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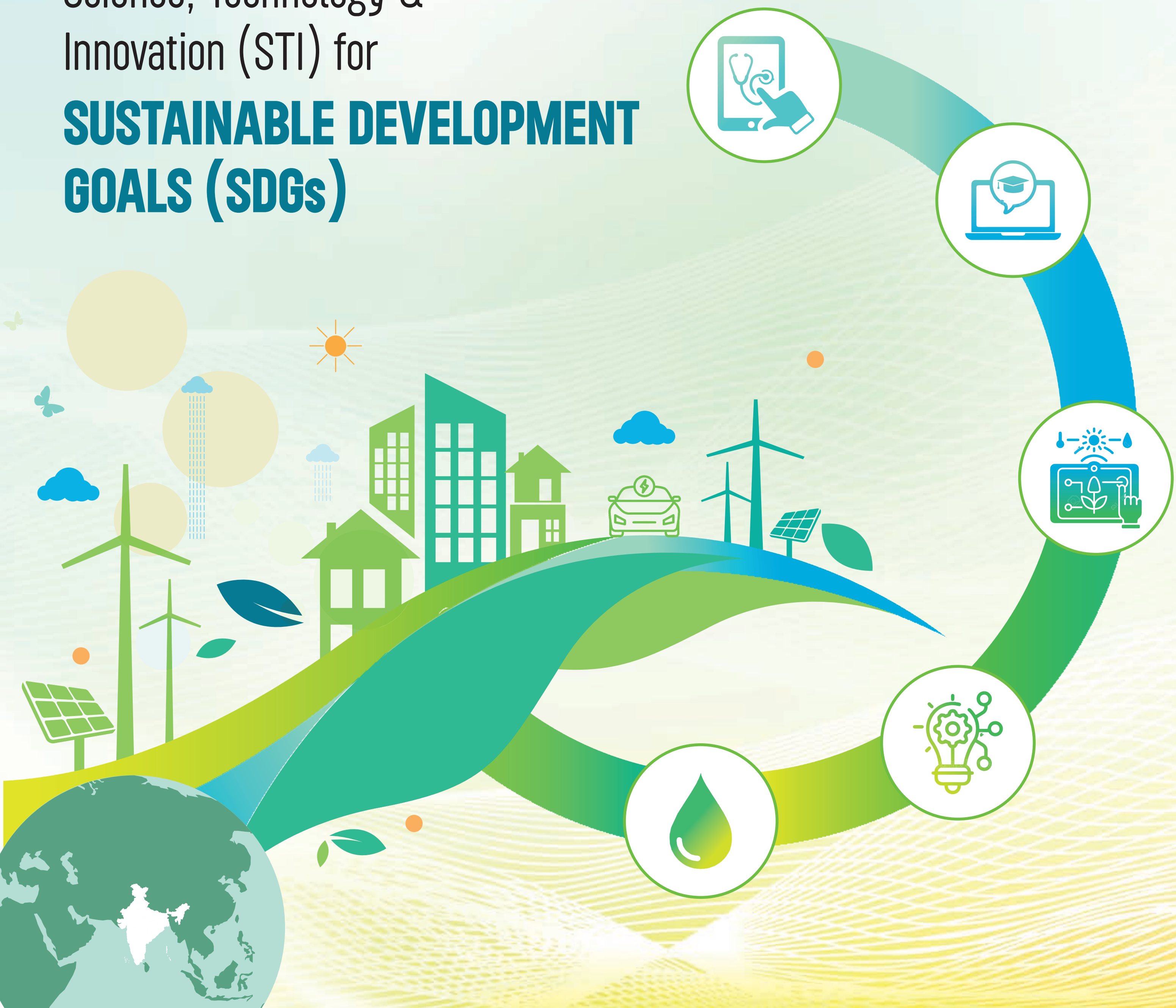
Science, Technology &
Innovation (STI) for

SUSTAINABLE DEVELOPMENT GOALS (SDGs)



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Foreword

Dr Parvinder Maini

Scientific Secretary, Office of PSA

The concept of sustainable development has transcended from mere policy objective to being the key pillar in India's vision for 'Viksit Bharat' by 2047. This transition to a sustainable ecosystem is, now more than ever, facilitated by Science, Technology and Innovation (STI). Evident from the country's trajectory and its ambitions, Sustainable Development for India is not just about environmental preservation; it is an existential imperative that touches upon every facet of life, including quality of living, bridging disparities, fulfilment of the individual aspirations, and the country's pursuit of global leadership. It is about placing India on an upward direction when it comes to human development imperatives.

To achieve this, we must navigate the complex energy trilemma, the simultaneous pursuit of energy security, affordability, and environmental sustainability. This dual mandate requires us to achieve what many consider to be contradictory — rapid economic growth to elevate our citizens' lives and equally rapid decarbonisation to meet our global responsibilities.

India is marching towards a secure and sustainable energy ecosystem through its commitment as well as targeted implementation efforts. A testament to this progress is the achievement of 50% non-fossil fuel installed capacity in 2025, meeting our national target five years ahead of the 2030 deadline. This Solar Surge, which has seen our solar capacity expand forty-fold over the last decade, is driven by flagship programs like PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan), which empowers our rural farmers, and the PM Surya Ghar Muft Bijli Yojana, which brings clean energy directly into ten million homes. These are not just infrastructure projects; they are social interventions that use technology to democratise energy and foster behavioural shifts toward sustainability.

The Office of the Principal Scientific Adviser (OPSA) plays a vital role in integrating science, sustainability, and governance, ensuring that scientific progress is embedded within the machinery of the state. Through the Prime Minister's Science, Technology, and Innovation Advisory Council (PM-STIAC), we appraise emerging scientific domains and develop futuristic roadmaps that guide our national missions. Our role is to provide pragmatic, objective advice that translates India's scientific potential into tangible outcomes. Whether it is through the conceptualisation of the National Green Hydrogen Mission, the strategic Research & Development (R&D) clusters, the MAHA-EV Mission, or the international engagements like India-EU TTC, the Office is building a science-policy interface that is grounded in the realities of implementation and public need.

We are reimagining logistics through Zero-Emission Trucking corridors, investigating the potential of Small Modular Reactors (SMRs) to augment our clean energy mix, and pioneering a roadmap for Carbon Capture, Utilisation, and Storage (CCUS). **Reinforcing this commitment, the Union Budget 2026-27 has allocated ₹20,000 crore over five years to advance CCUS technologies across five key sectors: Chemicals, Power, Steel, Cement, and Refineries.** The CCUS programme is critical for capturing and reusing carbon dioxide before it enters the atmosphere.

However, it must also be underlined that while there is a lot of talk about achieving the Sustainable Development Goals (SDGs) by 2030, the year is only a milestone, not the destination. Our vision must look Beyond 2030, towards the horizon of 2070, when India aims to reach net-zero emissions. The journey beyond this decade will be significantly more challenging, as it requires us to solve the challenges faced by hard-to-abate sectors like steel, cement, and long-haul transport, where simple electrification is not enough. Here, the role of STI becomes even more critical. We are pioneering a roadmap for Carbon Capture, Utilisation, and Storage (CCUS) and investigating the potential of Small Modular Reactors (SMRs) to augment our clean energy mix. We are also reimagining our logistics through Zero-Emission Trucking corridors, recognising that the backbone of our economy must also become the backbone of our climate resilience.

To enrich the ongoing discourse, this edition of Vigyan Dhara examines how STI is being deployed, and how it can be leveraged more effectively to advance Sustainable Development Goal 7 (Affordable and Clean Energy) and Sustainable Development Goal 13 (Climate Action), with the aim of building a future that is not only prosperous but fundamentally resilient. The focus in this issue is sharpened on the two mentioned goals that are the twin engines of our transition and cannot be approached in silos. This edition of Vigyan Dhara also celebrates the crucial players in the ecosystem, our startups and innovators who are turning scientific discovery into impactful ventures. We see biotechnology startups like String Bio utilising gas fermentation to turn methane, a potent greenhouse gas, into sustainable protein. We see space-tech pioneers like GalaxEye preparing to launch multi-sensor satellites that will provide the granular environmental data needed for precision agriculture and disaster management. And we see AI-driven platforms like Ambee providing the hyperlocal environmental intelligence that allows us to anticipate and act with precision. This is the 'Vigyan Dhara', the flow of science, that will fuel our future.

The increasing global temperatures symbolise a major uncertainty in our shared future, and the sole way to navigate this uncertainty is by persistently striving for scientific excellence and cooperative innovation. India's approach to STI-driven advancement is increasingly becoming a beacon for the Global South, demonstrating that a country can develop and become more sustainable at the same time.

The path after 2030 will necessitate asking tougher questions, nurturing stronger collaborations between academia and industry, and preserving our resilience in response to emerging global challenges. The scientific groundwork we are establishing today will guarantee that India not only fulfils its obligations but also rises as a worldwide leader in the sustainable age. Let us keep utilising the strength of science and innovation to ensure a more sustainable, cleaner, and thriving future for everyone.

Ayushee Chaudhary
Former
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Harnessing the Future: STI as the Bedrock for Sustainable Development

01

Image Credits: AI Generated

The pursuit of development has always been closely linked to scientific progress. From improvements in agriculture and health to advances in energy and infrastructure, science has enabled societies to grow and prosper. However, the scale and nature of today's global challenges, particularly climate change and energy security, demand a critical analysis of how development is planned and delivered.

In 2015, the international community collectively acknowledged this challenge by adopting the 2030 Agenda for Sustainable Development, anchored in the 17 Sustainable Development Goals (SDGs). These goals recognise that economic growth, social inclusion, and environmental protection must progress together. With the rising fluctuations in temperatures and climate across the world, SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) become especially significant with the interconnectedness of energy systems and climate outcomes.

As the global community navigates the critical midpoint of the 2030 Agenda for Sustainable Development, the imperative to accelerate progress has reached a decisive juncture. The United Nations (UN) SDGs represent more than a collective ambition; they constitute a rigorous, evidence-based framework designed to ensure planetary health and human prosperity. However, the UN SDG Report 2024 indicates that only 17% of SDG targets are currently on track, with progress on nearly half being classified as "minimal or moderate." In this high-stakes landscape, Science, Technology, and Innovation (STI) are a key engine for action, helping to reshape our global path and turn policy ambition into real results by using existing knowledge and infrastructure.

Image Credits: AI Generated

STI for the SDGs

STI serves as the foundational bedrock for the SDGs by providing the empirical data necessary for informed governance and the technical solutions required to scale interventions in complex environments. For a rapidly evolving economy like India, the synergy between scientific advancement and sustainable targets is not merely a choice but a strategic necessity. By leveraging frontier technologies, from green hydrogen and precision agriculture to satellite-based climate monitoring, nations can "leapfrog" traditional, carbon-intensive developmental paths. This approach allows for the decoupling of economic growth from environmental degradation, ensuring that the march toward prosperity does not come at the cost of the Earth's vital systems.

The recognition of STI as a "Means of Implementation" is formalied under SDG 17 (Partnerships for the Goals), yet its influence is inherently cross-cutting. The UN Technology Facilitation Mechanism (TFM) underscores that scientific knowledge and technological diffusion are the most potent tools available to combat poverty, disease, and the escalating climate crisis.

STI provides both the "how" and the "why" of sustainable development. It offers the analytical tools to understand the interdependencies between different goals and the innovative hardware to address them.

The 17 SDGs are designed as an "indivisible whole," acknowledging that progress in human development is frequently contingent on environmental stability and energy security. India has emerged as a global leader in integrating STI roadmaps with national development plans, serving as a pilot country for the UN Global Pilot Programme on STI for SDGs Roadmaps.

According to the NITI Aayog SDG India Index 2023-24, the country's composite score has improved to 71, up from 66 in 2020-21. This growth is largely attributed to a robust focus on technology-led social delivery and a mission-mode approach to infrastructure.

The following table, derived from the NITI Aayog SDG India Index 2023-24 and the Ministry of Statistics and Programme Implementation (MoSPI) National Indicator Framework, highlights the measurable impact of technology-led interventions.

Goal	Key Indicator	National Target(in %)	Latest Status (2024)
SDG 7	Percentage of households electrified	100	~100
	Percentage of LPG+PNG connections against total households	100	96.35
SDG 13	Disaster Readiness Score (Notre Dame Global Adaptation Initiative (ND-GAIN) Index)	1	0.394
	Industries complying with environmental standards	100	94.86
	Electricity generation from renewable energy	50	43.28

SDG 7: Affordable and Clean Energy

Energy serves as the "golden thread" connecting every aspect of modern life, yet the challenge of universal access remains a global hurdle. According to the 'Tracking SDG 7: The Energy Progress Report 2024,' nearly 685 million people worldwide still lack basic electricity access, necessitating an energy transition that is both equitable and technologically sound. To address this, SDG 7 aims to ensure access to affordable, reliable, sustainable, and modern energy for all. In the Indian context, this goal has achieved "front-runner" status with a remarkable score of 96, driven primarily by Science, Technology, and Innovation. As discussed at the World Economic Forum (WEF) 2026, India is leveraging Digital Public Infrastructure (DPI) for energy by utilising AI and IoT to create smart grids. These grids are essential for managing the variable nature of renewable energy, thereby reducing transmission losses and enhancing overall reliability. Furthermore, the National Green Hydrogen Mission represents a peak STI intervention, harnessing advanced electrolysis and storage technologies to transform India into a global hub for clean fuel production.

SDG 13: Climate Action

The urgency of SDG 13, which calls for immediate action to combat climate change and its impacts, cannot be overstated, as climate change represents a systemic risk to all developmental gains. The WEF Global Risks Report 2025 identifies extreme weather events as one of the most severe threat to global stability over the next decade. The NITI Aayog 2023-24 report highlights a significant leap in India's climate action score, largely because STI provides the dual tools of mitigation and adaptation. India’s disaster preparedness and risk management capabilities have been significantly strengthened through the integration of space-based observations and technologies. Under the Indian Space Research Organisation’s (ISRO) Disaster Management Support Programme (DMSP), satellites provide near-real-time remote sensing data that enhances hazard monitoring, early warning, and decision-making for disasters such as cyclones, floods, landslides, and forest fires. These space-based inputs support national and state disaster management authorities with actionable information before, during, and after events, improving preparedness and response planning. Simultaneously, the UJALA scheme for LED distribution serves as a landmark example of how standardizing and scaling a specific technological innovation can result in massive, measurable carbon sequestration and enhanced energy efficiency across the nation.

Strengthening the STI Ecosystem

Achieving the 2030 targets requires a fundamental shift from isolated innovations toward a systemic STI ecosystem. The UN STI Forum has warned that the concentration of scientific capacity in only a few nations threatens the universal nature of the SDGs, making technology transfer and capacity building vital to closing the digital and scientific divide. Moreover, transitioning to clean energy requires massive capital investments; therefore, STI must be supported by "blended finance" models to successfully move high-potential technologies from the laboratory to the commercial market. Finally, the success of these endeavors depends on mission-oriented governance, where STI roadmaps are directly aligned with specific SDG indicators. This alignment ensures that every unit of investment in Research and Development contributes to a measurable and impactful developmental outcome for the planet.

