



Research Article

Imperatives of Nuclear Energy in India's Clean Energy Transition

Sitakanta Mishra and Pranav Bhaskar

*School of Liberal Studies, Pandit Deendayal Energy University, Gujarat, India,
<https://pdeu.ac.in/>*

Abstract: Climate change is a reality, and India has been proactive in addressing the issue both nationally and in cooperation with the global community, despite its demographic and developmental imperatives. While exploring technological solutions to curb domestic carbon emissions in various sectors in the short term, India is also attempting to rationalize its energy mix for long-term sustainability by opting for green and clean energy options. To navigate this transition, India has planned a judicious combination of energy sources to meet its self-set goal of net-zero emissions by 2070. In the process, it is promoting a long-term low-carbon development strategy and aims to generate at least 50 percent of its electricity from renewable sources by 2030. Solar and wind energy projects, in particular, are being promoted aggressively through government incentives, leading to a visible increase in renewable energy production. However, nuclear energy remains a cost-effective and stable baseload alternative power source that should be promoted simultaneously to help India achieve its clean energy transition smoothly in a carbon-constrained world. This article argues that nuclear energy is a viable option for meeting India's climate change obligations while sustaining its high economic development trajectory.

Keywords: India, energy transition, nuclear energy, net zero emissions, energy security, climate change, green energy, clean energy options.

Introduction

Climate change is anthropogenic and requires national and global efforts to address the menace. India, though it currently emits less carbon than the global

average, has “partaken in the collective effort”¹ as a responsible member of the community of nations “by doing more than its fair share.”² Critics often ignore India’s imperatives to balance economic development with meaningful climate action, as well as its traditional lifestyle inherent in “sustainable living.”³ However, as the world’s most populous country, and aiming to become the third largest economy by 2030, its energy needs are expected to grow about 1.5 times faster than the global average over the next three decades.⁴ This, in turn, would boost India’s carbon emissions dramatically. If drastic actions are not undertaken in the next decade, India could be blamed for not acting responsibly to protect vulnerable people affected by climate change, both inside and outside the country.

India has made several preparations to address climate change, including the National Action Plan on Climate Change (NAPCC) in 2008, which outlined eight National Missions on climate change.⁵ As part of its commitment toward climate change obligations, India has individual commitments under its “Nationally Determined Contributions” to reduce carbon emissions “to limit the global temperature increase to 1.5 degrees Celsius above pre-industrial levels.” Moreover, India has pledged to achieve net-zero emissions (NZE) by 2070, two decades later than other major emitting countries, such as the USA and China, which have set this goal for the middle of this century.⁶

However, all these steps will not shield India from global pressure to make judicious choices regarding energy sources, especially by aggressively pursuing a “green and clean energy transition.” Within less than five decades, India must achieve this target without disrupting its economic growth trajectory or quality of life, though determining the right pathway remains a matter of introspection. At the Conference of the Parties (COP26)—the UN Climate Change Conference in Glasgow in November 2021—Prime Minister Narendra Modi presented India’s climate action plan consisting of five nectar elements (*Panchamrit*): increasing non-fossil fuel energy capacity, harnessing renewable energy, reducing carbon

¹ Government of India, “Climate Change and India: Why We Must Look at the Problem Through Our Lens,” *Economic Survey 2023-24*, Chapter 13, p. 447, <https://www.india budget.gov.in/budget2024-25/economicsurvey/doc/eschapter/echap13.pdf>.

² Ministry of Environment, Forest and Climate Change, “India Is Part of the Solution and Is Doing More Than Its Fair Share to Address Climate Change,” *Press Release*, February 2, 2023, <https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1895857>.

³ Jyoti Bajpai, “Sustainable Living Through India’s Traditional Practices, Lifestyle and Cultural Wisdom,” *Idealistic Journal of Advanced Research in Progressive Spectrums* 3, no. 10 (October 2024): 181-188, <https://journal.ijarps.org/index.php/IJARPS/article/view/438>.

⁴ International Energy Agency (IEA), *World Energy Outlook 2022*, Revised Version, November 2022, <https://www.iea.org/reports/world-energy-outlook-2022>.

⁵ Government of India, Ministry of Science and Technology, “Climate Change Programme,” accessed September 15, 2024, <https://dst.gov.in/climate-change-programme>.

⁶ “United States,” CLIMATEWATCH, accessed March 16, 2025, https://www.climate watchdata.org/countries/USA?end_year=2021&start_year=1990.

emissions, lowering the carbon intensity of the economy, alongside the pledge for the NZE goal.⁷

