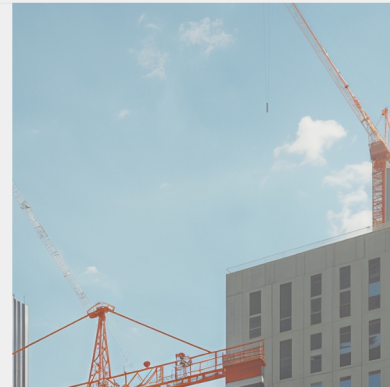


NEF Brew

Monthly Insights

CLIMATE-RESILIENT INFRASTRUCTURE
FOR A RISK-PRONE FUTURE



POLICY INSIGHTS REVIEW

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Executive Director's Message

Resilience, Reform and Readability: Shaping the Next Phase of India's Growth

The March edition of NEF Brew reflects a growing realisation in India's policy and economic discourse that resilience is no longer a parallel objective to growth; it is now central to it.

Across this issue, we bring together diverse yet deeply connected perspectives that examine how India must prepare for a future shaped by climate volatility, resource constraints and shifting global economic structures. The underlying message is clear: the quality of growth will increasingly matter as much as the pace of growth.

A highlight of this edition is the Special Feature on food safety infrastructure, authored by Shri Rajit Punhani, IAS, CEO, FSSAI, along with Dr. Alka Rao. This contribution stands out not only for its depth of analysis but also for its institutional relevance. It demonstrates how climate resilience must extend beyond infrastructure and energy systems to critical areas such as public health and food security. The article offers a compelling framework for building a risk-resilient ecosystem through circularity, standards, and technological strengthening an area that will only grow in importance.

We are equally encouraged to feature an international contribution in this issue. The article by Mahathi Gandhi, PhD candidate at Seoul National University, brings a global lens to India's strategic positioning in critical minerals and clean energy transitions. As India engages more deeply with global supply chains and geopolitical shifts, such perspectives enrich our understanding and strengthen NEF Brew as a platform with both national and international relevance.

This issue also carries contributions from emerging scholars, including Zidhan Nadaf from Pondicherry University, alongside research-driven work by the NEF team. The articles on green finance, climate-resilient infrastructure, nature-based solutions, and public health risks such as asbestos, collectively highlight a common challenge, India's development systems must evolve from being output-driven to being future-ready and risk-aware.

Taking Forward NEF ECON 90: From Videos to Accessible Knowledge

An important step forward for NEF has been the evolution of our NEF ECON 90 initiative.

Originally conceptualised as a series of short, under-90-second videos to explain complex economic issues in a simple and engaging format, ECON 90 is now being expanded into a complementary written format within NEF Brew.

We are consciously publishing articles in simplified, accessible language, supported by infographics, so that complex policy and economic issues can be understood not only by experts, but also by students, practitioners, and informed citizens.

This approach has been adopted on the advice of one of the country's most senior, respected and experienced civil servants, who emphasised that policy knowledge must not remain confined to specialists it must travel wider to shape informed public discourse.

Both the NEF ECON 90 videos and the corresponding articles are now available on our website, and we will continue to build this as a distinctive knowledge bridge between research and public understanding.

The Road Ahead

As NEF Brew evolves, our objective is clear to position it not merely as a newsletter, but as a credible, accessible and forward-looking policy publication. We remain committed to bringing together voices from government, academia, industry and young researchers, and to presenting ideas that are rigorous in analysis yet clear in communication.

India's development journey is entering a more complex phase. The challenge ahead is not only to grow, but to grow with resilience, intelligence and strategic clarity.

NEF Brew will continue to contribute to that journey.