For instance, the practical application of STI is well demonstrated through targeted government initiatives like the PM-KUSUM scheme, which solarises the agricultural sector. By drawing on solar PV technology to power irrigation, this initiative simultaneously addresses SDG 7 by providing clean energy and SDG 13 by reducing the carbon footprint of food production. Furthermore, a UNECE case study on the enforcement of solar standards in Tanzania highlights that STI extends beyond new inventions to include the development of rigorous quality and regulatory standards that ensure sustainable and reliable technology deployment. By creating solar modules that operate efficiently in high-heat desert environments, innovators ensure that renewable infrastructure remains durable and cost-effective. A 2025 'World Economic Forum report, From Paradox to Progress: A Net-Positive AI Energy Framework,' outlines how AI can be strategically designed and deployed to optimise energy use across industrial and energy systems, enabling AI's energy and emission benefits to outweigh its own energy footprint and support net-zero ambitions. The report underlines that intentional design, coordinated governance, and international collaboration are essential to ensure that AI contributes meaningfully to energy efficiency and decarbonisation at scale.

The indicators from the NITI Aayog 2023-24 report serve as evidence that when STI is placed at the heart of policy, rapid progress is not just possible—it is inevitable. However, the journey to 2030 requires us to accelerate the pace of discovery and deepen international collaboration to ensure that no nation is left behind in the green revolution.

The transition to a sustainable world is fundamentally a scientific challenge and an unparalleled innovative opportunity. The synergy between SDG 7 and SDG 13 provides a blueprint for this global transformation. By harnessing the power of STI, we are not merely mitigating crises; we are actively designing a future that is resilient, equitable, and sustainable for generations to come.

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India's Measures for SDG 7 & SDG 13

SDG 7

Affordable and Clean Energy

SDG 7 aims to ensure that everyone has access to affordable, reliable, and environmentally friendly energy. In this direction, India is continuously moving towards a sustainable and inclusive energy system by expanding renewable energy, promoting energy efficiency, and ensuring access to electricity across the country.

Universal Energy Access

- **Saubhagya Scheme:** Electrification of rural and urban households
- **Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY):** Strengthening rural power infrastructure
- **Integrated Power Development Scheme (IPDS):** Improving urban power distribution

Renewable Energy Expansion

- **Target:** 500 GW non-fossil capacity by 2030
- National Solar Mission
- Rooftop Solar Programme
- Ultra Mega Solar Parks
- Wind, Bio-energy, Small Hydro projects

National Green Hydrogen Mission

- **Target:** 5 million metric tonnes per year by 2030
- Focus on steel, fertilizers, refineries

Energy Efficiency

- Unnat Jyoti by Affordable LEDs for All (UJALA) LED Scheme
- Perform, Achieve and Trade (PAT) Scheme
- Star Labelling Programme
- Energy Conservation Building Code (ECBC)

Power Sector Reforms

- Ujwal DISCOM Assurance
- Yojana (UDAY) Scheme
- Smart meters
- Renewable Purchase Obligations

International Leadership

- International Solar Alliance (ISA)

SDG 13

Climate Action

SDG 13 calls for urgent action to tackle climate change and its impacts. In the Indian context, this means policies aligned with global climate commitments, national missions for mitigation and adaptation, low-carbon development pathways, and promoting sustainable lifestyles with citizen participation.

Global Commitments

- Paris Agreement
- 45% reduction in emissions intensity by 2030
- 50% non-fossil power capacity
- Net Zero target by 2070

National Action Plan on Climate Change (NAPCC)

- Eight national missions covering energy, water, agriculture, habitat, and ecosystems

Carbon Sink & Nature-Based Solutions

- Green India Mission
- **Target:** 2.5–3 billion tonnes CO_2 equivalent carbon sink
- **Carbon Capture, Utilisation and Storage (CCUS) Mission** - Industrial decarbonisation and net-zero targets by 2070

Low-Carbon Transport

- FAME I & II (Electric Vehicles)
- EV charging infrastructure
- Ethanol blending (E20)
- Metro and public transport

Urban Climate Action

- City Climate Action Plans
- Heat Action Plans
- Atal Mission for Rejuvenation and Urban Transformation (AMRUT) Mission

Climate Adaptation & Disaster Resilience

- Early warning systems
- Climate-resilient agriculture
- National Disaster Management Authority (NDMA) initiatives

Carbon Markets & Policy

- Indian Carbon Market
- Energy Conservation Amendment Act, 2022
- Green bonds

Behavioural Change

- Lifestyle for Environment (LiFE) Movement
- Climate education and awareness

SDG 7 & SDG 13

Together, SDG 7 and SDG 13 reinforce India's transition to clean energy while driving climate mitigation and long-term sustainability.

Clean energy reduces emissions

Energy efficiency lowers demand

EVs and green hydrogen cut fossil fuel use

Nidhi Aggarwal
Former Junior Policy Fellow, PAIU-OPSA

Decarbonising India's Hard-to-Abate Sectors: Challenges, Socio-economic Impacts, and the Role of Industry–Academia Collaboration

Image Credits: Licensed stock visuals.

02

Climate change stands as one of the most pressing challenges facing humanity, demanding urgent and coordinated action across all sectors of the economy. While the global transition towards clean energy has gained momentum, several sectors remain particularly difficult to decarbonise. These are commonly referred to as "hard-to-abate" sectors. Understanding their nature, challenges, and socio-economic implications is essential for India's pathway towards achieving its net-zero ambitions and meeting the Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

Understanding **Hard-to-Abate Sectors**

Hard-to-abate sectors are industries and economic activities where achieving net-zero emissions is constrained by high capital costs, technological limitations, or a combination of both. These sectors form the backbone of modern economies, and their large scale, long asset lifetimes, and deep integration into supply chains make rapid transitions particularly challenging. Consequently, aggressive decarbonisation measures can carry significant socio-economic implications.

Globally, hard-to-abate sectors are most often discussed in the context of SDG 7, focusing on energy transition. However, in India's context, certain sectors also emerge as hard-to-abate when viewed through the lens of SDG 13, given their critical role in climate action and emissions reduction.

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Hard-to-Abate Sectors in the Context of SDG 7: Energy Transition

A significant concentration of India's fossil fuel resources is locked into hard-to-abate industries, with natural gas being most heavily utilized, followed by substantial portions of the country's coal and oil reserves. Research from MIT projects that emissions from these sectors could grow by 2.6 times between 2020 and 2050 if left unaddressed. This trajectory underscores the urgency for targeted policy interventions, reflected in India's Union Budget 2024–25 proposal to develop a dedicated roadmap for hard-to-abate sectors with a focus on energy efficiency.

For India, five sectors are particularly significant in this context:

Steel Sector

The steel industry accounts for nearly 10–12% of India's CO_2 emissions, and steel capacity is projected to double by 2030. Steel remains indispensable for infrastructure and industrial development, and production volumes cannot be easily curtailed. Moreover, the sector's high energy requirements cannot be met by renewable sources alone in the near term. According to a Council on Energy, Environment and Water (CEEW) report, decarbonising India's existing steel capacity would require an additional USD 283 billion in capital expenditure and USD 8.8 billion annually in operating costs. In response, the government's 'Greening the Steel Sector in India: Roadmap and Action Plan' aims to position India as a global leader in green steel through clean energy adoption, advanced technologies, and circular economy practices.

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Cement Sector

Nearly 50% of greenhouse gas emissions from cement manufacturing arise from the chemical process of limestone decomposition, making fuel switching alone insufficient (Roadmap for Cement Sector Decarbonisation, NITI Aayog 2026). Cement remains essential for construction and infrastructure, and process emissions present a structural challenge to decarbonisation.

Source: economictimes.indiatimes

Power Sector

According to IMF 2023 report, the power sector contributes around 37% of India's total emissions and over 60% of CO_2 emissions. As of October 2025, fossil fuels accounted for approximately 49% of installed power capacity, lower than non-fossil sources for the first time, as stated by a PIB report. Despite this shift, India contributed 31% of global energy-sector emissions growth over the decade to 2024, increasing to 37% in the past five years. Rising electricity demand from industry and households, combined with historical reliance on coal, continues to drive emissions growth.

Source: economictimes.indiatimes

Road Transportation

Road transport, particularly heavy-duty trucking, accounts for about 12% of India's energy-related CO_2 emissions. According to 'Towards Decarbonising Transport 2023 - A Stocktake on Sectoral Ambition in the G20', transport emissions are projected to rise by 65% by 2030 and 197% by 2050 compared to 2020 levels. With road transport handling 87% of passenger movement and 60% of freight traffic, as per MoRTH data, abrupt transitions away from this mode are not feasible given India's economic growth trajectory.

Source: economictimes.indiatimes

Micro, Small and Medium Enterprises (MSMEs)

MSMEs consume nearly 25% of industrial energy demand and emit around 110 million tonnes of CO_2 equivalent annually, according to TERI 2022 report. Energy consumption in this sector is projected to increase by almost 50% by 2030. However, most MSMEs operate as small or cottage industries, making investments in capital-intensive energy-efficient technologies particularly challenging.

Hard-to-Abate Sectors in the Context of SDG 13: **Climate Action**

From a climate action perspective, hard-to-abate sectors can also be defined as those that are difficult to address but critical to achieving India's climate commitments. An analysis of India's Nationally Determined Contributions (NDCs) under the Paris Agreement highlights two such sectors.

Agriculture, Particularly Animal Husbandry

India ranks first globally in methane emissions from the agricultural sector as revealed by The Global Methane Status Report 2025, with methane being responsible for approximately 23% of global warming caused by greenhouse gases. Studies show that of agricultural methane emissions, 63% originate from livestock and nearly 11% from rice cultivation. India has the world's largest cattle population and is the second-largest rice producer globally. At the same time, agriculture remains the country's largest employer, with around 85% of farmers classified as small and marginal. Recognising the livelihood risks, the Ministry of Environment, Forest and Climate Change (MoEFCC) cited concerns for small farmers as a key reason for India not signing the Global Methane Pledge. As a result, agriculture remains a sector where emissions reduction must be carefully balanced with socio-economic realities.

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Tourism

Tourism presents a complex challenge. India ranks 14th globally in international tourism receipts, with estimated foreign exchange earnings being USD 16.928 billion in 2022. Tourism supports extensive forward and backward linkages and is a critical economic driver for several regions, such as Kashmir's winter tourism, the Rann Utsav in Gujarat's Kutch region, and emerging village tourism models that supplement rural incomes while preserving cultural heritage.

However, increasing tourist inflows place mounting pressure on natural ecosystems through higher demand for power, water, infrastructure, and waste management. Climate change further threatens tourism itself, with melting glaciers and reduced snow cover in Himalayan destinations, rising sea levels in coastal regions, and heatwaves reducing the attractiveness of cities like Jaipur. Aligning tourism growth with sustainability objectives is therefore essential for reducing emissions while safeguarding livelihoods. Global climate law and policy analysis also underlined that India urgently needs to align with sustainability goals to lower its carbon footprint and promote eco-friendly tourism practices.

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Beyond Hard-to-Abate:
Identifying Critical Sectors for Climate Resilience

Alongside hard-to-abate sectors lies a category of critical sectors, those that are disproportionately impacted by climate change and therefore serve as key indicators for achieving SDG 13.

While hard-to-abate sectors contribute significantly to emissions, critical sectors reflect the consequences of climate change.

For India, these include:

Climate-Induced Disaster Management

that has become increasingly complex as adaptation and mitigation may not be enough to manage climate change impacts. India is susceptible to wide-scale climate change-related risks due to its various climate zones, topography, and ecosystems. The Global Climate Risk Index 2021 ranks India as the 7th most affected nation by climate change. With 80% of India's population living in districts highly vulnerable to extreme weather events, enhanced policy efforts are required to protect vulnerable populations and property (Climate Vulnerability Index, CEEW).

Urban Green Cover

that has the potential to address the Urban Heat Island Effect and air pollution in rapidly urbanising India. By 2050, it is projected that India will have added 416 million urban dwellers (UN DESA - World Urbanization Prospects, The 2018 Revision). The increasing urban population has led to shrinking green spaces, and unplanned urbanisation worsens the situation. Research shows that strategically placed trees can reduce urban air temperatures by up to 2-8°C, significantly lowering cooling costs and improving outdoor comfort.

Climate-Related Health Impacts

manifest through increasing incidences of communicable and non-communicable diseases. Climate-sensitive infectious diseases (CSIDs) are influenced by changes and variations in climate and weather. Communities with limited healthcare access, inadequate housing, and poor sanitation are more vulnerable. As highlighted by the World Bank, India is particularly vulnerable due to its geographical location in the sub-tropical region with a long coastline, high population density, lack of hygiene literacy, and socio-economic factors.

Socio-economic Implications Across Sectors

Addressing hard-to-abate and critical sectors has far-reaching socio-economic implications. Agriculture sustains millions of small and marginal farmers, while tourism supports regional economies and cultural livelihoods. While the industrial sector, consuming 56% of India's total energy demand, employs millions (Energy Statistics 2020, MoSPI); steel and cement form the foundation of infrastructure development, which are essential for a growing economy. The power sector's expansion is closely tied to economic growth and improved quality of life, while MSMEs play a vital role in employment generation, rural development, and women's economic empowerment.

Climate-induced disasters further expose vulnerable populations to disease, displacement, crop loss, and poverty, threatening biodiversity and food security. The interconnected nature of these sectors means that disruptions in one often cascade across others, amplifying systemic risks.

The Role of Industry-Academia Partnerships

Industry-academia partnerships emerge as catalysts supporting hard-to-abate and critical sectors, serving as the engine of innovation that bridges the gap between theoretical research and practical, market-ready solutions. This collaboration is particularly vital for India's journey toward SDG 7 and SDG 13. India's Global Innovation Index ranking (38th position out of 139 countries in 2025) is improving consistently.

The Role of Startups as Bridges:

Startups serve as a critical bridge between industry and academia, providing valuable insights into the industry ecosystem while driving research and innovation. In the steel sector, industry players support startups and collaborate with IITs for innovation support. Tata Power's partnerships with startups for energy efficiency solutions exemplify how established industry players can nurture innovative ventures. Startups like HankerLabs develop embedded electronics hardware solutions for disaster management.

Technology Transfer Through Government Facilitation:

Bridging the gap between laboratory research and marketable solutions remains one of the most significant challenges in innovation. Government initiatives create frameworks that accelerate this transfer. The Steel Research and Technology Mission by the Ministry of Steel promotes innovation and research, facilitating industry-academia partnerships to bridge technology gaps. The Ministry of Power's National Smart Grid Mission strengthens this ecosystem by fostering collaboration between industry, academia, and research institutions. These initiatives ensure that scientific discoveries don't remain confined to academic papers but reach real-world applications.

