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Green Hydrogen

A Silver Bullet for Decarbonization of Hard-to-Abate Sectors

TERRA YOUTH

The Day the Sparrows Fell from the Sky



IN CONVERSATION

Rahul Mehta,
Founder, Mehta Family Foundation and

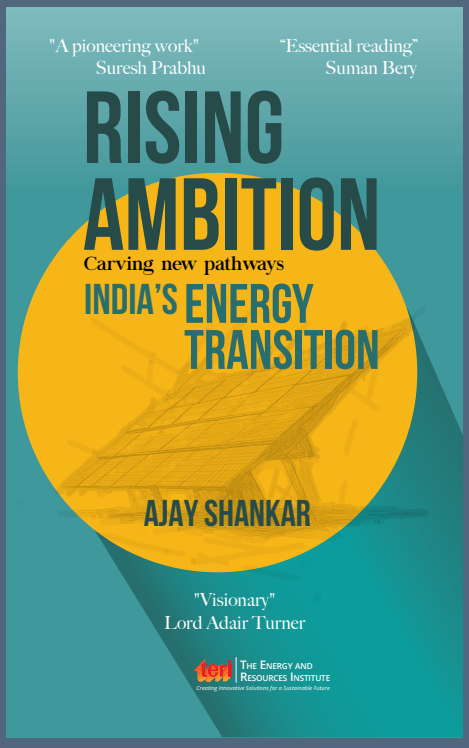
Prof. Pritee Sharma,
Head of the Mehta Family School of Sustainability, IIT Indore

SPECIAL HIGHLIGHTS

Deepening India's Secondary Market for Green Bonds

Bridging Agriculture, Energy, and Environmental Sustainability

teri



Rising Ambition Carving New Pathways India's Energy Transition

Ajay Shankar
Distinguished Fellow
The Energy and Resources Institute (TERI)

India aims to become net zero by 2070. This book sets out the pathways to net zero with key milestones. It suggests policy choices and ways to minimize the cost of this fundamental transition deriving lessons from the remarkable success that has been achieved in renewables. It makes the case that moving away from fossil fuels would also help India become a developed country with a competitive green economy.

Year: 2025
Size: 5 inch x 8 inch
Pages: 244
ISBN: 978-93-94657-19-9
Price: ₹495.00

"A meticulously documented analysis of India's decarbonization possibilities by one of our most thoughtful and experienced administrative scholars."

Suman Bery
Vice Chair, NITI-Aayog

"Becoming net zero while continuing to grow the economy would be one of India's critical challenges in the future. This is a pioneering work which gives an excellent and comprehensive analysis of the challenges and the best way to succeed."

Suresh Prabhu
Former Union Minister, Government of India

"Rising Ambition is analytically robust but also visionary and a critical guide to how India can both become a rich developed nation and make a major contribution to avoiding the potential catastrophe of global warming."

Lord Adair Turner
Chair Energy Transitions Commission

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EDITORIAL



> Green hydrogen offers a clean pathway for the hard-to-abate sectors where mitigating emissions appears a tall order.

Climate change remains the defining challenge of our time, driven by escalating greenhouse gas emissions from the power, industrial, and transport sectors. Despite the rapid expansion of renewable energy—now accounting for over 40 per cent of global electricity generation—so-called hard-to-abate sectors, including steel, cement, chemicals, aviation, and shipping, continue to contribute significantly to global emissions.

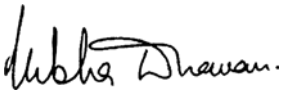
In this context, green hydrogen is emerging as a potentially transformative and sustainable solution. Unlike grey hydrogen, which is derived from fossil fuels, green hydrogen is produced through electrolysis using electricity from renewable sources and offers a viable low-carbon alternative in areas where direct electrification remains a challenge. Its applications are wide-ranging: from decarbonizing ammonia and methanol production to serving as a reductant in steelmaking, providing high-temperature industrial heat, and powering long-haul transport.

The cover story of this issue explores this transformative potential in depth. Green hydrogen offers a clean pathway for the hard-to-abate sectors where mitigating emissions appears a tall order. However, its adoption remains constrained by high costs relative to natural gas and grey hydrogen. In addition, higher uptake and scaling up its usage calls for substantial investments in production, storage, and transportation infrastructure to align with industrial demand.

These challenges are characteristic of a nascent industry competing with a conventional fossil fuel ecosystem that has evolved over several decades to achieve scale and cost competitiveness. Encouragingly, experience from other emerging technologies suggests that such barriers can diminish over time. As seen in the case of solar photovoltaics over the past decade, wider adoption and technological leapfrogging can significantly improve cost economics.

India's National Green Hydrogen Mission (2023) reflects this ambition, setting a target of producing 5 million tonnes of Green Hydrogen by 2030. The Mission emphasizes incentivizing the production of green hydrogen and its derivatives, alongside piloting applications in green steel, mobility, and shipping. Coupled with declining renewable energy costs and strong policy push, these efforts are expected to enhance the competitiveness of green hydrogen, particularly through strategies such as co-locating production with demand centres and scaling deployment. Backed by these developments, green hydrogen is well positioned to accelerate the global transition to net zero, especially in sectors once considered among the most difficult to decarbonize.

We hope you will find the articles in this issue both thought-provoking and inspiring, reinforcing our collective resolve to protect the planet's fragile equilibrium and advance towards a sustainable, carbon-neutral future.



Vibha Dhawan
Director-General, TERI



This is with reference to the article "Ubiquitous but Invisible High-Risk Chemicals" published in the February 26 issue of *TerraGreen*. The piece provides a clear and timely overview of PFAS, highlighting their persistence, widespread presence, and potential health risks. The article succeeds in simplifying a complex subject and drawing attention to an issue that often remains outside mainstream environmental discussions. Its emphasis on regulatory gaps and the urgent need for stronger monitoring is particularly relevant in the Indian context. Overall, the article is a valuable contribution and an important reminder of the need for greater awareness and policy action on such emerging environmental challenges.

Aditi Raman
Chennai, Tamil Nadu

This refers to the article on the revamping of Indian Climate Finance Taxonomy published in the February 26 issue of *TerraGreen*. The piece rightly highlights the transformative potential of directing billions towards climate action through a structured framework. While the taxonomy's intent is commendable, the concerns regarding ambiguities are equally significant. A lack of clear definitions and measurable criteria may create loopholes, allowing activities with limited environmental benefit to be labelled as "green." This risks undermining investor confidence and diluting genuine climate efforts. The article effectively underscores the need for transparency, robust safeguards, and alignment with global standards to prevent greenwashing.

Kanika Batra
New Delhi

This refers to the article on the burning of apple-pruning residue in Himachal Pradesh. The piece effectively highlights how this common practice, though convenient for farmers, contributes significantly to air pollution through emissions of $PM_{2.5}$, black carbon, and toxic gases. Particularly concerning is the impact on mountain regions, where temperature inversions trap pollutants and worsen air quality, posing serious health risks. The article's emphasis on practical, community-based alternatives such as mulching, composting, and shared chipping facilities is both constructive and timely. Encouraging supportive policies and biomass markets could further enable sustainable change. The article is a valuable call for balancing environmental protection with farmers' livelihoods.

Dr Rachna Gaur
Lucknow, Uttar Pradesh

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Livestock and Dairy Sector Contributes 85 Per Cent of Methane Emission in Himachal

The livestock and dairy production sector in Himachal Pradesh accounts for more than 85 per cent of the state's annual methane emissions, a new scientific assessment has warned, cautioning that the situation could worsen significantly if timely remedial measures are not adopted.

The findings are part of a report titled "Scientific Assessment of Tackling Non-CO_2 Emissions: Pathways for Himachal Pradesh". The report was released on February 24, 2026. The study highlights that methane emissions from livestock and domestic cattle form the overwhelming share of the state's non-carbon dioxide greenhouse gas burden, while the remaining 15 per cent is attributed to landfill sites, waste management and related sectors.

Source: https://indianexpress.com/

CPCB Report Flags Contamination in Punjab Groundwater

Fresh concerns have emerged over the safety of drinking water in Punjab after an assessment by the Central Pollution Control Board (CPCB) found contamination in groundwater sources at identified locations across rural and semi-urban areas of the state. The CPCB's regional directorate in Chandigarh constituted three monitoring teams to conduct groundwater sampling at 34 identified contaminated locations. The report was submitted to the National Green Tribunal (NGT) on April 2, which took *suo motu* cognisance of a report published in *The Times of India* highlighting groundwater pollution caused by agricultural run-off in Punjab, which has long been battling severe contamination of water due to unchecked dumping of untreated industrial waste, sewage, solid waste and excessive use of chemical fertilizers and pesticides.

Source: https://timesofindia.indiatimes.com/







Environmentalists Flag Negative Impact of 11,000 Litres of Milk Poured into Narmada River

Around 11,000 litres of milk were poured into Narmada River, often called the lifeline of Madhya Pradesh, in Sehore district on the culmination of a 21-day religious event as part of a sanctification ritual, prompting environmentalists to flag its negative impact on the ecosystem.

"Such large quantities of organic matter can deplete dissolved oxygen in water, adversely affecting the river ecosystem. These impact local communities dependent on the river for drinking water and threaten aquatic life as well as domestic animals," noted environmentalist and wildlife activist Ajay Dube said. Religious offerings should be symbolic and mindful, he asserted.

Source: https://www.deccanherald.com/



Threat to Over 2700 Buildings, Hydroelectric Projects in Kashmir from Five Glacial Lakes

A recent scientific study has raised serious concerns over the vulnerability of hundreds of households in Kashmir to Glacial Lake Outburst Floods (GLOFs), warning that at least five high-risk glacial lakes could potentially impact more than 2700 buildings, hydroelectric projects and infrastructure in the downstream areas in the Ganderbal, Shopian, and Kulgam districts.

The study, conducted by researchers from the Department of Geoinformatics at the University of Kashmir and published in the *Journal of Glaciology,* identifies five lakes—Bramsar, Chirsar, Nundkol, Gangabal and Bhagsar—as falling under the "very high susceptibility" category. Together, these lakes pose a threat to 2704 buildings, around 15 major bridges, road infrastructure and even a hydropower project located downstream.

Source: https://www.thestatesman.com/

Single-use Plastic Proliferates 89 Per Cent Places in Bhubaneswar, 86 Per Cent in Delhi



Amid strong calls for a blanket ban on single-use plastic (SUP), about 89 per cent places in Bhubaneswar have been found to be ruled by the banned SUP products, finds a recent survey. The Odisha capital, in fact, surpassed Delhi, Mumbai and Guwahati in the use of SUP products, revealed the field study carried out by Toxics Link, a New Delhi-based research and advocacy organization.

Toxics Link carried out on-ground assessment of the effectiveness of the SUP ban in different locations across Delhi, Mumbai, Bhubaneswar and Guwahati between April and August 2025. The methodology combined direct observation with structured survey tools to generate robust, city-level insights.

Source: https://www.newindianexpress.com/



Centre May Add Battery Storage under Revamped PM-KUSUM 2.0

The centre is considering incorporating a new provision for battery energy storage in the revamped Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan (PM KUSUM) scheme, as it works on formulating a new version of the flagship programme. Launched in 2019, the current PM-KUSUM scheme is set to expire soon, prompting discussions within the government on rolling out an updated version, likely to be called PM-KUSUM 2.0. While the current scheme focuses on solarization of agricultural pumps, it does not include battery storage. The addition is actively under consideration in order to address the growing challenge of mismatch between agricultural power demand and solar generation patterns.

Source: https://indianexpress.com/

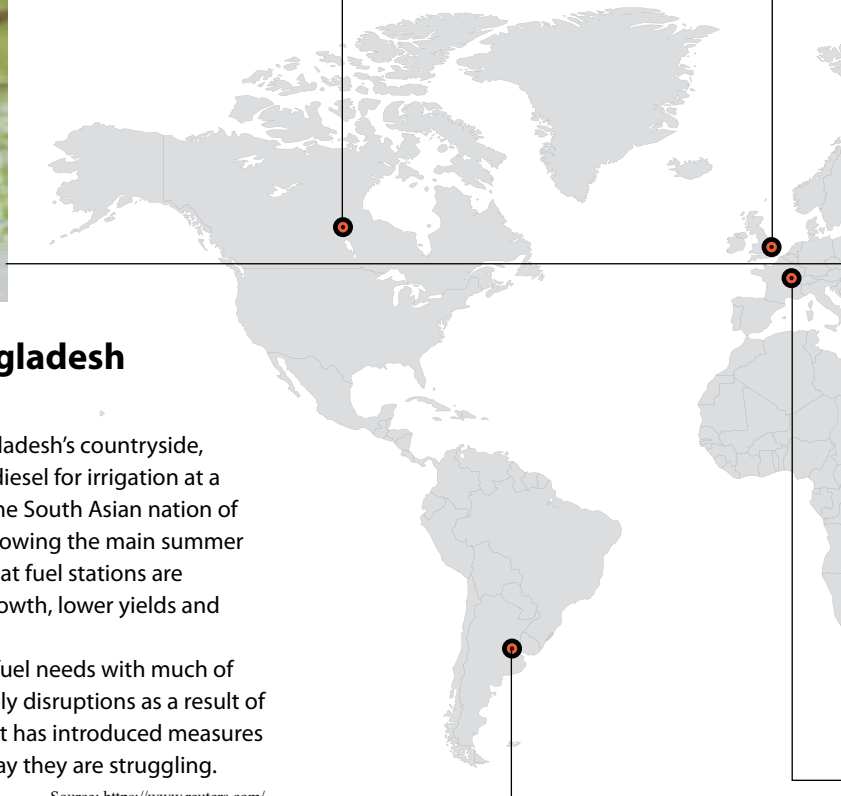


Canada Aims to Double Areas Protected from Development by 2030

Canada aims to double the size of lands and water that are protected from development by 2030 as part of a new C$3.8 billion nature strategy, Prime Minister Mark Carney told reporters recently. Ottawa will fund up to 14 new marine protected and conserved areas, and at least 10 new national parks and freshwater national marine conservation areas. It will also fund up to 10 new national marine conservation areas and 15 national urban parks. This will protect at least 1.6 million sq. km (620,000 square miles) of lands and up to 700,000 sq. km of oceans over the next four years.

Source: https://www.reuters.com/





War-fuelled Diesel Crunch Hits Bangladesh Farmers in Key Planting Season

The fuel crunch from the Iran war is rippling through Bangladesh's countryside, leaving tens of thousands of farmers struggling to secure diesel for irrigation at a critical stage of the paddy season. Rice is a staple food in the South Asian nation of 175 million people and late March is a crucial window for sowing the main summer crop. But diesel shortages, rationed sales and long queues at fuel stations are disrupting irrigation, heightening concerns about plant growth, lower yields and increased losses for farmers.

Bangladesh relies on imports for 80 per cent of its refined fuel needs with much of that coming from the Middle East. Price volatility and supply disruptions as a result of the war have squeezed supplies, but while the government has introduced measures to conserve energy and find new sources of fuel, farmers say they are struggling.

Source: https://www.reuters.com/

Argentina Passes Reform to Ease Mining Activity in Glacier Regions

Lawmakers in Argentina approved a government-backed reform recently that aims to promote mining investment in glacier regions, a step environmentalists and scientists have said would weaken protections and threaten water resources. Pushed by libertarian President Javier Milei's government, the reform drew controversy for allowing provinces to set their own glaciers and periglacial protection standards. This shift, critics say, could undermine safeguards for high-altitude ice formations that serve as key freshwater reserves. The measure is expected to generate $165 billion in exports by 2035 and create thousands of jobs, Economy Minister Luis Caputo said on X.

Source: https://www.reuters.com/

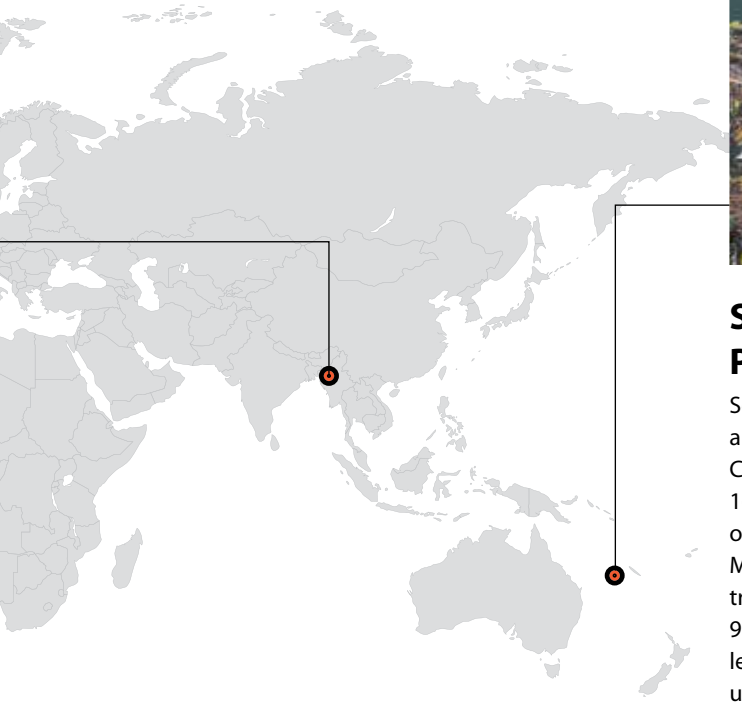




Golden Eagles could be Reintroduced to England after More than 150 Years

"The world is grown so bad that wrens make prey where eagles dare not perch." So wrote Shakespeare in Richard III, in a line of social commentary that feels ever more relevant with age. A note of good news then, in a world of so much bad, that the eagles the Bard was probably referring to could finally be reintroduced to England after more than 150 years. The golden eagle, which was common in Shakespearean England—and which he mentioned more than 40 times, according to some scholars—has been largely absent from the country's skies, with only a handful of pairs seen in the past 150 years.

Source: https://www.theguardian.com/





Seventy-Three Per Cent of World's Marine Protected Areas Polluted by Sewage

Seventy-three per cent of the world's marine protected areas (MPAs) are polluted by sewage, according to a new study by the Wildlife Conservation Society (WCS) and the University of Queensland. Over 16,000 MPAs globally were evaluated during the study, the findings of which was published in *Science Direct* titled 'Ocean & Coastal Management'. In the ocean regions most critical for coral reefs and tropical sea life, the problem is even worse: between 87 per cent and 92 per cent of protected areas are affected, and typical pollution levels inside these zones are ten times higher than in surrounding unprotected waters.

