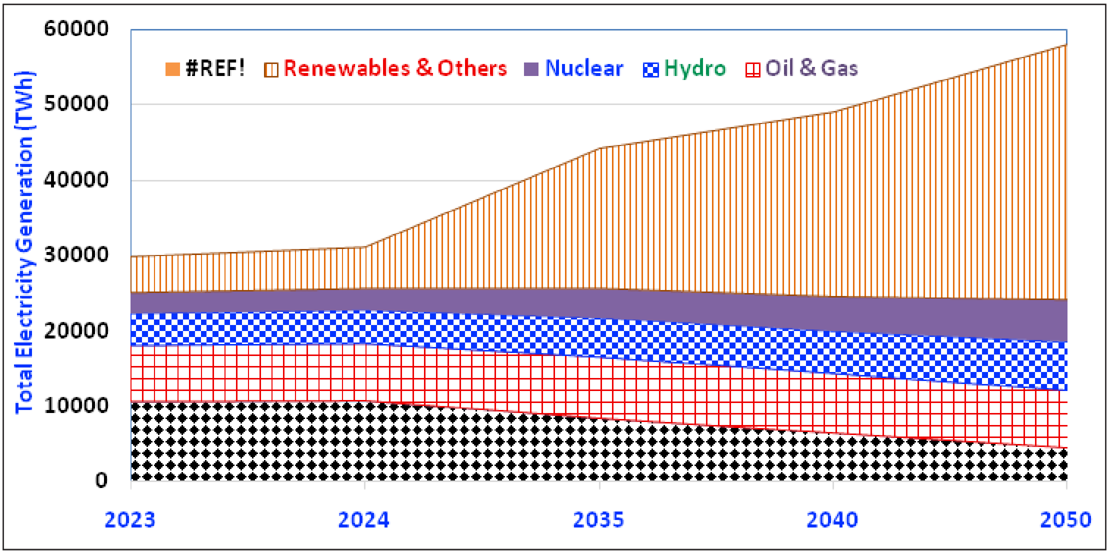
This article was received from the author on March 10, 2026.

National Security Vol. 9, No. 3, 2026
(July - September 2026) Page 409-430, ISSN 25-81-9658 (O)

DOI: http://doi.org/10.32381/NS.2026.09.03.4

The International Energy Agency (IEA) projects world energy supply to rise by 0.7% to 1.2% per annum till 2035, and by 0.5% to 1% per annum between 2035 and 2050.[1] While the share of renewables will increase by 4 to 5% per year till 2050, all sources of energy are necessary to meet the world's growing energy needs, especially in the developing countries (Figure 1).

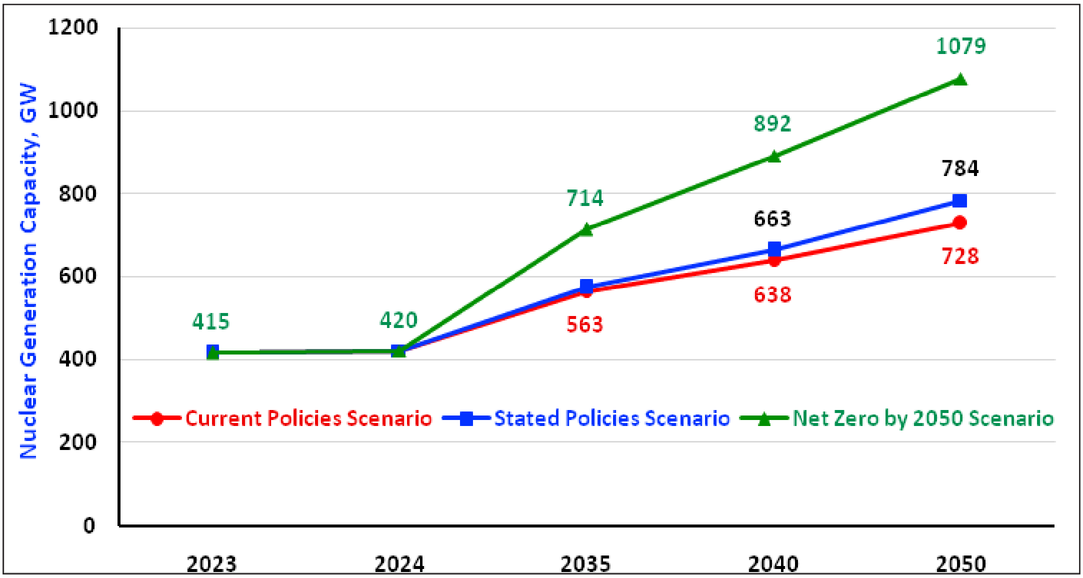
Figure 1: IEA (2025) Stated Policies Scenario: All Energy Sources are Required to Meet Demand



Source: IEA, 2025

Energy Security, Energy Access and Energy Affordability are key factors for economic development. Deep decarbonisation with clean and firm energy sources that can supply reliable energy on a sustained basis 24×7 is the key to energy security and reliability. Therefore, nuclear energy is making a comeback as a vital source in our armoury to limit global warming. As per the IEA the installed generation capacity of nuclear energy is projected to increase from the current 420 Giga Watt (GW) to a level of 728 to 1079 GW by 2050 (Figure 2).[2] According to the IEA, 400 NPPs in the world generated 2835 Terawatt-hour (TWh) of electricity in 2024, which is 9% of the globe's total electricity generation of 31,229 TWh.[3] They have also helped in avoiding approximately 1.5 billion tons of CO2 emission.[4] In comparison, coal-fired TPPs and solar Photovoltaic (PV) plants generated 10,797 TWh and 2073 TWh in 2024.[5] As per the World Nuclear Association (WNA), the global average capacity factor of all operating NPPs, was 83% in 2024, which is more than four times the capacity factor of solar PV plants without storage.[6]