To achieve the desired economic growth and NZE goal, while keeping in mind the expected population growth and energy intake, India needs to increase its energy generation threefold (18,900–22,300 TWh/yr) by 2070, according to Bhattacharyya and coworkers.⁸ Meanwhile, carbon emissions are projected to triple by 2030; therefore, India's energy transition pathway is bound to be intricate. The emphasis on renewable energy sources is prudent, but for the urgent decarbonization of the entire economy, a judicious mix of energy sources is essential while maintaining upward economic growth. The target of meeting 50 percent of its energy needs from renewables (solar and wind) by 2030 is desirable, but their high degree of variability and intermittency leads to high system costs. As stated by Prime Minister Modi in Glasgow, India will need \$ 1 trillion (about \$ 160 billion per annum, as per the International Energy Agency) for "climate finance" by 2030,⁹ indicating the challenges of finding sustainable and cost-effective resources for India's green energy transition. According to mathematical modeling developed by the Indian Institute of Technology Bombay (IIT Bombay) for the Vivekananda International Foundation (VIF) Task Force (2021) on "India's Energy Transition in a Carbon-Constrained World," India's energy transition to the NZE stage by 2070 would cost \$ 11.2 trillion in a nuclear-dominated scenario, while the cost in a renewable-dominated scenario would be 28 percent higher, at \$ 15.5 trillion.¹⁰

Scheme and Methodology

This article scrutinizes India's renewable energy choices and the imperatives of nuclear energy in the pursuit of clean energy transition, in comparison to other renewable sources, to meet the NZE goal. It begins with the projected renewable energy production in tandem with India's self-set goal of energy transition. Subsequently, the article highlights the importance of nuclear energy as a viable option for India. By adopting a comparative approach based on empirical data and open-source literature, this study examines the competitiveness, cost-effective-

⁷ Ministry of Environment, Forest and Climate Change, "India's Stand at COP-26," *Press Release*, February 3, 2022, <https://pib.gov.in/PressReleasePage.aspx?PRID=1795071>.

⁸ Rupsha Bhattacharyya et al., "Estimating Minimum Energy Requirement for Transitioning to a Net-Zero, Developed India in 2070," *Current Science* 122, no. 5 (2022): 517-527, 517, <https://doi.org/10.18520/cs/v122/i5/517-527>.

⁹ Prime Minister's Office, India, "National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow," *Press Release*, November 1, 2021, <https://pib.gov.in/PressReleasePage.aspx?PRID=1768712>.

¹⁰ Vivekanand International Foundation (VIF), "India's Energy Transition in a Carbon-Constrained World," VIF Task Force Report, 2021, 201-202, www.vifindia.org/sites/default/files/India-s-Energy-Transition-in-a-Carbon-Constrained-World-Final-Report.pdf.

ness, and efficiency of nuclear energy projects vis-à-vis renewable projects. However, all renewable energy options as components of India's energy basket for the transition toward clean energy are not undervalued in this article. The article argues that nuclear energy holds a comparative advantage as the most viable component for India to meet its rising energy demand, which also has the potential to support its net-zero emissions goal.

While highlighting the competitive advantage and merits of nuclear energy in India's clean energy transition drive, it also examines the risk factors associated with the expansion of the nuclear energy sector, such as public acceptance, safety and security, and geopolitical concerns in the region. In the concluding section, the article suggests that the government must create a level playing field and extend comparative patronage to the nuclear energy sector to effectively decarbonize the entire economy without interrupting economic growth. It also prescribes a toolkit to enhance domestic public acceptance of nuclear energy projects, given that public perception of anything nuclear remains largely negative.

Demand Projections and Self-Set Goals

Replacing fossil fuel consumption with renewables to decarbonize the entire economy is impossible. Focusing on only one sector, like the power sector—which accounts for nearly 49 percent of India's CO₂ emissions¹¹—will also not help attain NZE. India has to decarbonize its transport sector, residential uses, agriculture, and the industrial sector simultaneously, all of which require stable baseload power. According to the Ministry of Power, the bulk of electricity in India is generated from thermal sources (mostly coal-based).¹² As of June 2025, this accounted for 240 GW, or 50.52 percent of installed capacity, followed by solar, wind, and hydropower, respectively.¹³ Meanwhile, to pursue fast GDP growth (reaching \$ 8.6 trillion by 2040) and fast industrialization amid rapid population growth, India's energy consumption will be "more than double" by 2040,¹⁴ while electricity demand in particular will triple under current policies.¹⁵

¹¹ Abhijeet Agrawal, "Watts of Change: Power Sector Leads the Charge for a Just Transition," *PowerLine*, December 22, 2023, <https://powerline.net.in/2023/12/22/watts-of-change-power-sector-leads-the-charge-for-a-just-transition/>.

¹² Ministry of Power, "Adequate Capacity Available in the Country to Meet the Rising Demand of Power: Shri R. K. Singh, Union Power & NRE Minister," July 27, 2023, <https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1943368>.

¹³ "India's Energy Landscape: Powering Growth with Sustainable Energy," Press Information Bureau, June 22, 2025, <https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=154717&ModuleId=3>.

¹⁴ International Energy Agency (IEA), *India Energy Outlook 2021*, World Energy Outlook Special Report (Paris: IEA, February 2021), <https://www.iea.org/reports/india-energy-outlook-2021>.

¹⁵ IEA, *India Energy Outlook 2021*, 78.