Policy and Strategy Alignment Through Funding:

Collaborative research helps align academic inquiry with national and global sustainability goals through strategic funding mechanisms. Initiatives such as the Clean Energy International Incubation Centre (CEIIC) and Startup India provide funding, mentorship, and resources to new ventures in clean energy. The National Clean Energy Fund (NCEF) cultivates robust tripartite partnerships to accelerate innovation in the power sector. Government-funded research organisations like the National Council for Applied Economic Research (NCAER) and the Bureau of Energy Efficiency (BEE) collaborate with academia to identify and address energy efficiency challenges faced by SMEs. When industry provides market insights through these funded partnerships and academia offers technical expertise, the resulting innovations directly address policy priorities.

Direct Industry Support Creating Skill Development:

Research and innovation in IITs on smart grids, solar photovoltaics, and energy storage receive support from key industry players in the power sector. This direct industry investment in academic research ensures that research priorities align with practical needs while creating a workforce equipped with skills in emerging clean technologies. Students gain exposure to industry problems while industries benefit from fresh perspectives and cutting-edge knowledge from academia.

Innovative Solutions from Academic Institutions:

IITs, NITs, and state universities conduct research focused on energy-efficient technologies suitable for various sectors. IIT Kharagpur has developed low-cost energy auditing tools for SMEs, while NIT Trichy has researched energy-efficient production processes for SME-intensive sectors. IIT Madras has researched alternative cement types with lower carbon footprints, while NIT Rourkela has focused on improving the energy efficiency of cement kilns. IIT Delhi has developed electric buses with advanced battery management systems and charging infrastructure specifically designed for Indian conditions. These innovations demonstrate how academic research can directly address industry challenges.

ICAR's partnerships with institutions like BAIF Development Research Foundation for producing Harit Dhara (the anti-methanogenic feed supplement) demonstrate how agricultural research institutions can collaborate with development organisations to deploy innovations at scale. The collaboration between the Odisha government and the private sector in developing Early Warning Systems for Cyclones showcases how partnerships can create effective disaster management solutions that save lives.

Sustainable Environment and Ecological Development Society (SEEDS) works in partnership with vulnerable communities, combining traditional knowledge with innovative approaches to build climate resilience.

Knowledge networks established through initiatives like the National Mission on Strategic Knowledge for Climate Change facilitate data sharing and exchange across institutions. Krishi Vigyan Kendras (farm science centres) conduct capacity-building programs across the country, translating academic research into practical guidance for farmers - a direct application of research to field-level challenges.

The transition of India's hard-to-abate and critical sectors requires systemic alignment between scientific innovation and socio-economic resilience. This evolution will be shaped by indigenous technological solutions—ranging from green hydrogen and circular industrial processes to biotechnological interventions in agriculture—supported by robust digital infrastructure for monitoring and risk management. By institutionalising collaborative ecosystems involving government, industry, and academia, India is laying the foundation for a future where climate action and economic development reinforce each other rather than compete.

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Thoughts
from the
Leaders

As the global community accelerates its pursuit of SDG 7 and SDG 13, India stands at a critical juncture where innovation must meet scale. Achieving a net-zero economy requires more than a singular focus on solar and wind; it demands a sophisticated technological mix that addresses industrial emissions, fuel versatility, and grid reliability. In this special feature, we present perspectives of some prominent experts from the sector who are at the helm of India's scientific and energy policy. From the necessity of Carbon Capture to the potential of Green Hydrogen and the steadfast reliability of Nuclear Energy, these insights outline the multifaceted STI (Science, Technology, and Innovation) framework essential for India’s long-term energy security and climate resilience.

03

CCUS: A Cornerstone of India's Net-Zero Transition

Dr V. K. Saraswat
Member (S&T), NITI Aayog

Carbon Capture, Utilisation, and Storage (CCUS) offers India a scientifically robust pathway to decarbonise its economy while sustaining long-term growth. India emits roughly 4 $GtCO_2e$ (Gigatonnes of Carbon Dioxide Equivalent) annually, representing 8% of global emissions. Yet, its historical contribution is limited to just 3–4% of cumulative emissions since the Industrial Revolution, and per-capita emissions remain low at 2–3 tCO_2e, far below the global average. The decarbonisation challenge is concentrated in power and heavy industry. Coal-based power contributes ~39%, while steel and cement together add nearly 30%. These sectors face technological and economic constraints where renewable energy alone cannot yet deliver deep emissions reductions at scale.

Here, CCUS becomes indispensable. Mature technologies such as amine-based post-combustion capture, oxy-fuel cement kilns, and blast-furnace gas recycling can abate over 90% of emissions at major point sources. India's 2070 net-zero ambition is further strengthened by the DST's 2025 R&D Roadmap, which prioritises membrane separation and chemical looping technologies to push capture costs below $30 per tonne.

India also possesses substantial geological storage potential, around 750 MTPA across the Cambay and Krishna-Godavari basins. These formations can securely store CO_2 for millennia while supporting enhanced oil recovery and new utilisation pathways. Scaling pilot projects such as ONGC's Hazira initiative (bio-fixation) into industrial CCUS hubs, supported by carbon markets, carbon credit mechanisms, carbon taxation, and production-linked incentives, positions CCUS as a cornerstone of a low-carbon, resilient Viksit Bharat.

The Critical Role of Nuclear Energy as an Alternative to Complement Renewables in Ensuring India's Long-term Energy Security

Dr Ajit Kumar Mohanty,
Secretary, Department of Atomic Energy (DAE)

Our choices today will define the legacy that we leave for future generations. While India is committed to Net Zero emissions by 2070, we also bear the responsibility of lifting millions out of poverty. This dual challenge requires an energy transition that is not just clean, but robust and reliable to cater to Viksit Bharat.

Renewable energy sources are shaping the clean energy transition and India is already the world's third-largest producer. However, we know that the renewables alone cannot meet our needs for stable, round-the-clock electricity in the coming years which will see large scale expansion in a variety of domains in general and the energy-hungry data centres that will power the digital world in particular. The electricity demand for these AI based data centres will be massive for running their servers and cooling the systems, resulting in huge carbon footprints. This necessitates a strategic pivot to nuclear energy in our energy mix, which can offer the stability of thermal power with minimal carbon footprints.

India's nuclear energy journey has been marked by scientific achievement and global responsibility. We have operated reactors safely for over five and half decades, expanded a robust domestic ecosystem and maintained global leadership in nuclear technology.

Our approach is deeply rooted in the Indian ethos of frugality and resource optimization. The three-stage Indian nuclear power programme envisioned by Dr Bhabha was based on precisely these values, driven by a strong pursuit of self-reliance. It is based on a closed fuel cycle and optimal utilisation of India's nuclear resources of modest uranium and abundant thorium.

Currently, India has 8,780 MW of installed nuclear power capacity and is producing over 56 Billion Units of clean electricity annually, avoiding about 49 million tons of CO_2 emissions. Continuous, safe and stable operation of our Nuclear Power Plants (NPPs) for more than a year has been recorded 53 times so far which is a major enabling factor towards inculcating societal acceptability of nuclear power.

To systematically augment the availability of nuclear power, we are in the process of adding another 13,600 MW by 2032 and increase the total installed nuclear power capacity to 22.8GW. Our ultimate target is 100 GW of nuclear capacity by 2047, the Amrit Kaal commemorating the centenary of our independence.

Transcending electricity generation through nuclear energy will be the key to decarbonizing "hard-to-abate" heavy industries like steel, cement, and petrochemicals by providing high-temperature industrial heat and facilitating clean hydrogen production.

Towards accelerating this transformation, we are investing ₹20,000 crore in the Research & Development of advanced Small Modular Reactors (SMRs) for flexible deployment, to enhance energy accessibility in hitherto unexplored regions and terrains. Furthermore, the enactment of the SHANTI Act, 2025 establishes a legislative framework to facilitate private sector participation ensuring affordability for the envisaged large scale extension of our nuclear power program.

Thus, a systematic and dedicated effort is in progress towards achieving high degrees of the 4As, namely Acceptability, Availability, Accessibility, and Affordability, which are the key dimensions that determine the level of energy security of the country.

This comprehensive approach ensures that our march towards a high level of energy security is safe, scalable, and inclusive while maintaining energy sovereignty.

Strategic Vision for Green Hydrogen

Positioning India as a Global Leader

Shri Santosh Kumar Sarangi,
Secretary, Ministry of New and Renewable Energy (MNRE)

India's National Green Hydrogen Mission, launched in January 2023 with an outlay of ₹19,744 crore, embodies a bold strategic vision to establish the country as a global hub for production, utilisation, and export of green hydrogen and its derivatives. Targeting at least 5 MMT annual production capacity by 2030, and supported by 125 GW of renewable energy addition, the Mission is driving decarbonisation of hard-to-abate sectors, reducing import dependence, and abating 50 MMT of CO_2 emissions annually, while attracting over ₹8 lakh crore in investments and creating more than 6 lakh jobs.

Key enablers include the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme, which has awarded incentives for 3 GW annual electrolyser manufacturing capacity and over 850,000 tonnes of green hydrogen production. Pilot projects in steel, mobility, and shipping are demonstrating viability, complemented by Hydrogen Valley & Hubs, R&D investments, skill development for thousands of trainees, and the notified Green Hydrogen Certification Scheme ensuring credibility.

Emphasising technology neutrality, innovation across pathways, and inclusive growth, the Mission equips young researchers, engineers, and entrepreneurs to lead in this transformative sector. By leveraging low-cost renewables and robust policies, India is poised to supply affordable clean fuels globally, forging a sustainable, self-reliant energy future.

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Electricity Security for India to become a Developed Country by 2047

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04

Reliable electricity security is the cornerstone of India's economic transformation and sustainable development. Consequently, Sustainable Development Goal (SDG) 7 seeks to ensure "affordable, reliable, sustainable, and modern energy for all." As of 2023, India ranked 130th in the United Nations' Human Development Index (HDI) with a score of 0.685, placing it in the 'medium HDI' category according to UNDP Human Development Report, 2025. While India is on track to reach 'high HDI' status within the next decade, our national ambition is to become a developed country by 2047. Realising this vision requires raising our HDI to 0.800, the current threshold for 'very high' human development, a feat that necessitates a robust and secure electrical infrastructure

Electricity is the core driver of modern economies and International Energy Agency's (IEA) 2025 projections indicate that electricity demand will continue to grow much faster than overall energy use in all future scenarios. To achieve an HDI of 0.800, data estimates that India's per-capita electricity consumption must exceed 5,100 kWh/year compared to the FY 2024-25 level of 1460 kWh. Therefore, a secure, reliable, and affordable electricity supply is becoming more important than ever.

India is the third largest electricity generator in the World. According to Central Electricity Authority (CEA) data, India's electricity generation (utilities and captive power plants) has increased at a Compounded Annual Growth Rate (CAGR) of 4.88 percent between FY 2014-15 and FY 2024-25. As of March 31, 2025, coal-based Thermal Power Plants (TPPs) and Variable Renewable Energy (VRE) sources like solar and wind power plants accounted for 48 percent (268 GW) and 32.6 percent (181 GW) of the All-India installed electricity generation capacity (557 GW), respectively. With a share of 32.6 percent in the country's installed electricity generating capacity, VRE sources generated only 13 percent (268 TWh) of the total electricity generation [2059 Terawatt hours (TWh)] in India during FY 2024-25 while TPPs contributed 74 percent [1519 TWh] of the electrical energy generated with a share of only 48 percent in the generation capacity. Analysis of CEA in 2025, indicates that 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 goals (Figure 1).

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Further, the limited flexibility (ramp-up and ramp-down of electricity generation) of TPPs is critical for the National Power Grid to integrate the intermittent electricity generation by solar and wind energy in India as well as the peak demand for electricity during the 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 2). As shown in Figure 2, the peak solar generation on this day was less than 65 GW, though the installed generation capacity of All-India grid-connected solar energy plants exceeded 105 GW in March 2025. Further, as shown in Figure 2, coal-fired TPPs contributed 170 – 176 GW of electricity on the all-time peak solar day to meet the electricity demand before sunrise and after sunset. The All-India peak demand for electricity which generally occurs after sunset (7 – 8 pm) cannot be substituted by VRE sources without extensive storage facilities that are still at an early stage of development in India. Therefore, TPPs are necessary to meet the baseload (steady demand during the entire 24 hours of the day) electricity demand in the country.

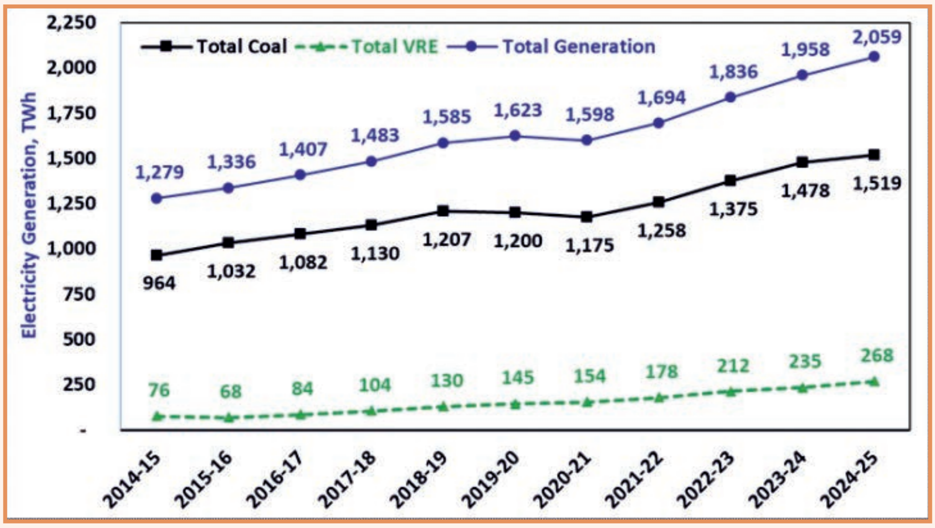

Figure 1. Growth of coal-based versus solar and wind (VRE) power generation in India (data: CEA, 2025)

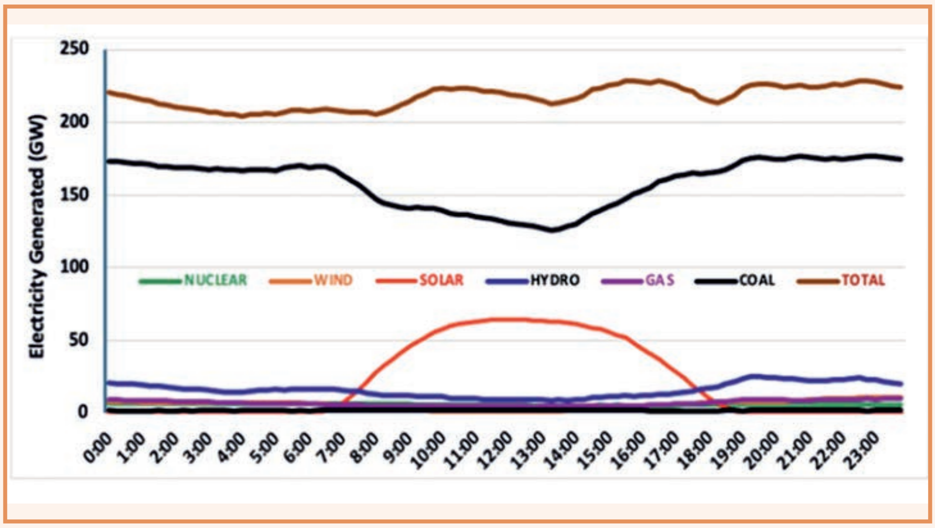

Figure 2. All-India source-wise generation recorded during the all-time high of solar generation on April 23, 2025 (data: Grid India, 2025)

Since coal is the only modern, domestic source of energy that the country has in adequate quantities, the Government of India (GOI) has raised the target for TPP capacity to 307 GW by the year 2034–35 to ensure the country's energy security and enable the country's development. This is an increase of 81 GW from the 226 GW of installed TPP capacity as on 30 November 2025. Even when the share of coal-based electricity in India's total generation mix reduces progressively when the share of electricity generated from non-fossil fuel sources (hydro, nuclear, solar, wind, battery storage, and pumped storage) increases to meet the long-term goal of Net Zero by 2070, the generation of coal-based electricity from TPPs will increase for the next 15-20 years before tapering down gradually after 2040.