Figure 2: Significant Growth in Nuclear Energy (71% to 257%) is Projected in all IEA (2025) Scenarios



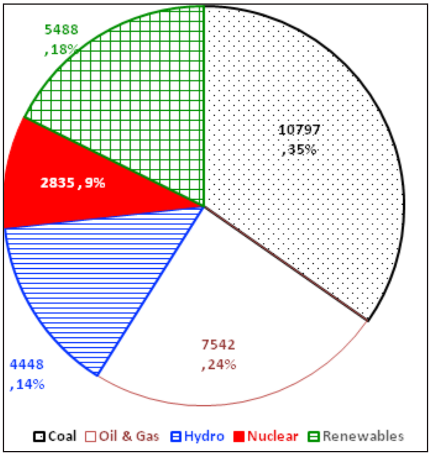
Source: IEA's World Energy Outlook (2025)

India's Electricity Scenario

The source-wise electricity generation in India in 2024 is compared with the world scenario in Figure 3.[7] As shown in Figure 3b, 73% of India's electricity generation is produced from coal, which is currently, India's only modern energy source to meet the demand of its growing population and satisfy the country's development needs. Further, Variable Renewable Energy (VRE) sources (mainly solar and wind energy), hydro, nuclear, and natural gas generated 11.3%, 9.9%, 2.5%, and 3.3% of the total electricity generated in India in 2024, respectively.

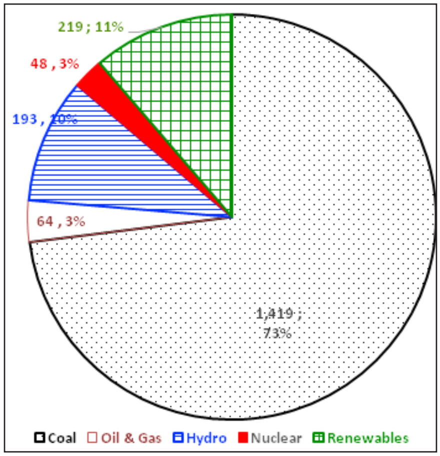
Despite the record increase in the installed power generation capacities of renewable energy from 36% to 42% of the total installed electricity generation capacity of utilities between April 2025 and March 2026, VRE sources contributed less than 17% of the total electricity generated in Financial Year (FY) 2025-26.[8]

Figure 3a: Global Electricity Generation in 2024



Source: IEA, 2025

Figure 3b: Electricity Generation in India, 2024



Source: IEA, 2025

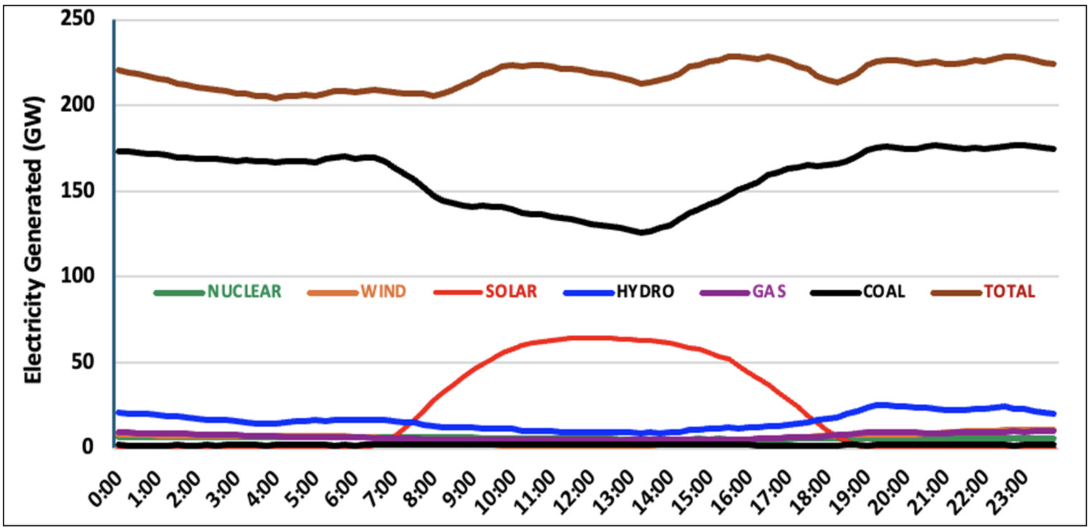
This is due to the low capacity factors of solar and wind energy sources. Specifically, analysis of Central Electricity Authority (CEA) data on renewable energy generation indicates that the 10-year all-India average capacity factor of solar power plants in India is approximately 17.4%.

Moreover, the diurnal variability of solar and wind plants necessitates the ramp-up and ramp-down of electricity generation from TPPs to integrate the intermittent electricity generation by solar and wind energy in India, and cater to the peak demand for electricity during non-solar hours. This is illustrated by analysing the source-wise power generation data recorded by Grid India (2025) on April 23, 2025, which is the day that witnessed the highest-ever solar generation in India (Figure 4).[9] As shown in Figure 4, grid-connected solar power plants contributed a maximum of only 66.6 GW to meet the all-India demand of 227 GW, even though the generation capacity of grid-connected solar plants exceeded 105.6 GW in March 2025.[10] In energy terms, grid-connected solar power plants in India contributed only 534 Gigawatt-hour (GWh), which was only 10% of the total electrical energy (5187 GWh) supplied by the National Grid on this day. As shown in Figure 4, TPPs contributed 170 to 176 GWs of electricity on the all-time peak solar day to meet the electricity demand before sunrise and after sunset. A similar supply pattern was seen on May 21, 2026 when the National Grid supplied more than 270 GW of electricity to satisfy the country's record power demand. Analysis of Grid India data indicates that TPPs generated a maximum of 185 GW on May 21 and supplied 75% of India's total generation after sunset, when solar generation had declined to zero after peaking at 80 GW mid-day.[4] Therefore, solar plants can meaningfully reduce coal-fired generation after sunset only when the surplus energy generated by them during the day can be stored for use after sunset.[11]