According to Central Electricity Authority projections, India's energy demand will increase from 1,566 TWh in 2021–22 to more than 2,047 TWh in 2026–27.¹⁶

The NZE goal by 2070 is not just about reducing greenhouse gas (GHG) emissions from fossil fuel use through renewables. It also involves removing GHGs from the atmosphere by creating carbon sinks and deploying carbon capture technologies. Above all, the green energy transition should be an economic opportunity rather than a disruptive process. Increasing the use of renewable energy is desirable. Still, it is a misperception that India's entire energy needs to support a good standard of living can be sourced only through solar, wind, or bioenergy, as these sources have serious limitations. Renewable sources such as solar, wind, and geothermal are promising, and India is actively expanding its capacity to harness them, but these sources often face challenges in terms of consistent and reliable power generation and scalability to meet large-scale energy demands.¹⁷ The technology to harness renewable energy is not yet mature enough to provide baseload power for heavy industries. Except for hydropower in pockets where it is plentiful, no such energy source is suitable for large-scale and stable power generation. Therefore, India has a strong case for expanding the role of nuclear energy, which is a clean and stable baseload power source. Despite its meagre contribution to total electricity generation today, nuclear energy holds substantial promise as dispatchable non-fossil power to meet India's growing energy needs and support the clean energy transition.

The Imperatives of Nuclear Energy

Perceptibly, the nuclear energy sector in India is not a priority compared to renewables in the context of the green energy transition, probably because of its high capital cost, long gestation period, and public concerns. It is also considered a "conventional" and "non-renewable source of energy" that, even if zero-carbon, cannot be "a people-centric energy transition mechanism."¹⁸ This was reportedly the reason why nuclear energy was not included in the 2023 G20 Summit agenda under India's presidency.¹⁹

According to a study by Jawerth in the *IAEA Bulletin*, "Nuclear power is the second-largest source of low-carbon energy used today to produce electricity,

¹⁶ IEA, *India Energy Outlook 2021*.

¹⁷ Sudhir Pathak, "The Challenges and Solutions in Scaling up Renewable Energy," *Hero Future Energies*, October 8, 2024, www.herofutureenergies.com/blog/renewable-energy-challenges-and-solution/.

¹⁸ Ministry of Power, Government of India, "G20 Energy Transitions Working Group Deliberations Conclude Successfully with Shared Views and Consensus on Priority Areas," Press Information Bureau, February 6, 2023, <https://www.pib.gov.in/PressReleaseDetail.aspx?PRID=1896807>.

¹⁹ Ministry of Power, Government of India, "G20 Energy Transitions Working Group Deliberations Conclude Successfully."

following hydropower.”²⁰ Rafael Mariano Grossi, the Head of the IAEA, on the sidelines of the 2022 G20 Bali Summit, said that “as a collective community... [we must] be very clear that we will need nuclear power... and nuclear deserves a footing equal to other low-carbon sources in the green transition....”²¹ Therefore, the carbon-free record of nuclear energy cannot be overlooked simply because of its non-renewable nature when the world has few energy alternatives.

Currently, the share of nuclear power in India’s total electricity generation is around 3 percent, which is far behind major economies like France (62.6 percent), the European Union (20 percent), and the United States (20 percent). China is in the process of commissioning “at least 150 new reactors in the next 15 years”²² to boost its nuclear power share up to 10 percent. In India, a total of 23 power reactors are in operation with a combined capacity of 7,480 MWe, and ten more reactors are under construction, which will add 8,000 MWe soon.²³ With the progressive completion of reactors under construction, 12 reactors approved, and 28 planned, nuclear power generation capacity will reach 22,480 MWe by 2031.²⁴

India aims to meet 9 percent of its electricity requirements from nuclear power by 2047,²⁵ a target that appears comfortably achievable. If nuclear capacity can be ramped up further, India could produce 50–60 GW and 80–90 GW of nuclear energy by 2050 and 2070, respectively,²⁶ catering to more than 25 percent of its electricity demand. According to DAE projections, “the total electricity generated from nuclear power plants during the last ten years (2013–14 to 2022–23) was about 411 BUs, averting the release of about 353 million tons of CO₂ equivalent to the environment,” and this figure will multiply in the longer

²⁰ Nicole Jawerth, “What Is the Clean Energy Transition and How Does Nuclear Power Fit in?” *IAEA Bulletin* 61, no. 3 (2020), <https://www.iaea.org/bulletin/what-is-the-clean-energy-transition-and-how-does-nuclear-power-fit-in>.

²¹ Rafael Mariano Grossi, “The Power of Nuclear,” The Global Governance Project, 2022, www.globalgovernanceproject.org/the-power-of-nuclear/rafael-mariano-grossi/.

²² Dan Murtaugh and Krystal Chia, “China’s Climate Goals Hinge on a \$440 Billion Nuclear Buildout,” *Bloomberg*, November 2, 2021, www.bloomberg.com/news/features/2021-11-02/china-climate-goals-hinge-on-440-billion-nuclear-power-plan-to-rival-u-s.

²³ Department of Atomic Energy, “Government Has Initiated Steps to Increase the Nuclear Power Capacity from 7480 MW to 22480 MW by 2031-32, Says Union Minister Dr Jitendra Singh,” Press Information Bureau Delhi, December 20, 2023, <https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1988863>.