Source: https://www.deccanherald.com/

Interest in EVs Surges in Europe as Fuel Prices Jump After Iran War

Car buyers' interest in electric cars has surged across Europe since the start of the war in Iran, as the rising cost of petrol highlights the cheaper power available from a plug. Online marketplaces in the UK, Germany, France and Spain reported huge increases in inquiries about electric vehicles since the start of the conflict in February. The war caused rapid increases in petrol prices and protests around the world, while electricity prices have not been as badly affected. The first strikes were launched on February 28, causing turmoil on global commodities markets as Iran effectively shut down the strait of Hormuz, a key route for oil and gas exports.

Source: https://www.theguardian.com/



Union Budget 2026 Signals a Shift

From Farm Subsidies to Outcome-Driven Agricultural Research

In this article, **Dr Pushplata Singh** highlights that the Union Budget 2026 for agriculture marks a decisive recalibration of India's farm policy, signalling a gradual transition from a subsidy-reliant, relief-driven approach to a more technology-enabled, outcome-oriented, and sustainability-focused growth paradigm.

While short-term input subsidies and free distributions have historically helped cushion farmers against price shocks and climatic uncertainties, their long-term effectiveness in improving farm incomes, resource efficiency, and ecological sustainability has remained limited. Persistent challenges such as uneven access, fiscal leakages, weak targeting, and indiscriminate use of fertilizers, water, and agrochemicals have contributed to soil degradation, groundwater depletion, declining factor productivity, and environmental pollution—often without proportionate gains in yields or farm profitability. Recognizing these systemic limitations, the Union Budget 2026 places greater emphasis on innovation-led, precision-based interventions that empower farmers with better tools, information, and choices rather than deepening dependency on subsidies alone.

A certain message emerging from the budget is that future productivity growth must be driven by resource efficiency. The emphasis on advanced agricultural technologies—such as smart and customized agri-inputs, precision nutrient management, sensor- and satellite-enabled irrigation scheduling, and AI-driven decision-support systems—reflects the growing recognition that incremental increases in conventional fertilizer and input use are no longer viable in a resource-constrained and climate-stressed environment. These technologies guide actionable pathways to reduce input wastage, optimize timing and dosage, and enhance resilience to climatic variability. However, their success will depend on the simultaneous development of enabling policy frameworks and adaptive regulatory mechanisms to translate technological potential into widespread field-level adoption.

To operationalize this vision, the government must move beyond pilot-scale initiatives and prioritize large-scale deployment of precision agriculture through robust institutional mechanisms. Strengthening extension systems—by integrating digital advisory platforms, mobile-based decision tools in local languages, and village-level agri-tech facilitators—will be critical for accelerating adoption. Public investment should prioritize outcome-linked incentives, such as rewarding measurable reductions in fertilizer use, water consumption, or greenhouse gas (GHG) emissions, instead of subsidizing inputs indiscriminately. Linking precision practices to dynamic soil-health data, water budgeting, and crop-specific advisories generated by the Indian Council of Agricultural Research (ICAR) institutes and Krishi Vigyan Kendras (KVKs) across states, districts, blocks, and villages can help institutionalize data-driven farming decisions across India's diverse agro-climatic zones.

The budget also implicitly aligns agricultural productivity goals with India's broader climate and environmental commitments. Integrated nutrient, water and pest management, early detection of pest and disease outbreaks, and climate-resilient crop management practices can significantly reduce emissions of nitrous oxide, methane, carbon dioxide, and particulate pollutants such as $PM_{2.5}$, while sustainably maintaining or enhancing yields. Policy action in this area should focus on embedding agriculture more firmly within national climate missions, including the development of robust measurement, reporting, and verification (MRV) frameworks aligned with global standards for tracking emission reductions and ecosystem services from farming systems. Such frameworks could enable farmers to access emerging carbon-credit markets, results-based climate finance, and sustainability-linked value chains, thereby creating additional income streams associated with environmental performance.

Beyond crop production, the Union Budget 2026 adopts a more holistic and forward-looking approach to rural livelihoods by extending focused policy support to allied sectors such as fisheries, dairy, and poultry. These sectors offer faster income realization, higher employment intensity, and greater resilience to climate risks compared with monocropping systems. From a policy

perspective, diversification into allied activities should no longer be treated as a peripheral intervention but as a core strategy for income stabilization and rural economic resilience. Actionable measures must therefore focus on integrated value-chain development—covering breed improvement, feed and nutrition efficiency, animal health services, cold-chain and processing infrastructure, and assured market access.

One of the most consequential signals in the Union Budget 2026 is the recalibration of research allocations to institutions such as the Indian Council of Agricultural Research (ICAR). While this adjustment may appear constraining in the short term, it reflects a strategic push towards greater efficiency, accountability, and impact orientation in public agricultural research. The policy intent is clear: research investments must deliver measurable, scalable, and field-ready outcomes rather than incremental or siloed scientific outputs. This shift places a responsibility on the research ecosystem to realign priorities towards problem-driven innovation that directly addresses emerging challenges such as climate change, declining soil fertility, water scarcity, pest resistance, and nutritional security.

To meet these expectations, agricultural research institutions must strengthen translational research frameworks that bridge the gap between laboratory discoveries and on-farm adoption. This includes prioritizing demand-driven research agendas co-designed with farmers, extension agencies, and industry stakeholders. Developing climate-resilient nutritionally enhanced seed varieties, next-generation smart agri-inputs with higher nutrient-use efficiency, and integrated crop management packages tailored to specific agro-ecological conditions should be central to research planning. Moreover, specialized ICAR institutes working on fisheries, poultry, and livestock should intensify research to develop improved breeds and production systems that can contribute to addressing India's malnutrition challenge. Equally important is the establishment of clear performance metrics—such as adoption rates, income gains, resource savings, and environmental benefits—to evaluate research outcomes.

Public–private partnerships (PPPs) will play a critical role in maximizing the impact of limited public research funds. By leveraging private-sector capabilities in product development, manufacturing, and distribution, public research institutions can accelerate the scaling of innovations while ensuring affordability and accessibility for smallholders. Policy frameworks should therefore facilitate co-funding mechanisms, shared intellectual-property models, and regulatory fast-tracking for validated technologies that demonstrate clear public-good benefits. Encouraging start-ups and agri-entrepreneurs to collaborate with public research institutions can further strengthen regional innovation ecosystems. Equally vital is investment in human capital and institutional capacity to support dynamic, outcome-driven research. Such research demands interdisciplinary expertise spanning agronomy, soil science, climate modelling, data analytics, economics, and social sciences. Rather than pursuing overlapping institutional mandates, clearer mission-oriented research priorities should be assigned to institutes funded by ICAR, the Department of Biotechnology (DBT), and the Department of Science and Technology (DST). Capacity-building programmes for researchers, extension professionals, and policy implementers must therefore be prioritized to ensure that scientific advances translate into behavioural change at the farm level. Strengthening monitoring systems and feedback loops between farmers and researchers can help refine technologies in real time and enhance their relevance across diverse farming contexts.

In essence, the Union Budget 2026 articulates a clear policy direction: sustainable agricultural growth in India will increasingly be driven by technology-enabled precision farming, diversification, and measurable outcomes rather than by indiscriminate input intensification. The emphasis on outcome-oriented research reflects the growing recognition that science must deliver solutions that are not only innovative but also adoptable, scalable, and impactful. The success of this transition will depend on coherent implementation, stronger institutional coordination, and sustained investment in extension systems, research translation, and farmer capacity-building. If executed effectively, this policy shift could place Indian agriculture on a more resilient, resource-efficient, and income-secure path—benefiting farmers, consumers, and the environment alike. ■



Dr Pushplata Singh, Senior Fellow and Director, Sustainable Agriculture Division, TERI, New Delhi.

AI Uses as Much Energy as Iceland

But Scientists Aren't Worried!

AI's growing energy use sounds alarming, but its global climate impact may be far smaller than expected. Researchers found that while AI consumes huge amounts of electricity, it barely moves the needle on overall emissions. The real impact is more localized, especially around data centres. Meanwhile, AI could become a powerful tool for building greener technologies.

Artificial intelligence (AI) is often blamed for driving up energy use and worsening climate change, but new research suggests its overall impact on global emissions is surprisingly small. The findings even point to potential environmental and economic benefits as AI continues to expand.

Researchers from the University of Waterloo and the Georgia Institute of Technology analysed data from across the US economy alongside estimates of how widely AI is being used in different industries. Their goal was to understand what might happen to energy use and emissions if AI adoption keeps growing at its current pace.

Data from the US Energy Information Administration shows that 83 per cent of the US economy still relies on fossil fuels such as petroleum, coal and natural gas, all of which produce greenhouse gases when burned. The researchers found that AI-related electricity use in the US is comparable to the total energy consumption of Iceland. Even so, this increase is too small to significantly affect emissions at the national or global level.

Local Effects near Data Centres

"It is important to note that the increase in energy use is not going to be uniform. It's going to be felt more in the places where electricity is produced to power the data centres," said Dr Juan Moreno-Cruz, a professor in the Faculty of Environment at Waterloo and Canada Research Chair in Energy Transitions.

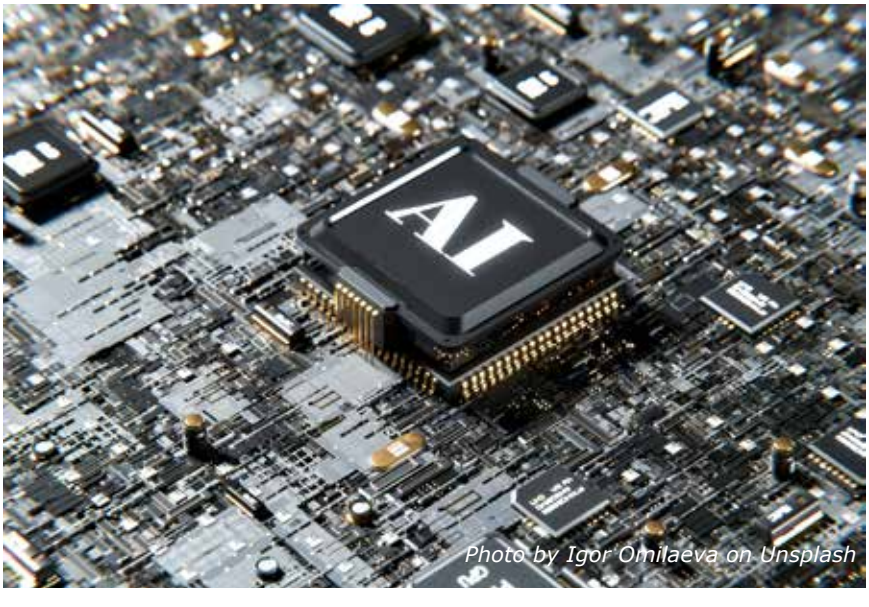


Photo by Igor Omilaeva on Unsplash

"If you look at that energy from the local perspective, that's a big deal because some places could see double the amount of electricity output and emissions. But at a larger scale, AI's use of energy won't be noticeable."

The study did not focus on how local economies might be affected in regions where data centres are concentrated, but the broader findings remain encouraging.

AI as a Potential Climate Solution

"For people who believe that the use of AI will be a major problem for the climate and think we should avoid it, we're offering a different perspective," Moreno-Cruz said. "The effects on climate are not that significant, and we can use AI to develop green technologies or to improve existing ones."

To reach these conclusions, Moreno-Cruz and fellow environmental economist
Dr Anthony Harding evaluated different sectors of the economy, the types of jobs within them, and how many of those roles could be handled by AI. The researchers plan to expand their analysis to other countries to better understand how AI adoption could influence energy use and emissions worldwide.

The study, "Watts and Bots: The Energy Implications of AI Adoption," was published in *Environmental Research Letters*.■

Source: www.sciencedaily.com

Scared of Spiders?

Scientists Say the Real Nightmare is Losing Them

Spiders and insects may not be fan favourites, but they are vital to the health of ecosystems—and scientists barely know how they're doing. Researchers found that nearly 90 per cent of North America's insect and arachnid species have no conservation status, leaving their fate largely unknown. Even more striking, most states don't protect a single arachnid species. The study warns that these overlooked creatures are essential to planetary health and urgently need better monitoring and protection.

Members of the arachnid class—think spiders, scorpions and harvestmen (daddy long legs)—often trigger feelings of fear or disgust. Despite this reaction, these animals play an essential role in maintaining healthy ecosystems. As global biodiversity declines, including what some researchers describe as an "insect apocalypse," two ecologists at the University of Massachusetts Amherst set out to examine how insects and arachnids are doing in the United States. What they uncovered was striking: there are enormous gaps in the available data. Their findings, recently published in *PNAS*, highlight an urgent need to better study, protect and appreciate insects and arachnids, which form a critical foundation for planetary health.

"Insects and arachnids are fundamental for human society," says Laura Figueroa, assistant professor of environmental conservation at UMass Amherst and the study's senior author. "They help with pollination and biological control of pests; they can serve as monitors of air and water quality, and they have worked their way deeply into many cultures throughout the world"—think of Aragog in the Harry Potter book series, for example. "Many people care about popular charismatic animals on the planet, like lions and pandas, which, justly, have received international conservation attention. Given that insects and arachnids don't usually get the same attention, we wanted to know how they were doing."

To understand the condition of these often overlooked creatures, Figueroa and her graduate student Wes Walsh, the paper's lead author, compiled conservation assessments for the 99,312 known insect and arachnid species living in North America north of Mexico. The results were startling. "Almost 90 per cent—88.5 per cent to be precise—of insect and arachnid species have no conservation status," says Figueroa. "We simply have no idea how they are doing. Almost nothing is known about the conservation needs of most insects and arachnids in North America."

The limited information that does exist is uneven. Much of the available research focuses on aquatic insects that help scientists monitor water quality (mayflies, stoneflies, and caddisflies). Meanwhile, more visually appealing insect groups such as butterflies and dragonflies receive a disproportionate share of conservation protections.

"Arachnids, in particular, are really missing from conservation; most states don't even protect a single species. We need more data and protection for insects, but also arachnids," says Walsh.

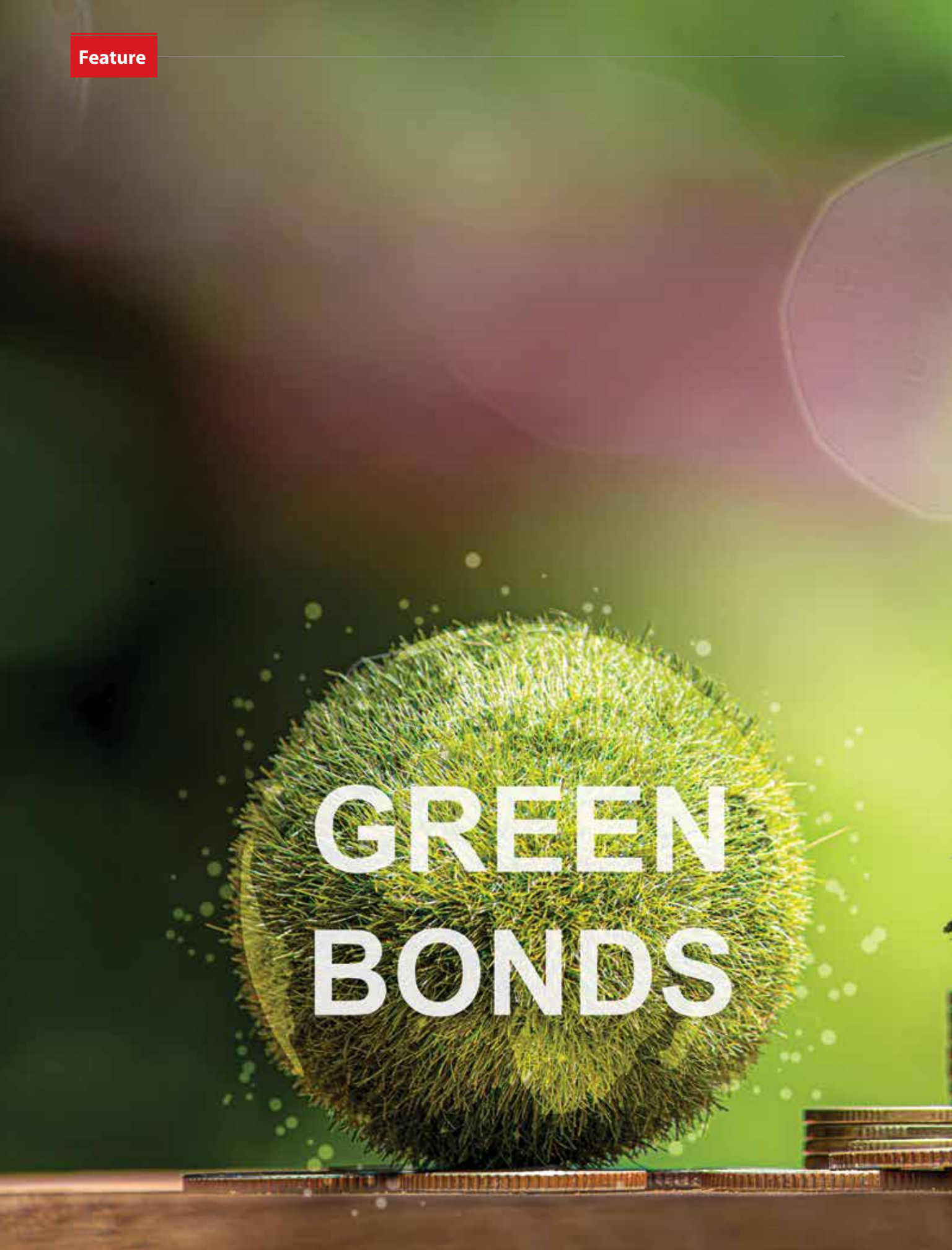


Photo by Leigh Miles on Unsplash

Conservation Protection Varies by State

The researchers also found patterns in which states are more likely to protect these species. States that depend heavily on extractive industries such as mining, quarrying and oil and gas extraction tended to offer fewer protections for insects and arachnids. In contrast, states where public attitudes are more environmentally focused were more likely to safeguard a larger number of species.■

Source: www.sciencedaily.com


GREEN
BONDS

Deepening India's Secondary Market for Green Bonds

Opportunities, Challenges and a Strategic Growth Path

In this article, **Dr Ria Sinha** says India's green bond market has grown significantly, reaching about USD 55.9 billion by 2024, but remains underdeveloped in secondary market liquidity and investor participation. While issuances by corporates, sovereigns, and municipalities have expanded climate financing, most bonds are held to maturity, limiting trading and price discovery. Weak liquidity, limited ESG mandates, and lack of supportive policies constrain the emergence of a "greenium." Strengthening secondary markets through benchmark issuances, market-making, tax incentives, and improved transparency is essential to mobilize private capital and support India's low-carbon transition.