Therefore, despite India's success in achieving 50% of installed power generation capacity through non-fossil fuel sources, 44 GW of VRE projects awarded by renewable energy implementation agencies like the Solar Energy Corporation of India (SECI) and NTPC Green Energy Ltd. (NGEL), are unable to sign Power Purchase Agreements (PPAs) with Distribution Companies (DISCOMs) due to lack of offtake for day-time power not backed by grid-connected storage.[12]

As per the Ministry of New and Renewable Energy (MNRE), "*the grid integration challenge for solar energy is its variability and intermittency, which complicates the task of maintaining real-time grid stability, power quality and supply demand balance. Our conventional grid infrastructure was not originally built to accommodate such high levels of variable and decentralized power flows. These fluctuations caused by changing weather and daylight conditions can lead to overvoltage, frequency deviations, congestion, and even curtailment when supply exceeds local demand or transmission capacity*."[13]

Figure 4: All-India Source Based Generation Recorded During the all-time high of Solar Generation on April 23, 2025

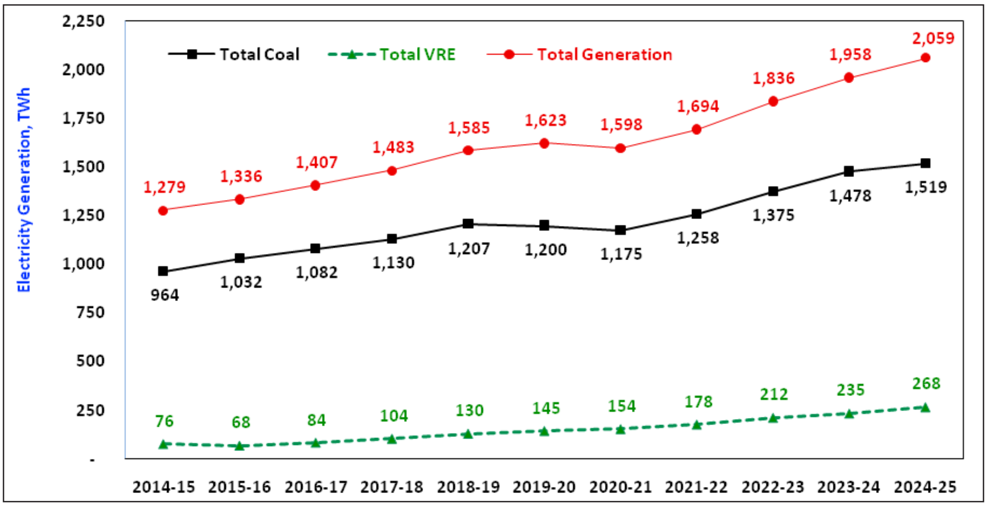


Source: Grid India, 2025

As per Grid India, *"the Grid frequency in May 2025 frequency touched 50.48 Hz and persistently hovered above the safe limit of 50.5 Hz during the solar hours despite ramping down TPPs to 58% and curtailing 10 GW of solar power generation. This is a cause of concern for safe and secure grid operation."*[14]

However, such hidden costs of grid integration of solar energy are not assessed during the techno-economic comparison of solar versus other non-fossil fuel based sources of energy, especially, nuclear. The above facts explain why TPPs continue to be the lynchpin of the Indian electricity grid since electricity generation by non-fossil fuel (hydro, nuclear, solar, and wind) sources is unable to meet India's growing demand for electricity, which is directly linked to India's development (Figure 5).[15]

Figure 5: Growth of coal-based versus solar and wind (VRE) power generation in India



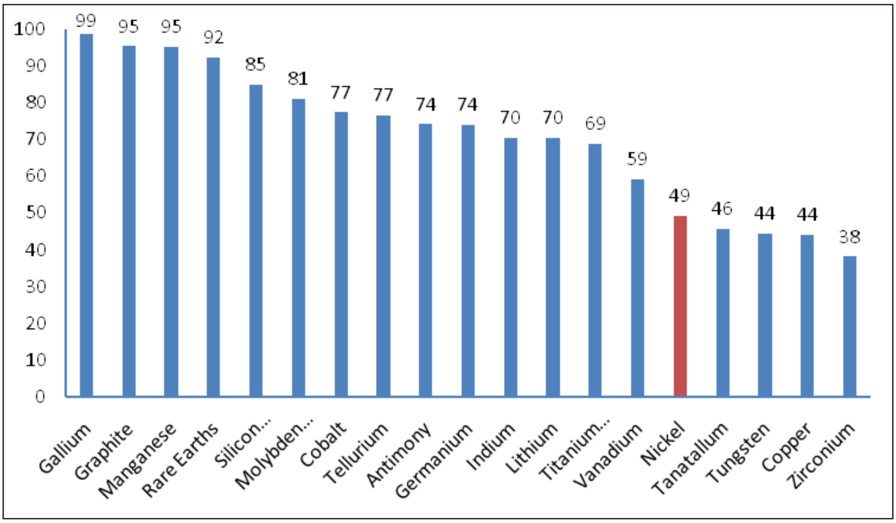
Source: CEA, 2025

India's Energy Transformation

The National Electricity Plan published by the CEA in December 2023 envisaged a grid-scale Battery Energy Storage Systems (BESS) of 8.68 GW/34.72 GWh and an All-India pumped storage capacity of 7.45 GW by March 2037.[16] However, as of December 2025, the installed grid-connected capacities of battery storage and pumped storage in India are only 0.2 GW[17] and 4.6 GW, respectively.[18] This lag between the requirement and installed capacities for energy storage is a critical bottleneck in increasing grid integration of intermittent and variable electricity generation from solar and wind energy plants. Since the progress in BESS installations is lagging behind NEP projections, the government is incentivising the enhancement of BESS by implementing Viability Gap Funding (VGF) schemes with a total outlay of Rs. 9160 crores and a Production-Linked Incentive (PLI) scheme to create 10 GWh of 'Advanced Chemistry Cell' manufacturing capacity in the country.[19]