²⁴ Department of Atomic Energy, “Dr Jitendra Singh Says Nuclear Power Capacity Set to Increase from 7480 MW to 22480 MW by 2031,” Press Information Bureau Delhi, July 20, 2023, <https://pib.gov.in/PressReleasePage.aspx?PRID=1941010>.

²⁵ Ministry of Science & Technology, “India Is Committed to Achieve the Net Zero Emissions Target by 2070 as Announced by MP Modi, Says Dr. Jitendra Singh,” Press Information Bureau, September 28, 2023, <https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1961797>.

²⁶ Deloitte, FICCI, “India’s Energy-Transition Pathways: A Net-Zero Perspective,” 2023, 22, <https://www2.deloitte.com/content/dam/Deloitte/in/Documents/energy-resources/in-eri-India%E2%80%99s20energy-transition%20pathways-noexp.pdf>.

run.²⁷ In 2020–21 alone, nuclear power avoided 41 million tonnes of CO₂ emissions compared to the emissions that would have been generated by coal-based thermal power plants for the same amount of energy produced.²⁸

It is axiomatic that GDP growth, energy demand, and carbon emissions are correlated.²⁹ As economies grow, energy demand and consumption increase, and carbon emissions rise. According to the Ministry of Power, India's per capita emissions in 2022 grew by 5.1 percent to reach 2.29 tonnes, which is significantly lower compared to the global average of 6.3 tonnes.³⁰ However, it is expected that with faster economic growth and continued urbanization, India's carbon emissions, unless intervened, will grow phenomenally, making it the third-biggest polluter after the United States and China.

Owing to the aggressive emphasis on renewables during the last decade, as of June 2025, non-fossil fuel sources accounted for 49 % (235.7 GW) of India's total installed electricity generation capacity (476 GW).³¹ And well before 2030, India is likely to achieve 50 percent of its electricity demand from renewables, as pledged at COP26 in Glasgow, which will reduce emission intensity by 45 percent.³² But this will not solve the energy transition burden immediately. In the long run, as economic growth accelerates amidst industrialization and population growth, India's energy demand will grow exponentially – around 24,470 TWh as projected by the model prepared by IIT Bombay for the VIF Task Force.³³ The need for baseload energy for heavy industries will compel India to seek stable energy sources, and nuclear energy is the best candidate besides hydroelectric power (42 new hydro projects are under construction).³⁴

²⁷ Department of Atomic Energy, "Union Minister Dr. Jitendra Singh Says, Presently (2020-21) Nuclear Power Is Saving 41 Million Tonnes of CO₂ Emissions Annually, Compared to the Emissions that Would Be Generated by Equivalent Electricity Generation from Coal Based Thermal Power Plants," Press Information Bureau, March 15, 2023, <https://pib.gov.in/PressReleaseDetailm.aspx?PRID=1907214>.

²⁸ Department of Atomic Energy, "Presently (2020-21) Nuclear Power Is Saving 41 Million Tonnes of CO₂ Emissions Annually."

²⁹ Namit Sharma, Bram Smeets, and Christer Tryggstad, "The Decoupling of GDP and Energy Growth: A CEO Guide," *McKinsey & Company*, April 24, 2019, accessed May 15, 2024, <https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-decoupling-of-gdp-and-energy-growth-a-ceo-guide>.

³⁰ Livemint, "India's per Capita Carbon Emissions Remain Low amidst Climate Change Concerns: Union Power Minister," July 21, 2023, <https://www.livemint.com/industry/energy/indias-per-capita-carbon-emissions-remain-low-amidst-climate-change-concerns-union-power-minister-11689948764652.html>.

³¹ "India's Energy Landscape: Powering Growth with Sustainable Energy."

³² Ministry of Power, Government of India, "Need to Shift Climate Change Narrative from Total Emissions to Per Capita Emissions of Each Country: Union Minister for Power and New & Renewable Energy," Press Information Bureau, August 25, 2023, <https://pib.gov.in/PressReleaseSelfframePage.aspx?PRID=1952260>.

³³ VIF, "India's Energy Transition in a Carbon-Constrained World," Chapter 8.

³⁴ Ministry of Power, "G20 Energy Transitions Working Group Deliberations Conclude Successfully."

Owing to two other important reasons, nuclear energy should be preferred vis-à-vis renewables. First, nuclear power plants have a smaller land footprint than renewables. In particular, solar energy requires a much larger land footprint than nuclear energy. Though the exact amount of land required can vary depending on the type of PV panels used, the spacing between rows of panels, the terrain, etc., a typical utility-scale solar plant may require anywhere between two to five acres of land for every megawatt (MW) of power capacity.³⁵ According to a study by Kiesecker and colleagues, India's commitment to reduce carbon emissions through increased renewable energy production to 175 GWe by 2022 required from 55,000 to 125,000 km² of land (5.5 to 12.5 million hectares), "roughly the size of Himachal Pradesh or Chhattisgarh, respectively."³⁶ A study by van de Ven and coauthors highlights that by 2050, if 78 percent of electricity generation in India is derived from solar PV on land, and about 3 percent from rooftop solar PV, it would occupy more than 137–182 percent of urban land area, 1.9–2.5 percent of crop area, and 1–1.4 percent of total land area.³⁷ Moreover, by 2023, around "74 % of solar development in India was built on landcover types that have natural ecosystem preservation or agricultural value."³⁸ When the solar energy expansion drive intensifies further, competition for land will aggravate.