India's green bond market has transitioned from early experimentation in the 2010s (with the launch of first green bond by Yes Bank in 2015 to issue of first sovereign green bond by RBI in 2023) to a credible and dynamic segment of the domestic debt capital market but it remains nascent, especially when it comes to secondary market liquidity, pricing dynamics and investor participation. Over the past decade, issuers have increasingly turned to green-labelled instruments to fund climate mitigation and sustainable infrastructure projects, yet the full potential of green finance particularly in catalysing private capital at scale remains constrained by structural market gaps. Strengthening the secondary market for green bonds is therefore not just a technical financial objective but a strategic imperative to unlock deeper climate capital flows for India's low-carbon transition.

Evolution of the Green Bond Market in India

Green bonds were first introduced globally in the mid-2000s but began gaining traction in India in the mid-2010s as part of broader sustainable finance efforts. Early issuances were dominated by corporate and financial entities focused on renewable energy and energy efficiency projects. Over time, regulatory frameworks evolved with SEBI's green debt securities guidelines and the introduction of sovereign green bonds (SGrBs), intended to deepen the domestic yield curve and signal institutional commitment to climate financing.[1]

By the end of 2024, India's cumulative issuance of green, social, sustainability and sustainability-linked (GSS+) debt with green bonds forming the majority reached approximately USD 55.9 billion, up about 186 per cent since 2021. Green-labelled instruments account for roughly 84 per cent of that total, reflecting a steady rise in use-of-proceeds finance aligned with climate and sustainability objectives.[2]

Despite this growth, green bonds still represent a small proportion of the overall fixed-income universe in India. As of early 2023, GSSS bonds accounted for only around 3.8 per cent of the domestic corporate bond market, underscoring the relative infancy of the green bond segment compared with conventional debt.[3]

[1] Details available at https://www.climatebonds.net/news-events/press-room/press-releases/indias-sustainable-debt-market-tops-usd-55-9-billion-new-mufg-cbi-report-maps-rapid-growth-pathways-2030

[2] Details available at https://www.climatebonds.net/news-events/press-room/press-releases/indias-sustainable-debt-market-tops-usd-55-9-billion-new-mufg-cbi-report-maps-rapid-growth-pathways-2030

[3] Details available at https://timesofindia.indiatimes.com/indias-green-bond-issuances-just-3-8-pc-of-overall-domestic-corporate-bond-market-report/articleshow/97804501.cms

Major Issuers and Investor Participation

India's green bond market today reflects a diverse issuer base that spans corporate, sovereign, and municipal entities. The largest corporate issuer, Greenko Group, has deployed green bond proceeds across hydro, solar and wind projects in multiple states, demonstrating how private platforms are leveraging capital markets to scale renewable infrastructure. Since January 2023, the GoI has added further credibility to the market by raising approximately INR 477 billion through multiple sovereign green bond tranches, contributing to the formation of a domestic green yield curve.

Very recently, Bank of Baroda (BoB) undertook a INR 10,000 crore infrastructure bond issuance—the first such issuance by an Indian bank—marking a significant milestone in the renewable energy finance space. Public financial institutions such as Rural Electrification Corporation (REC) Limited and Indian Renewable Energy Development Agency (IREDA) have also emerged as repeat issuers, using green bonds to expand lending for renewable energy and energy-efficient infrastructure. With coupon rates typically ranging between 6.5 and 8.4 per cent, these issuances align closely with conventional investment-grade debt, underscoring that green bonds in India are financially competitive instruments rather than concessional products. REC's successful international issuances including USD and JPY denominated bonds with post-issuance assurance, further signal the growing integration of Indian green debt into global capital markets.

At the sub-national level, municipal issuances such as those by Vadodara, Ahmedabad, Indore and Ghaziabad illustrate the expanding geographic footprint of green finance. Retail participation thresholds as low as INR 10,000 have begun to democratize

access to climate infrastructure financing. Meanwhile, exchanges are responding to this evolution: BSE's India International Exchange has launched the Global Securities Market (GSM) Green platform, providing a formal listing and trading infrastructure for green, social and sustainability bonds—an important step towards institutionalizing secondary market activity.

On the demand side, institutional investors' banks, insurance companies, mutual funds and foreign portfolio investors continue to dominate. Retail participation, though growing through brokerage apps and digital bond marketplaces, remains limited. This asymmetry between issuer ambition and investor breadth is one of the structural features shaping India's secondary green bond landscape.

Sectoral Focus in India's Green Bond Financing

Predominantly in India, green bond proceeds have largely been directed towards core climate mitigation sectors. Renewable energy particularly solar, wind, and related grid infrastructure accounts for the largest share, in line with the country's non-fossil capacity goals. Sovereign green bond frameworks also prioritize sustainable transport and energy-efficient infrastructure, including transport electrification, railway electrification, and efficiency improvements. Urban water and waste management have emerged as important areas as well, with municipal



issuances such as Vadodara's wastewater infrastructure bond demonstrating how city-level sustainability projects can attract climate capital. Beyond these established sectors, interest is gradually growing in newer transition areas such as just transition initiatives, green buildings and climate adaptation, which often require innovative financing structures and credit enhancements to mobilize private investment.

The Case for a Strong Secondary Market for Green Bonds

A vibrant primary market alone cannot sustain a climate finance ecosystem. What ultimately determines the credibility and scalability of green bonds is the strength of their secondary market. Active trading enables transparent price discovery, allowing investors to compare green bonds with conventional securities and assess whether a pricing premium often termed the 'greenium' truly exists. Without such transparency, claims of preferential pricing remain anecdotal rather than structural.

Liquidity is equally critical. Investors, particularly institutions managing large portfolios, require confidence that bonds can be bought and sold efficiently without excessive transaction costs. Where liquidity is weak, bonds are often held to maturity, restricting turnover and suppressing market dynamism. For issuers, this illiquidity can translate into muted pricing advantages and limited repeat issuance incentives.

Moreover, a functioning secondary market strengthens the broader ecosystem. It supports the emergence of benchmark indices, encourages market makers to provide continuous quotes, and enhances analytical coverage. Over time, this infrastructure fosters innovation including sustainability-linked instruments, blended finance structures and credit-enhanced green bonds, all of which depend on credible price signals.



Present Challenges in India's Secondary Green Bond Market

Despite strong issuance momentum, India's secondary green bond market remains structurally shallow. A significant proportion of bonds are held to maturity by institutional investors, leaving limited tradable volumes in the market. Small issue sizes and concentrated ownership in a few institutional portfolios further reduce turnover, weakening price discovery and bid-ask depth.



The limited emergence of a meaningful greenium illustrates this challenge. In mature European markets, green bonds often trade at slightly lower yields than their conventional counterparts, with greenium yields varying in the range of 3–14 bps[4] reflecting strong demand and ESG integration mandates. In India, however, sovereign green bonds have generated only marginal yield differentials often in the range of 0–6 basis points suggesting that demand remains broad-based rather than green-specific.[5] Without deeper institutional ESG mandates and retail participation, pricing advantages are unlikely to widen.

Policy architecture also plays a role. While regulatory frameworks for issuance and disclosure have strengthened, measures specifically aimed at enhancing secondary liquidity such as designated market makers, repo eligibility, capital incentives, or tax advantages remain limited. In the absence of such mechanisms, green bonds compete directly with more liquid conventional securities.

Finally, the ESG investment ecosystem itself is still evolving. Although disclosure norms have improved and sustainability-linked frameworks have gained clarity, standardized impact reporting, independent verification and widely followed green bond indices remain in development. Until investors can consistently measure environmental outcomes and compare performance benchmarks, trading depth will likely remain constrained.

Global Benchmarks: Mature Secondary Green Bond Markets

The experience of mature green bond markets offers valuable lessons for India's secondary market development. In Europe, sovereign green bonds have evolved into benchmark securities that trade actively and anchor broader sustainable debt ecosystems. Germany's 'Green Bunds,' for instance, are issued alongside conventional twin bonds of identical maturity, allowing investors to directly compare pricing between green and non-green securities.[6] This structure enhances price transparency and supports consistent secondary trading, helping establish credible green yield curves.

France has followed a similar path, issuing large, multi-maturity sovereign green bonds that serve as reference points for institutional portfolios. The scale and regularity of these issuances have ensured that the bonds remain liquid in secondary markets, with narrower bid-ask spreads and visible pricing differentials relative to conventional Obligations Assimilables du Trésor (OATs).[7] Over time, this depth has attracted global investors and strengthened France's position as a leader in sustainable sovereign finance.

In the United Kingdom and Spain, repeated sovereign green bond issuance has similarly contributed to market liquidity. The UK's green gilts, listed on the London Stock Exchange's Sustainable Bond Market, benefit from active trading infrastructure and strong institutional ESG mandates.[8]

Beyond sovereign debt, corporate green bonds in Europe and North America trade regularly on electronic platforms such as MarketAxess[9] and Bloomberg, enabling transparent secondary pricing and global portfolio integration. Large issue sizes, diverse investor bases, and well-developed ESG disclosure frameworks ensure that green bonds are embedded within mainstream fixed-income strategies rather than treated as niche products.

Taken together, these global examples highlight a critical point: secondary market depth is not merely a by-product of primary issuance. It emerges from scale, repetition, investor mandates, credible reporting standards,

[4] Details available at https://www.mdpi.com/2227-9091/11/1/14

[5] Economic Survey 25-26; details available at https://www.indiabudget.gov.in/economicsurvey/doc/echapter.pdf

[6] Details available at https://www.bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Public-Finances/Sustainable-Development-Strategy/green-german-federal-securities-restricted/2020-11-18-green-bond-framework-englisch.pdf?__blob=publicationFile&v=1&utm_source=chatgpt.com

[7] Obligations Assimilables du Trésor, a French term for French Govt. Bonds

[8] Details available at https://www.lseg.com/en/media-centre/press-releases/2021/uk-lists-its-10bn-inaugural-green-gilt-london-stockexchange#:~:text=LSEG%20welcomes%20the%20UK%20Government's%20inaugural%20green,12%2Dyear%20bond%20maturing%20on%2031%20July%202033.

[9] It is one of the leading fixed income electronic trading platforms for institutional investors and dealers.

and robust trading infrastructure.[10] For India, the lesson is clear. Building a vibrant secondary green bond market will require moving beyond sporadic issuance towards systematic benchmark creation, enhanced liquidity mechanisms and broader investor integration.

Public Policy and Private Sector Roles in Strengthening Secondary Markets

Strengthening the secondary market will require coordinated intervention across policy, market infrastructure, and investor behaviour. A logical starting point lies with sovereign issuance strategy. By issuing green bonds regularly across standard maturities such as 5, 10 and 20 years, the government can create benchmark securities that anchor a transparent green yield curve. Benchmark bonds naturally trade more frequently, serve as pricing references for corporate issuances and improve market confidence.

Equally important is the development of active market-making. Financial institutions incentivized to provide continuous buy and sell quotes can narrow bid-ask spreads and improve liquidity. Regulatory measures such as repo eligibility or capital treatment incentives would further encourage participation by banks and primary dealers.

Taxation policy may also influence retail engagement. Currently, green bonds offer no preferential tax treatment compared with conventional securities. Partial tax incentives or capital gains benefits could improve post-tax returns and broaden the investor base.

Beyond policy levers, transparency remains foundational. Standardized impact reporting aligned with



international frameworks such as ICMA's Green Bond Principles or Climate Bonds Initiative (CBI) standards can strengthen investor trust and differentiate credible instruments from weakly labelled products. The development of green bond indices and analytical tools tracking pricing performance would also enhance secondary market visibility.

Finally, innovation in credit enhancement and blended finance structures can expand the pool of investible securities. Guarantees, aggregator bonds and risk-sharing facilities could make climate projects in harder-to-finance sectors such as just transition or adaptation more attractive to mainstream investors.[11]

Conclusion: A Strategic Imperative for Climate Capital

India's green bond market has advanced from experimental beginnings to a significant emerging market segment, with cumulative issuance of nearly USD 55–56 billion across climate-aligned debt by the end of 2024.[12] With over more than INR 31,000 crore projects lined up for funding through green bond proceeds in FY27,[13] secondary market liquidity, pricing dynamics and investor breadth remain underdeveloped compared with mature global peers. Without stronger trading platforms, clearer price discovery and broader investor engagement, the market will struggle to scale and attract sufficient private capital to meet India's climate finance needs estimated at USD 1.3 trillion by 2030.[14]

A robust secondary green bond market is not an end in itself, but an essential enabler of climate capital flows, innovation and sustainable infrastructure financing. By learning from global benchmarks, enhancing policy frameworks, and democratizing access for a wider investor base, India can turn its green bond market into a powerful engine for sustainable development mobilizing domestic and international capital to fund the transition to a low-carbon, resilient economy. ■

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[10] Economic Survey 25-26; details available at https://www.indiabudget.gov.in/economicsurvey/doc/echapter.pdf

[11] Details available at https://www.reuters.com/world/india/global-credit-guarantor-bets-big-india-with-500-million-plan-exec-says-2025-11-10/

[12] Details available at https://www.climatebonds.net/news-events/press-room/press-releases/indias-sustainable-debt-market-tops-usd-55-9-billion-new-mufg-cbi-report-maps-rapid-growth-pathways-2030

[13] Details available at https://economictimes.indiatimes.com/news/economy/finance/projects-worth-31000-crore-to-be-funded-mainly-via-green-bonds-in-fy27/articleshow/127949205.cms?utm_source=chatgpt.com&from=mdr

[14] Details available at https://economictimes.indiatimes.com/industry/banking/finance/india-to-need-1-3-trillion-green-social-funds-by-2030-says-report/articleshow/122111525.cms



From Classrooms to Climate Leadership

Shaping India's Sustainability Future

The Mehta Family Foundation (MFF) has been associated with the Indian Institute of Technology (IIT) system for over two decades. Today, MFF runs 8 Mehta Family Schools across 6 IITs in areas such as AI, biosciences, and sustainability; subjects core to India's future growth story. Here, we are in an exclusive email conversation with **Rahul Mehta**, Founder, Mehta Family Foundation and **Prof. Pritee Sharma**, Head of the Mehta Family School of Sustainability, IIT Indore.



We read that Mehta Family Foundation (MFF) has pioneered new educational models within the IIT system—from Data Science to Sustainability. What motivated the Foundation to focus so strongly on talent creation, and how do you decide which disciplines are most critical for India's future?

Rahul Mehta: Our focus on talent creation stems from a fundamental belief, that India's greatest resource is the untapped intellectual potential of our young people. When we started working with IITs over two decades ago, we observed that Industry was moving at a pace that was dramatic and we asked ourselves: what could India achieve if we equipped our brightest minds with skills that were not just relevant, but anticipatory? We decided to focus on building capacity for the future in emerging fields, rather than scrambling to catch up after the market had already moved.

As for deciding which disciplines matter most, we don't rely on guesswork. The process is initiated as in-depth discussions among the IITs and MFF, including our CARE (Collaborative for Academic and Research Excellence) Advisors composed of leading academicians across top international universities. Together we analyse global economic megatrends through comprehensive research and stakeholder consultations. Second, we examine where India has natural competitive advantages, whether demographic, geographic, or institutional. Third, we identify capability gaps where targeted intervention can create disproportionate impact.

Data Science emerged from this framework in 2016. We saw AI would reshape every sector, yet India's universities were producing virtually no qualified data scientists at that time. Today, our pioneer IIT Guwahati programme has become a model replicated across other institutes, with the first undergraduate batch being successfully placed at global firms.

Sustainability followed similar logic. India faces existential climate risks—water stress, agricultural vulnerability, and clean energy. Yet we were importing both technology and expertise to address these challenges. We recognized that sustainability is an economic opportunity and the global green economy will be worth trillions.



Rahul Mehta



Prof. Pritee Sharma

Looking ahead, what is MFF's vision for India's role in the global sustainability landscape? How do you see India transitioning from being a technology importer to a knowledge exporter in this critical domain?

Rahul Mehta: I believe we are at an inflection point. For too long, sustainability conversations have been dominated by Western institutions and corporations, with India cast as either victim or student. That narrative is not just limiting but also wrong.

Our straightforward yet ambitious vision is that India should become the global South's intellectual hub for affordable, scalable sustainability solutions. Not by copying models designed for wealthy, temperate nations, but by pioneering approaches that work in hot, resource-constrained, densely populated environments—conditions that characterize most of the developing world.

The transition from importer to exporter is already underway,

though its early days. The Centres of Excellence being established at our IIT Indore's School of Sustainability will be focusing on Energy Systems and Battery Technology, Environmental Economics and Environmental Law, and Water and Climate Studies, building a comprehensive knowledge architecture for sustainable development that the Global South desperately needs.

The pathway requires three simultaneous shifts. First, research infrastructure which is investing in labs, datasets, and computing power that can support world-class work. Second, talent density which requires creating clusters of expertise that generates collaborative breakthroughs rather than isolated projects. Third, market linkages to connect academic research with industry partners and policy frameworks, ensuring innovations get deployed at scale.

I am particularly excited about what can be defined as 'frugal sustainability', which are high-impact solutions designed for low-resource contexts. This is India's comparative advantage. When our researchers develop a solar microgrid controller optimized for irregular power, or a water purification system that costs a tenth of Western equivalents, they are creating knowledge products that billions of people need.

We are also seeing a promising movement in policy. The government's National Action Plan on Climate Change and ambitious renewable energy targets create demand signals that draw private investment and talent. MFF's role is catalytic in the sense that we de-risk early-stage research, train the human capital, and build the institutional foundations that make sustained innovation possible.

Within a decade, I envision Indian institutions regularly publishing breakthrough sustainability research, Indian startups exporting clean technology to global markets, and Indian professionals being recruited worldwide as domain experts, simply because they are producing superior solutions to shared challenges.

How do you see "intellectual infrastructure"—the human talent to design, govern, and scale systems such as solar parks, EV corridors, and green hydrogen—as equally vital to India's green transition?