However, the future growth in BESS capacity in India has been made more challenging by the geographic concentration in the refining capacity of key energy minerals. The IEA (2025) indicates that the average market share of the top three refining nations of Critical Energy Transition Minerals (CETMs) rose from 82% in 2020 to 86% in 2024.[20] More worrisome is the fact that more than 70% of the refining capacity for 19 of the 20 CETMs is concentrated in China as shown in Figure 6.

Figure 6: China's Dominance in Refining Capacity of New Energy Minerals



Source: IEA, 2025

As per a NITI Aayog study of the supply and demand for CETMs:[21]

- Copper and graphite emerge as CETMs with the highest cumulative demand the projected requirements of more than 20 Mt of copper and 14 Mt of graphite by 2050. Copper's dominance is due to its universal application across solar PV, wind turbines, EV batteries, EV motors and electrolysers while graphite demand is almost entirely from battery anodes.

- Solar technologies, while dominated by silicon, rely on strategic minerals such as Gallium, Germanium and Tellurium.
- EV batteries and BESS drive high demand for Graphite, Lithium, Nickel, Phosphorous, Cobalt and Vanadium.
- EV motors and wind technologies depend heavily on Neodymium, Praseodymium, Dysprosium and Terbium.

China has demonstrated its willingness to 'weaponise' its domination of critical and rare earth minerals and green energy technologies. This raises a key question on whether India's energy transition will result in a new set of dependencies for critical minerals while replacing the current dependence on imports of crude oil and natural gas. The government has launched several initiatives to provide critical minerals' security, including a National Critical Minerals Mission, as well as foreign collaborations and partnerships with several countries, including the United States and Australia.[22] However, the fruits of these partnerships are also influenced by the geopolitical situation while the National Critical Mineral Mission is in its early stages. They can be achieved only through more harmonious foreign relations, continuous follow-up and constant vigil due to geopolitical uncertainties.

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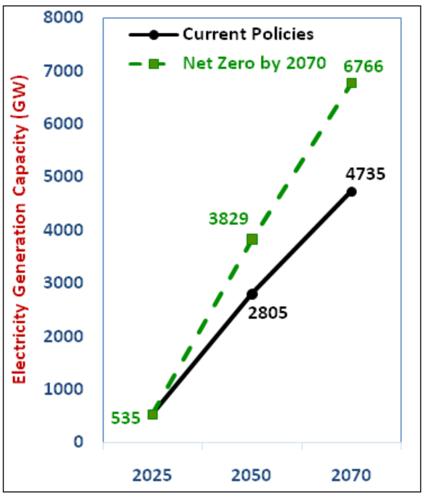
Energy Transformation to Achieve Viksit Bharat by 2047 and Net Zero by 2070

India has a vision of realising a Viksit Bharat by 2047 and has committed to achieving Net Zero Carbon Emissions by 2070. Energy is at the centre of India's development transformation. Rise in incomes, industrial development, urbanisation and improving access to services, will inevitably increase energy demand in India. Pursuing development aspirations and net zero goals simultaneously has no historical precedent for a country of India's size at this stage of development. Since India's energy transition requires a Whole-of-Economy approach, the NITI Aayog put together ten Inter-Ministerial Working Groups (IMWGs) with key stakeholders from government and non-government organisations, internal and external experts, to develop roadmaps for the transition of all key sectors. The key premise of this integrated set of studies is that "*India must adopt a 'Development First' approach to avoid* *stunted development*." The projections drawn by the NITI Aayog based on detailed modelling exercises and extensive stakeholder consultations are summarised in the following graphs (Figures 7a & 7b and 8a & 8b).[23]

As shown in Figure 7a, India's electricity generation capacity must be increased by over seven times, its 2025 level of 535 GW, by 2050 to meet the electricity needs of a Viksit Bharat and reach a level of 6766 GW, which is more than 12 times the current installed capacity to achieve Net Zero by 2070.[24] Correspondingly, India's total electricity generation must be enhanced by five times the 2025 level of 2000 TWh by 2050, to achieve a Viksit Bharat and raised further to a level of 16,000 GW to reach Net Zero by 2070 (Figure 7b).[25] This growth in electricity generation will ensure that India's per-capita electricity consumption in 2050 reaches 4,800 kWh in the Current Policy Scenario and 6,400 kWh in Net Zero Scenario. By 2070, the per capita electricity consumption is projected to reach 7,400 kWh in Current Policy Scenario (CPS) and 10,000 kWh in Net Zero Scenario (NZS).[26]

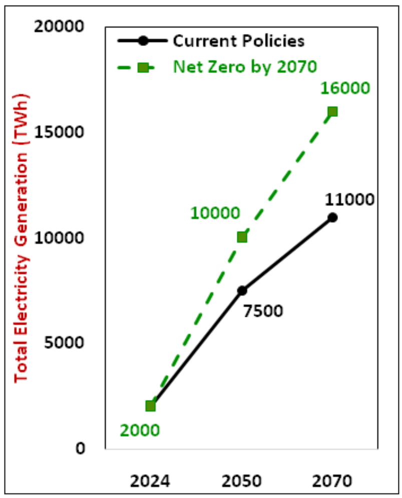
India has a vision of realising a Viksit Bharat by 2047 and has committed to achieving Net Zero Carbon Emissions by 2070. Pursuing development aspirations and net zero goals simultaneously has no historical precedent for a country of India's size at this stage of development.