Under these circumstances, the affordability of electricity generated by TPPs is important to enhance energy access and per capita electricity generation to achieve India's growth aspirations. At the same time, it is critical to address the environmental and climate impacts of thermal power generation based on scientific studies as explained in the following paragraphs.

In August 1990, the Central Pollution Control Board (CPCB) specified the minimum stack height of a TPP with a generation capacity exceeding 200 - 490 MW to be 220m while TPPs with capacities of 500 MW and above were mandated to have a minimum stack height of 275m. These limits were set based on atmospheric and pollution studies conducted by CPCB in 1984. Prior to December 7, 2015, there was no specific standard for Sulphur Dioxide (SO_2) emission from TPP stacks though CPCB had mandated limits for stack emissions of Particulate Matter (PM) pollution. Though the Ministry of Environment, Forest and Climate Change (MOEFCC) mandated the SO_2 stack emission norms in December 2015 and 537 TPPs (204 GW capacity) were identified for installation of Flue Gas Desulphurisers (FGDs); only 44 TPPs (22.6 GW) had commissioned FGDs till November 2015.

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In the meantime, CSIR-NEERI conducted a nationwide study in 2024 and found that the ambient SO_2 concentrations in India are generally compliant with the National Ambient Air Quality (NAAQ) standard of 80 g/m^3. This is due to the very low sulfur content of Indian coals (which fuels 94% of the electricity generated by TPPs) coupled with the TPP stack heights of 220 – 275m that ensures dispersion of SO_2 in India's tropical climate and the short lifespan of SO_2 in the atmosphere (Srikanth et al., 2024).

Particulate Matter (PM) pollution is the key concern related to air pollution from TPPs. After conducting real-world measurements in cities without TPPs as well as in cities with TPPs, with and without FGDs, scientists from the Centre for Atmospheric Sciences in IIT-Delhi (2024) concluded that, "installing FGD systems with an 87.5% SO_2 removal efficiency in all coal-based TPPs across India would reduce PM2.5 concentrations by up to 4.56% (2.89 µg/m^3) and PM10 concentrations by up to 3.21% (3.15 µg/m^3) across all surveyed cities and seasons." Therefore, eliminating all SO_2 emissions from TPPs would result in only a marginal improvement in PM levels in cities with diverse sources of air pollution, including transport.

In this context, OPSA initiated a research project at the National Institute of Advanced Studies (NIAS). NIAS presented key findings of all three independent, scientific studies (CSIR-NEER, IIT-Delhi, and NIAS) at two key stakeholder meetings convened by OPSA and MoEF&CC. The key common point in the scientific studies conducted by these independent research institutions is that fitment of FGDs in all TPPs in India is not necessary to comply with the NAAQ standards whose compliance is essential to safeguard public health. The studies conducted by NIAS and IIT-Delhi also indicate that the Installation of FGDs in TPPs impact global warming by increasing the specific coal consumption of TPPs and also removing coolant sulphate aerosols which mask global warming. FGDs also enhance freshwater consumption in inland TPPs at a time when water availability is a concern in many regions of India. Therefore, indiscriminate installation of FGDs on all TPPs (which predominantly use low-Sulphur Indian coal) to control SO_2 emissions from the TPP stacks will impact global warming as well as water stress in India with limited impact on

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PM pollution. The NIAS study also highlighted that indigenous High-efficiency Electrostatic Precipitators (ESPs) can be retrofitted in TPPs at a cost of 25% of that of FGDs with minimal shutdowns. Installation of such ESPs will reduce PM pollution from TPP stacks by 99.97% with no increase in CO_2 emissions or water consumption.

Based on average cost estimates for wet FGDs (Rs. 1.2 Crores per MW of installed capacity), the nationwide retrofitting of FGDs in all TPPs in India with a cumulative power generation capacity of 212 GW (as of May 2023) was estimated to cost Rs.2.54 Lakh Crores in capital expenditure. Capital expenditure in TPPs contribute to the fixed costs of electricity generation while the incremental coal, water, and limestone consumed to operate the FGDs increase the energy charges of TPPs. CEA (2025) estimated the average increase in levelized electricity tariff due to FGD installation to be 49 Paise/kWh.

It is against this background of scientific evidence and tariff impacts that the advisability of imposing SO_2 stack emission norms in all TPPs in the country was re-examined by GOI in 2024-25. On July 11, 2025, MoEF&CC issued a Gazette Notification on the category wise applicability of SO_2 emission standards in TPPs in India based on the aforesaid scientific studies and the analysis of ambient SO_2 concentrations across the country, including areas near TPPs. This notification applies the precautionary principle for controlling and abating air pollution in densely populated and other air pollution sensitive areas, while also emphasising on resource conservation by avoiding additional consumption of coal, water, and limestone to operate the FGDs. One of the policy goals was to avoid increasing CO_2 emissions from FGD operations and eliminate the incremental mining and transportation of coal and limestone required for operating freshwater FGDs.

This notification mandates control of SO_2 emissions from TPPs in all Category A TPPs located within 10 km of the boundaries of the National Capital Region or cities with million-plus population. The installation of FGDs in Category B TPPs located within 10 km of "Critically Polluted Areas" or "Non-attainment" cities would be decided based on the recommendations of an Expert Appraisal Committee (EAC) in MoEF&CC.

There are 131 cities in India which are either having million-plus population or are classified as Non-Attainment Cities. Therefore, the control of SO_2 emissions in TPPs falling within Category A or Category B will provide the greatest benefit in abatement of TPP pollution to the cities having the highest need for reducing PM pollution. On the contrary, exempting TPPs in Category C (other than Category A and Category B TPPs) does not impact public health since these TPPs must comply with the stack emission standards for PM pollution which were tightened significantly in 2017.

The strategic implementation of FGDs based on the scientific studies has strengthened India's energy security by avoiding extensive TPP shutdowns for retrofitting FGDs and avoiding the tariff hikes due to the indiscriminate installation of FGDs all over India. Based on a sound scientific approach and real-world studies in India, this policy has targeted the control of PM pollution from TPPs by deploying indigenously developed, low-cost high-efficiency ESPs in preference to FGDs based on imported technology. The timely implementation of this science-based mandate will safeguard public health while providing modern, reliable, and affordable electricity to all Indians and achieve India's development goals.

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Featured Interview

Clean Energy, Climate Action, and India's Global Leadership for SDGs 7 & 13

In an exclusive interview for Vigyan Dhara, Dr Ajay Mathur, Professor of Practice at the School of Public Policy, IIT Delhi, shares his perspectives on the role of Science, Technology and Innovation (STI) in advancing the Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). In a conversation with Ms. Ayushee Chaudhary, Dr Mathur reflects on India's progress towards the 2030 targets, drawing on his extensive experience including his tenure as Director General of the International Solar Alliance (ISA), The Energy and Resources Institute (TERI), the Bureau of Energy Efficiency, and as Interim Director of the Green Climate Fund. Selected excerpts from the interview are presented here, while the complete conversation can be accessed through the QR code provided.

Dr Ajay Mathur,
Professor of Practice at the School of Public Policy, IIT Delhi

05

Core Challenges for SDG 7 and 13

Ayushee: As India moves towards its net-zero goals, how do you see STI shaping the next generation of clean energy systems, particularly in support of SDG 7 and SDG 13?

Prof. Ajay Mathur: As far as SDG 13 and 7 are concerned, I see three key challenges. The first is the need for low-cost batteries or solar systems in general, but batteries in particular. The second is water management technologies. We use about 7 billion cubic meters of water in Indian agriculture every year - approximately one-third more than our agricultural land needs, indicating a potential to reduce this consumption by at least 20 to 25 percent. The third critical area, from both climate and energy perspective, is space cooling. As incomes rise, households increasingly adopt conditioners, and fans to begin with. Therefore, having efficient buildings, fans, and air conditioners is critical.

Ayushee: Given the challenge of achieving universal energy access while meeting climate goals, how can STI support practical strategies to help countries balance these objectives?

Prof. Ajay Mathur: I will answer through an example. One of the findings from 2023 was that in many African countries, where large-scale grid extension is being considered, it is often cheaper to set up solar mini-grids than to extend the grid, particularly when grid extension exceeds 10 kilometres, and in areas where electricity is not currently available. This highlights the need for appropriate technical and financial models, as well as innovations in how electricity is used to enhance incomes, for instance in improving grain milling. These must go hand in hand with efforts to reduce the costs of batteries and solar panels.

There is significant momentum today around joint procurement across countries. Individually, many countries have limited demand, which keeps prices high. Aggregating demand across neighbouring countries can help bring costs down. Some efforts are underway, but much more needs to be done.

Ayushee: You have often spoken about the challenge of providing last-mile energy access while simultaneously decarbonising. For a developing country, is there still a trade-off between energy equity and climate action?

Prof. Ajay Mathur: This is fundamentally a question of technological innovation. If you had asked me this three years ago, I would have said yes—there was a trade-off. Today, however, we are in a very different position. Solar power combined with batteries is now cheaper than fossil fuels and can be deployed effectively even in rural areas through solar mini-grids. This has transformed the equation. While solar costs have fallen by nearly 90 per cent since 2010, it is the dramatic reduction in battery prices that has truly broken this limit, enabling both energy access and decarbonisation simultaneously.

Technological Efficiencies and Scaling Solutions

Ayushee: Solar cells have emerged as one of the cheapest sources of electricity, but they are intermittent. As we look at the next decade, which energy storage technologies do you see becoming the standard for stabilising the Indian grid—pumped hydro, solid-state batteries, or others?

Prof. Ajay Mathur: The way I see it, over the past two years, we have reached a point where round-the-clock renewable electricity (solar plus wind plus storage) is available at prices competitive with new coal-based power. Pumped hydro, however, is highly site-specific. Wherever it is feasible, we should certainly use it. Batteries, on the other hand, are far more versatile and can be deployed almost everywhere, across cities, dense population centres, and solar mini-grids located in agricultural regions. In my view, the future will be determined by a cost competition between these two technologies — pumped hydro constrained by the availability of suitable sites, and batteries constrained by the duration for which they can meet demand, as grid requirements evolve.

Ayushee: How do we address hard-to-abate industrial sectors such as steel and cement? Do you see green hydrogen or Carbon Capture and Storage (CCS) becoming commercially viable globally, or particularly for Indian industry, by 2030 or before 2040?

Prof. Ajay Mathur: At current costs, green hydrogen, even at around USD 4.5 per kg, is more economical than carbon capture and storage, which costs USD 50 or more per tonne of CO_2 sequestered. While future technological developments will matter, I see much greater progress in green hydrogen than in CCS. In my view, green hydrogen is likely to prevail because prices are declining, whereas CCS depends heavily on suitable geological storage. If storage sites are distant, the cost of transporting CO_2 becomes a major challenge.

Ayushee: Many promising clean energy and climate technologies struggle to move from pilot stages to scale. What do you see as the most binding systemic barriers, globally, and particularly in India - whether regulatory, financial, institutional, or social? And which reforms would you prioritise to unlock large-scale deployment?

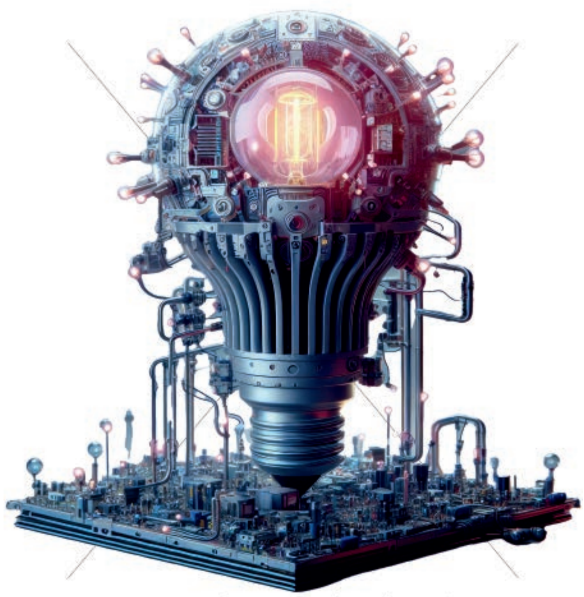
Prof. Ajay Mathur: My approach is fundamentally driven by demand. When introducing new technologies, it is best to test them in what I call a "sandbox"- small enough that failure does not harm the entire system, yet large enough to demonstrate scalability. We did this, for example, through the Electricity Act of 2003, where renewable energy was placed in such a sandbox. State regulators were mandated to procure a certain percentage of electricity from renewables, initially 2 or 3 per cent, which was gradually increased so that the impact on consumers remained minimal, typically less than 3-4 paise per kilowatt-hour. This approach has led us to a point where solar, wind, and battery-based power is now cheaper than coal.

Regulatory changes are therefore essential, but social acceptance also matters, and electricity, fortunately, is universally acceptable. What we found through the work of ISA was the critical need for capacity building and regulatory reform. In many countries, electricity investment is largely government-driven, but this must shift towards private investment, as renewables are more capital-intensive and less operationally intensive than fossil fuels. Additionally, the transition from fossil fuels to renewables itself necessitates regulatory change. While these reforms are partly country-specific, the need for capacity building and regulatory reform is universal, if we are to accelerate the global shift to renewables.