Prof. Pritee Sharma: India as a young nation with a rapidly expanding population, is witnessing rising consumption demands across energy, materials, goods, and services. Meeting these demands sustainably, amid scarce natural resources and the global imperative of carbon-responsible growth, requires thoughtful restructuring of both production and consumption pathways. This transition cannot be achieved through physical infrastructure alone. It must be anchored in education, awareness, and strong policy interventions at multiple scales.

To advance a green, resource-efficient economy, India needs to build knowledge and skill-based human capital capable of conceiving ideas, designing for sustainability, and innovating clean technologies. The goal is to develop capable talent at all levels and in large numbers not only to support India's green growth, but also to provide pathways for other emerging economies seeking low-carbon development models.

Demand for expertise in green sectors is already rising rapidly, requiring robust knowledge architecture backed by research and development, digital systems, standards and regulations, and large-scale training ecosystems. Schools, universities, and higher-education institutions must therefore cultivate a skilled workforce, offer reskilling opportunities for existing professionals, and foster industry-academia collaboration alongside policy think tanks and regulators.

Investing in this talent pipeline will convert India's demographic advantage into "climate intellectual capital," enabling the country to innovate at scale and lead the clean-technology value chain. In this sense, intellectual infrastructure becomes the true multiplier, ensuring that physical assets like steel, silicon, and capital translate into a just, competitive, and resilient green economy.



The Mehta Family School of Sustainability at IIT Indore is being called India's first undergraduate programme that blends Environmental Economics with Sustainable Engineering. What makes this model distinctive, and how will it prepare students to become both innovators and policy shapers?

Prof. Pritee Sharma: The B.Tech in Environmental Economics and Sustainable Engineering at IIT Indore has been conceived as a first-of-its-kind undergraduate programme in India that holistically integrates engineering,

economics, and policy for sustainability. At a time when the world requires professionals who can bridge climate science, technology deployment, resource efficiency, and public policy, this programme will create graduates who are trained to become technology innovators, climate experts, and policy shapers.

What distinguishes the programme is its interdisciplinary design, combining rigorous foundations in engineering and natural sciences with environmental economics, system modelling, and climate governance. Students will develop the capacity to understand and integrate the complexities of socio-ecological systems with industrial processes, infrastructure planning, and environmental regulation.

The curriculum is built around three core verticals:
(i) Environmental Economics and Policy
(ii) Water and Climate Modelling
(iii) Energy Systems and Sustainable Engineering

Through these pillars, students will be trained in plant design, industrial and chemical processes, sustainable manufacturing, and computational climate modelling. Alongside technical competencies, they will gain exposure to ecological systems, regulatory frameworks, disaster resilience, carbon neutrality strategies, green finance, sustainability communication, and environmental compliance, equipping them for leadership roles across sectors.

A key strength of the programme is its experiential learning architecture. Hands-on laboratories, industry-linked modules, field immersion, and both micro and macro project-based learning will ensure that students graduate with practical problem-solving experience aligned to real-world sustainability challenges**.**

In your view, what kind of professionals will define the next decade of India's climate and sustainability sector? Why do you believe the world now needs integrators—people who bridge technology, policy, and economics—rather than narrow specialists?
Prof. Pritee Sharma: India stands at a critical juncture, simultaneously poised for transformative economic growth and acutely vulnerable to climate risks ranging from severe weather events to slow-onset stresses such as heatwaves and droughts. Navigating this dual challenge demands a new generation of professionals who can integrate technological innovation, economic reasoning, policy insight, and environmental systems thinking to build resilient and sustainable development pathways.

The next decade of India's climate and sustainability landscape will be shaped by individuals who combine deep domain expertise with interdisciplinary fluency. These professionals will not only specialize in areas such as clean energy, water systems, climate modelling, circular economy, and sustainable infrastructure, but will also understand regulatory frameworks, behavioural and market dynamics, resource governance, and ecological resilience.

Such leaders will operate across industries including agriculture, infrastructure, and services, ensuring sustainability considerations are embedded throughout production and distribution systems. They will be equipped to translate scientific knowledge into actionable policy, convert technological solutions into scalable business innovations, and align development goals with natural-resource stewardship and climate justice.

Climate resilience is being compared to the next industrial revolution. What parallels do you see between the IT revolution of the 1990s and India's potential sustainability revolution in the 2030s?
Prof. Pritee Sharma: The IT revolution of the 1990s demonstrated how India could leapfrog global transitions when equipped with the right talent and strategic vision. India's ability to absorb and scale the gains of the digital era was built on a foundation of high-quality technical education, English-proficient engineering talent, and deliberate policy support, which enabled the country to become a global services hub.

A similar opportunity now exists as the world enters a sustainability and climate-resilience revolution, potentially unfolding even faster than the IT boom. Global demand for clean energy, low-carbon materials, circular-economy products, nature-positive infrastructure and climate-risk services is set to rise sharply. This transition will be driven by disruptive innovations in energy systems, green manufacturing, materials science, and climate technologies, fundamentally reshaping how goods and services are produced and consumed.

To harness this opportunity, India must invest with equal seriousness in R&D, skilled human capital, climate-tech entrepreneurship, and green public infrastructure. Building capabilities in renewable energy generation, storage and grid technologies, sustainable industrial processes, climate modelling, biodiversity-integrated development and nature-based resilience systems will be essential. Strategic public and private investment, along with forward-looking regulation and mission-driven institutions, can position India as a global climate solutions provider.

While India became a back-office and innovation partner to the world in the digital era, it now has the potential to become a climate-mitigation and resilience champion, shaping global sustainability supply chains and pioneering models of inclusive green growth for both urban and rural communities.

If the 1990s proved that talent and preparedness can change India's trajectory, the 2030s offer an opportunity to build upon that legacy, transforming India into a leader of the sustainability revolution. ■


H2
H2 HYDROGEN
ZERO EMISSION
CLEAN ENERGY OF THE FUTURE

Green Hydrogen

A Silver Bullet for Decarbonization of Hard-to-Abate Sectors

Climate change remains humanity's most pressing challenge, driven by rising emissions from power, industry, and transport. Although renewables supply over 40 per cent of global electricity, sectors such as steel, cement, chemicals, aviation, and shipping continue to emit heavily. **Dr M R Nouni** highlights green hydrogen as a transformative solution. Produced using renewable energy, it offers a clean alternative where electrification is difficult. It can decarbonize ammonia and methanol production, support steelmaking, provide industrial heat, and fuel long-haul transport. While costs remain high, scaling and co-location are expected to improve competitiveness. India's National Green Hydrogen Mission targets 5 million tonnes by 2030, positioning green hydrogen as key to achieving net-zero goals.





Climate change and environmental degradation is often cited as the most serious long-term threat being faced by humankind.[1] It causes global warming; more extreme weather resulting in droughts, floods, intense storms, wildfires; rising sea levels, ocean acidification, and significant impacts on ecosystems, food, water, and human health, leading to species loss, food insecurity, displacement, and increased health risks such as heat stress and diseases.

The most important factors driving climate change are human activities, primarily caused by burning fossil fuels for generating power; for obtaining energy needed for producing industrial goods like cement, iron, steel, electronics, plastics, clothes, etc.; and operating different means of transportation. These activities release massive amounts of greenhouse gases (GHGs) like CO_2, causing the planet to warm. Deforestation, intensive agriculture and meeting energy needs of residential and commercial buildings for lighting, heating, cooling and operation of different appliances also significantly contribute to GHG emissions by releasing stored carbon and producing methane and nitrous oxide.[2]

GHG Emissions

Global GHG emissions have been witnessing an increasing trend mainly due to the increase in emissions from China and the other emerging economies from the beginning of the 21st century. Global GHG emissions in 2024 reached 53.2 Gt CO_{2eq} (without land use, land use change and forestry), of which total energy-related CO_2 emission was 37.8 Gt. Consequently, atmospheric CO_2 concentration has reached 422.5 ppm in 2024.[3,4] Hard-to-abate sectors that include heavy-duty trucking, shipping, aviation, iron and steel, and chemicals and petrochemicals alone contribute approximately one-quarter of the world's energy consumption and around one-fifth of total CO_2 emissions. While their full decarbonization will require a combination of approaches, effective emission reduction pathways for these sectors rely primarily on renewable energy and energy efficiency.[5]

Energy Transition

Climate change mitigation or decarbonization involves reducing GHG emissions by transitioning

[1] Details available at https://www.un.org/en/un75/climate-crisis-race-we-can-win#:~:text=Climate%20change%20is%20the%20defining,time%20for%20bold%20collective%20action; last accessed on March 12, 2026

[2] Details available at https://www.un.org/en/climatechange/science/causes-effects-climate-change; last accessed on March 12, 2026

[3] Details available at https://edgar.jrc.ec.europa.eu/report_2025#:~:text=Main%20findings,and%20most%20recent%20activity%20data; last accessed on March 12, 2026

[4] Details available at https://www.iea.org/reports/global-energy-review-2025/co2-emissions; last accessed on March 12, 2026

[5] IRENA, Decarbonising hard-to-abate sectors with renewables: Perspectives for the G7

to renewable energy, boosting energy efficiency in buildings and transport; adopting clean coal technologies for power generation and nuclear energy; switching to mass public transport, electric vehicles and clean fuels such as natural gas/biogas and biofuel for transport; promoting sustainable land use (reforestation and better farming), and capturing carbon through carbon capture and storage (CCS) and forestation efforts. To combat climate change, it is necessary to reach "net zero," meaning emissions released become equal to those removed. According to the International Renewable Energy Agency, key drivers of energy transition are electrification and energy efficiency, enabled by the use of renewables, hydrogen, and sustainable biomass. This pathway, which requires a massive change in how societies produce and consume energy, would result in substantial reductions in CO_2 emissions, which can be achieved through—appreciable increases in generation and direct use of electricity produced from renewable sources; significant improvements in energy efficiency; electrification of end-use sectors; use of green hydrogen and its derivatives; and increased use of bioenergy in association with CCS.[6]

Increasing Penetration of Renewables in Power Sector and Implications Thereof

Renewable energy sources are displacing electricity generated from coal and natural gas that has resulted in avoiding billions of tonnes of CO_2 emissions cumulatively. The share of non-fossil (including hydro and nuclear) in global electricity generation has reached about 40.9 per cent of 30,937 TWh in 2024 driven by record growth in renewables especially





solar, up from around 33.5% of 24,003 TWh in 2015.[7] Though, heat wave-related spikes in 2024 led to increased demand for fossil fuel-based electricity.[8] This growth in renewable power generating capacity is critical, as fossil fuel-based power generating units are the largest source of global GHG emissions and contributed close to 15 Gt of CO_2 emissions in 2024 [8].8 Global renewable energy-based electricity generation capacity increased from 1223.5 GW in 2010 to 4448.1 GW in 2024, showing an increase by around 260%.[9] The costs of generating electricity from solar and wind have dropped dramatically, making them the most affordable sources of new power in most parts of the world today. This economic viability accelerates the transition away from carbon-intensive fossil fuels. Many countries have set ambitious targets for renewable energy power. For example, India aims to have 500 GW power generating capacity by 2030 based on non-fossil sources, having already achieved more than 200 GW by November 30, 2025.[10]

However, accelerating the penetration of renewable energy in the energy systems of the countries requires continued innovation and investment in the areas of energy storage, electrification of different sectors and modernization of electricity grid. To address the issue of intermittency of solar and wind power, advancements in energy storage technologies like batteries and pumped hydro storage are essential for grid stability and supply of 24x7 reliable power. To extend decarbonization beyond power sector, utilizing clean electricity to

6 IRENA, World energy transitions outlook 2022

7 Details available at https://ember-energy.org/data/electricity-data-explorer/; last accessed on March 12, 2026

8 Ember, Global Electricity Review 2025

9 Details available at https://www.statista.com/statistics/1094331/global-renewable-capacity-cumulative/#:~:text=In%20total%2C%20global%20installed%20renewable,worldwide%20from%202010%20to%202024; last accessed on March 12, 2026

10 Details available at https://www.pib.gov.in/PressReleasePage.aspx?PRID=1795071&reg=3&lang=2; last accessed on March 12, 2026



power transportation and industrial processes in hard-to-abate sectors is crucial. Besides, it will also necessitate upgrading electricity grids that will allow it to handle the dynamic flow of energy from diverse and decentralized renewable sources, which inherently are variable and intermittent in nature.

Despite policy push being provided to increase share of renewable power in the total power mix to decarbonize it, difficulties are being faced in implementation of the projects due to delays in creating necessary transmission infrastructure to transmit renewable power from remotely located assets to load centres and inadequate energy storage capacities. Moreover, there are issues relating to stability of power grid with increasing penetration of renewable power and all these factors are contributing to increased curtailment from renewable power generating units. In the absence of adequate energy storage capacity, excess generation and curtailed power from renewables could be utilized for green hydrogen generation, which can be stored for long durations and used for power generation as and when generation from renewable systems falls and thereby helping in balancing the grid. Green hydrogen so produced can also be used for blending with natural gas by injecting it into the gas grid.



Apart from power sector that contributed about 40 per cent GHG emissions in 2024, decarbonization of hard-to-abate sectors with its share of GHG emissions being nearly half of the power sector is equally important to mitigate climate change implications. Petroleum refineries contributed about 1 per cent of GHG emissions in 2024. For the decarbonization of chemicals, fertilizers, cement, iron and steel, refineries, aviation, shipping, and heavy-duty transport—where reducing GHG emissions is challenging due to (a) energy-intensive processes, (b) reliance on fossil fuels, and (c) a lack of easy substitutes—significant innovations such as the use of green hydrogen, CCS, and electrification are required.

Green Hydrogen—A Potential Energy Vector for Decarbonization

Presently, almost the entire hydrogen is produced globally by reformation of fossil fuels, which is called grey hydrogen as CO_2 produced during reformation process is not captured. Total production and consumption of hydrogen during 2024 was about 100 million tonnes (MT), of which only about 100 kilo-tonnes can be termed as green hydrogen, which is produced usually by splitting water using renewable electricity. Hydrogen demand in India has been estimated as 10 per cent of the global demand, i.e., about 10 MT. Petroleum refineries, ammonia and methanol production units are major consumers of hydrogen with respective shares of 43 MT, 33 MT, and 16.5 MT in 2024. Most of grey hydrogen production and consumption facilities are generally co-located. Petroleum refineries utilize hydrogen for hydro-cracking and desulphurization. Grey ammonia is synthesized by combining nitrogen captured from atmosphere and grey hydrogen produced by reformation of natural gas or coal using Haber-Bosch process. Ammonia in turn is used to produce fertilizers such as urea. Methanol is produced from syn-gas ($CO+H_2$) obtained by reformation of natural gas or coal. Grey hydrogen used in refineries and chemical industry can be replaced by green hydrogen. Therefore, interest in green hydrogen, which is a versatile energy carrier and a feedstock for several industrial applications is growing during the last one decade with more than 65 countries announcing their hydrogen strategies or policies.[11]

Green hydrogen is considered as potentially important for decarbonization of hard-to-abate sectors

[11] IEA, Global Hydrogen Review 2025



because (a) it offers a clean fuel/feedstock replacement where electrification is tough, (b) it provides high-temperature heat, (c) green hydrogen works as a reducing agent, and (d) replacing fossil-derived hydrogen. Green hydrogen can replace fossil fuels in ammonia and methanol production and acts as a reductant in steelmaking and thereby cutting process emissions. It can also be used in furnaces in industries such as cement, glass, and aluminium, where high heat is needed but electric solutions are inefficient. It offers a zero-emission alternative for long-haul trucking, shipping, and aviation where batteries are too heavy.

Green hydrogen production units can be co-located with consumption centres in the industry. Modern electrolysers can produce pressurized hydrogen to suit the requirement of the industrial processes, thereby avoiding the need for pressurizing it. In view of waiver of inter-state transmission system charges for green hydrogen production, renewable energy generation systems which are space intensive and green hydrogen production units can be located at different locations. With co-located green hydrogen production facility complexities associated with hydrogen production, storage and transport and unfavourable economics arising from it could be obviated.

Hydrogen system is complex if point of production and consumption are located afar as hydrogen needs to be compressed or liquified to improve its volumetric storage capacity after its production followed by its storage and transportation. All these processes are energy intensive and therefore resulting in reduced overall efficiency. Compression, storage and transportation costs will become very small in case production and consumption centres are either co-located or nearby. This can be attempted for industrial applications subject to availability of sufficient space for installation of green hydrogen system.

The main barrier to growth or slow adoption of green hydrogen is its present high cost in comparison to natural gas and grey hydrogen. Further, it requires massive investment for creating infrastructure for its production, storage and transportation for meeting demands of the industrial processes. These constraints arise as green hydrogen industry is in the nascent stage and is competing with fossil fuel industry which has taken several decades to reach the present level of development and cost competitiveness. In a new and emerging technology, cost economics is expected to become favourable with its wider adoption and learning experience, as was witnessed in the case of power generation from solar photovoltaics in the last one decade. In this context, the cost discoveries that have been witnessed for green ammonia production for 13 projects in India during the last six months are encouraging. The prices were in the range of INR 49.75/kg to INR 64.74/kg with weighted mean price of INR 53.27/kg, in comparison to landed cost of USD 515/tonne (INR 42.29/kg considering 1USD = INR 86) for imported grey ammonia. This was about 26 per cent more expensive compared to imported grey



ammonia.[12] The cost gap between green and grey ammonia may disappear in the near future.

IEA observes that deployment of green hydrogen production technologies faces significant barriers, as the system is deeply locked-in due to sunk costs in existing production capacities and established infrastructure. Enabling a structural shift will therefore require ambitious policy action.[11]

Progress Achieved So Far for Decarbonization of Hard-to-abate Sectors in India

The National Green Hydrogen Mission (NGHM) was announced by the Government of India in 2023 for 5 MT of green hydrogen production by 2030 with initial financial outlay of INR 19,744 crore for providing incentives for manufacturing of electrolysers and production of green hydrogen; pilot projects and R&D.[13,14] The major focus of the Mission is for incentivizing production of green hydrogen and its derivatives like green ammonia and projects for production of 0.865 MT of green hydrogen and 0.724 MT of green ammonia for production of fertilizers have been approved up to November 30, 2025.[12,15] The pilot projects are related to the use of green hydrogen for production of low carbon steel, mobility and shipping. A pilot project for demonstration of 15 fuel cell based and 22 hydrogen internal combustion engine-based vehicles and establishing 9 hydrogen refuelling stations with an aim to assess various issues relating to operation and economics of hydrogen fuelled mobility is under implementation in the different parts of the country.[16] As a part of the NGHM, Deendayal Port Authority, Kandla; Paradip Port in Odisha and VO Chidambaranar Port in Tamil Nadu have been identified for development as hydrogen hubs, with capability of handling, storage and generation of green hydrogen by 2030.[17] Petroleum refineries at Panipat (IOCL) and Vishakhapatnam (HPCL) have taken up projects for production and utilization of green hydrogen of 10 kT and 5 kT respectively for initiating use of green hydrogen in their operations.[18] Price of hydrogen discovered for these projects was in the range of INR 328/kg to INR 336/kg (plus applicable GST), which is nearly two times of the price of grey hydrogen. An 8 kg/h capacity electrolyser-based green hydrogen system was deployed in a steel mill in Hissar for metal treatment in 2024.[19] A green hydrogen plant of 95 TPA was also installed in a float glass manufacturing facility at Soniyana in Chittorgarh district in Rajasthan in 2024.[20] All these projects indicate that efforts for decarbonization of hard-to-abate sectors have been initiated using green hydrogen.