Figure 7a: Total Installed Generation Capacity



Source: NITI Aayog, 2026

Figure 7b: Total Electricity Generation

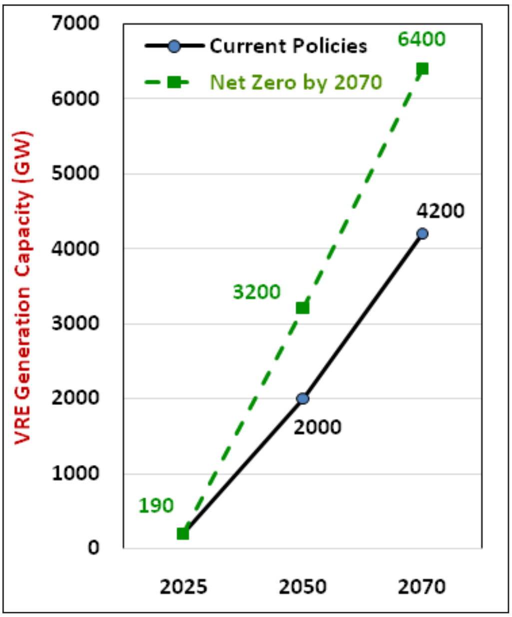


Source: NITI Aayog, 2026

The disproportionate increase in India's electricity generation (16,000 TWh) in the Net Zero Scenario by 2070 compared to the Current Policy Scenario (11,000 TWh) is required to hike the share of electricity in India's energy sector from the current level of 21% to 60% by 2070. The higher levels of electricity generation in the NZS compared to the CPS are required to achieve rapid electrification of the transport sector which is largely dependent on imported oil and natural gas today.[27]

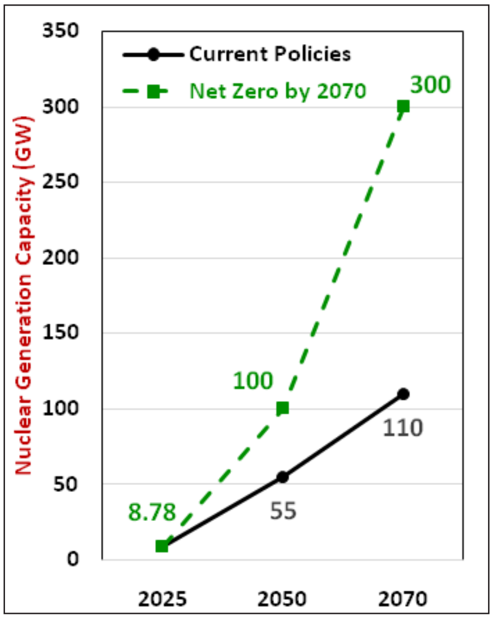
The growth of VRE sources (mainly, solar and wind) as per the NITI Aayog scenarios is shown in Figure 8a.[28] The increase in VRE capacity by over 16 times the current level in the NZS by 2050 requires BESS capacity to reach a level of 1300 GW from the current level of 0.2 GW in the CPS and 2500-3000 GW in the NZS. Similarly, Pumped Storage Plants (PSPs) are projected to rise to a level of 110 GWs in the CPS and 150-165 GW in the NZS by 2070.[29]

Figure 8a: VRE Installed Generation Capacity



Source: NITI Aayog, 2026

Figure 8b: Nuclear Power Generation Capacity



Source: NITI Aayog, 2026

While NPPs contributed 9% of the electricity generated in the world, they contributed only 3% of the electricity generation in India. Since a quantum leap in nuclear energy is required to meet India's Net Zero goal while progressing our development aspirations and strengthening our energy security, the Government of India (GOI) is desirous of giving a significant push to nuclear energy as a clean baseload source and a central pillar in India's long-term energy transition strategy (Figure 8b). The GOI has announced a Nuclear Energy Mission with a target of reaching 100 GW of nuclear power capacity by 2047 from the 2025 level of 8.78 GW.[30]

A quantum leap in nuclear energy is required to meet India's Net Zero goal while progressing our development aspirations and strengthening our energy security.

Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India Act

Studies in the United States and the European Union (EU) have demonstrated that, without a significant contribution from nuclear power, the journey to net zero will be more challenging and expensive.[31,32] The rapid expansion of NPPs is a reliable and efficient way to mitigate climate change and achieve multiple development goals since nuclear power can generate firm, zero-carbon electricity at affordable tariffs, while, providing important co-benefits such as high-skill jobs in technology, manufacturing and operations, besides enhancing community development.

Further, India has been constructing, operating and maintaining NPPs based on indigenous designs as well as American and Russian designs for more than 40 years. Public exposures to ionising radiation around NPPs in India are consistently two to three orders of magnitude below the safe exposure limit (one mSv per year) mandated by the AERB based on international norms. In fact, the natural background doses of ionising radiation in several parts of India are much higher than the minor contribution from NPPs.[33] While these findings based on a rigorous analysis of scientific and epidemiological data, collected around operating NPPs in India, they are disclosed in AERB's annual reports, in replies to Parliament questions and in peer-reviewed journal articles, but are not widely known to the general public. Consequently, several people around future NPP sites may still entertain unfounded beliefs regarding radiation from NPPs in India.

The NIAS has been advocating the benefits of major nuclear power expansion in India and other coal-dependent G20 countries since 2023.[34] A study by Garg et al. (2024) has also confirmed the need for nuclear power to be enhanced to a level of 300 GW by 2070 to play a major role in India's future electricity mix beyond 2050.[35] As shown in Figure 8b, a NITI Aayog analysis has also confirmed this target.