Ayushee: While we often focus on generating clean energy, you have emphasised the importance of saving it. With India's cooling demand projected to rise sharply, how can we prevent a cooling crunch? Is the Energy Conservation Building Code sufficiently ambitious to address intensifying heat-waves? And could you help our audience better understand what the "cooling crunch" means?

Prof. Ajay Mathur: Typically, the first appliance people buy is a fan, so efficiency here is critical. Conventional fans consume 60–70 watts, while efficient models use around 35 watts. The challenge is that the upfront cost of efficient fans is higher, and first-time buyers are often price-sensitive. Providing loans or installment-based payment options for energy-efficient products can make a significant difference. As incomes rise, people move from fans to air conditioners. While star-rating systems for air conditioners exist, we need to be far more aggressive in tightening these standards over time.

The cooling crunch refers to the sharp rise in electricity demand driven by cooling. By 2030, nearly one-fourth of India's total electricity consumption is expected to be for cooling, up from about 16-17 per cent today. This surge raises serious questions about how demand will be met. In my view, the solution lies in efficient buildings, fans, and air conditioners.



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Finance, Policy, and Workforce Enablers

Ayushee: Clean energy transitions are as much about finance as they are about technology. As you rightly mentioned, innovation alone is not sufficient; demand also plays a critical role in sustaining the transition. In this context, what role can innovative financing mechanisms and public–private partnerships play in accelerating climate solutions aligned with the SDGs?

Prof. Ajay Mathur: Broadly, this requires making finance far more accessible to ordinary consumers. Typically, people have to approach the bank for a loan. Instead, can financing come directly to the consumer? For instance, when you buy a car, the dealer offers multiple loan options on the spot. Can we create similar mechanisms for clean energy products? I believe we can.

For this to happen, companies selling products, whether air conditioners or solar installations, need to work alongside financing institutions to offer installment-based payment options. In this model, the finance company pays the product company upfront, while the consumer repays the loan in installments.

Ayushee: Beyond this, what structural changes are needed in the global financial architecture to de-risk investments, particularly in developing countries?

Prof. Ajay Mathur: In solar energy alone, global renewable investments are around USD 10 billion. However, 74 per cent of this has gone to developed countries, OECD nations, and China, while Africa has received only about 2 per cent. This led us to examine the underlying issues.

One major challenge is investor perception- the belief that investments in developing countries are risky and repayments uncertain. However, the data tells a different story. In Africa, 98 per cent of solar loans have been repaid; in India, the figure is around 96 per cent. While the base is smaller, the repayment performance is strong. This is largely a perception problem.

Perceptions can be addressed through guarantees. If developed countries provide guarantees, private capital can flow more confidently into developing nations. In my view, this is the most significant structural change needed to unlock large-scale investment.

Ayushee: Policies and regulatory frameworks play a major role in shaping these structural changes. Could you outline how clean energy policies have evolved in India and the world, as well as how you see them progressing?

Prof. Ajay Mathur: Over time, ambitions have steadily increased. When the Electricity Act was introduced in 2003, the targets were modest. Today, we are adding gigawatts of solar and wind capacity each year. This happened not only because of government commitment, but also because prices declined due to innovation and smart policy design.

The introduction of competitive bidding and reverse auctions drove prices down significantly, making electricity cheaper and more accessible.

The question now is whether we can replicate this success for decentralised systems such as solar mini-grids, where electricity is still relatively expensive. I believe that guarantees and assured demand can help reduce costs in this segment as well.

Ayushee: What key policy or regulatory strategies in India, would you say, have been particularly successful?

Prof. Ajay Mathur: One of the most significant achievements has been near-universal access to electricity, with over 99 per cent of households now connected. This is crucial for development, as electricity enables income-generating activities and improves quality of life. This success was driven by three factors: a clear policy direction, adequate budgets supported by strong institutions such as NTPC (National Thermal Power Corporation), PFC (Power Finance Corporation), and REC (Rural Electrification Corporation) and well-defined standard operating procedures. So, in my view, these three elements are essential for any policy to succeed.

Ayushee: From a public policy and workforce development perspective, how should India reskill and prepare its workforce for the energy and climate transition, and what key skills will be essential to support innovation, implementation, and SDG-aligned outcomes?

Prof. Ajay Mathur: I chair a committee focused on identifying the skills required for the next generation, so this is an area we have examined closely. One of the most critical competencies, particularly for engineers and innovators, is the ability to manage uncertainty. Demand patterns are changing rapidly, whether due to the rising use of air conditioners or the intermittent nature of renewable energy, which in turn makes storage essential. Innovation must therefore focus on bridging gaps between fluctuating demand and supply. This calls for training in areas such as power electronics, demand balancing, and process management. In industrial systems like steel manufacturing, for instance, material flows continuously, requiring a deep understanding of process integration and buffering. Equally important is large-scale upskilling of technicians responsible for installing and managing solar and wind systems. These roles increasingly demand multiple skills within a single worker, unlike earlier centralised models. While India has initiated green skilling programmes, these need to be significantly expanded.

Future Opportunities and India's Global Leadership

Ayushee: Drawing on your experience at TERI and ISA, what key lessons from India's clean energy journey could be scaled or adapted for other countries in the Global South, especially in policy design, technology, and capacity building?

Prof. Ajay Mathur: The first lesson is focus. Developing countries face growing energy demand, and investments must prioritise renewables over fossil fuels. Second, tools like auctions and reverse auctions are highly effective in reducing costs. Incentives and subsidies, particularly for decentralised applications, have also helped make electricity more affordable. Third, capacity building is critical. Countries need skilled professionals to design and implement clean energy or water management systems. Indian technologies can be adapted abroad, for example, our energy-efficient water pumps are now widely used in Africa. Similarly, solar cold rooms developed in India, which store cooling during the day for night use, are gaining global adoption. Lastly, technology localisation is key. Many countries pay high prices for imported solar panels due to transport costs. By exporting solar cells instead, they can manufacture panels locally, creating jobs and lowering electricity costs.

Ayushee: In that context, India's role also extends to global science diplomacy in clean energy and climate action. How do you see this evolving?

Prof. Ajay Mathur: India consistently highlights that demand in developing countries is rising, while in developed countries, demand is relatively static. Solutions for countries like India must address growing demand, not just existing infrastructure. For instance, solar works well during the day, but developing countries also need solutions for nighttime energy. Diplomacy often overlooks this because of the OECD (Organisation for Economic Co-operation and Development). India, therefore, can lead the Global South in future-focused solutions rather than retrofitting existing systems.

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Ayushee: Lastly, if you were to identify one or two mission-mode initiatives where India could lead globally on STI for SDG 7 and 13 over the next decade, what would they be?

Prof. Ajay Mathur: This brings us to the place where we started. I'd focus on three mission-mode projects:

Water management technologies
household and industrial solutions with wide applicability in the developing world.

Battery technologies
particularly high-temperature batteries for grid storage, making energy storage more efficient and affordable.

Space cooling technologies
advanced cooling solutions, including innovative window systems, developed in India for global use.

These initiatives could position India as a technology leader while addressing critical global challenges. Additionally, identifying products from the mission is important, but again creating demand is equally crucial. Demand can be generated in different ways in different countries. In India, we often rely on competitive frameworks and the principle that the future will be better than today. Applying such principles effectively to help stimulate demand is crucial.

Scan the QR to watch the entire interview

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Shweta Rajpal Kohli
CEO, Startup Policy Forum

Low-Carbon Innovation is **Transforming India's EVs**

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India stands at a pivotal intersection of global climate action, balancing the demands of a surging economy with an ambitious commitment to net-zero. As the world's third-largest carbon emitter, India's move toward carbon innovation is an economic necessity born of geographic vulnerability. The nation faces severe challenges: rising temperatures directly impact the livelihoods of nearly 46 per cent of the national workforce tied to agriculture, while escalating extreme weather events continue to inflict a toll on infrastructure and food security.

To alleviate the existential threat posed by climate vulnerability, India has pledged transformative targets through its updated Nationally Determined Contribution: a 45 per cent reduction in emissions intensity by 2030, a 50 per cent increase in non-fossil power capacity, and net-zero emissions by 2070. These commitments position India as a climate leader, demonstrating that developing economies can pursue prosperity while safeguarding the planet.

This ambition is most visible in the transport sector, where the drive toward net-zero emissions by 2070 is being operationalised through a domestic revolution in electric mobility. Over the past five years, India has witnessed a transformation in the adoption of non-fuel engine systems. The most aggressive integration is currently found in the two- and three-wheeled categories.

According to VAHAN and a report from the India Energy Storage Alliance (IESA), electric vehicle sales reached 2.3 million units in 2025, with electric two-wheelers accounting for 57 per cent, or 1.28 million units, of total sales.

At this juncture, rather than merely adopting technologies, India is emerging as a global hub for scalable, low-carbon innovation, developing robust, high-utility, and resilient vehicles to meet the demands of its unique landscape.

Startups, particularly electric two-wheeler (E2W) makers, are at the forefront of this revolution, transforming a niche market into a mainstream industrial powerhouse.

Currently, India is home to nearly 400 dedicated EV startups that are disrupting every link in the value chain, from high-performance two-wheelers and heavy-duty cargo trikes to sophisticated battery-swapping networks. This entrepreneurial surge is backed by capital. In 2025, Indian EV startups attracted $1.4 billion in funding, a 27 percent year-on-year increase, as investors pivot from seeing EVs as a climate-conscious choice to a proven, commercially sustainable frontier for the next generation of global transportation.

This article examines the leading startups in India's electric vehicle sector, specifically the companies that have pushed the boundaries of proprietary technology and high-precision engineering.

Ather Energy

From IIT Lab to E2W Leadership

ATHER

In just over a decade, Ather Energy has grown from an IIT Madras lab project into one of India's leading electric two-wheeler innovators, selling 500,000 scooters and driving E2W penetration above 15 percent. The company's success lies in building technology purpose-built for Indian conditions from the ground up and entirely in-house.

The Technology

Ather Energy's founders, Swapnil Jain and Tarun Mehta, set out to solve mobility challenges on India's busy roads with an electric scooter that becomes smarter through continuous data collection. Their team engineered a complete technological ecosystem: a lithium-ion battery delivering 75km range, a motor built to withstand rough conditions, and a touchscreen dashboard designed to withstand extreme heat, dust, and vibrations. The Ather 450's edge lies in 50+ IoT sensors capturing granular data on driving patterns, road conditions, and performance. This network enables rapid over-the-air firmware updates and real-time optimisations at zero cost to customers.

The Impact

Founded at IIT Madras in 2013, Ather exemplifies patiently building technology for India, in India. The founders quickly identified that E2Ws, popular in China, would not suit the Indian market. Over the past decade, the company developed an E2W platform that outperforms global competition while remaining cost-effective for Indian customers.

The Challenge

E2W players must navigate supply chain challenges across chips, magnets, and semiconductors while localising quickly to meet the government's ambitious targets. Ather achieved this through vertical integration. During the semiconductor crisis of 2022, Ather acquired chips from multiple sources and integrated them rapidly into production, capitalising on the government's Faster Adoption and Manufacturing of Electric Vehicles (FAME) revision to accelerate E2W adoption. A similar strategy proved effective during the recent magnet crisis.

The India Factor

Ather's tech stack is purpose-built for Indian users. Indian two-wheelers require higher durability and power while offering exceptional value within tight cost structures. Ather's E2Ws offer far more features than their global peers at a fraction of the cost. Vertical integration of technology enables this. Ather builds all key pieces of E2Ws in-house, including the battery management system (BMS), vehicle control unit (VCU), motor controller, and the entire software stack. This enables lower bill-of-materials costs, faster product and feature delivery, and resilience against supply chain shocks.

The Future

Ather has built strong technology foundations and organisational practices that enable continued EV penetration through R&D on multiple products. The company is now applying its scooter playbook to motorbikes and expanding its scooter portfolio to make electric mobility mainstream in India and globally.

Source: inc42.com

River Mobility

Making the SUV of e-scooters

In just over two years, River has deployed over 21,000 of its flagship Indie e-scooters and raised ₹575 crore from global investors. The company benefited from reimagining the two-wheeler not just as a mode of transport but as a versatile utility vehicle tailored for the country's diverse demands.

The Technology

River's founders, Aravind Mani and Vipin George, sought to drive change in India's two-wheeler transport segment. With a focus on safety, utility, and versatility, River launched its flagship model, River Indie, in 2023 and positioned it as an "SUV of e-scooters" capable of handling rugged Indian roads with motorcycle-like stability. River Indie is equipped with a 4kWh battery that powers a 6.7kW motor, capable of propelling the scooters to a top speed of about 90kph. Its 43-litre boot is the largest on any scooter in India today.

The Impact

As of December 2025, River has rolled out 21,306 Indies on Indian roads, with 85 stores across India. It doubled its sales in six months after hitting 10,000 scooters.

The Challenge

The primary challenge in the Indian market has been to navigate the "hardware graveyard" mentality of the ecosystem, where raising capital for a physical automotive brand was met with investor scepticism. Beyond funding, River, like other EV companies, faces a critical supply chain bottleneck with rare-earth magnets, forcing it to source from other countries across the world, which carries the risk of supply chain disruptions.

The India Factor

The founders tailored the Indie's ergonomics for comfort during long hours in traffic, featuring the longest and widest seat in the category. This is most evident in its integrated crash protection; the scooter comes with built-in safeguards that protect the bodywork from scratches in tight parking spots.

The Future

River plans to scale its state-of-the-art manufacturing facility in Hoskote, Karnataka. The company intends to build a wider ecosystem of utility-focused accessories and amplify modular upgrades. Additionally, River plans to have 100 stores by March 2026 and a new factory to support the manufacturing of new products. Ultimately, the aim is to become a market leader in the e-scooter segment by developing a new category of multi-utility vehicles that demonstrate that electric mobility can offer the rugged versatility of an SUV without losing the classic soul of a two-wheeler.

Source: bikewale.com

Ultraviolette Automotive

Engineering High-Performance e-motorcycles

Ultraviolette has carved out a distinct niche in India's electric mobility landscape by proving that low-carbon innovation can coexist with high-octane performance. Established in 2016, the Bengaluru-based startup combines aerospace engineering and automotive design, which powers its flagship F77 motorcycles.

The Technology

Founders Narayan Subramaniam and Niraj Rajmohan built Ultraviolette's flagship F77 motorcycles. These models include a proprietary battery management system and a vehicle operating system developed entirely in-house. The motorcycles promise peak power of 30kW, with a real-world range of 300 km, using aviation-grade thermal management, and a patented five-level safety system.

The Impact

Since launching the F77 in November 2022, with deliveries beginning in January 2023, Ultraviolette has expanded its presence in over 30 Indian cities. It has also taken its uniquely Indian story to the world by establishing a presence in 12 European countries, and plans to expand further in Latin America and Southeast Asia. The company has raised $149 million to date, including a $45 million round in December.