Conclusions

Emphasis on decarbonization and net zero is going to be even stronger in the coming years which will help in exponential growth of the renewable power sector globally as well as in India. This along with decline in the costs is expected to create a favourable ecosystem for growth of green hydrogen which is expected to expedite decarbonization of hard-to-abate sectors. ■

Dr M R Nouni has been associated with power and renewable energy sectors for nearly four decades. He worked at the Ministry of New and Renewable Energy (MNRE), Government of India, for about three decades and was involved in policy formulation and implementation RD&D.

[12] Details available at https://renewablewatch.in/2025/09/25/green-ammonia-uptake-competitive-bids-in-recent-seci-auctions-reflect-demand-readiness/; last accessed on December 18, 2025

[13] MNRE, National Green Hydrogen Mission, 2023

[14] Details available at https://mnre.gov.in/en/national-green-hydrogen-mission/ ; last accessed on March 23, 2026

[15] Details available at https://seci.co.in/nghm; last accessed on March 23, 2026

[16] Details available at https://pib.gov.in/PressReleasePage.aspx?PRID=2107795; last accessed on March 23, 2026

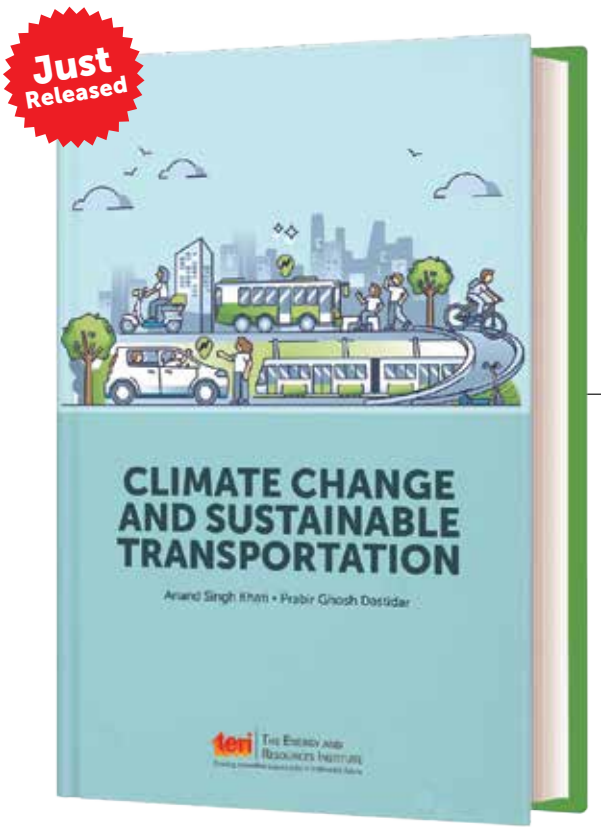
[17] Details available at https://m-economictimes-com.cdn.ampproject.org/c/s/m.economictimes.com/industry/renewables/ril-lt-welspun-to-lead-massive-rs-1-lakh-crore-investment-in-green-hydrogen-ammonia-units-at-kandla/amp_articleshow/109173708.cms; last accessed on March 23, 2026

[18] Details available at https://www.linkedin.com/posts/arjunmehta_abu-dhabi-company-ocior-energy-wins-bid-to-activity-7351117624614735872--VUb?utm_source=share&utm_medium=member_desktop&rcm=ACoAACErnjcB43N6_W9TDQBxlq47rXZjcwPyOfY; last accessed on March 23, 2026

[19] Details available at https://stainless-steel-world.net/jsl-use-green-hydrogen-in-hisars-stainless-steel-plant/; last accessed on March 23, 2026

[20] Details available at https://inoxairproducts.com/airproductsnews/inox-air-products-commissions-its-first-green-hydrogen-plant-at-asahi-indias-soniyana-facility-at-chittorgarh/; last accessed on March 23, 2026

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Why Kolkata Keeps Shaking

Unravelling the Science behind Recurrent Earthquakes

Earthquake tremors were felt in the city of Kolkata throughout the month of February 2026, prompting people to rush out of high-rise buildings onto the streets in panic. The tremors were experienced not only in Kolkata but also in neighbouring districts. Why has the state of West Bengal, including its capital Kolkata, been repeatedly affected by earthquakes? **Dr Shamim Haque Mondal** explores this question in the article.

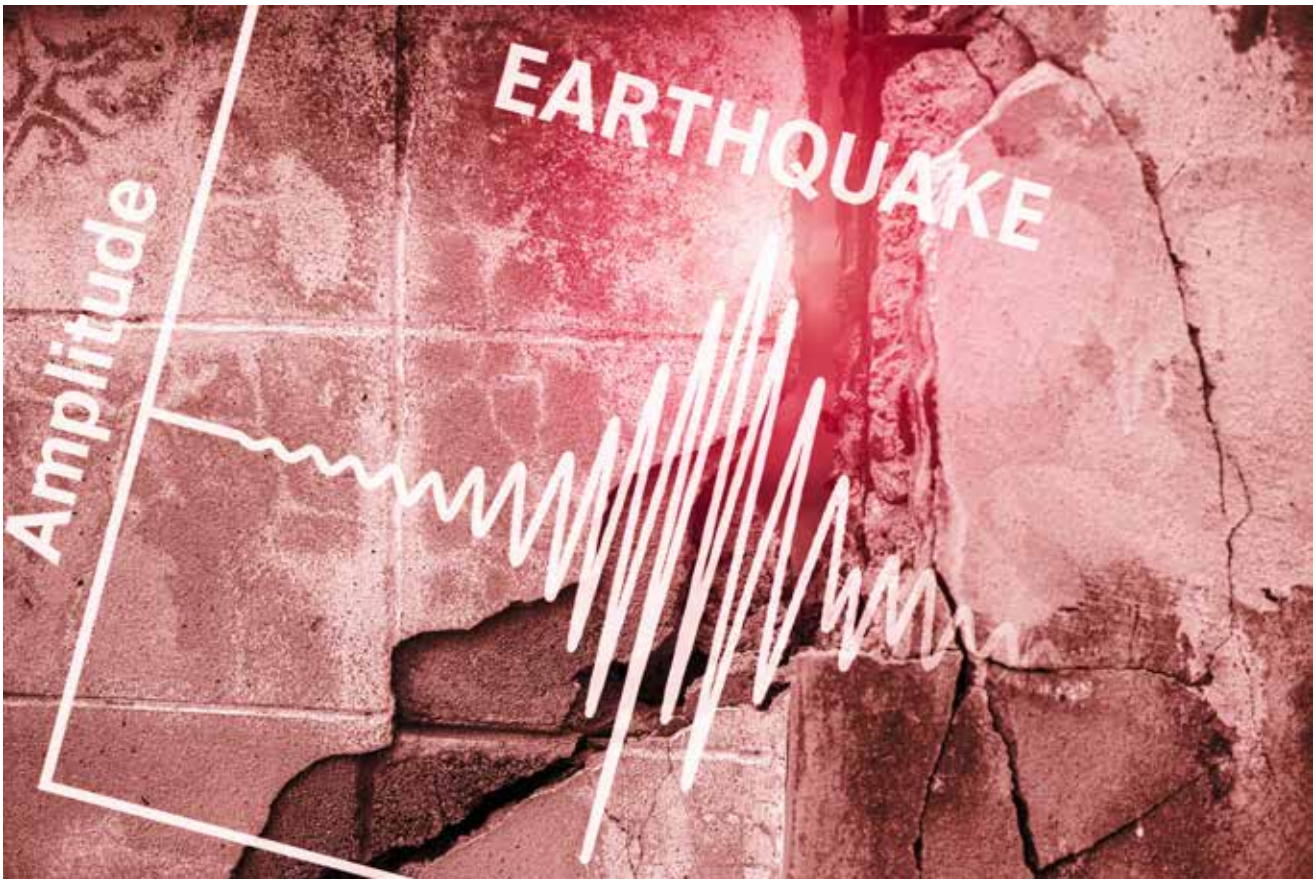
Let us first examine why earthquakes occur. In fact, behind every earthquake lie millions of years of geological evolution and the complex movement of tectonic plates deep beneath the Earth's surface. Our planet is made up of three layers: the core, the mantle, and the crust. At the core is a molten metal core surrounded by a mantle, or a layer of hot solid rock. At the outermost level, the part formed by the shifting tectonic plates is called the crust. These plates on top of the mantle can move in any direction at any speed, generating energy. When these moving plates occasionally move on top of each other, a large amount of energy is released and the surface shakes, which we call an earthquake. A tsunami occurs when the same phenomenon occurs at the bottom of an ocean. Geologists believe that earthquakes cause a change in pressure on Earth, which can cause moderate to mild tremors for several hours after the main tremor, which scientists call aftershocks.

The point in the Earth's interior where an earthquake originates is called the hypocentre, and the point where it meets the Earth's surface perpendicular to the surface is called the epicentre. The lower the depth of the epicentre of an earthquake, i.e., the greater its destructive power if it originates near the Earth's surface, the less damage is caused if it originates far below the Earth's surface. Seismic waves propagate along the radius, causing the vibrations that occur at great depths of the Earth's surface to lose their strength as they reach the Earth.



The epicentre of the earthquake in late February 2026 was in Ashashuli Upazila of Satkhira, Bangladesh; its epicentre was located about 9.8 km below the ground. Geographically, it is an active geostrategic region covering the whole of West Bengal and Bangladesh, including Kolkata, at the junction of the Indian Plate and the Eurasian Plate. The Indian Plate is moving northeastward towards the Eurasian Plate at a speed of about 5 cm per year. As a result of this increasing pressure, there is a tremendous amount of instability in the foothills adjacent to the Himalayas and in the deep fault lines of the Bengal basin. When this stored energy goes beyond a certain limit, tremors are felt on the surface of the earth. The Satkhira region is adjacent to the Sundarbans, and there are numerous small 'local faults' or local faults under the ground; it is likely that cracks in one of these fault lines were the source of yesterday's earthquake.

Many people may wonder that if the epicentre of the earthquake is in Satkhira, why was such a strong tremor felt in Kolkata? Or is it because it has been going on for so long? Therefore, we have to understand the nature of the soil in the surrounding areas of Kolkata. The whole of South Bengal, including Kolkata, is made up of soft silt brought by the Ganges-Brahmaputra River. This increased the intensity of the earthquake.



In geological terms, this is called 'local site amplification.' Seismic waves, or ground waves, mainly resonate more in soft sediment than in rocky soil. Again, the submerged sediment adjacent to the river behaves like a liquid during vibration, which is called 'liquefaction.' That's why the vibration lasts for about 40 seconds.

Now the question is what is the reason for such frequent earthquakes in Kolkata?

West Bengal state in India and Bangladesh lie mainly on the Bengal Basin, under which an important geological line, the Eocene Hinge Line, runs. More precisely, it extends to the northeast, very close to Kolkata and Satkhira. If there is any instability under the ground along this line, it can pose a big danger to Kolkata. In addition, experts believe that the 'Main Himalayan Thrust,' which is located under the Himalayan mountain region, has not seen any major cracks for a long time, i.e., no manifestation of geothermal energy. There may be a possibility of that energy coming out through repeated small vibrations. And once there is an earthquake, the underground structure loosens, and if there is an earthquake in the area again in a few days, it is very worrying. Meanwhile, Tilottama's geological balance is constantly being disturbed by uncontrolled urbanization and the construction of housing by filling up wetlands.

Kolkata and its adjoining areas fall under 'Seismic Zone 3,' which is of moderate to high risk, especially the old and congested areas of north Kolkata and central Kolkata. Older houses in the city do not have modern earthquake-proofing systems, while most of the new housing in East Kolkata, Salt Lake, New Town, and Rajarhat has been built by filling up marshes. Because of the low pressure resistance of the lower sediments in these areas, the potential for earthquake damage is high. We should remember that two consecutive earthquakes in a month are not isolated events but are part of a long-term geological process. Although Kolkata does not lie directly on any major earthquake-prone fault, there is a risk from active faults in the surrounding region. These recurring tremors serve as a reminder that nature may appear to relent, but it never truly does. ■

Dr Shamim Haque Mondal, Physics Division, State Forensic Science Laboratory, Kolkata, West Bengal.

Crop Residue Management

Bridging Agriculture, Energy, and Environmental Sustainability

This article by **Gaytri Soni** explores sustainable crop residue management as a solution to balance agricultural productivity and environmental protection. It highlights the drawbacks of open-field burning, including air pollution and soil degradation, and presents alternatives such as biochar production, pellet fuel, biodegradable mulches, livestock feed, biogas generation, textile fibres, and bioplastics. These approaches convert waste into valuable resources, enhance soil health, reduce emissions, and support circular economy practices, offering farmers environmentally friendly and economically viable pathways towards sustainable agriculture.

As global agriculture struggles to produce balanced rising food demand with environmental sustainability, farmers across the continents face the long-standing challenge: how to manage crop residues in a way that protects productivity while reducing pollution. What to do with the millions of tonnes of stalks husks, and leaves that remain after harvest is a problem that farmers face everywhere from the rice fields of South Asia to the maize belts of Africa and the American Midwest of the United States.

From the past few decades farmers have used open-field burning as a quick and affordable way to prepare land for the next planting. However, the repercussions are becoming more difficult to manage nowadays. Burning crop residue now contributes to seasonal air pollution, releasing particulate matter, greenhouse gases, and hazardous substances that deteriorate soil quality and also severely affect human health. In order to promote long-term farm resilience, scientists and farmers are advocating more sustainable substitutes. Here are a few methods to use crop residues efficiently in sustainable ways:



Biochar Production

Crop residues play a vital role in biochar production, which provides a sustainable method of handling agricultural waste while enhancing soil health and lowering the emission of greenhouse gases. Straw husks, stalks, and other residues are transformed into biochar (a stable form of carbon) by pyrolysis, a high-temperature process carried out in anaerobic conditions. Pyrolysis of these residues produces biochar containing 50–80 per cent carbon,[1] depending on the feedstock and process. Biochar not only improves soil fertility by improving soil carbon, water holding capacity, nutrient availability, and microbial activity, but is also an efficient method for recycling biomass. Furthermore, the production of biochar aids in the long-term carbon sequestration, which helps in mitigating climate change. It also promotes circular agriculture by converting farm waste into soil amendment.

Pellet Fuel

Residues such as straw, corn stalks, rice husks, and sugarcane bagasse are collected, dried and compressed into pellets by the pelletization process. These pellets can be used in boilers stoves, and power plants to generate heat and electricity. The calorific value of pellets ranges from 14 to 18 MJ/kg,[2] comparable to low-grade coal, and their ash content ranges from 2 to 10 per cent,[3] depending

[1] Details available at https://www.mdpi.com/2311-5629/9/3/67

[2] Details available at https://fabon.in/biomass-pellet-production-raw-materials-cost-benefits/

[3] Ibid.



Photo by Erwan Hesrya on unsplash.com

on the feedstock. These pellets are very energy efficient, and they're easy to store and transport. Pellet fuels are not only a sustainable energy source but also manage crop residues and lower greenhouse gas emissions, contributing to cleaner energy production and better environmental sustainability.

Mulch Films and Bio-mats

Crop residues are being used as biodegradable films and mats that are applied to the soil surface to control moisture and prevent weed growth. As residue break down with time, they improve water-holding opportunity, soil fertility, and microbial activity while also adding organic matter. Crop residue also lowers the need for plastic mulches, improving soil health and environmental preservation.

Nutrient-Enriched Feed and Fodder Blocks

Crop residues are a valuable resource for livestock when processed into fodder blocks and nutrient-enriched feed. According to The Food and Agriculture Organization (FAO),[4] billion tonnes of crop residues4 such as cereal straws, maize stalks, rice husks, and sugarcane tops, with a significant portion utilized as livestock feed per annum. Normally, crop residues are low in protein and digestibility, but nutritional values can be improved by supplements such as urea, molasses, minerals, and vitamins. These enriched feed blocks improve milk production weight gain and general animal health by giving livestock a concentrated, balanced diet during the dry season or feed shortage. In addition to crop residue management, it also lowers livestock feeding expenses.

Anaerobic Digestion for Biogas

Crop residues are valuable feedstock for anaerobic digestion, which produces methane-rich biogas. Depending on feedstock and digestion technology, anaerobic digestion of these residues can produce 100–400 m^3 of biogas per tonne[5] of dry matter. To meet rural energy demands, countries such as India, China, Brazil, and Germany are increasingly using crop residues in both small scale and large scale. Nutrient-rich digestate left after biogas production is used as organic fertilizer.

Textile Fibre and Fabric

Residues such as flax, banana stems, pineapple leaves, hemp stalks, and sugarcane bagasse contain natural fibres that can be extracted and processed into non-woven fabrics, yarn, and biodegradable textiles. For instance, pineapple leaf fibres (PALF) are used in composite textiles and industrial fabrics while banana fibres extracted from stem is used for making ropes, mats, and eco-friendly fabrics. Utilizing crop residue not only provides alternative to cotton fibre but also lowers water consumption and supports circular economy initiatives in fashion and textile sector.

Biodegradable Plastics

Corn stover, rice husk, wheat straw, and sugarcane bagasse are increasingly being used as raw materials for biodegradable plastics. Biopolymers such as polylactic acid (PLA) and cellulose-based materials are derived from lignocellulosic biomass and naturally break down in soil. Globally, the bioplastic market is expected to reach 5.73 million tonnes by 2029,[6] with a significant contribution to feedstock supply.