According to mathematical modeling by IIT Bombay (VIF Task Force), India will "need 14,680 GW of solar energy if it relies mostly on renewables," which "would require a total land area of 412,033 km²."³⁹ However, according to a report by Sukhatme, India has barren and uncultivated land of only 200,000 km².⁴⁰ To address the issue of land shortage, rooftop solar panel installation has been advocated. The Government of India has recently announced that 10 million households will install rooftop solar panels, but this cannot be a substitute for

³⁵ KP Group, "Land Requirements for Solar Power Plants in India: Key Insights," accessed June 24, 2025, <https://kpgroup.co/blog/land-requirements-for-solar-power-plants-in-india/>.

³⁶ Joseph Kiesecker et al., "Renewable Energy and Land Use in India: A Vision to Facilitate Sustainable Development," *Sustainability* 12, no. 1 (2019), 281, <https://doi.org/10.3390/su12010281>.

³⁷ Dirk-Jan van de Ven et al., "The Potential Land Requirements and Related Land Use Change Emissions of Solar Energy," *Scientific Reports* 11, no. 1 (2021), 2907, <https://doi.org/10.1038/s41598-021-82042-5>.

³⁸ Zoya Ada Hussain, "The Balance Between Expanding Renewable Projects and Feeding India's Population," *Mongabay*, September 4, 2023, <https://india.mongabay.com/2023/09/the-balance-between-expanding-renewable-projects-and-feeding-indias-population/>.

³⁹ VIF, "India's Energy Transition in a Carbon-Constrained World," Chapter 8.

⁴⁰ S.P. Sukhatme, "Can India's Future Needs of Electricity Be Met by Renewable Energy Sources? A Revised Assessment," *Current Science* 103, no. 10 (2012): 1153-1161, <https://www.currentscience.ac.in/Volumes/103/10/1153.pdf>.

land-based solar plants due to limitations such as natural disasters and maintenance issues.⁴¹ In fact, the goal of attaining 40 GW of rooftop solar power by 2022 could not be achieved; instead, by the end of 2023, only 11 GW of rooftop solar energy had been generated.⁴²

According to a report by the Institute for Energy Economics and Financial Analysis (IEEFA), in the process of achieving India's mid-century net-zero goal through renewable energy transition, land use on the higher side would be between 50,000 and 75,000 km² for solar, and 15,000–20,000 km² for wind (total project area).⁴³ Most studies on this issue agree that the pattern of land use may constrain the clean energy transition in the decades ahead; therefore, careful planning is needed. On the other hand, many argue that “the land requirement will be reduced to 183,565 km²” if India relies on nuclear power to produce the same amount of energy.⁴⁴ More importantly, solar plants can be accommodated within nuclear project premises.

In terms of cost competitiveness, nuclear energy generation and transmission costs are also lower than those of renewables. As green energy sources, solar and wind power have low generation costs since their sources are free and receive many government subsidies for promotion. However, they generate energy with a “high degree of variability,” resulting in “high system costs.” According to the World Nuclear Association, “the grid-level system costs for intermittent renewables are large (\$ 8-\$ 50/MWh),” whereas “nuclear system costs are \$ 1-3/MWh.”⁴⁵

Undoubtedly, renewables provide the lowest-cost option for decarbonizing the economy, but it is a myth that they are the only lower-cost source compared

⁴¹ Rituraj Baruah, “Rooftop Solar Installations for 10 million Households: PM Modi,” *mint*, January 23, 2024, www.livemint.com/economy/rooftop-solar-installations-for-10-million-households-pm-modi-11705948682002.html.

⁴² “PM Modi Announces Rooftop Solar Scheme, His 1st Decision after Ram Temple Inauguration,” *The Economic Times*, January 22, 2024, <https://economictimes.indiatimes.com/industry/renewables/pm-modi-announces-scheme-to-install-rooftop-solar-systems-in-1-crore-homes-his-first-decision-after-ram-temple-inauguration/articleshow/107058370.cms>.

⁴³ Charles Worringham, “Renewable Energy and Land Use in India by Mid-Century,” Institute for Energy Economics and Financial Analysis (IEEFA), September 2021, https://ieefa.org/wp-content/uploads/2021/09/Renewable-Energy-and-Land-Use-in-India-by-Mid-Century_September-2021.pdf.

⁴⁴ Dinkar P. Srivastava, “Opinion: Climate Change and Energy Transition,” *ETEnergy-world.com*, September 25, 2023, <https://energy.economictimes.indiatimes.com/news/renewable/opinion-climate-change-and-energy-transition-by-dinkar-p-shrivastava/103922020>.