The Challenge

Ultraviolette's success proves that the Indian consumer is willing to pay premium prices for EVs built on solid technology. However, the company is aware that geopolitical factors can affect the supply of rare-earth magnets, which are essential for Ultraviolette's high-performance motors. Volatility in semiconductors and cells is also another global risk that could impact production. To counter this, it has a diversified supply chain across Korea, Japan, Taiwan, and India.

The India Factor

Ultraviolette is addressing a unique segment that EV makers usually don't consider: performance enthusiasts. It is building technology stacks locally, testing extensively on Indian roads, and building thermal management systems capable of handling extreme Indian weather conditions. The company's success in foreign markets is proof that Indian startups can compete globally in high-technology automotive segments.

The Future

Ultraviolette aims to scale its production capacity to 1 lakh units and plans to IPO by 2027. Its upcoming platforms, Shockwave and Tesseract, aim to bring high-performance technology at more accessible price points.

Source: zigwheels.com

Yulu

Democratising Urban Micro-Mobility

Yulu Bikes, founded in 2017 by Amit Gupta, RK Misra, Hemant Gupta, and Naveen Dachuri, is one of India's most visible micromobility companies. It operates shared electric two-wheelers in several major cities, including Bengaluru, Mumbai, Delhi, and Hyderabad.

The Technology

Yulu operates two primary vehicle categories:

1. Yulu Miracle is a pedal-assisted electric cycle for personal and shared rides.
2. Yulu DeX is a seated electric scooter designed for last-mile delivery, logistics, and cargo transport.

The platform integrates IoT-enabled vehicles with a smartphone app that enables GPS tracking, keyless ignition, and digital payment systems. The company also operates a battery-as-a-service (BaaS) system through its Yuma Energy unit, offering swappable, charged EV batteries that eliminate range anxiety and cut upfront costs through subscription. Riders use the Yulu app to locate swapping stations in their vicinity to swap depleted batteries for charged ones in under a minute for seamless micro-mobility.

The Impact

Yulu is transforming India's last-mile delivery landscape with its electric fleet. The company operates a fleet of over 45,000 vehicles and powers over 20 million green deliveries every month, saving over 2 million kg of CO_2. It has powered over 350 million e-commerce deliveries until December 2025, with an over 35 percent fleet share at major quick-commerce dark stores in India.

The Challenge

Shared mobility faces unique Indian challenges, including extreme weather that affects vehicle durability, limited parking infrastructure, and user behaviour that requires robust theft prevention. Yulu addressed these through hardened vehicle designs, designated parking zones negotiated with municipal authorities, and IoT-enabled geo-fencing.

The India Factor

Yulu understood that Indian cities require affordable, flexible mobility options beyond traditional vehicle ownership. By pricing short rides for individuals at a base price of ₹5 per minute and an additional ₹2.5 per minute, and distance-based packs for quick e-commerce delivery personnel, it has made sustainable transport accessible to a wide variety of Indians.

The Future

Yulu is scaling its business partner franchise model to dozens of cities. It plans to deploy 1,00,000 vehicles and expand into 25-30 cities, supported by potential funding rounds and existing investors.

Source: yulu.bike

Euler

Powering Heavy-Duty Commercial Vehicles

While most startups focus on the passenger or commuter segment, Euler has focused on the commercial three- and four-wheeler segment. Founded in 2018 by Saurav Kumar, a Delhi College of Engineering and Cornell University alumnus, Euler is focused on building EVs that match or exceed the payload of fossil fuel-based commercial vehicles.

The Technology

Euler's product range includes vehicles with payloads ranging from 768 kg to 1 tonne. Its HiLoad EVs feature a proprietary 13 kWh battery pack with an advanced thermal management system, delivering a real-world range of 110-200 km. The vehicles also feature a patented liquid-cooling system that can withstand extreme ambient temperatures.

The Impact

As of January 2025, 7,000 Euler vehicles were deployed in 15 cities, in partnership with most major e-commerce and logistics companies. The company has raised ₹1,420 crore in funding until September 2025.

The Challenge

The primary hurdle in Euler's case is the duty cycle, or vehicle operation frequency, and long-haul expectations of Indian commercial operators. Unlike personal scooters, cargo vehicles must run 10-12 hours a day with heavy loads. Overcoming scepticism about battery life and ensuring a robust service network for businesses are some operational challenges it faces.

The India Factor

Euler's design is a direct response to Indian infrastructure. Their EVs are built to handle uniquely Indian conditions of waterlogged streets, unpaved "last-mile" alleys, and overloaded cargo conditions.

The Future

Euler plans to expand from 55 cities in September 2025 to 100 cities by the end of FY26. It also plans to expand beyond India into Southeast Asia, Africa and Latin America.

Source: eulermotors.com

The Path Forward

The launch of the Rs 1 lakh crore Research Development and Innovation (RDI) Fund by the Indian government, coupled with the Mission for Advancement of High Impact Areas on Electric Vehicles (MAHA-EV), marks a definite shift towards decarbonisation in a self-reliant manner. By bridging the gap between academic research, on-the-ground innovation, and mass adoption, the government has incentivised EV entrepreneurs to turn their electric vision into a sustainable business model. Supported by the government's PM E-Drive Mission and a renewed emphasis on indigenous innovation, EV startups will build the next generation of dependable electric vehicles that push boundaries of mass-market logistics and personal mobility. Creating these foundational technology nodes locally will become the sovereign backbone of sustainable global transport, one which the world follows.

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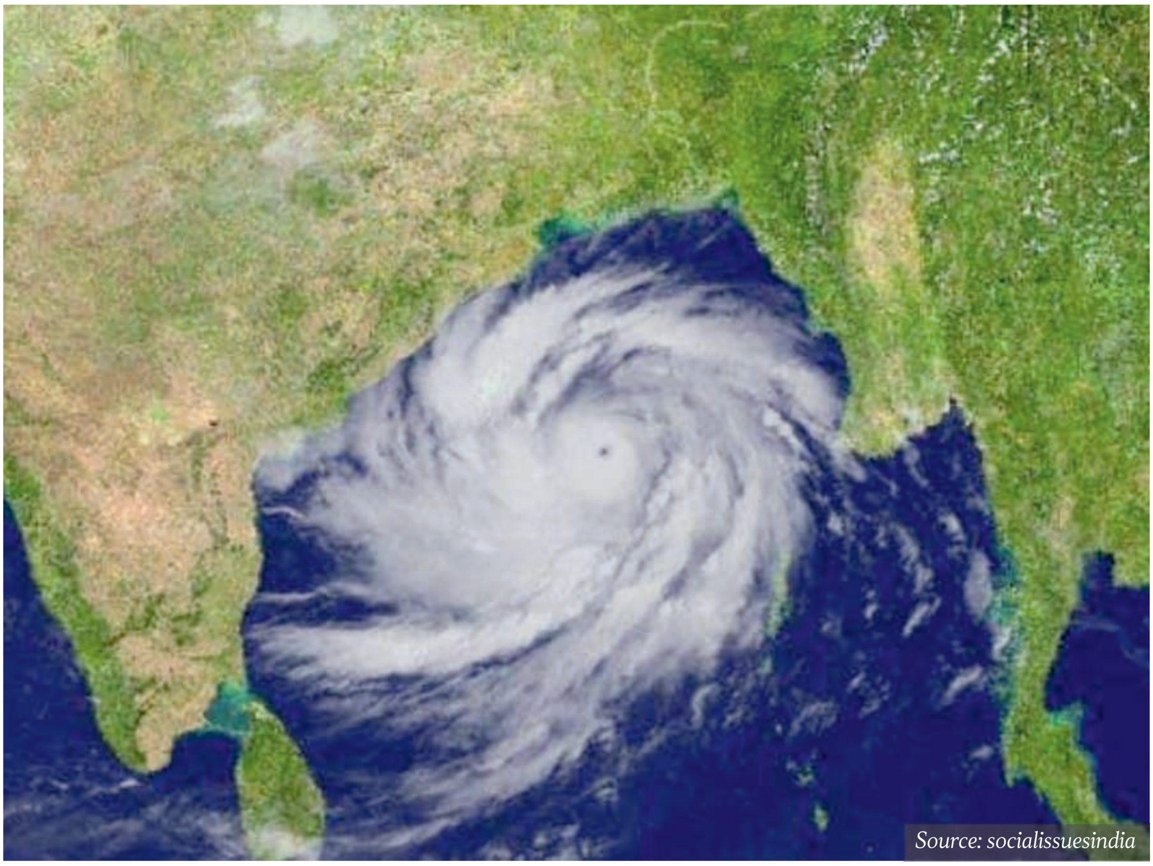
Challenges in Integrating Science, Technology, and Innovation for Climate Resilience in India

07

Image Credits: Licensed stock visuals.

Experiences of Golabandha, a fishing village in the Rangeilunda block of Ganjam district, Orissa, during Cyclone Phailin in October 2013 illustrates both the value and the limits of scientific and technological systems. Despite timely early warnings and cyclone alerts that enabled mass evacuations and saved thousands of lives compared to the 1999 super cyclone, the fisher families of Golabandha faced devastating losses. ~700 houses were severely damaged, 305 boats destroyed, and over 2,500 livestock perished. While early warning systems successfully reduced mortality, they could not prevent the collapse of livelihoods. Fishermen lost their primary source of income, with 72.67% of 300 fishing families in Ganjam district experiencing income declines. They had to wait weeks before resuming fishing, and the recovery was prolonged.

Technology has reached vulnerable communities, but the supporting delivery systems, financial mechanisms, and context-specific solutions have lagged behind. This disconnect between scientific prediction and equitable protection of livelihoods underscores India's broader climate resilience challenges.


Source: socialissuesindia

The Developmental Challenge of **Climate Change in India**

Climate change is as much a developmental challenge as an environmental one. While the country has committed to a 45% reduction in emissions by 2030 and achieving net-zero by 2070, escalating climate change threatens millions of livelihoods. Climatic variability is marked by an increase in mean temperature, heavier rainfall, and more dry days, intensifying extremes. These risks cut across food security, public health, energy access, urbanisation, and livelihoods, rendering resilience a systemic rather than sectoral concern. In this context, STI has emerged as a key policy lever for advancing climate action while sustaining growth and equity.

India's STI trajectory has evolved in response to the shifting political economy and development priorities. Early policies focused on building scientific capacity for nation-building, while subsequent frameworks increasingly deploy innovation for sustainable development. From a significant shift that occurred with the Science, Technology and Innovation Policy (STIP) 2013, which formally integrated innovation into policy discourse to the draft STIP 2020 that emphasises Open Science, mission-mode delivery, and alignment with the Sustainable Development Goals (SDGs), including climate-related aspects.

Global frameworks such as the SDGs and the Sendai Framework for Disaster Risk Reduction reinforce the central role of STI ecosystems, high-quality risk data, early warning systems, and anticipatory planning in building climate resilience.

However, the application of STI is neither neutral nor self-executing. Outcomes are shaped by institutional arrangements, power relations, and delivery mechanisms. These dynamics are critical when assessing resilience outcomes for vulnerable populations and shaping equitable development. To understand these, we must examine how STI interventions are currently playing a role across India's critical sectors.

Current STI Approaches to **Climate Resilience in India's Rural and Urban Sectors**

Extreme climate events have differential impacts across rural and urban contexts. We will explore STI interventions in the agricultural and fisheries sectors as pathways for rural resilience, while addressing urban resilience from an SDG perspective.

STI in the Agricultural Sector

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Agriculture highlights both the promise and limits of STI-led resilience. Research has remarked how flagship programmes such as the National Innovations on Climate Resilient Agriculture (NICRA), demonstrate the effectiveness of climate-resilient technologies. They can yield significant gains under stress conditions, including yield increases of 10–98% during drought years, net returns of up to ₹30,000 per hectare from water-focused interventions, and improvement in groundwater stability. However, these outcomes conceal major delivery gaps, as farmers face weak extension systems, limited financing, and high capital costs for technologies such as drip irrigation. These barriers are especially pronounced for women farmers, reflecting governance and delivery failures rather than technological ones.

STI in the Fisheries Sector

India's fishing communities face compounded climate risks from cyclones, sea-level rise, ocean warming, habitat loss, and coastal erosion, yet remain marginal to formal innovation and adaptation frameworks. Climate change has intensified economic vulnerability by altering fish migration patterns, increasing fuel costs, and degrading coastal aquifers and aquaculture systems. Women-dominated post-harvest activities operate under unsafe and informal conditions, with limited access to technology, early warning systems, or disaster preparedness. Policy responses remain fragmented, focusing on episodic disaster relief, stock regulation, and large harbours, while neglecting chronic climate stress, climate-informed fisheries management, and small landing centres. Although traditional ecological knowledge offers valuable insights for climate resilience, adaptation efforts largely privilege technological solutions over co-production, thereby positioning communities as passive recipients. Bridging this gap requires integrating STI with gender-responsive governance and systematically incorporating traditional ecological knowledge.


Image Credits: Licensed stock visuals.

STI for Urban Resilience

Cities are climate-vulnerability hotspots, facing cascading risks from urban heat islands that raise temperatures by 3–5°C, flooding from overwhelmed drainage systems, water scarcity, and infrastructure failures during extreme events. Urban resilience refers to a city's capacity to anticipate, prepare, respond, and recover from such impacts. As hazards vary by geography, settlement patterns, and economic structures, STI-driven, systems-oriented approaches are essential. For example, Surat's multi-hazard early warning systems and flood risk mapping; and Ahmedabad's heat action plan are replicable STI governance models. However, such models remain exceptions in urban India.


Image Credits: Licensed stock visuals.

STI is central to translating climate risk awareness into actionable resilience. Climate modelling, high-resolution hazard mapping, and real-time data enable more precise anticipation of flooding and heat stress. Early warning systems, climate-responsive infrastructure standards, and decision-support tools can shift cities from reactive response to preventive planning. Digital public infrastructure integrating climate data with urban services further supports targeted investments and reduces service disruptions. Outdated master plans, weak enforcement of building codes, and the exclusion of informal settlements constrain adaptation efforts.

Scaling urban resilience, however, requires governance reform alongside technology. Smart city initiatives prioritise efficiency and digitalisation but rarely embed climate resilience, leaving STI interventions fragmented and insufficient to address systemic climate risks.

Need for Integrating Indigenous and Local Knowledge into STI for Climate Resilience

While science and technology underpin India's climate resilience strategies, indigenous and local knowledge systems are under-institutionalised in risk reduction and adaptation. Communities have long relied on diversified cropping systems, phenological indicators, traditional water-harvesting structures, and customary ecosystem management to anticipate and respond to climatic variability. Rooted in long-term environmental observation, these practices offer context-specific adaptation insights that align closely with disaster risk reduction and inclusive governance. Specific indigenous practices demonstrate climate-adaptive potential. For example, the Apatani community in Arunachal Pradesh practices an integrated rice-fish farming system that maintains soil fertility and water retention while providing year-round nutrition. This centuries-old practice is recognised for its climate resilience under variable monsoons. Common carp (Cyprinus carpio), locally known as Ngihi, is introduced into the paddies where it feeds on insects and pests, while its excreta enriches the soil with nutrients, eliminating the need for chemical fertilizers.