To achieve this twelve-fold jump in nuclear energy capacity to 100 GW by 2047 for a Viksit Bharat and then raise it to 300 GW by 2070 to achieve Net Zero, Parliament has enacted in 2025, the SHANTI Act after repealing the Atomic Energy Act and the Civil Liability for Nuclear Damage Act.[36] The SHANTI Act, 2025 ("Act") *inter alia*, permits the GOI, any government company, company incorporated in India, or any Joint Venture (JV) between such companies to set up nuclear power plants of any capacity and undertake associated activities under a licence or safety authorisation. However, certain activities of a sensitive nature (e.g., uranium mining and processing, uranium enrichment, heavy water production and the management of spent fuel and high-level radioactive waste) are reserved exclusively for the government or its institution(s).

The Act also permits any company with the appropriate license or authorisation to import uranium fuel, though it permits only GOI-owned companies to mine, transport and process uranium and thorium. Further, any 'source' material and fissile material in any form, produced within India or imported, shall remain under the surveillance and control of the GOI for the purposes of accounting, and will be subject to safeguards specified by the GOI. While the SHANTI Act permits companies with the requisite safety authorisation to procure and/or import uranium fuel for use in an NPP, after the spent fuel removed from the reactor is cooled in the NPP premises, the operator shall turn over the spent fuel to the GOI.

The SHANTI Act, 2025 confers a statutory status on the AERB to make it more effective and empowers the GOI to appoint a Nuclear Damage Claims Commission (chaired by a person who is a sitting/retired high court judge) to adjudicate claims for nuclear damage. While the operator is liable for any nuclear damage except in case of war, terrorism and grave natural disasters, the maximum amount of liability is graded in steps from Rs.100 crores to Rs. 3000 crores depending on the capacity of the reactor. While the limit of liability for existing reactors with an electricity generation capacity of 540–1200 MWe is retained at Rs. 1500 crores, this has been reduced to Rs. 300 crores for reactors of 50 – 250 MWe. Further, the operator's right of recourse to the supplier is protected only if such a right is expressly provided for in a contract, or if the nuclear incident has occurred because of commission or omission of an individual with an intention to cause nuclear damage. The GOI proposes to create a Nuclear Liability Fund if the amount of compensation exceeds these limits, besides invoking the Convention on Supplementary Compensation to which India is a signatory.

Brief on Current Status of Ongoing Global Expansion in Nuclear Energy

As per the International Atomic Energy Agency (IAEA), 63 new NPPs are under construction with a combined electricity generation capacity of 66 GW.[37] Of these, China alone is building 29 NPPs with a total capacity of 29.6 GW. The revival of nuclear power worldwide commenced after more than 20 countries signed a historic declaration at COP 28 in December 2023 to triple their nuclear power capacities by 2050. As of date, 33 countries have endorsed this pledge. The United States Department of Energy (US DOE) projects that the annual global investment in nuclear energy will rise to over USD 100 billion in the 2030s.[38] The US DOE is also taking several actions to expedite SMRs to reach a steady state addition of SMR capacity @13 GW/year starting by 2030 till total nuclear power capacity is doubled to 200 GW. The British Government has selected Rolls Royce to set up SMRs with a capacity of 470 MW in the United Kingdom with the help of government subsidy.[39] In November 2025, the US DOE awarded USD 400 million each in federal cost-shared funding to the Tennessee Valley Authority (TVA) and Holtec Government Services to support the early deployment of SMRs in the United States.[40] Finally, the World Bank (WB), the International Financial Corporation (IFC) and the Asian Development Bank (ADB) have reversed their earlier decisions to avoid financing NPPs, while several global financial institutions are now ready to support Nuclear Power Plants.[41]

Further, a few technology companies and utilities have entered into agreements to extend the lifetime of existing NPPs in USA and/or set up SMRs on brownfield sites to meet the growing demand for clean and firm (24x7) power for energy guzzling industries, data centres and the Grid. However, other than the SMR projects under construction in Russia (RITM-200N), Canada (BWRX-300) and China, all other NPPs under construction globally are equipped with large reactors based on Nth of a Kind (NOAK) designs and Light Water Reactor (LWR) technology. In India, four NPPs based on Russian LWR technology (1000 MW each) and four NPPs based on Pressurised Heavy Water Reactor (PHWR) technology (700 MW each) are currently in the construction stage.

While Tarapur 3 and 4 units (commissioned 20 years ago) were built in 60 months, the median time to build one NPP in India is 123 months, which is the highest in the world. China has a median construction time of 68 months, while the median build time for a NPP in South Korea is 65 months.[42] For example, the Brownfield NPP projects implemented by the DAE-controlled Nuclear Power Corporation Limited (NPCIL) in Gujarat (Kakrapar 3 and 4) and Rajasthan (Rajasthan 7 and 8) sanctioned in December 2009 were scheduled to be commissioned by December 2015 and December 2016, respectively. However, the Kakrapar Units 3 and 4 and Rajasthan Unit 7 commenced commercial operation in FY 2023-24 and April 2025, respectively, while Rajasthan Unit 8 is expected to be put into commercial operation only in 2026.[43] As per the Ministry of Statistics and Programme Implementation (MOSPI), all these four 700 MW projects based on indigenous technology have suffered unforeseen challenges leading to major delays and cost overruns.[44] As per MOSPI reports the four LWR-based NPPs under construction by NPCIL with Russian assistance in Kudankulam, Tamil Nadu, continue to be affected by time and cost overruns.

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Generally, project developers account for unforeseen challenges that may arise during the construction process by adding contingency costs into the project budget. Contingency costs decrease the financial risks associated with such uncertainties, but are insufficient to mitigate cost escalations in NPP projects because they address the symptom (the overrun), but not the cause of the overrun.[45] One of the proven strategies to avoid cost overruns is to construct a fleet of NPPs of similar design so that the supply chain and workforce become more efficient with time due to a "learning curve". This is the rationale behind the GOI ordering ten NPPs based on indigenous 700 MW PHWR technology in fleet mode. Another strategy adopted by Western countries is to incentivise the development and deployment of First-of-a-Kind (FOAK) installations of the most promising SMR designs that are standardised for serial manufacture in a factory with more controlled conditions and can be licensed for installation in a variety of site conditions with vastly reduced time-consuming onsite construction.