Conclusion

Effective management of crop residue management transforms agricultural waste into a way that supports soil health, environment, and clear energy. Farmers can boost productivity while contributing to cleaner air and sustainability by adopting sustainable practices and reducing residue burning. Crop residues provide a route towards sustainable agriculture, circular economy principles, and a greener future for communities around the world by turning what was once thought of as waste into useful input. ■

Gaytri Soni is a writer covering agriculture, nature, environment, and sustainability. She holds an MSc in Agriculture and draws on her academic background to produce clear, accessible writing on agricultural innovation, climate challenges, and environmental issues.

[4] Details available at https://www.longdom.org/open-access-pdfs/crop-residues-for-sustainable-livestock-production-2329-888X.1000e108.pdf

[5] Details available at https://openagriculturejournal.com/VOLUME/14/PAGE/219#:~:text=To%20date%2C%20maize%20is%20the%20dominant%20substrate,only%20on%20the%20kind%20of%20crop%20and

[6] Details available at https://www.european-bioplastics.org/market/

From Framework to Function

India's Carbon Market Takes Shape

The launch of the Indian Carbon Market (ICM) Portal at Prakriti 2026 marks India's shift from policy intent to implementation in climate action. Anchored in the Carbon Credit Trading Scheme (CCTS), it establishes a unified framework combining compliance, voluntary participation, and market incentives. Supported by robust MRV systems and digital infrastructure, the market aims to ensure transparency, credibility, and scalability. Positioned within evolving global mechanisms, it also drives green investment and economic transformation. While challenges remain, this milestone signals India's move towards a functional, globally relevant carbon market, says **Manish Dabkara** in this article.

The launch of the Indian Carbon Market (ICM) Portal at Prakriti 2026 marks an important moment in India's climate journey. While policy intent has been clear for several years, this development signals something more fundamental—the transition from ambition to implementation.

For a long time, discussions around carbon markets in India have remained largely conceptual—anchored in policy announcements, consultations and evolving frameworks. The operationalization of the ICM portal changes that. It introduces a centralized digital infrastructure that will underpin the administration, tracking and scaling of India's domestic carbon market.

This is not merely a technological addition. It represents the beginning of a functioning system.

A Shift in India's Climate Policy Architecture

At the heart of this transition is the Carbon Credit Trading Scheme (CCTS), notified in 2023 following amendments to the Energy Conservation Act in 2022. The introduction of the CCTS marks a clear shift in India's climate policy from a largely energy efficiency driven compliance approach to a broader greenhouse gas (GHG) emission intensity-based regime.

This shift is significant. Energy efficiency has long been a cornerstone of India's climate action with programmes such as Perform, Achieve and Trade (PAT) delivering measurable results across industrial sectors. However, as India's economy continues to grow, a more comprehensive framework is required, one that captures emissions more holistically and enables market-based mechanisms to drive reductions.

The CCTS is designed to do precisely that. It brings together compliance obligations, voluntary participation and market-based incentives into a unified structure. In doing so, it lays the foundation for a domestic carbon market that is both scalable and adaptable.



Building the Foundation

Over the past two years, the Bureau of Energy Efficiency (BEE) has undertaken substantial work to establish the building blocks of this market. This includes identifying energy-intensive sectors under the compliance mechanism, notifying GHG intensity targets for nearly 490 obligated entities and developing detailed Monitoring, Reporting and Verification (MRV) and assurance procedures. In parallel, offset methodologies have been approved and Accredited Carbon Verification Agencies (ACVAs) have been operationalized to support independent verification.

These are not minor steps. They are foundational elements of any credible carbon market.

The effectiveness of the CCTS will ultimately depend on how well these systems function in practice. A robust MRV framework, in particular, will be



critical. Without consistent, transparent and standardized measurement and verification, the credibility of carbon credits and by extension, the market itself can be undermined.

As the framework moves into implementation, ensuring uniform interpretation and application of MRV requirements across obligated entities, non-obligated participants and verification agencies becomes a key priority. Capacity building, technical training and institutional coordination will play an equally important role in this phase.

Beyond regulatory design, the success of India's carbon market will also depend on the depth of institutional readiness across stakeholders. Carbon markets are not only policy instruments but also technical systems that require a shared understanding of methodologies, data protocols and verification standards. For many obligated and non-obligated entities, this represents a new layer of operational complexity. Building familiarity with emission accounting practices, ensuring data integrity and aligning internal processes with MRV requirements will take time. In this context, sustained capacity building across industry, verification bodies and regulators will be essential to ensure that the system functions consistently and delivers credible outcomes at scale.

The Role of Digital Infrastructure

The ICM portal sits at the centre of this evolving ecosystem. By providing a unified platform for registration, tracking, issuance and management of carbon credits, it brings much-needed transparency and efficiency to the system. Digital infrastructure, particularly when integrated with MRV processes, has the potential to significantly enhance data reliability and reduce administrative complexity.

More importantly, it helps build trust. In carbon markets globally, concerns around transparency, double counting and verification have often limited confidence. A well-designed digital platform, supported by strong governance can address many of these concerns by ensuring that every credit issued is traceable, verifiable, and accountable.

While the current focus of the ICM portal is on domestic projects under the CCTS, its future ambition towards global interoperability is noteworthy. As carbon markets become increasingly interconnected, the ability to align with international systems and standards will be essential.

Connecting to the Global Carbon Ecosystem

India's approach to carbon markets is unfolding at a time when international cooperation is gaining renewed attention. Mechanisms under Paris Agreement Article 6 are shaping how countries engage in cross-border carbon transactions while also raising the bar for transparency and environmental integrity.

In this context, India's emphasis on credible MRV systems, stakeholder consultation processes and standardized methodologies is particularly relevant.

Each CCTS project incorporates a global stakeholder consultation process, allowing inputs from a wider community beyond national boundaries. This is an important step towards aligning domestic mechanisms with global expectations of transparency and inclusiveness.

If designed and implemented effectively, India's carbon market could not only serve domestic climate goals but also position itself as a credible participant in the global carbon ecosystem.

Carbon Markets as Economic Enablers

One of the most notable aspects of India's approach is the way carbon markets are being framed, not merely as compliance tools but as instruments of economic transformation.

This framing matters. By linking carbon markets to investment, innovation and entrepreneurship, India is recognizing their potential to channel capital into clean technologies, renewable energy and emerging sectors such as green hydrogen. It also opens pathways for participation from a diverse range of stakeholders including MSMEs and rural communities.

In this sense, carbon markets become more than a mechanism for emission reduction. They become a platform for enabling green growth.



However, realizing this potential will require careful balancing. Market signals must be strong enough to drive meaningful action while regulatory frameworks must remain clear, consistent and credible.

Challenges on the Path Ahead

While the progress so far is significant, the road ahead is not without challenges.

The transition from framework to function is often the most complex phase in the lifecycle of any market. Ensuring consistency in MRV practices, building technical capacity across sectors and maintaining the integrity of issued credits will require sustained effort.

There is also the question of market dynamics. The availability of high-quality, credible credits and the systems to verify them will play a crucial role in determining how the market evolves. As participation expands, maintaining confidence among stakeholders will be essential.

Equally important is the need for policy coherence. As domestic mechanisms interact with international frameworks, aligning rules, definitions and standards will become increasingly important to avoid fragmentation.

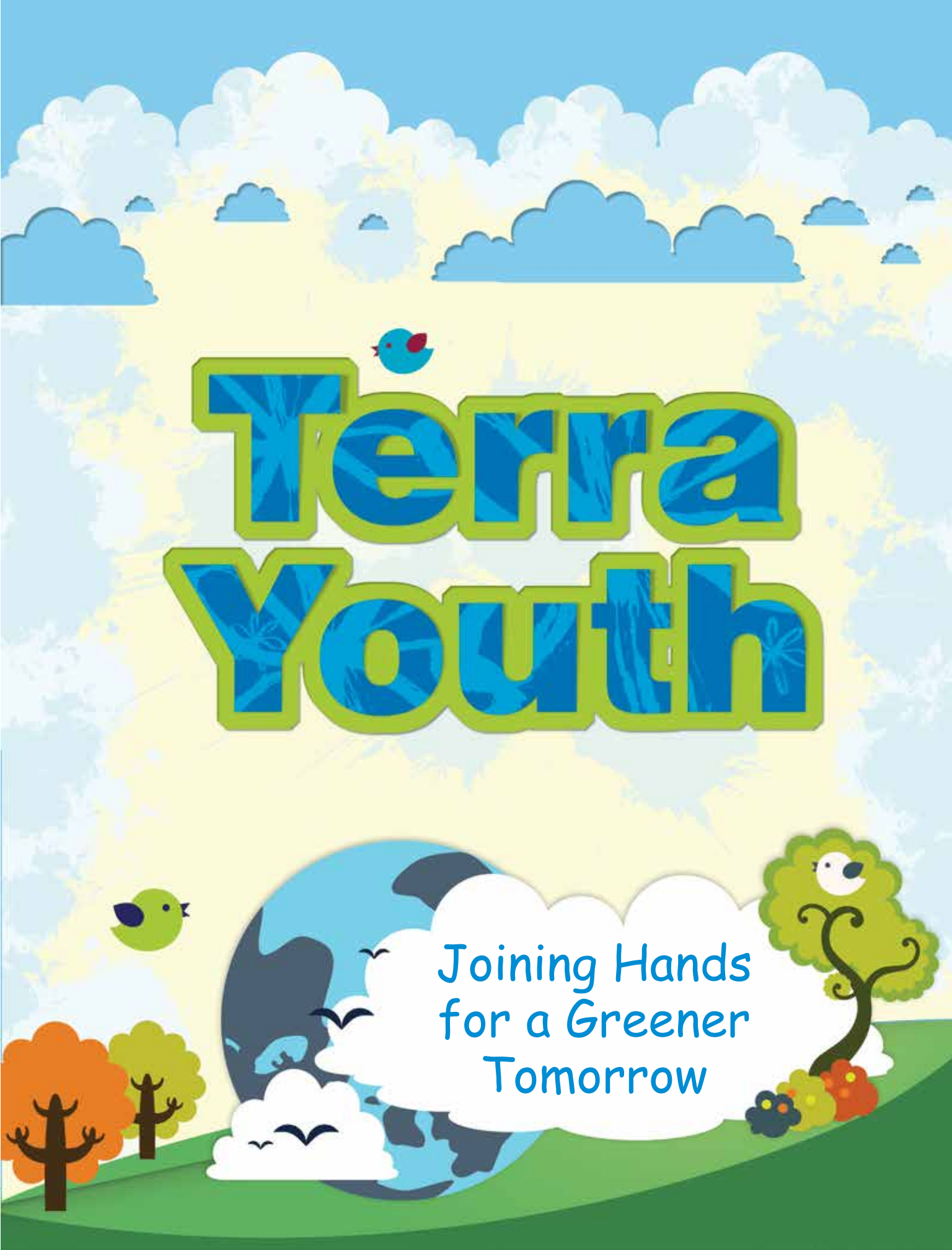
A Defining Moment

The launch of the ICM portal does not mark the completion of India's carbon market journey. Rather, it marks the beginning of a more operational phase, one where systems, institutions and markets must work together in practice.

It is a defining moment because it signals intent backed by infrastructure. India has already demonstrated that climate action and economic growth can move together. The next phase will test how effectively this principle can be translated into a functioning carbon market that is credible, inclusive, and globally relevant.

If executed well, India's carbon market has the potential to become not only a domestic policy tool but also a model for emerging economies navigating similar transitions. The foundations have been laid. The focus now shifts to implementation and to the choices that will shape the market in the years ahead.■

Manish Dabkara, Chairman and Managing Director, EKI Energy Services and President Carbon Markets Association of India.


Terra Youth
Joining Hands for a Greener Tomorrow

The Day the Sparrows Fell from the Sky

A small bird, a great folly—and the fragile memory of coexistence

Moving from historical tragedy to present-day neglect, **Rajshekhar Pant** reflects on the quiet disappearance of sparrows from our cities and the fragile bond they share with human life. Blending memory, ecology, and cultural insight, the piece is both a warning and a gentle appeal to restore space for one of our oldest companions.

They came in a blur of wings and panic. A trembling cloud of small birds, their frantic chirping swallowed by a louder, harsher sound rising from below.

A crowd surged after them—men, women, children—armed not with weapons, but with noise. Tin cans, metal plates, hollow pipes, drums, sheets—anything that could be struck, beaten, clanged into a relentless din. They ran, shouting, laughing, screaming, as if possessed.

The intent was chillingly precise: do not let the birds rest. Keep them airborne. Drive them past endurance.

And so the sky became a trap.

Exhaustion took over. One by one, the tiny bodies faltered, dropped, and lay still upon the earth.

What followed was even more unsettling. The fallen birds were gathered. Strung together. Worn as garlands by children and women, as if this were celebration, not slaughter.

This is no allegory, no fevered imagination, no scene from dystopian fiction. This was China, between 1958 and 1960. And the victim of this collective frenzy was the sparrow.



The Campaign Against a Bird

In the charged early years of the Great Leap Forward, Mao Zedong sought to catapult China into economic supremacy. Among the many sweeping measures of that era was the "Four Pests Campaign," which declared war on rats, flies, mosquitoes—and sparrows.

The reasoning, stark in its simplicity, proved catastrophic in its consequences. A single sparrow, it was claimed, consumed four pounds of grain each year. In a nation already strained by hunger, this statistic was enough to condemn the bird.

The masses responded with fervour. But while flies buzzed on and rats multiplied in shadow, the sparrow—unguarded, trusting, woven into human proximity—became the easiest target.

Cities turned into theatres of extermination. In Beijing alone, millions were killed. In Shanghai, nearly two hundred thousand vanished within days. Nests were torn apart, eggs crushed, fledglings destroyed.

Even embassies became unlikely sanctuaries. When sparrows sought refuge atop the Polish embassy in Beijing, the mob could not enter—but it did not relent. For two days and nights, the building was ringed with noise. When



Photo by Sreenivasa on unsplash.com

silence finally fell, it was the silence of death. The roof had to be cleared with shovels.

Competitions were organized. Victories applauded. A species diminished not by necessity, but by zeal.

When Silence Invited the Locusts

Then came the reckoning.

With sparrows gone, the skies emptied—but the fields did not remain untouched. Insects surged. Locust swarms descended with terrifying force, stripping crops bare.

By 1960, China was in the grip of the Great Chinese Famine—one of the deadliest in human history. Official records speak of 15 million deaths; many estimates suggest a toll closer to 70 million. Hunger deepened into horror.

In eliminating the sparrow, a vital thread in the ecological fabric had been severed. The small bird that nibbled at grain also devoured insects, protecting harvests in ways statistics had failed to capture.

Eventually, in an almost surreal reversal, sparrows had to be imported—from the Soviet Union—to restore balance.

It remains, perhaps, one of the starkest reminders of how fragile and intricate ecological systems truly are—and how easily human certainty can unravel them.

The Quiet Disappearance

Today, we no longer wage open war on sparrows. Yet, in quieter ways, we continue to edge them out.

According to the Royal Society for the Protection of Birds, sparrow populations have declined by nearly 60 per cent over the past four decades. Across India, the picture is uneven but troubling. Studies by the Indian Council of Agricultural Research point to sharp declines in several regions, with coastal belts witnessing drops of up to 80 per cent.

In some cities, the numbers are startlingly low—reduced to mere hundreds, even dozens.

The loss is not always dramatic. There is no sudden silence, no singular event. Instead, it is a thinning—a gradual absence. A morning less alive than it once was.

An Ancient Companionship

And yet, the story of the sparrow is deeply intertwined with our own.

Research by the Royal Society of London suggests that this companionship stretches back nearly 11,000 years, to the dawn of agriculture.

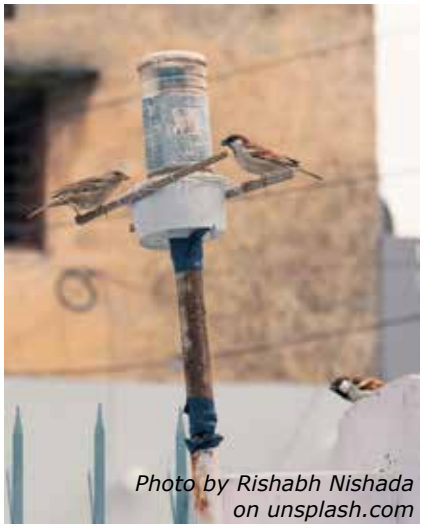


Photo by Rishabh Nishada on unsplash.com

As humans settled, sowed, and stored grain, the sparrow followed—adapting, enduring, sharing our spaces.

Alongside the dog, it may well be among our earliest fellow-travellers.

In India, the familiar house sparrow—dust-bathing in courtyards, fluttering along verandas—has long been part of everyday life. A bird of proximity, not wilderness. Of homes, not forests.

Cities without Corners

What, then, has changed?

Our homes, for one. Smooth walls, sealed glass, sterile lines—modern architecture leaves little room for nesting. The quiet corners and crevices that once welcomed sparrows have vanished.

Urban green spaces have shrunk. Pesticides have reduced insect populations. Competition from proliferating pigeons has intensified.

There are darker undercurrents too—sporadic reports of sparrows entering the food chain, of traditions revived without reflection.

Piece by piece, the conditions that sustained this small companion have been altered.

A Return, A Warning

There is, however, a measure of hope.

Conservation efforts led by individuals such as Mohammed Dilawar and organizations like Nature Forever Society have rekindled awareness. The institution of World Sparrow Day has brought global attention to their plight. Countries such as Britain, Italy, France, Germany, and the Czech Republic have designated them as rare birds. In India, Delhi declared the sparrow its state bird in 2012.

In some regions, sparrows are returning. In parts of the Himalaya—such as in my own town, Bhimtal—their numbers have risen noticeably, aided by favourable conditions and human goodwill.

Yet even here lies a subtle caution. Too much dependence on human feeding can erode their natural resilience. The sparrow, after all, is not merely a beneficiary of care—it is a creature of remarkable adaptability, capable of foraging widely, surviving independently. Naturally capable of flying at speeds of 30 miles per hour and known to forage for over 830 types of food (as noted in the *Handbook of Texas*), sparrows are highly adaptable. In my small garden, they consume everything—from vegetable seeds to flower buds.

More Than a Bird

There are those who caution against close proximity, citing disease risks. But such concerns, manageable with simple hygiene, pale before what is truly at stake.

For the sparrow is not just a bird. It is memory. It is rhythm. It is culture.