Source: aquadapt.org

This symbiotic relationship yields ~4,500-5,200 kg of rice per hectare alongside 150-500 kg of fish annually, providing food security even under erratic monsoons. The system's water retention capacity buffers against both drought stress and flash floods; hazards that have intensified in the Eastern Himalayas.

In semi-arid Rajasthan, traditional water harvesting structures such as Khadins and Johads capture monsoon runoff, recharge groundwater, and support agriculture during extended dry spells. India's STI and adaptation frameworks have positioned such knowledge as supplementary, restricting its integration. Therefore, STI interventions need to reimagine the integration of indigenous knowledge into formal research, extension, and decision-making processes. Bridging this gap requires co-production of climate-resilient solutions, supported by institutional mechanisms that recognise, validate, and scale locally grounded adaptive practices.

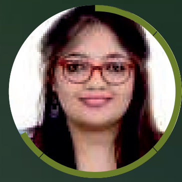
STI Pathways for a for a Climate-Resilient India

India's experience with climate resilience shows that while science and technology provide a strong foundation, their impact depends on effective governance, financing, and delivery systems. Climate-resilient technologies, scientific knowledge, and indigenous practices already exist, offering a clear opportunity to scale impact.

The challenge is largely systemic rather than technological. Limited last-mile delivery, inadequate access to finance, and weak local capacity constrain the uptake of proven solutions, while formal and indigenous knowledge systems remain insufficiently integrated. Recognising women as knowledge holders and agents of adaptation, rather than only as vulnerable groups, enhances both equity and effectiveness. Reframing STI as an enabling ecosystem supported by stronger local an inclusive governance, participatory planning, institutional reform, and adaptation-focused climate finance can unlock more inclusive resilience outcomes.

By aligning innovation with equitable governance and delivery mechanisms, STI can drive a climate-resilient India that not only manages climate risks but also advances sustainable and inclusive development.

India's climate resilience challenge is shaped less by gaps in science or technology and more by the institutional and governance systems that determine how innovation is deployed. While the country possesses strong scientific capacity, proven climate-resilient technologies, and rich indigenous knowledge, translating these strengths into impact requires governance-driven STI pathways that prioritise inclusive delivery, cross-sectoral coordination, local capacity, and knowledge co-production. Aligning STI and governance with climate risk realities across rural and urban contexts is essential to ensure that STI becomes a catalyst for sustainable development in a climate-changed future.



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A Systems Approach to India's Net-Zero Journey: Harnessing Science, Technology, and Innovation

Image Credits: Licensed stock visuals.

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Why a Systems Approach Matters for **Climate?**

As per the World Meteorological Organisation (WMO) report, the year 2025 was among the second warmest on record, reflecting a pattern of eleven consecutive years of record temperatures, accompanied by historically high levels of carbon dioxide, methane, and nitrous oxide in the atmosphere. Between 2015 and 2024, the Earth was approximately 1.24 °C warmer than during pre-industrial times, with nearly all this warming (~1.22 °C) attributed to anthropogenic activities. This underscores the need for significantly stronger mitigation action than previously envisaged, with global emissions required to reach net-zero around 2050 to limit temperature rise to 1.5 °C, as outlined in the 2018 Special Report by the Intergovernmental Panel on Climate Change (IPCC).

Achieving these ambitious targets will require energy systems to move rapidly towards net-zero, or even net-negative, emissions. This calls for moving beyond piecemeal policy and technology interventions, towards a coherent, systems-oriented approach, where STI informs policy and investment decisions across the entire lifecycle of energy systems—from resource extraction and materials processing to deployment, operation, and end-of-life management. In practice, a systems-oriented approach recognises that progress in any part of the energy transition is inherently interdependent with advances elsewhere, with STI acting as the connective tissue across these elements.

For instance, scaling solar and wind power is not only a question of installing generation capacity, but also of developing advanced power electronics, viable energy storage technologies, robust grid management software, and efficient forecasting tools that enable the reliable integration of variable generation. Even decarbonisation solutions that are frequently addressed through technology-specific policies, such as batteries or low-carbon fuels, are embedded within wider systems involving critical minerals, supply chains, infrastructure, markets, and end-use behaviour. Without coordinated STI efforts across these interconnected stages, policy interventions risk delivering fragmented outcomes rather than durable, system-wide transformation.

Image Credits: Licensed stock visuals.

India’s Climate Commitments and the **Role of S&T**

India's energy transition rests on the large-scale deployment of non-fossil energy sources such as solar and wind, supported by energy storage systems to ensure reliability on the generation side, while demand-side transformation spans industry, transport, housing, and other end-use sectors. The Panchamrit pledge, a five-fold strategy to address climate change, signals a clear national commitment to climate mitigation. It is supported by ongoing efforts to strengthen coordination across policymakers, scientific and academic communities, think tanks, financial institutions, and industry. In parallel, the promotion of LiFE (Lifestyle for Environment) reflects an explicit policy emphasis on embedding citizen participation and behavioural change as integral elements of India's climate action framework.

While the Panchamrit pledge and LiFE provide the strategic and societal foundations for India's climate response, their effective realisation ultimately depends on how technologies are developed, adopted, and deployed at scale. India has launched a suite of missions, policies, and schemes such as the National Green Hydrogen Mission, the Advanced Chemistry Cell Production Linked Incentive (ACC-PLI) scheme, the National Policy on Biofuels (2018), the PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE), the National Critical Minerals Mission (NCMM), and others. These initiatives include provisions for in-house and captive research and development, with the intention of increasing local value addition and the indigenisation of critical technologies. Taken together, these efforts span multiple segments of interconnected value chains, from critical minerals and manufacturing to low-carbon fuels, mobility, power systems, and others, underscoring the need for coordination across missions rather than siloed implementation.

The country is at a critical juncture where STI-led price discovery for emerging clean technologies, coupled with effective demand-side programme design, is no longer optional but necessary to strengthen domestic capabilities and advance self-reliance. Currently, several emerging clean technologies carry a cost premium that slows large-scale deployment and dampens demand; a clear example is green hydrogen (produced through electrolyser and biomass-based pathways), which continues to be priced well above grey hydrogen (derived from fossil fuels), contributing to its currently subdued uptake. Addressing the cost gap requires a concerted and sustained focus on research and development, particularly to improve electrolyser efficiency and develop cost-effective alternatives to imported components, especially within the balance of plant—the supporting systems and equipment that make the main technology operate efficiently.

However, cost and performance outcomes for individual technologies are rarely determined in isolation, but by interdependencies across supply chains and industrial ecosystems. These systems and technologies are deeply intertwined, with gaps in one segment often constraining outcomes elsewhere. For instance, constraints in the availability and processing of critical minerals such as nickel and cobalt, which are essential for electrolyser manufacturing, directly influence progress under the National Green Hydrogen Mission. Similarly, the limited availability of indigenous technical capabilities for large-scale midstream processing of lithium ore, which is critical for battery energy storage systems, has been constantly cited as a factor affecting the performance of the ACC-PLI scheme. Continued dependence on imported processed critical minerals exposes domestic markets to global price volatility and geopolitical risks.

The aforementioned system-level interdependencies extend beyond domestic deployment challenges to shape how Indian industries engage with evolving international compliance regimes, especially in hard-to-abate sectors such as aviation, shipping, steel, and others. Aligned with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) framework, India has notified SAF blending targets of 1% by 2027, 2 % by 2028, and 5% by 2030 for international flights. However, the long-term financial viability and scalability of SAF will depend on STI-led advances in sustainable feedstock pathways and technology diversification (including gasification, Fischer–Tropsch, Alcohol-to-Jet, green hydrogen-derived e-fuels, and others) to reduce land-use pressures, contain costs, and avoid reliance on a single production pathway.

Similar dynamics are evident in other hard-to-abate sectors such as shipping and steel, where rising carbon costs are expected to increasingly influence commodity prices. In the marine sector, meeting the International Maritime Organisation's (IMO) net-zero ambitions will require dedicated research and development to enable the safe and cost-effective use of alternative fuels such as green ammonia and green methanol. For the steel sector, advancing low-carbon production technologies (direct reduction of iron ore using green hydrogen, electro-winning, and others) will be critical not only for maintaining industrial competitiveness, but also for reducing exposure to carbon pricing at the border, such as the European Union's Carbon Border Adjustment Mechanism (CBAM), to be levied from January 2026. These linkages across aviation, shipping, and steel are indicative of wider feedback loops across the energy system. Compliance-driven decarbonisation pathways for these sectors hinge on the timely availability of renewable electricity, energy storage, and green hydrogen, and these ecosystems must advance in parallel rather than in sequence.

Science Diplomacy and Global Partnerships for **Energy Systems**

As these technological and cost challenges cut across sectors and borders, their resolution increasingly depends not only on domestic innovation efforts but also on coordinated international action and science diplomacy. Advancing SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) requires recognising climate change as a shared global threat, for which the energy transition constitutes a collective global remedy. Therefore, India places science diplomacy at the centre of its energy transition strategy to manage shared risks, accelerate innovation, and shape globally coherent energy pathways.

By prioritising the development of complementary capabilities rather than competing across all technology frontiers, India is actively engaged with platforms such as the International Solar Alliance (ISA), the Global Energy Alliance for People and Planet (GEAPP), India-EU Trade and Technology Council (TTC), and others. These platforms attempt to demonstrate how cooperation grounded in shared data, mutual trust, and aligned technical and sustainability standards can reduce technology costs, enable interoperability of emerging solutions, and expand access through distributed and green grid systems via coordinated capacity-building, technical collaboration, and policy exchange. Building on these models, some existing platforms can be leveraged to strengthen collaboration, while also offering valuable cues for designing new, dedicated, and focused partnerships. Mechanisms such as joint ventures, collaborative R&D programs with matching grants, and consolidated data platforms for shared learning can significantly enhance cooperation. Such partnerships not only drive technology scale-up and innovation but also create a strong business case for unlocking and mobilising international climate and green energy finance—ensuring that it flows in the right direction to support a just, inclusive, and sustainable energy future.

As mentioned previously, India has begun to deploy a range of enabling instruments to strengthen its science, technology, and innovation ecosystem for the energy transition, including mechanisms such as viability gap funding (for example: Battery Energy Storage Systems), and the launch of the ₹1 lakh crore Research, Development, and Innovation (RDI) fund for clean energy and other sunrise sectors under the Anusandhan National Research Foundation (ANRF). These mechanisms are expected to encourage greater private-sector participation, demand-led research, and the scaling of technologies, while addressing the ‘valley of death’ between innovation and deployment.

Given the capital-intensive nature of clean technology projects, engaging international finance institutions to establish blended finance mechanisms and robust risk-mitigation instruments is essential to crowd in private capital. On the demand side, targeted policy instruments such as technology-specific procurement mandates within public systems can help create early and predictable markets. The effectiveness of these instruments will depend on their ability to operate as a coherent system and on how effectively they are sequenced, integrated, and evaluated across sectors and value chains. The ultimate success of these efforts will depend not merely on their design but on robust execution, monitoring, and evaluation, supported by outcome-based metrics such as emissions reductions, improved and equitable access to clean energy, enhanced air quality, and broader social inclusion, reflecting the integrated priorities of people, nature, and climate.

India's journey to net-zero is complex and interconnected, spanning technology development, policy coordination, industrial ecosystems, and international collaboration. By adopting a systems approach anchored in STI, the country can not only achieve its climate commitments but also foster sustainable growth, energy self-reliance, and global leadership in the clean energy transition. Success will depend on coordinated execution, monitoring, and the active participation of citizens, industry, and international partners alike.

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Vivek Raina
Former Junior Policy Fellow, PAIU-OPSA

Science Advice for Steering Sustainable Development

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As India marches on towards attaining its commitments under the Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), the role of STI has become indispensable in shaping credible, scalable, and equitable solutions. Translating India's ambitious climate and energy goals into actionable pathways, requires technological capability. It also needs coherent science-policy integration, mission-oriented research, and sustained coordination across ministries, institutions, industry, and international partners. In this context, the Office of the Principal Scientific Adviser (OPSA) to the Government of India plays a critical role as the apex science advisory body, anchoring national policy decisions in scientific evidence and long-term technological foresight. By aligning research priorities with national development objectives, OPSA helps translate India's ambitious climate and clean energy goals into actionable and implementable pathways.

Through strategic advisory platforms, mission-driven initiatives, and international partnerships, OPSA has contributed to embedding STI into policies and programmes aligned with these SDGs. Collectively, these efforts also underscore India's engagement with global discourse on sustainable energy transitions, equitable access to clean technologies, and collaborative innovation for climate mitigation.

Initiating Action Towards the **Net-Zero**

PM-STIAC, under the aegis of OPSA, provides strategic guidance across priority domains such as clean energy, sustainable mobility, climate resilience, and environmental sustainability. For instance, PM-STIAC has been instrumental in shaping India's STI engagement with the SDGs by guiding the design and rollout of national missions that directly address fossil fuel dependence and greenhouse gas emissions. Several of these initiatives have focused on advancing low-carbon technologies while strengthening indigenous research and manufacturing capabilities.

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A prominent example is the **Electric Vehicle (EV) Mission,** a cornerstone of India's transition to cleaner and more affordable energy systems. The mission aims to accelerate EV adoption across the country by fostering domestic R&D, developing robust technical standards, and enabling stakeholder engagement across the innovation ecosystem. By promoting decarbonised transport systems and indigenous technological capacity for e-mobility components, the mission contributes directly to SDG 7 and SDG 13.

Complementing this effort is the **Zero-Emission Trucking (ZET) initiative,** another flagship programme guided by OPSA. While medium- and heavy-duty trucks represent a relatively small share of India's vehicle fleet, they account for a disproportionately high share of fuel consumption and transport-related emissions. Addressing this segment is therefore essential for achieving meaningful emission reductions.

'Technology Assessment of ZET on the Delhi-Jaipur' Corridor presented to Hon'ble Minister (RT & H), Shri Nitin Gadkari (on 21 November 2023)

India's **Science and Technology (S&T) Clusters** play an important role in translating national climate and energy priorities into region-specific interventions. Across the country, these clusters have implemented initiatives addressing decarbonisation, resource efficiency, urban sustainability, and climate resilience. Examples include urban mobility and public health assessments in Bengaluru, water and marine sustainability initiatives in Odisha, air pollution mitigation and green mobility projects in Delhi, data-driven resource efficiency systems in Jodhpur, carbon accounting and green hydrogen planning in Pune, hydrogen ecosystem development in Hyderabad, and sustainable e-waste management in Visakhapatnam. Collectively, these efforts demonstrate how local innovation ecosystems can contribute to national SDG objectives.