Site Selection Studies for Nuclear Power Plants

In December 2024, the NPCIL published a Request for Proposal (RFP) from private companies to set up Bharat Small Reactors (BSRs) as per the prescribed terms in the RFP. BSRs are being designed as an upgraded version of the 220 MW PHWRs operating in India for more than 40 years with more safety features to facilitate a smaller "Exclusion Zone" compared to the larger (700 MW/1000 MW) NPPs under construction in India. As per the RFP, the private company has the right to use/sell the electricity generated from the NPP as a captive power plant as per the Electricity Act. While this RFP was formulated to comply with the Atomic Energy Act and the CLND Act in the pre-SHANTI Act period, the

NPCIL has extended the deadline for submitting the RFP several times (latest deadline being March 2026) since the legal framework governing the nuclear power sector has undergone a complete change following the enactment of the SHANTI Act.

Following the advice of the DAE and the NPCIL, the NIAS commenced the task of identifying candidate sites for NPPs (both BSRs and larger reactors) by applying remote sensing and advanced Geographic Information System (GIS) techniques, as well as secondary data from published sources.[46] These desktop NPP site selection studies are based on the AERB Siting Code as well as the NPCIL checklist, which is based on Appendix B of the AERB Siting Code. The NIAS site selection studies, which benefitted from earlier research conducted at NIAS under the guidance of BARC/AERB/NPCIL, considered the following key aspects:

- Geological and Seismotectonic Aspects of the region.
- Water Requirements.
- Buffer zones from Notified Protected Areas, hazardous industries and defence installations. Specifically, NPP sites were selected at a distance of at least ten kilometres from the boundary of a "Protected Area" area under the Wildlife Protection Act, or the Biodiversity Protection Act.
- Standoff distances from population clusters. To ensure minimum people displacement for the construction of a NPP, the site must be in a place with negligible population within the exclusion zone that extends to one kilometre (km) from the centre of each reactor. The Emergency Planning Zone (EPZ) of an NPP extends to 16 km from the centre of each reactor. NPP sites should ideally be located at least 16 km away from the boundaries of towns having a population exceeding one lakh as per the 2011 Census, so that the town is not covered in the EPZ of the NPP.
- Besides the cooling water requirement of 9,000 m^3/hr for a 2x700 MWe PHWR-based NPP, NPPs must have ready access to an ultimate heat sink. While coastal sites are preferable, several coastal regions are ruled out due to one or more factors, including, active faults, population density, hilly terrain and the presence of military/strategic installations, major infrastructure facilities, and "Protected Areas."

As part of NIAS's ongoing work with several reputed companies interested to contribute to India's NEM, site selection reports have been prepared for 39 candidate sites for NPPs. Since these sites were planned with an exclusion zone (site boundary) of one kilometre from the centre of each reactor, each site can also accommodate four 700 MW reactors, resulting in a total capacity of 2800 MW per site subject to site investigations of the geological and seismotectonic conditions of the region, the geotechnical aspects of the site area and the availability of land and water from the state government. Therefore, some of these sites may be rejected if site investigations by the NPP developer indicate geological surprises, or the state government is unwilling and/or is unable to allocate the required land and water for the NPP, or if the developer fails to win public support for the NPP.

Even if all these 39 sites are mobilised by the project developers (which is unlikely due any one of the above reasons), the total NPP capacity addition in India from all the above sites would be less than 110 GW. Moreover, sufficient number of greenfield sites complying with the current AERB Siting Code for NPPs are not available to meet the target of 300 GW for nuclear power generation by 2070. This can be attributed to geology and seismotectonic aspects, high seismicity levels in large parts of the country, high population density, national security and freshwater stress. This proves the need for SMRs to supplement the role of conventional NPPs and enable India to achieve Net Zero by 2070 with energy security.

Sufficient number of greenfield sites complying with the current AERB Siting Code for NPPs are not available to meet the target of 300 GW for nuclear power generation by 2070. This proves the need for SMRs to supplement the role of conventional NPPs and enable India to achieve Net Zero by 2070 with energy security.

Why do we Need SMRs to Complement Conventional NPPs in India

SMRs offer:

- Smaller core damage frequency and source term.
- Enhanced seismic isolation to enable standardisation of design.
- Greater control over project cost and time due to reduced onsite construction.
- Passive safety features to reduce the potential for unsafe radioactive releases.
- Smaller exclusion zone and Site Boundary EPZ unlike conventional NPPs, which require a 16-km EPZ.
- Lower specific water consumption compared to conventional NPPs.
- Site flexibility due to a combination of all the above reasons.

While the FOAK SMRs under implementation in China, Russia, Canada, the US, and the UK are very expensive, SMR deployment will reach NOAK scale around 2035. SMR costs will come down with serial manufacture since there is a pent-up demand for SMRs in several countries. Therefore, as per the G20 declaration after the New Delhi G20 summit in 2023, India can emerge as a global hub for SMR manufacturing, if one or more SMR developers tie up with reputed heavy industries in India for setting up SMR manufacturing plants in India with international safeguards.[47] In line with the New Delhi G20 Declaration, Washington has granted specific authorization to Holtec International, with GOI concurrence, to sell Holtec's SMR-300 for deployment in India by sharing the necessary technical information with three Indian companies – Larsen & Toubro, Tata Consulting Engineers and Holtec Asia.