If the day comes when children no longer recognize its chirping—when songs like "*Chi-chi karti aayi chidiya…*" fade into obscurity, when wisdom enshrined in the folklore like—"*kalsa pani garam rahe, chiriya nahaye dhoor / cheenti le anda chadhe, to barish bharpoor* (If the sparrow bathes in dust, the weather stays warm; If ants carry eggs uphill, rains will soon follow") —is allowed to recede to oblivion—something more than a species will have been lost.

We will have lost a quiet, enduring bridge between human life and the living world around it.

The Sound We Must Not Lose

The story of the sparrow is, in the end, a story of proportion—of knowing what to take, what to leave, and what to protect.

We have seen what happens when that balance is broken with force. It would be a quieter tragedy if we were to lose it through indifference.

And so, perhaps, the task before us is simple: To leave a little space. To listen a little more. To let the small, familiar sound of *chi-chi* continue—not as an echo of the past, but as a living note in the present. ■



Rajshekhar Pant is an amateur filmmaker photographer, and writer who has written over a thousand write-ups, reports, etc., published in the leading newspapers and magazines of the country.

India and IFAD Sign US$46 Million Agreement

To Boost Climate-Resilient Farming in Mizoram

The Government of India and the International Fund for Agricultural Development (IFAD) have signed a $45.78 million financing agreement to strengthen market-led, inclusive and climate-resilient agricultural value chains in Mizoram, India. The Fostering Climate Resilient Upland Farming Systems in the Northeast (FOCUS 2.0) will be implemented in full alignment with Mizoram's Bana Kaih policy—an initiative promoting self-reliance and sustainable livelihoods—and India's national priorities for inclusive and climate-resilient growth.

The project builds on Phase 1 (2018–2024) where participants increased their income by 43 per cent through integrated farming systems combining climate-smart practices, livestock support, and improved market access. FOCUS 2.0 will expand coverage from six to all 11 districts in Mizoram to reach 150,000 people over six years, from 2026 to 2032.

"The programme responds by scaling up the successful models from Phase I and linking them to structured markets such as farmer producer organizations, aggregation, and processing centres, and formal buyer arrangements with agribusinesses," said Marc de Sousa-Shields, IFAD Country Director and Representative, India.

In rural Mizoram, landholdings are small and fragmented, productivity is low, and communities face extreme weather events. Many households rely on shifting cultivation—a traditional practice where land is farmed temporarily and then left fallow—which under shorter cycles, can reduce yields and limit market participation. Markets also remain underdeveloped.

The programme will support smallholder farmers and rural enterprises to move from subsistence to market-oriented production by improving how crops and livestock products are produced, aggregated, processed and sold—for example, through better storage and collection centres, financial and capacity building support to farmer groups and local businesses, and stronger links to local and regional markets. It will also promote climate-resilient farming practices to enhance productivity while reducing vulnerability to climate risks.

The investment will build market infrastructure that can withstand extreme weather conditions/events, provide support armer producer organizations and self-help groups, and improve financial and digital inclusion. These efforts will enable rural producers to access markets, grow small and medium agribusinesses, and increase incomes. ■

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Nature-Based Holi

A Sustainable Celebration

In this article **Rangeet Mitra** advocates for a sustainable, nature-based celebration of Holi by highlighting the environmental and health hazards of synthetic colours, water wastage, and plastic pollution. It promotes the use of DIY natural colours made from flowers, fruits, and kitchen ingredients as safer, eco-friendly alternatives. Emphasizing dry Holi and community initiatives such as tree planting and clean-up drives, it underscores collective responsibility. The article also notes the growing role of Gen Z in driving eco-conscious practices and the use of technology for awareness. Overall, it calls for preserving Holi's cultural spirit while adopting environmentally responsible practices for a greener future.

Traditionally marked by colourful powders and water play, Holi often leaves behind environmental damage due to synthetic chemicals, water wastage, and plastic litter. In 2026, embracing nature-based practices is not just a trend but a conscious choice—one that enables responsible celebration while preserving the festival's joyful spirit and cultural heritage.

The Environmental and Health Costs of Traditional Holi

The traditional methods of Holi celebration come with significant environmental and health implications. Synthetic colours often contain harmful chemicals such as lead, mercury, and chromium, posing serious health risks. These chemicals can cause skin irritation, allergic reactions, eye damage, and other long-term health issues. The disposal of these chemicals into water bodies and soil further pollutes the environment, harming aquatic life and ecosystems. Moreover, the extensive use of water for playful splashing contributes to water scarcity, especially in drought-prone regions. Plastic packaging from commercial colours and water balloons





exacerbates the plastic pollution crisis. Recognizing these issues is crucial for transitioning to more sustainable practices.

DIY Natural Colours: A Palette from Nature

Opting for DIY natural colours is a cornerstone of a sustainable Holi. These homemade alternatives reduce exposure to harmful chemicals while fostering a deeper connection with the natural world. Simple kitchen ingredients, along with readily available flowers and leaves, can create a stunning array of colours:

- **Pink Paradise**: Blend beetroot with a little water, filter the juice, and mix with arrowroot powder (or wheat flour, maida, or rice flour for a powder-like texture) until the desired pinkish-powdery texture is achieved. Add talcum powder or rosewater for fragrance. For a paste, women in Davanagere use apples and watermelons.
- **Feeling Blue**: Repeat the pink process with red cabbage. Adding baking soda to the red cabbage juice before mixing with the powder can result in a cyan shade.
- **It Was All Yellow**: Mix turmeric powder with water, then combine with arrowroot powder until you achieve a yellow powder consistency. Repeat the talcum step for fragrance. Alternatively, mix turmeric powder with gram flour (besan) for a vibrant yellow gulal.
- **Give the Green Light**: Blend coriander, spinach, mint, or neem leaves with water, and repeat the blending process to get a pastel green colour. Neem and betel leaf extracts are also used for their herbal properties and skin benefits.
- **Sunny Side Up**: Use orange marigold flowers or orange food colour, repeating the process for the green colour.
- **The Rush of Red**: Use red hibiscus flowers or dried rose petals, repeating the technique mentioned above. Kachnar flowers, are also being used to create herbal gulal.

Using wild berries, chamomile, and daisies can produce various calming and aromatic hues. Patna's Rajendra Prasad Central Agricultural University (RPCAU) also promotes organic and herbal gulal.

Dry Holi: Conserving Water, Maximizing Fun

Reducing water consumption is vital for an eco-friendly Holi. Celebrating a dry Holi with flowers, herbal gulal, and natural powders helps conserve precious water resources. Flower petals such as marigold, rose, and hibiscus can create a colourful, festive atmosphere without harming the environment. These biodegradable options offer fun without the wastage of water. In Cuttack, the Reiki Mission has been celebrating Holi with flowers for years, showcasing a beautiful connection with nature. This approach not only reduces environmental impact but also fosters a sense of community and harmony.

Community Initiatives: Spreading Awareness and Action

Community-led initiatives play a pivotal role in promoting sustainable Holi

celebrations. These initiatives foster environmental awareness and strengthen communal bonds, and can include:

- **Tree Planting Drives**: Participating in tree-planting activities to offset carbon emissions and promote biodiversity.
- **Clean-Up Campaigns**: Organizing community clean-up drives to remove plastic and other waste after the celebrations.
- **Supporting Local Artisans**: Purchasing organic gulal and other eco-friendly products from local artisans to support sustainable livelihoods and rural economies.
- **Women Empowerment through Sustainable Holi**: In Davanagere, Karnataka, a group of women have been celebrating Holi with herbal pastes instead of chemical-laden colours for over a decade. They prepare natural colours at home using vegetables, herbs, fruits, buttermilk, and yogurt. This initiative not only promotes eco-friendly practices but also empowers women by providing them with opportunities to create and sell organic gulal, contributing to their economic independence. Shantipur in West Bengal is famous for its herbal abeer makers who produce natural colours using traditional methods.

Gen Z: Leading the Charge for Sustainable Celebrations

Gen Z is spearheading the shift towards greener Holi practices. This generation is increasingly aware of the environmental impact of their actions, and they are actively seeking sustainable alternatives. Their commitment to eco-friendly Holi celebrations includes:

- **Avoiding Plastic**: Choosing to avoid single-use plastics like water balloons and plastic bags.
- **Reusable Decorations**: Opting for reusable and biodegradable decorations.
- **Sustainable Fashion**: Choosing clothing made from natural fibres and eco-friendly dyes.
- **DIY Projects**: Engaging in DIY projects to create natural colours and decorations.



Sustainable Practices for a Joyful and Responsible Holi

To ensure a sustainable and joyful Holi, consider adopting the following practices:

- **Make or Buy Natural Colors**: Use homemade or locally sourced natural colours
- **Say No to Plastic**: Use reusable bags and containers
- **Conserve Water**: Celebrate a dry Holi or use recycled water for water play
- **Plant Trees**: Organize or participate in tree-planting drives
- **Support Local Artisans**: Buy organic gulal from local artisans

The Role of Technology

Technology can be leveraged to promote sustainability:

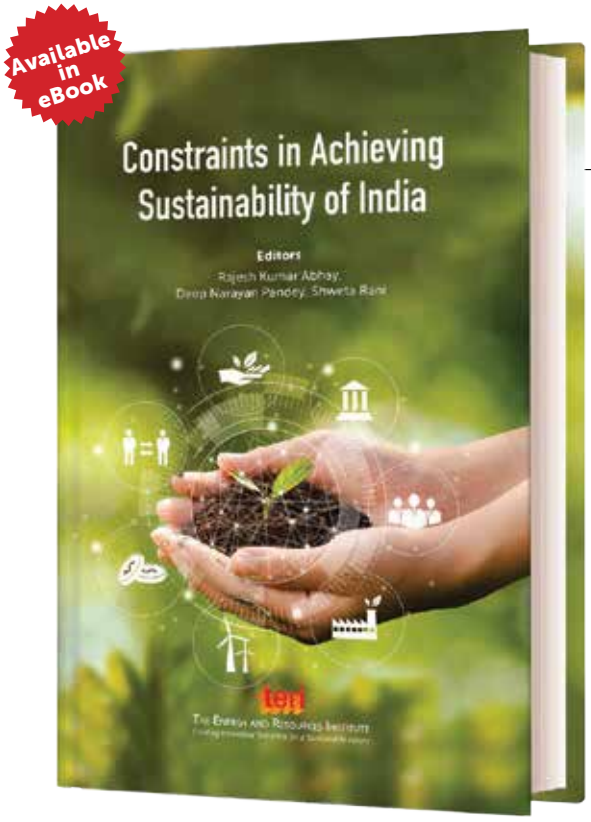
- **Social Media Campaigns**: Launch awareness campaigns on social media platforms to educate people about the benefits of eco-friendly Holi celebrations.
- **Online Tutorials**: Share DIY recipes for natural colours and sustainable celebration tips through blogs and video tutorials.
- **Digital Invitations**: Replace paper invitations with digital invitations and e-cards to reduce paper waste.

Embracing the Colours of Nature

Let all of us pledge to celebrate with nature, opting for sustainable practices that honour both our cultural heritage and the health of our planet. By embracing natural colours, conserving water, supporting local communities, and spreading awareness, we can transform Holi into a truly sustainable and joyful festival for all. The market is also seeing a shift in demand for organic Holi colours, with many consumers consciously choosing natural alternatives over traditional chemical-laden options. Let this Holi be a testament to our commitment to a greener, healthier, and more vibrant future. ■

Rangeet Mitra is a development professional with over eight years of expertise in nature-based solutions, climate change adaptation, sustainable livelihood development, environmental management, and policy design and implementation. Holding a B.Tech in Chemical Engineering and dual MBAs in Public Systems (Environment) and Creative Design, he has driven projects that merge technical precision with community-centred approaches.

Study of the challenges to sustainable development via scientific means



Major topics covered

- Sustainable Development: concept, components and history
- Environment, Culture, and Sustainable Development
- Sway of Indian Cinema in Diffusing Environmental Sentience
- Poverty Lines and Poor in India
- Sanitation Workers and Associated Problems for the Sustainability of Religious Events
- Assessment of Basic Infrastructure Development and Associated Issues in India

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Purpose of the book is to develop, contribute, and disseminate scientific knowledge pertaining to the issues related to sustainable development. The chapters are developed so that the contents can facilitate comprehension of the major constraints in achieving sustainability including but not limited to environmental, social, economic, and governance-related issues from local, regional, to national level. Resource management, climate change, agriculture, population, education, women, poverty, infrastructure, crime, corruption, governance, are the other relevant topics that have been both identified and suitably discussed. *Constraints in Achieving Sustainability of India* can be utilized as a guiding tool for realizing sustainability in development, especially, in the Indian context.

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Birding in Pará

A Day in the Heart of the Amazon Rainforest

Sharif Qamar's fascinating account captures a deeply personal journey into one of the world's richest ecological landscapes. Beginning near Belém in Brazil's Pará state during COP30 in November 2025, the narrative blends travel, birding, and reflection. From first sightings of hummingbirds to rare encounters like the Dot-eared Coquette, the experience unfolds as both an exploration of extraordinary avian diversity and a lesson in patience, endurance, and wonder. Through vivid encounters and local stories, the author reveals the Amazon not just as a biodiversity hotspot, but as a living, fragile ecosystem that leaves a lasting imprint on the observer. Keep reading to learn more…

It was my first birding adventure in the Amazonian forest of Brazil that began in the north-western state of Pará, a region that feels like a living, breathing encyclopaedia of avian life. The birding spot was very close to the city of Belem, the venue for the UN Climate Change Conference (COP30) held in November 2025. For anyone who has ever dreamed of immersing themselves in the dense jungles of the Amazon, Pará offers a kaleidoscope of species—hummingbirds, manakins, flycatchers, warblers, toucans, aracaris, hawks and vultures—all hidden within the green ecosystem of towering trees and winding streams.

It was November 10, 2025, the day etched in my memory as the beginning of a journey that would redefine how I see birds, forests, and even myself. Fernanda and Danielson, the warm-hearted duo behind Para Birding Tours, picked me up from Belem in the early hours. Their enthusiasm was contagious, and their knowledge of the forest promised a day of discovery. Joining us was a student from Canada who, like me, had travelled to Brazil for COP30, but could not resist the lure of birding in the Amazon.



With Peter Kaestner and the Birding Group

Road to Refúgio dos Naturalistas

We set off along the four-lane highway towards Santa Bárbara, the city slowly giving way to countryside. Soon the road narrowed into two lanes, and eventually into a dirt track that wound its way towards a small *comunidade*—the community where Fernanda and Danielson lived. An hour's drive from Belem, their lodge, aptly named *Refúgio dos Naturalistas*, was nestled in the forest, a sanctuary for birders and nature lovers alike.

On the way, our conversation focussed on Brazil's staggering bird diversity. With 1,972 recorded species, the country is a paradise for ornithologists and birders like us. Of these, nearly 1,300 species are found in the Amazon forests alone. The landscape here is dotted with *igarapés*—small streams that weave through the jungle, often tumbling into waterfalls. These waterways provide refuge to warblers, hummingbirds, and birds of prey, creating microhabitats that sustain life in amazing variety.

As we drove deeper into the forest, very close to the lodge, we passed an old, dilapidated building. Fernanda explained that it was the residence of a French


White bearded Manakin

wildlife researcher who had dedicated years to studying Brazil's fauna. It was here that Danielson started learning about birds, sparking a passion that eventually led him to study biology and eventually venture into guided tours for enthusiasts like us.

By 6 o'clock in the morning, we reached the lodge. A table awaited us, spread with local delicacies and home-grown fruits. The aroma of fresh coffee along with the earthy scent of the forest. Breakfast was not just a meal—it was an initiation into the rhythms of the Amazon.

My First Hummingbird

As I sipped the refreshing glass of *Capuacu* (an Amazonian superfruit) juice, a flash of movement caught my eye. Hovering near the flowers by the entrance was a Grey-breasted Sabrewing, my very first hummingbird sighting. For years, I had admired these tiny marvels in photographs and documentaries, in awe of their tireless quest for nectar. It is the only bird species to fly forward as well as backwards. Seeing one in real life was a moment of pure wonder. In fact, every bird I would encounter that day would be a 'lifer'—a first-time sighting—but hummingbirds hold a special place in the heart. Their iridescent feathers and relentless energy embody the magic of birding.

Into the Forest

Fuelled by breakfast, we set out into the nearby trail and the first bird we encountered was a Lettered Aracari, its colourful plumage glowing against the green backdrop. My excitement betrayed me—I moved too quickly, and the bird flew off. Lesson learned: patience is the birder's greatest tool.


Hooded Gnateater


Refúgio dos Naturalistas - The lodge

As we walked, the forest revealed its treasures: Palm Tanager, Silver-beaked Tanager, Kiskadee, Paradise Jacamer, Roadside Hawk, and the magnificent White-throated Toucan. Parakeets, parrots, and macaws appeared in distant flashes of colour, while a Yellow-headed Vulture perched solemnly atop a dead tree, visible through a gap in the canopy.

The Dot-eared Coquette

The highlight of the morning was yet to come. We positioned ourselves near a flowering tree, where two birders from the United States had been waiting patiently for a couple of hours. Their target was the Dot-eared Coquette, a near-threatened hummingbird prized for its charisma and rarity.

When the bird finally appeared, it was as if the forest itself held its breath. For just a few minutes, the Coquette perched itself at the tip of a flowering tree, its delicate form shimmering in the light. The sight electrified us all, including veteran birder Peter Kaestner, who had joined us. Kaestner, a career diplomat who served in India and went for birding with Dr Salim Ali, celebrated for becoming the first person to see 10,000 bird species in a lifetime in early 2024, smiled like a child rediscovering joy. That is the power of birding: no matter how experienced you are, each encounter feels like the first.

Chasing the Trogon

Later, we pursued the Green-backed Trogon, which perched gracefully on a mango tree branch near a house in the *comunidade*. Back at the lodge, we explored the campus and were rewarded with a lingering view of a Spotted Tanager, which posed obligingly for photographs.

The heat and humidity of the Amazon are relentless, and after a short rest, we set out again—this time for Balneário Gunma. Our target was the Hooded Gnateater, endemic to northern Brazil. True to form, it landed on a perch exactly where we hoped, allowing us a clear photograph.

Nearby, the forest offered more marvels: the White-bearded Manakin and the Red-headed Manakin. The latter is famed for its courtship dance, a performance of hops and flips designed to impress females. Sadly, I could only manage a blurry photo, but the memory of its acrobatics remains vivid, a reminder that not every treasure can be captured on camera.