CCS EV AC Fast (Type 2) Chargers by DRIIV Cluster of OPSA

The Mission for Science and Technology-based Sustainable Livelihood System (**Mission सहSANKALP**- Science and Advanced Networks for Knowledge-driven Action for Livelihood Promotion) harnesses STI to tackle climate change, pandemics, and resource scarcity threatening agriculture, fisheries, and forestry. Approved by PM-STIAC in January 2023, the mission strengthens resource management, value chains, and community resilience while aligning with SDGs. Led by OPSA with DST as nodal ministry, it unites 15 ministries through a three-tier governance structure: a PSA-level Steering Committee for policy oversight; a Strategic Planning Committee for progress tracking; and DST's Technical Advisory Group for technical validation.

The **National Green Hydrogen Mission (NGHM)** seeks to position India as a global clean hydrogen leader. By 2030, it aims to leverage 125 GW of dedicated renewable capacity, attract over ₹8 lakh crore in investments, create 6 lakh jobs, cut fossil fuel imports by more than Rs. 1 lakh crore annually, and avoid nearly 50 MMT of GHG emissions yearly. As of May 2025, 19 companies secured 862,000 tonnes of annual green hydrogen capacity, 15 firms gained 3,000 MW electrolyzer manufacturing capacity, and pilots launched in steel, mobility, and shipping. PSA serves on the Cabinet Secretary-led Empowered Group and chairs the NGHM Advisory Group for tech advice; OPSA co-organises the annual International Conference on Green Hydrogen with MNRE since 2023 (including the September 2025 R&D Conference); holds representation on MNRE's Local Value Addition Committee for the electrolyser PLI Scheme; and advises on technology pathways, electrolyser innovations, global benchmarks, R&D gaps, roadmaps, and collaboration opportunities.

Hon'ble Prime Minister Narendra Modi meets European Commission President Ursula von der Leyen at Hyderabad House in New Delhi, with a hydrogen-powered bus visible in the background

Roadmaps
for the Path Forward

Recognising the need to address emissions from hard-to-abate sectors, PM-STIAC, with active support from OPSA, also enabled the development of the R&D Roadmap to Support India's Net Zero Targets through Carbon Capture, Utilisation, and Storage (CCUS). The 25th PM-STIAC meeting deliberated robust policy frameworks for CCUS deployment in India, alongside India's carbon market and credit scheme to drive emissions reduction, low-carbon pathways, and market incentives for mitigation technologies. The roadmap released by DST in December 2025, outlines a coordinated approach to accelerating innovation, deployment, and investment in CCUS technologies, while emphasising national research capacity, industry engagement, enabling frameworks, and infrastructure development.

The transport sector is a significant contributor to energy demand and greenhouse gas emissions, making it central to India's SDG 7 and SDG 13 commitments. To address this challenge, OPSA further guided the development of the e-Mobility R&D Roadmap for India as a strategic blueprint that places science and innovation at the core of sustainable transport transitions. The roadmap identifies priority areas for research and development, including energy storage cells, advanced materials, next-generation charging and refuelling technologies, and innovations in power electronics.

It outlines concrete research projects and technical priorities over a five-year horizon, aligned with India's commitments to reduce emissions intensity of GDP by 45 percent by 2030 and achieve net-zero emissions by 2070. A key emphasis of the roadmap is building indigenous capacity in energy storage and mobility technologies, which is critical for enhancing energy security and reducing dependence on imported fossil fuels. By focusing on breakthroughs in battery technology, charging infrastructure research, and materials innovation, the roadmap establishes a scientific foundation for decarbonising road transport and advancing clean energy systems consistent with SDG 7 and SDG 13.

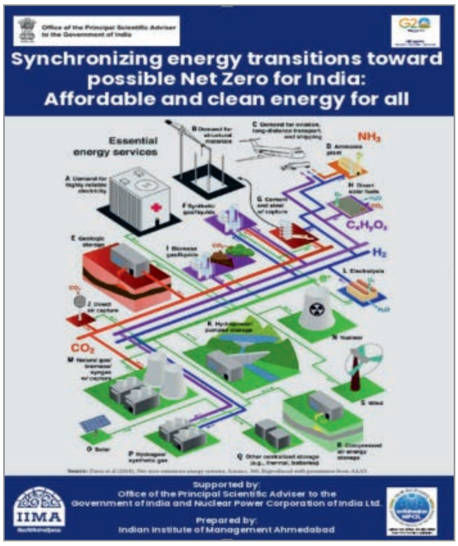
The Technical Roadmap for Deployment of ZET in India, prepared by OPSA's Consultative Group on e-Mobility, outlines a sequence of technical actions required for large-scale adoption of battery electric trucks, hydrogen fuel cell vehicles, and other zero-emission solutions.

These actions include development of field data systems, product development pathways, national standards for critical technologies, pilot implementation tools, and regulatory adjustments tailored to freight operations.

These technology-focused measures are designed to reduce greenhouse gas emissions, improve air quality, and strengthen energy security by shifting freight transport to cleaner propulsion systems powered increasingly by renewable energy. Supporting this technical roadmap, the Bharat ZET Policy Advisory identifies policy interventions to address infrastructure readiness, financing mechanisms, stakeholder incentives, and viable business models. OPSA has also released analytical studies such as the Priority Corridors for ZET, which identify freight routes where early deployment can maximise emission reductions and inform strategic infrastructure planning.

Together, the e-Mobility R&D Roadmap and ZET initiatives form a cohesive STI framework for decarbonising India's transport sector. They demonstrate how scientific insights can be integrated with implementation pathways to advance clean energy transitions and climate objectives in a practical and scalable manner.

Achieving SDG 13 requires integrated national strategies that balance economic growth with emissions reduction. The report 'Synchronising Energy Transitions Towards Possible Net Zero for India: Affordable and Clean Energy for All,' prepared by IIM Ahmedabad under the guidance of OPSA and launched in 2024, contributes to this objective. The report examines multiple technology pathways, including renewables, nuclear energy, and CCUS, and evaluates their cost implications, energy mix projections, and socio-economic impacts. By presenting evidence-based insights into long-term energy transitions, the study supports informed policy choices aimed at affordability, equity, and climate resilience.



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Emphasising STI for SDGs from **India to the World**

Addressing the scale and complexity of sustainable development challenges requires international collaboration. Recognising this, OPSA plays a key role in fostering global partnerships that support STI-driven solutions for SDGs. One such platform is Working Group 2 (WG2) on Green and Clean Energy Technologies under the India–European Union Trade and Technology Council (TTC). The India–EU TTC, announced in April 2022 and formally established in February 2023, is a high-level coordination mechanism designed to address strategic challenges at the intersection of trade, trusted technologies, and sustainability. Operating through three working groups, the TTC supports policy alignment, investment coordination, and innovation cooperation in a changing global landscape.

WG2 anchors the TTC's sustainability agenda by promoting cooperation in clean energy transitions, circular economy solutions, and environmental sustainability. Co-chaired by OPSA and the Directorate-General for Research and Innovation of the European Commission, WG2 focuses on joint research, innovation ecosystem engagement, and capacity building. OPSA has played a central role in shaping and operationalising WG2 since its inception. It supported the identification of priority areas and translated ministerial guidance into structured short-, medium-, and long-term cooperation roadmaps. Three priority research domains—waste-to-hydrogen, marine plastic litter mitigation, and battery recycling—were identified through this process.

Dr Parvinder Maini, Scientific Secretary, Office of PSA with Mr. Hervé Delphin, Ambassador of the EU to India

Key milestones include the launch of coordinated India-EU research and innovation calls with a combined investment of approximately ₹433 crore (€41 million), co-funded by Indian ministries and the EU's Horizon Europe Programme. These efforts are complemented by ecosystem engagement initiatives such as the India-EU Ideathon on Marine Plastic Litter and matchmaking events on battery recycling technologies, which have facilitated partnerships among startups, researchers, policymakers, and industry. Through workshops, technical meetings, and collaborative platforms, WG2 has enabled structured dialogue on standards development, joint R&D projects, and sustainable technology deployment. OPSA's leadership in WG2 highlights its role in aligning international cooperation with national priorities under SDG 7 and SDG 13.

2025 Edition of Chief Science Advisers' Roundtable (CSAR), Pretoria, South Africa

Additionally, the office is also active through the G20 Chief Science Advisers' Roundtable (CSAR), which was conceptualised during India's G20 Presidency in 2023 with technical contributions from OPSA, and provides a global platform for aligning STI policy with sustainable development goals. Under the G20 Presidency of South Africa, the CSAR adopted the theme "Equity-based Science, Technology and Innovation for Inclusive Human Development and Global Sustainability" highlighting the need for shaping a global STI agenda to support SDG implementation as well as just and equitable energy transitions. This has been reflected in the official Outcome Statement adopted in Pretoria which recognises the centrality of science, technology, and innovation in accelerating inclusive energy transitions, climate mitigation, and sustainable development, and underscores the need for STI to drive equitable access to clean technologies and knowledge systems worldwide. Beyond recognising the intrinsic link between STI and sustainable economic pathways, the CSAR 2025 prioritised building just energy transition frameworks that support a move away from carbon-intensive systems towards renewable and low-emission alternatives. This aligns very much with India's own clean energy commitments under SDG 7 and SDG 13.

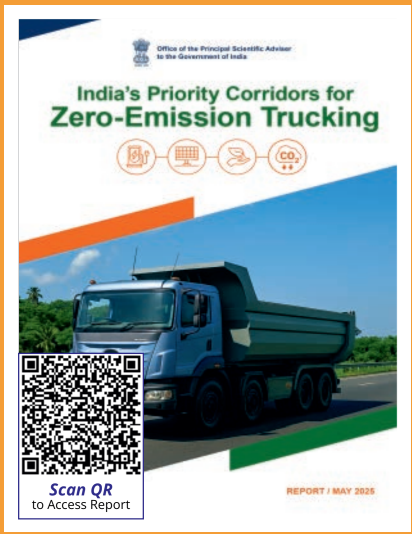
OPSA played a key advisory role in setting these agenda items for the G20-CSAR as well as supporting South Africa in executing the roundtable's strategic priorities, particularly with respect to embedding sustainability, inclusion, and equitable energy transitions into the global STI discourse. India's participation and thought leadership at G20-CSAR has included articulating mechanisms for STI capacity building for developing countries and frameworks for global energy equity, positioning OPSA as an influential voice in international science-policy ecosystems dedicated to sustainable development.

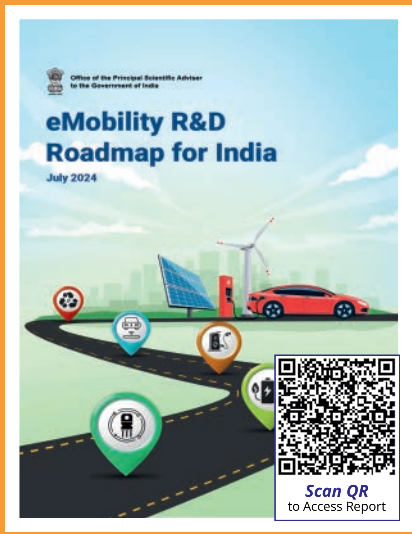
STI as a Transformational Force for **SDG 7 and SDG 13**

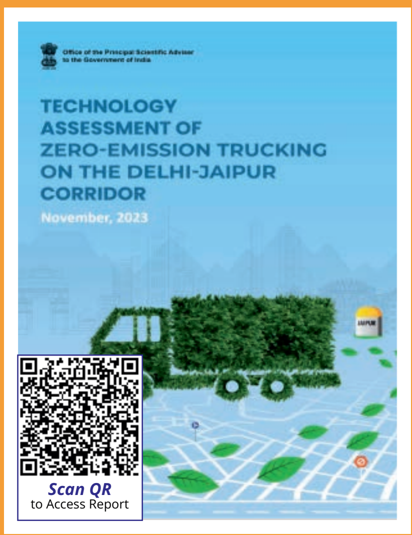
India's pursuit of affordable clean energy and climate action requires that STI remain central to policy and implementation. OPSA acts as a catalyst for this transformation by aligning research excellence, technological innovation, and cross-sectoral collaboration with national and global sustainability goals.

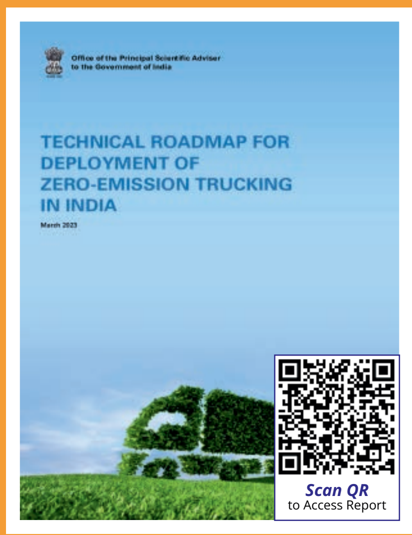
Through PM-STIAC, sectoral roadmaps, international partnerships, and evidence-based policy advisory, OPSA has helped embed sustainability into India's STI ecosystem. These efforts reflect a shift towards systems-level governance, where science, policy, and cooperation converge to support inclusive, affordable, and resilient energy transitions. As India navigates the dual imperatives of development and decarbonisation, OPSA's science-led, mission-driven approach offers a robust pathway for advancing SDG 7 and SDG 13.

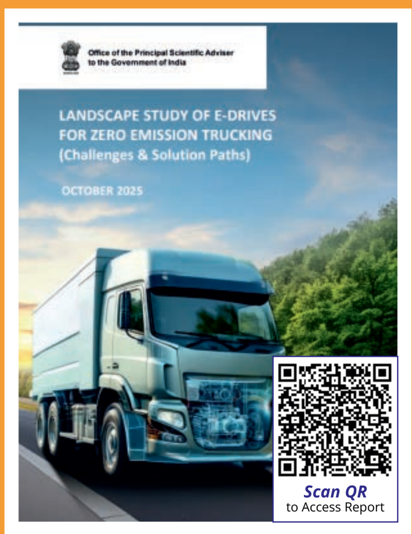
OPSA Knowledge Documents on **ZET**

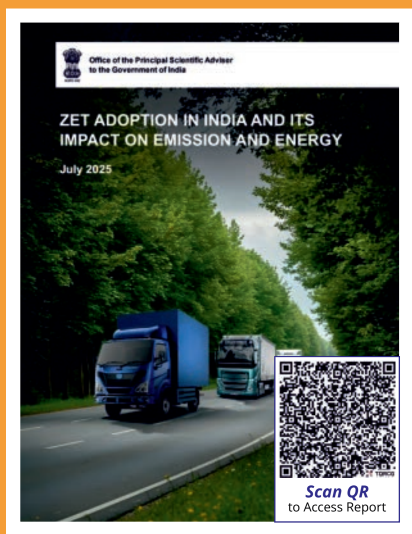












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