⁴⁵ World Nuclear Association, “Economics of Nuclear Power,” August 2022, accessed May 16, 2024, <https://world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power>.

to other clean energy options.⁴⁶ In India, the bid solar power tariff of \$ 27 /MWh is often referred to as low. According to Paul Butterworth's report, the upfront development costs of solar power tariffs are subsidized, and if the subsidy is taken into account, the true costs of solar energy are closer to ~\$ 69/MWh – broadly in line with unsubsidized costs of solar elsewhere.⁴⁷

According to Butterworth's report, Bhadla Solar Park in Rajasthan and Dholera Solar Park in Gujarat (India) have produced auctioned power tariffs through a competitive bidding process, ranging between INR 1.99–2.62/kWh. However, the basis of these tariffs is the government's Renewable Purchase Obligations (RPO) policy, which mandated large companies (captive companies or obligated entities) to purchase a given level of renewable power (set at 21 percent for 2022).⁴⁸ Furthermore, the Electricity Amendment Bill 2021 introduced specific provisions for penalties of up to INR 10 million for not meeting the RPO.⁴⁹

Other incentives include the "Feed-in Tariff," i.e., "the rate at which the generated electricity will be sold during the purchase agreement," and the "wheeling facility" to supply a direct off-taker via the grid.⁵⁰ In addition, much of the upfront investment costs of renewable projects are supported by both state and federal governments. Dholera Solar Park's infrastructure has been provided and developed by Gujarat Power Corporation Ltd. (GPCL), while Bhadla Solar Park has been developed by various joint venture companies of the Government of Rajasthan with financial assistance from the Union government. Besides, renewable tariffs do not take into account additional costs associated with grid balancing, storage, or some form of demand management. With the expansion of renewable energy infrastructure and an increase in its share in the total energy mix in the long run, the subsidy burden in transmission and grid stabilization will also increase.

Lastly, renewable energy technology is not yet fully mature, and battery storage systems are still evolving. Keeping in mind the net-zero emissions goal, a long-term trajectory for Energy Storage Obligations (ESO) has also been notified by India's Ministry of Power to ensure sufficient storage capacity is available in the long term. According to the National Electricity Plan (NEP) 2023 of the Central Electricity Authority (CEA), India's energy storage capacity requirement is projected to increase to 82.37 GWh in 2026–27, 411.4 GWh in 2031–32, and

⁴⁶ Paul Butterworth, "Indian Solar Is Not Cheap – It Is Simply Subsidised," *CRU Online*, January 10, 2022, <https://sustainability.crugroup.com/article/indian-solar-is-not-cheap-it-is-simply-subsidised>.

⁴⁷ Butterworth, "Indian Solar Is Not Cheap."

⁴⁸ Butterworth, "Indian Solar Is Not Cheap."

⁴⁹ Ministry of Power, Government of India, "The Electricity (Amendment) Bill, 2022," August 18, 2024, <https://prsindia.org/billtrack/the-electricity-amendment-bill-2022>.

⁵⁰ VIF, "India's Energy Transition in a Carbon-Constrained World," Chapter 8.

2,380 GWh in 2047. Under this trajectory, the ESO will gradually increase from 1 % in FY 2023–24 to 4 % by FY 2029–30, with an annual increase of 0.5 %.⁵¹

Similarly, solar installations in India have yet to prove their robustness and longevity. Even though solar insolation in India is very high, solar plant installations have an average load factor of around 15 percent (a high load factor is well above 20 percent). However, the data suggests that the load factors of solar parks in India are average, indicating that they are not yet efficient in tapping the abundant free resource. This could be due to maintenance issues, cleaning issues, inverter configurations, or the use of low-quality panels and inverters.

Comparatively, nuclear power projects have a long-range marginal cost (LRMC) advantage. As they operate for around 40 (+/-) years on average, the high upfront capital cost is recovered over their longer lifespan. Moreover, nuclear power plants have a higher Plant Load Factor (PLF) of around 85 percent, compared to solar at 20 percent and wind at 35 percent, which are available only for a few months a year in India.⁵² Therefore, solar power plants generate only about a quarter of the electricity capacity of nuclear power plants. With the availability of uranium after the Indo-US civil nuclear deal and NSG waiver, the capacity factor of Indian nuclear power reactors has increased. The first unit of the Kaiga Generating Station (KGS) registered a world record of 962 days of continuous operation until December 31, 2018, during which the unit “generated about 5 billion units of electricity at a Plant Load Factor (PLF) of about 99.3 %.”⁵³ Some Indian nuclear power reactors have achieved continuous operation of over 365 days on 39 occasions.⁵⁴ Three reactors—KGS-1 (962 days), RAPS-3 (777 days), and RAPS-5 (765 days)—have operated uninterruptedly for more than two years.⁵⁵ If given a level playing field vis-à-vis renewables, along with GST exemption for inter-state transfer of goods for nuclear project execution, nuclear electricity tariffs would decrease further, making it the most cost-effective sustainable power source.

⁵¹ Ministry of New and Renewable Energy, “Energy Storage Systems (ESS) Overview,” accessed on June 24, 2025, <https://mnre.gov.in/en/energy-storage-systemsess-overview>.