Dense canopy of the Amazon

Lunch and Evening by the River

On our way back to the lodge, we stopped for fresh açaí, a staple of the region. Lunch was simple yet nourishing: rice, black beans, salad, açaí, and fruits. Afterwards, I took time to relax and photograph two more hummingbirds—the Reddish Hermit and the White-chinned Sapphire. Their delicate beauty was a balm after the morning's exertions.

As the day waned, we headed towards the mighty *Furo das Marinhas*, a river that eventually merges into the South Atlantic. The journey was punctuated by sightings of Paradise Jacamer, Smooth-billed Ani, Yellow-shouldered Blackbird, White-flanked Antwren, Purple Honeycreeper, Guianan Puffbird, Tropical Kingbird, and Yellow-crested Tanager. Each bird added an adrenaline rush that helped us trudge along in the tough humid condition of the region.



Paradise Jacamer



Reddish Hermit



The enigmatic and elusive Dot-eared Coquette

The Challenge of Birding in the Amazon

Birding in this region is not easy. Unlike open landscapes where one can sit and wait, the Amazon demands movement. Trails must be walked, birds must be followed, and patience must be infinite. The hot, humid weather tests endurance, and the dense foliage often obscures views. Yet these challenges are part of the allure. Each sighting feels earned, each photograph a triumph.



White fronted Nunbird

By the time we returned to the lodge, exhaustion mingled with exhilaration. The day had been long, but it was also unforgettable. Pará had offered not just birds, but stories—of people like Fernanda and Danielson, whose lives are intertwined with the forest, and that of Peter Kaestner, whose passion proves that birding is a lifelong journey.

Reflections

As I lay down that night, the sounds of the forest echoing outside, I realized that birding in the Amazon is more than a hobby. It is a dialogue with nature, a reminder of the fragility and resilience of life. Each bird is a messenger, carrying stories of survival, adaptation, and beauty.

The Amazon is often described as the lungs of the planet, but it is also its heartbeat. Unfortunately, we keep hearing about the rapid pace at which the Amazon is being negatively impacted due to deforestation and human activities. To walk its fragile trails, to watch the birds, is to feel that pulse. And in Pará, on that November day, I felt it deeply. ■

Sharif Qamar, Fellow and Associate Director, TERI (follow him on Instagram @peaceinwild).

Green Guardians

Community Action by The Hans Foundation for Fire-Safe Forests

The Hans Foundation's forest fire initiative in Himachal Pradesh highlights the power of community-led conservation. By mobilizing villagers through awareness campaigns, school activities, and cultural programmes, the project built a strong network of "Green Guardians." Training, mock drills, and toolkits enabled rapid fire response, while sustainable fodder practices reduced dependence on forest burning. Integrating traditional knowledge with modern strategies, 210 villages developed fire-focused action plans. The initiative demonstrates that empowered communities can effectively prevent forest fires, while future efforts aim to convert fire-prone pine needles into sustainable livelihood opportunities.

Every summer, the forests of Himachal Pradesh brace themselves for a familiar threat: forest fires. These fires not only destroy trees and wildlife but also endanger the very livelihoods of the people who live alongside the forests. Yet, the strongest defence against this recurring disaster doesn't come from machines or policies alone; it comes from the people themselves.

Recognizing this, The Hans Foundation (THF) launched its project "Prevention and Mitigation of Forest Fire in Himachal Pradesh" with a simple but powerful idea: empower communities to become guardians of their forests. And in the financial year 2024–25, this idea translated into remarkable on-ground accomplishments across Himachal Pradesh.

Communities at the Heart of Action

Instead of treating villagers as mere beneficiaries, THF placed them at the centre of conservation. Across Himachal Pradesh, awareness drives, volunteer mobilization, and practical trainings turned local residents into an active Green Guardians Network.

Twenty-two school rallies brought together over 4000 students, making young learners ambassadors of forest safety.

Thirty-six quiz and painting competitions engaged 1770 children, combining creativity with conservation lessons.

Villages came alive with 42 *nukkad nataks* (street plays) and 30 puppet shows, reaching nearly 3100 people with powerful, relatable messages on preventing fires.

These activities not only spread knowledge but also broke deep-rooted myths, like the belief that burning grasslands improves fodder, replacing them with safer, scientific practices.



From Awareness to Action

Awareness alone isn't enough. Fires demand rapid response, and for that, communities need skills and tools.

In collaboration with the Forest Department, SDRF, NDRF, DDMA, and Fire Services, THF organized 21 mock drills, training 1056 volunteers as first responders across different fire prone areas.

To strengthen their preparedness, 210 fire-fighting and fuel load clearing toolkits were distributed across villages.

When the fire season arrived, these volunteers didn't just stay they actively supported the Forest Department on the ground, proving how local vigilance can stop a small spark from becoming a raging inferno.

Greener Solutions for Fodder

One of the root causes of uncontrolled fires in Himachal Pradesh is the age-old practice of burning grasslands for "better fodder." To provide a safe and sustainable alternative, THF introduced fodder management training.

7 training sessions were held with the support of IGFRI and KVKs, where 500+ farmers learned sustainable fodder practices.

To further ease dependency on forests, THF distributed 560 kg of berseem seeds and 1680 kg of oat grass seeds among 560 farmers, helping them cultivate nutritious fodder right on their farmland.

This not only reduced pressure on forests but also created a steady source of fodder for livestock.



Reviving Wisdom, Building Plans

In the hills of Himachal, age-old knowledge about forests has been passed down quietly from one generation to the next. Elders often remember when fire lines were cleared collectively before the summer or when families would gather pine needles and use them in innovative ways: like bedding for cattle, mulching in farms, or even as a protective layer for fruit packaging. Such practices were not just resourceful, but also kept fire hazards under control.

THF's project tapped into this wisdom, creating a bridge between traditional practices and modern fire-prevention strategies. Villagers were encouraged to revisit these safe methods and adapt them for present-day needs. For instance, instead of leaving dry chir pine needles, one of the most fire-prone materials to accumulate on the forest floor, communities were trained to put them to practical use in their homes and farms.

But wisdom alone isn't enough; it needs structure. To give direction to these efforts, the project introduced Village Action Plans (VAPs) through Participatory Rural Appraisal (PRA) exercises. These plans are essentially "community blueprints" for fire safety, prepared by the villagers themselves. Each plan maps the village's major resources, pinpoints fire-prone spots, outlines locally available solutions, and assigns responsibilities to different groups. This ensures that when the fire season arrives, every household knows its role and every village has a coordinated strategy.

By the end of FY 2024–25, 210 villages had prepared detailed fire-focused VAPs, marking a significant milestone. These plans are more than documents, they are symbols of ownership. With a target of 700 villages, THF is gradually helping transform forest fire prevention from a government-led programme into a community-driven movement rooted in both heritage and future readiness.



Fodder seed distribution and training

Looking Ahead

The year's achievements underline one truth, forest fire prevention is people-powered. When communities are trusted and equipped, they transform from victims of disaster into protectors of nature. But the journey doesn't end here. The biggest challenge remains: finding cost-effective ways to utilize the massive fuel loads of chir pine needles. If converted into biofuel or other products, this hazard could become a livelihood opportunity, turning into hope for both forests and people. ■

Article contributed by Dr Muskaan Negi, Mahima Paswan, and Vikas Sharma.

Porites rus

Can a Coral Species Help Us Tackle Climate Change?

In January 2025, an international citizen science initiative recorded an astonishing synchronous spawning of a resilient coral species—*Porites rus*. The event is particularly significant, as *Porites rus* has been documented to be highly adaptable and capable of withstanding temperature fluctuations and bleaching events. Read on as **Dr Rina Mukherji** explores this remarkable phenomenon in greater detail…

French Polynesia is a group of 121 dispersed islands and atolls stretching over 2000 km in the Pacific Ocean, located in the southern hemisphere, and is part of Oceania. Lying between Hawaii and Australia, these picturesque islands are home to a huge network of coral reefs, and a variety of fish.

Spearfishing is a traditional occupation of the natives, fish being typical to Polynesian cuisine. Every individual and family here remains deeply connected to the lagoons and reefs, whatever his profession. This has been true of Vetea Liao, too, who belongs to a spearfishing family. Trained as a marine biologist in Australia and France, Vetea Liao made use of his native understanding of the marine environment, coral reefs, and marine animal behaviour, refining the same through scientific study. An unexpected daytime coral spawning event in November 2014, involving the *Porites rus* species, which Vetea Liao witnessed on retuning to his native land, brought in a turning point in his career.

To understand this phenomenon, one must realize that *Porites rus* is one of the commonest coral species found in the South Pacific region, especially French Polynesia, with a wide distribution as far north as the Red Sea. Generally termed the pillar and plate coral species, *Porites rus* is known to be most adaptable and resilient to temperature fluctuations, bleaching and high sea surface temperatures. A gonophoric species, meaning that colonies of *Porites rus* are either male or female, spawning events are marked by male colonies releasing sperms into the water, followed by the female colonies releasing the eggs a little after. The timing is exact and easily predicted. In fact, as per expert observers, the event is known to be on the 5th day after the full moon, from November to April. In the case of the pillar type variant of the species, the time is 1.30 am after sunrise, while for the plate variant the time is 5 am after sunrise. (These timings are as recorded in the southern hemisphere.)



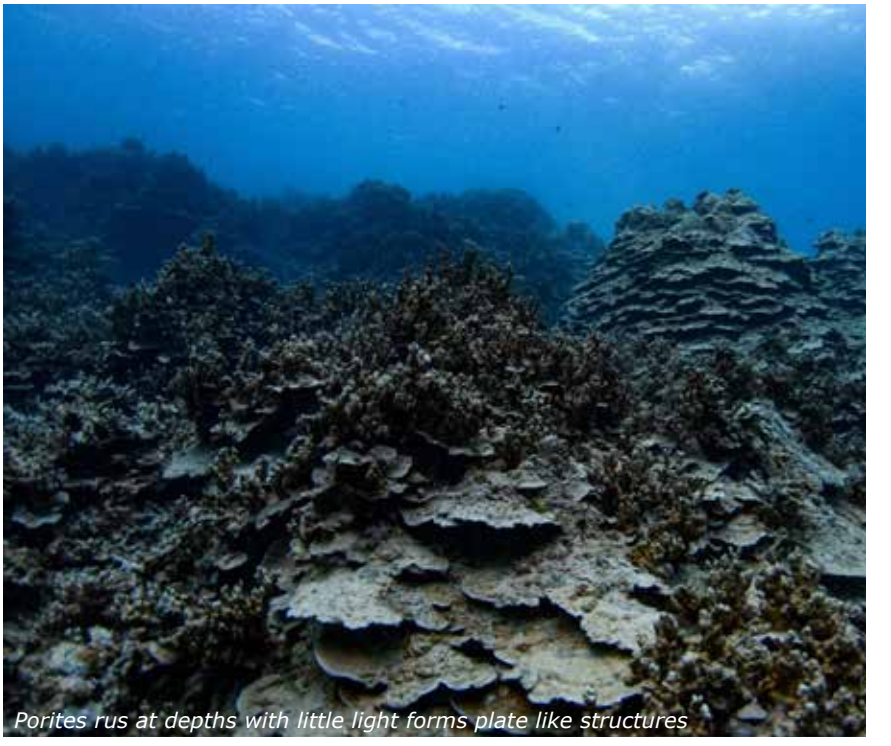
Vetea Liao and his team

During the spawning event, at the exact time, the spawning manifests itself with a light veil, or white cloud, forming around the (male) colony. This gradually turns into a dense cloud. The female spawning begins about 20 minutes after the male spawning phenomenon. The 0.5-mm eggs are oval in shape and comparatively less visible than the male cloud.

The chance sighting of coral spawning in 2014 of *Porites rus* during spearfishing set Vetea Liao thinking about whether

the reproductive cycle of corals could be linked to the lunar cycle. When friends referred him to a scientific article from 2011, which talked of the *Porites rus* coral species spawning at the same time of the lunar cycle in Zanzibar, Vetea Liao felt that it would be possible to predict the phenomenon accurately. In 2019, his hypothesis was vindicated when he and four other friends could demonstrate the simultaneous occurrence of coral spawning in two islands of French Polynesia. Subsequently, the group grew to become one comprising 13 members, who would note synchronized spawning of the *Porites rus* species in five different islands of French Polynesia in 2020.

In 2021, Vetea Liao co-founded Tama nō te Tairoto ("Children of the Lagoon") to organize a network of observers across Polynesia and document synchronized spawning in coral reefs, with Dr Charlotte Moritz, a Fisheries Science and Aquaculture graduate, with a doctoral specialization in Mediterranean marine meta-communities, who had been running her own research consultancy since moving to French Polynesia in 2013. Her post-doctoral work on marine communities, and particularly reef environments, made her an ideal scientific expert for the organization.



Porites rus at depths with little light forms plate like structures

Liao and Moritz subsequently expanded their network on an international level, with several other friends engaged in scientific research, as part of their Connected by the Reef – Te Firi A'au project.

Once the network took formal shape, Tama nō te Tairoto went on to record a synchronous spawning event in 2023 of the *Porites rus* with the help of their citizen volunteers spread over French Polynesia in the Pacific, and Reunion Island in the Indian Ocean. Notwithstanding the overwhelming nature of the project, a number of factors, according to Vetea Liao, made it quite simple for citizen volunteers. For one, *Porites rus* colonies can be observed using only fins, mask, and snorkel (being in most places located by the coastline). Spawning occurs in the morning, and it is easy to indicate the exact minute when the spawning is expected to occur. No particular technical skills are required, as the phenomenon is easily visible, and observers only need a watch to record the exact time. The only requirement for a citizen observer is to correctly identify the species. "For this reason, we developed several technical guides with pictures to assist future observers: a species identification sheet, an observation protocol sheet, and a mobile application user guide," says Vetea Liao.



Porites rus colony covered by a cloud as eggs are released in the water

Meanwhile, the very exercise of data collection spurred the organization to evoke technology to simplify their work. Explaining the development, Vetea Liao


Porites rus colony

tells me, "… with the first observers, we exchanged data by email and Messenger, and I was responsible for compiling the data into an Excel spreadsheet. Later, we used Google Forms and other free tools to collect observations and share data." With financial support from the French Office for Biodiversity (OFB), the Directorate for the Digital Economy (DGEN), and the PEW Foundation, the application was launched in 2024. Developed in both French and English, the app allows observers to record the spawning of more than 70 marine species (fish, sea urchins, giant clams, corals), besides *Porites rus*.

Quite naturally, the mobile app became a key element in recording a similar synchronous event under the ambitious Connected by the Reef _ Te firi A'au project. Placing citizen science at the heart of this project, on January 18, 2025, using precise predictive information, and 400 citizen volunteers in 20 countries from Polynesia to Tanzania, spanning 18,000 km spread over the Pacific and the Indian Oceans, Liao and Moritz recorded the synchronicity in the spawning of *Porites rus* coral reefs.

On January 18, 2025, spawning was recorded 1h22 after sunrise in Tahiti and 1h23 after sunrise in Chumbe Island (Tanzania), revealing a global synchrony finely tuned to the moon and sunrise. Similar observations were made in New Caledonia, Mauritius, Réunion, Indonesia, the Maldives, and beyond, confirming the astonishing regularity of spawning time.

In addition to this, certain specific coral colonies had been monitored over several months. After the accumulation of data collected from 2014 to 2023 from 104 reef locations spread over 15 islands and multiple depths across the Indian and Pacific Oceans, a scientific paper was produced on the phenomenon by Moritz et al. Shining a Light on Daytime Coral Spawning Synchrony Across Oceans, which was published in Global Ecology and Biogeography (Wiley) in June 2025.[1]

Speaking of the experience, Dr Charlotte Moritz, says, "These monitoring sites that were regularly and accurately surveyed allowed us to capture the reproduction history of specific colonies. Notably, we observed that some of them could spawn several times within the spawning season, over consecutive months and even over two consecutive days, a fact that had not been reported in the literature at that time. Data started to accumulate and I was already part of Tama nō te Tairoto experienced observers' group when the organization asked me to analyse the data collected from 2014 to write a scientific article that would provide a strong basis for *Porites rus* reproduction processes: timing (spawning season, days in the lunar cycle and exact hour-minute of spawning), geographic extent, synchrony at different spatial scales, and relationships with environmental conditions (depth, temperature, and light).

Following successful completion of the project by Tama nō te Tairoto , and it (the project) being declared winner of the 2024 IFRECOR TO'A REEF Award, a lot of interest was generated owing to extensive media coverage. The fact that the project had been supported by the International Coral Reef Initiative (ICRI) and the United Nations Ocean Decade, besides IFRECOR (French Coral Reef Initiative), also helped. In French Polynesia, the General Directorate of Education and Teaching (DGEE) organized a huge event so that students from all marine educational areas could observe and appreciate the phenomenon. The achievement was also endorsed by the French Office of Biodiversity.

As of now, Porites rus is a well-documented example of a coral species exhibiting high resistance to elevated temperatures, sedimentation, strong hydrodynamic conditions, and ultraviolet radiation, although "this has not yet been explicitly or directly demonstrated" (to quote Dr Moritz). Controlled experiments and long-term observations are required to confirm this. But given what we know so far, "Porites rus could well prove a model species to investigate coral resistance versus vulnerability to climate change," as Dr Moritz points out.

In case that happens, Porites rus might provide an antidote to Climate Change for all mankind. ■

1 Details available at https://onlinelibrary.wiley.com/doi/10.1111/geb.70072)

Dr Rina Mukherji is a prolific writer who regularly contributes articles in TerraGreen.



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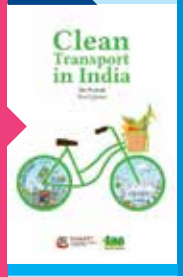
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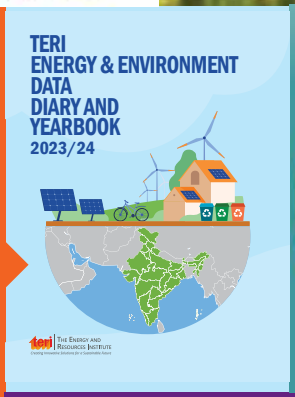
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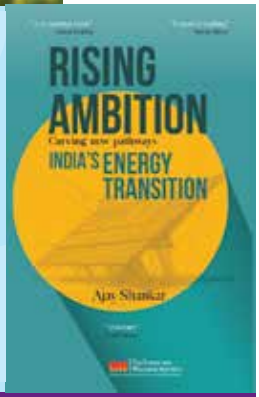


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