In a densely populated country like India, with hundreds of geological disturbances and thousands of seismic events, SMRs can complement conventional NPPs by repurposing Brownfield sites, thereby minimising land acquisition for plant, water, and grid connection. Therefore, SMRs are ideal for decarbonisation of steel and aluminium plants, besides the repurposing of coal-fired TPPs.

As per India's NEM, BARC and NPCIL have been tasked with the development of Bharat Small Modular Reactors (BSMR-200 MW) and SMR-55 MW besides BSRs. The Union budget 2025 has provided Rs.20,000 Crores toward the design and development of SMRs and their FOAK deployment.[48]

According to the DAE, the BSMR (200 MW) is based on the pressurised water reactor technology and is designed with passive safety features and several engineered safety systems to ensure nuclear safety during accidents. The concept design of BSMR has been completed and is in the approval stage. The estimated time for construction of BSMR is 60 to 72 months after receipt of project sanction, and the lead unit of the BSMR-200, as well as the first twin SMR-55 MW plant, are proposed to be set up in the Tarapur NPP site by 2033.

In the above context, the NIAS has commenced the identification of suitable TPP sites for SMRs. An ongoing NIAS study has identified 68 TPP sites which satisfy the current AERB criteria (barring the exclusion zone which is set at 500 m for SMRs) out of a total of 200 TPP sites studied across India. The overriding criterion was to limit the EPZ to the site boundary of the TPP site so that site flexibility is maximised with advanced technology, incorporating best-in-class passive safety features. As per the NIAS study, these 68 TPP sites that are suitable for installation of the BARC-55 twin SMRs after the progressive retirement of all thermal units in the site have a potential generation capacity of 32 GW by 2050 and 84 GW by 2070.[49] However, the number of SMRs and, therefore, the total electricity generating capacity by repurposing each TPP site will depend on the specific SMR design, plant layout and the exclusion zone mandated for the specific design.

Recommendations

To attain its 2047 and 2070 energy and carbon emission goals, the government must undertake a multi-pronged coordinated approach. The following measures would be crucial:

- While NPCIL conducts public awareness programme around the existing NPPs, as well as its under-construction NPP sites and the AERB discloses the radiation levels at the site boundaries of existing NPPs in their annual reports, these scientific findings are not widely known to the public. Since public support is critical to implement India's NEM the GOI can suitably advise the DAE and the AERB to publicise the results of the environmental surveys around various NPPs in India.
- Nuclear energy requires a multi-decade commitment from all stakeholders, including Central and State governments, power developers, manufacturers, regulators, financial institutions, academia and civil society. Multiple partnerships are necessary and handholding the private sector by the government is critical in matters related to finance, capacity building, fuel security and technology transfers, safety and tariffs.
- The role of the state governments is paramount to expedite the Nuclear Energy Mission. The GOI has to take them on board from the beginning since their cooperation is vital for the allocation of land and water for the NPPs, besides for mobilising critical public support.
- The GOI may suitably advise the RBI to classify Nuclear Power as a 'Green' energy source to enable NPPs to avail low-cost Climate/Green Finance from domestic as well as international financial institutions.
- The GOI has to implement a single-window clearance system for NPPs which have unique siting requirements by including all forest and environmental aspects assessed by the AERB with the help of suitable experts, rather than having independent Environmental Clearance, Forest Clearance and Coastal Regulatory Zone clearance processes administered by Ministry of Environment, Forest and Climate Change (MOEFCC) in parallel.

- Since the BARC and the NPCIL are tasked with setting up BSMRs (200 MW) and SMRs (55 MW) under the NEM, the AERB has to develop a separate siting code for SMRs since they are designed, manufactured, and operated to be inherently safer than conventional NPPs.
- To kick start the Make in India programme for Light Water Reactors (LWRs) and SMRs, the GOI has to launch a PLI scheme or provide Viability Gap Funding to a government company like Bharat Heavy Electronics Limited (BHEL), which has experience in manufacturing large NPP components, for acquiring the necessary technology and licenses, and enhancing their production facilities to manufacture LWRs and SMRs with progressively higher indigenisation. This will optimise the capital investments in NPPs and reduce electricity tariffs while promoting technology development and creation of high-skill, high-wage jobs.
- The GOI can task the BARC and the Nuclear Fuel Complex with the acquisition of the knowhow for uranium enrichment and manufacture of fuel assemblies for LWRs and SMRs under IAEA safeguards and provide adequate funding for these facilities. It has to support both the BARC/NPCIL for developing and testing thorium-rich fuels for long-term fuel security.
- The Homi Bhabha National Institute (HBNI) has to broaden the availability of its training programs for private and public companies entering the nuclear power sector and assist other academic institutions to train science and engineering graduates to work in NPPs.
- The DAE has to permit all companies in the nuclear power sector to access the testing and certification facilities in all DAE establishments since the new entrants will take time to create comparable facilities and get them licensed by the DAE and the AERB.
- Carbon pricing and incentives are necessary to expedite private sector investments in nuclear power. Further, nuclear power is ‘green’ with significantly lower CO2 emissions compared to solar energy over the lifecycle. Therefore, Britain has declared nuclear power to be eligible for its ‘Green Financing Program.’ Similarly, the RBI has to classify nuclear power as a ‘Green’ energy source to enable NPPs to avail green financing.

The timely implementation of the above recommendations is critical to expedite the Nuclear Energy Mission once the SHANTI Act is operationalised with the proposed notification of the rules and regulations by the GOI.

Acknowledgements

The author wishes to acknowledge the contribution of Dr. Kanaya Dutta and Ms. Bhargavi Vinakallu to the NIAS research report entitled, "Coal-To-Nuclear Transition with Small Modular Reactors," which explains the progressive repurposing of suitable TPP sites with SMRs. The author is grateful to Prof Krishnan and other team members at NIAS for their pioneering work on site selection for NPPs.

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