⁵² Jyoti Gulia and Vibhuti Garg, “Wind-Solar Hybrid: India’s Next Wave of Renewable Energy Growth: An Analysis of Tariff Trends, Policy and Regulation, and Challenges in a New Market,” Institute for Energy Economics and Financial Analysis, October 2020, https://ieefa.org/wp-content/uploads/2020/10/Wind-Solar-Hybrid-Indias-Next-Wave-of-Renewable-Growth_October-2020.pdf.

⁵³ Nuclear Power Corporation of India Ltd., “KGS-1 Sets New Benchmark in Continuous Operation,” 2019, accessed May 13, 2024, www.npcil.nic.in/WriteReadData/userfiles/file/Major_Achievements_Report_English_17012019_01.pdf.

⁵⁴ B.V.S. Sekhar, “Nuclear Power in India,” in *Atomic Energy in India: Achievements since Independence*, ed. A.K. Tyagi (Bhabha Atomic Research Centre, 2022), 98, <https://www.barc.gov.in/ebooks/9789356590526/paper08.pdf>.

⁵⁵ Department of Atomic Energy, Government of India, “Annual Report 2019-20,” 2020, IV, https://data.dae.gov.in/publication_Anuual_Reports/English-2019-2020/Annual2019-2020e.pdf.

India is also visibly gearing up its nuclear energy sector innovation, with required legislative reforms, capacity building, and adoption of best practices via foreign collaborations. Small Modular Reactors (SMRs), which dominate the nuclear narrative today as the new frontier of nuclear technology, promise to address existing critical issues in the sector. India envisions a greater role for SMRs in its energy transition roadmap and plans to venture into this domain by focusing on technology development, regulatory frameworks, and increased private participation through strategic partnerships.⁵⁶ As this technology is expected to take at least two decades to mature, the Union Budget 2025-26 has allocated INR 200 billion for the launch of the Nuclear Energy Mission, focused on R&D for at least five indigenously designed and operational SMRs by 2033. This indicates that India has positioned nuclear energy as a major pillar in its energy mix, in pursuit of its ambitious target of achieving 100 GW of nuclear power capacity by 2047.⁵⁷

Critical Concerns

Nuclear energy is well-suited to help India meet its climate change targets and align with its broader energy transition plans to achieve net-zero emissions by 2070. Nevertheless, this technology is highly sensitive due to its significant inherent risks—both domestically and internationally—concerning safety, security, safeguards, and geopolitical stability. At the domestic level, despite the absence of a widespread “green movement” and a prevailing political consensus in favor of nuclear technology, sporadic and localized public opposition has caused delays in project completion. Since technology is a social choice and there is an intricate relationship between science, technology, and society, no ambitious technological project can succeed without public acceptance. Greater public support for nuclear projects will occur only when concerns are thoughtfully addressed and the accrued benefits demonstrably outweigh the involved risks. There is no easy path forward, as numerous past accidents abroad have repeatedly reinforced public scepticism and fuelled anti-nuclear sentiment within India.

Secondly, India’s nuclear energy drive could be constrained by regional geopolitics, which are caught in a three-way strategic entanglement with Pakistan and China. A significant expansion of India’s nuclear energy sector would likely draw the attention of its rivals, potentially triggering a regional nuclear race. Pakistan could perceive this as a threat and respond by expanding its own nuclear arsenal. Consequently, India’s advancement in nuclear energy could have an indirect influence on Pakistan’s nuclear posture and security perceptions. In turn,

⁵⁶ National Institution for Transforming India, “A Report on the Role of Small Modular Reactors in the Energy Transition,” May 2023, <https://www.niti.gov.in/sites/default/files/2023-06/The-Role-of-Small-Modular-Reactors-in-the-Energy-Transition-05162023.pdf>.

⁵⁷ Government of India, Press Information Bureau, “Nuclear Power in Union Budget 2025-26,” Department of Atomic Energy, February 3, 2025, <https://static.pib.gov.in/WriteReadData/specificdocs/documents/2025/feb/doc202523495401.pdf>.

the China-Pakistan strategic nexus would likely deepen, and any resulting regional instability or escalation could adversely affect India's economic growth trajectory.

A third critical concern is the imperative to maintain India's positive record regarding nuclear safety, security, and safeguards. Any lapse—whether caused by human error, natural disaster, or geopolitical instability—would threaten to derail India's nuclear energy ambitions and could lead to erosion of public and political consensus. Therefore, it is paramount that India uphold the highest standards of nuclear safety and security, particularly given its location in a volatile, terrorism-prone, and disaster-susceptible region.

Conclusion

From a comprehensive standpoint, nuclear power is well-suited to be a major component of India's energy mix, serving as a key driver for the nation's transition to clean and green energy, provided it is managed with utmost efficiency. A pragmatic strategy for India to achieve its NZE goal by 2070 would be to foster a positive synergy between the promotion of renewables and nuclear power. To facilitate this, nuclear power should first be officially classified as a “clean energy” source and granted promotional policies and incentives similar to those provided to renewable energy projects. Furthermore, nuclear power projects should be accorded “must-run” status, on par with renewables, to position them rationally within India's energy transition framework. In a carbon-constrained world, it would be imprudent to overlook nuclear energy's carbon-free record simply because it is non-renewable.

To further streamline the integration of nuclear energy and cultivate public support, the national discourse on nuclear power should be framed within the context of “limited energy choices.” This approach highlights nuclear energy as a vital option among a finite set of resources, capable of providing an environmentally friendly solution to global energy security challenges. Over the past five years, India's energy landscape has been at the heart of a complex debate centered on climate change mitigation, energy security, and the role of nuclear technology. This presents a timely opportunity to involve the broader public as stakeholders in nuclear projects. It is particularly crucial to engage women, who are often highly motivated to learn and understand new information. Consequently, a feminist perspective should be incorporated into all public engagement initiatives of the nuclear establishment, recognizing that women constitute a significant portion of society grappling with daily energy shortages.

Additionally, a country-wide nuclear knowledge management (NKM) system must be devised by involving social scientists, researchers, and women alongside nuclear experts to eradicate prevailing societal misperceptions about nuclear technology. The younger generation must be equipped with foundational nuclear knowledge by integrating higher educational institutions with NKM plans. To broaden this educational outreach, non-technical courses for social science students—including NKM, Nuclear Psychology, Nuclear Language and Societal

Perception, and Nuclear Safety-Security-Safeguards—should be offered at both the diploma and post-graduate levels, through either regular or distance learning programs. To make these courses more appealing, a clear pathway to employment should be established: upon successful completion, students should be absorbed into the NKM system. This would not only enhance the employability of social scientists within the nuclear industry but also significantly contribute to addressing societal concerns surrounding nuclear projects.

As nuclear energy is a highly technology-intensive field, a concerted effort in public engagement and knowledge management is paramount to its success. To achieve these goals, India must urgently address public concerns regarding safety and security. Although the Indian nuclear establishment is actively engaged in public outreach, the general level of awareness in the country remains low regarding the use, misuse, and consequences of nuclear technology. It is therefore crucial to impart basic nuclear knowledge to the public, particularly to the younger generation and women, and to make them key stakeholders.

Beyond producing scientists and technocrats, a focused effort is required to cultivate a pool of “nuclear cheerleaders,” who need not be technocrats, to propagate the positive utility of nuclear energy to the public. In the current post-material phase of social evolution, public support for or opposition to nuclear projects is intrinsically linked to concerns about the environment, energy security, displacement, rehabilitation, and safety. A notable absence of charismatic scientific figures with popular appeal to champion nuclear projects in India has been observed, especially in the post-Bhabha-Nehru era. This is not to say that there is a lack of visionary political or scientific leadership today; rather, it points to a disjointed growth of science, society, and technology in the country, where these domains sometimes impede one another’s progress. Creating a dedicated pool of “nuclear cheerleaders” is, therefore, a critical necessity that would popularize the technology by addressing common public concerns in simple language.⁵⁸

As far as regional geopolitics is concerned, it is imperative to acknowledge the potential of India’s nuclear technology expansion to trigger a security dilemma, arms race, and nuclear proliferation in the region. It would be prudent for India to convey and engage all regional countries in constructive dialogue and confidence-building measures that define its nuclear expansion drive, which is focused on civilian applications.

There has been no precedent of a nuclear disaster in India yet. However, due to disasters elsewhere, the domestic nuclear program has often been scrutinized to assess its strength and standards. During the last eight decades, India’s nuclear program has remained committed to safety, with no incidents of radioactivity release beyond stipulated limits in the public domain. India’s nuclear power

⁵⁸ Sitakanta Mishra, “‘Nuclear Cheerleaders’ for India,” *Nuclear Asia*, March 8, 2018, <https://www.nuclearasia.com/views/nuclear-cheerleaders-india/2036/>.

plants have achieved over 611 reactor-years of safe operation as of March 2024.⁵⁹

Finally, as a key component of its nuclear knowledge management strategy, the nuclear establishment should consider creating a nuclear energy think tank. This body, composed of both social and nuclear scientists, would be responsible for generating research, addressing public concerns, and attending to nuclear-related issues across the country. This initiative would also help ease the burden on the scientific community, allowing them to dedicate their valuable time to accelerating nuclear projects. The think tank would be instrumental in shaping the national narrative on nuclear energy and guiding public opinion in a productive direction. Ultimately, a well-defined strategic plan is the way forward to fully harness the benefits of nuclear energy. This will enable India to position nuclear power as a compelling and essential choice for achieving its three-pronged goal of a smooth transition toward clean energy, meeting climate change targets, and ensuring long-term energy security.

Disclaimer

The opinions, findings, conclusions, and recommendations expressed in this publication are those of the authors and do not necessarily reflect the official policy or position of the Partnership for Peace Consortium, its participating institutions, or any governmental or international organizations affiliated with its governance structure.

About the Authors

Sitakanta Mishra is the Dean of the School of Liberal Studies at Pandit Deendayal Energy University, Gujarat, India. *E-mail:* sitakant@gmail.com

Pranav Bhaskar is a Doctoral Candidate at the School of Liberal Studies, Pandit Deendayal Energy University, Gujarat, India.

⁵⁹ International Atomic Energy Agency (IAEA), "Country Nuclear Power Profiles: India 2024," <https://cnpp.iaea.org/public/countries/IN/profile/preview>.

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