Jagdip Rana

Executive Director

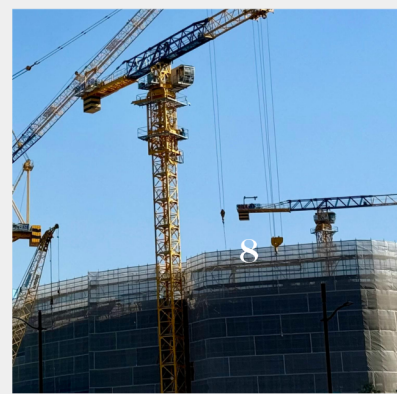
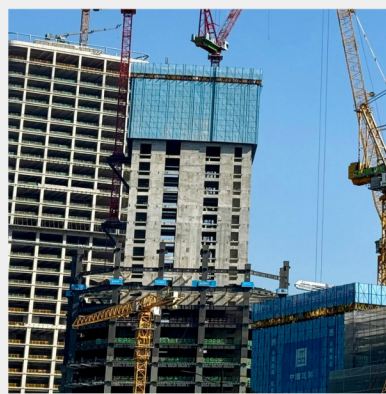
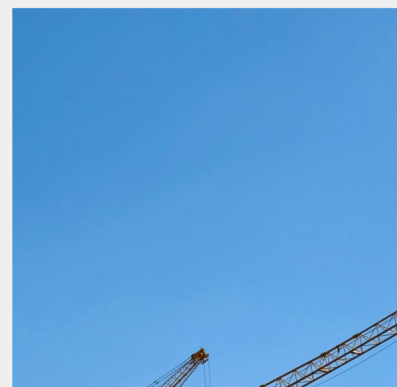
National Economic Forum (NEF)

Fresh Off the Press

Asia-Pacific Governments Push Climate-Resilient Housing as Core Urban Policy Priority

At the 2026 Asia-Pacific Forum on Sustainable Development, governments and multilateral agencies underscored that climate-resilient housing must be treated as core infrastructure policy, not a peripheral social sector issue. The discussions highlighted that rapid urbanisation and climate risks are converging most sharply in informal and vulnerable settlements, where inadequate housing significantly amplifies disaster exposure. Policymakers stressed the need to embed resilient construction standards, secure land tenure, and in-situ upgrading within national urban strategies. New evidence presented at the forum shows that upgrading housing systems at scale could increase GDP per capita by up to 10% while preventing millions of climate-related illnesses and deaths annually.

The policy shift is also driving calls for locally appropriate materials, passive cooling designs, and decentralised housing improvements, especially in tropical and flood-prone cities. Importantly, governments are now being urged to move beyond pilot projects toward system-wide guarantees of climate-resilient housing, integrating it with disaster risk reduction and climate adaptation frameworks. This marks a significant transition in global thinking - positioning housing not just as shelter, but as critical resilience infrastructure shaping urban futures.



Tamil Nadu Launches Urban Greening Policy as Climate Infrastructure Strategy

The Government of Tamil Nadu has introduced a comprehensive urban greening policy that explicitly frames green cover as a form of climate-resilient urban infrastructure. The policy mandates that cities achieve at least 15% green cover, integrating tree networks, green corridors, and ecological buffers into city planning. A key innovation is the use of GIS-based ecological mapping to identify heat-stressed zones and prioritise interventions, linking urban forestry directly with climate risk mitigation. The framework adopts a localised version of the 3-30-300 rule (visibility of trees, neighbourhood canopy cover, and access to green space), ensuring that resilience is embedded at the neighbourhood scale. It also promotes native, drought-resistant species, urban nurseries, and long-term maintenance systems to ensure ecological functionality rather than symbolic plantation drives. By linking green infrastructure with heat mitigation, flood control, and public health, the policy represents a shift toward nature-based urban resilience planning. Importantly, it incorporates citizen participation and digital monitoring dashboards, making it one of India's most structured attempts to mainstream green infrastructure as climate adaptation within urban governance.

UK Issues New Planning Guidelines Linking Housing Design with Climate Resilience

The United Kingdom has released new national planning guidelines that position climate resilience as a core requirement in housing development design. The guidelines call for integrating green spaces, biodiversity features, and flood mitigation measures into all new housing projects. Urban layouts are expected to incorporate nature-accessible neighbourhoods, while design features such as sustainable drainage systems and wildlife-friendly infrastructure are encouraged. The policy reflects a broader shift toward 'climate-proofed communities', where housing developments are planned as integrated socio-ecological systems rather than isolated built assets. However, the guidelines remain non-binding, raising concerns among experts about enforcement and long-term impact. Critics argue that voluntary standards may not be sufficient to counter rising climate risks, particularly in flood-prone areas. Nevertheless, the move signals an important policy direction - embedding climate resilience, biodiversity, and liveability within mainstream housing regulations. It also complements upcoming building standards that may mandate solar panels and heat pumps, indicating a gradual tightening of sustainability norms in the built environment.

New Study Flags Rising Climate Risk in Housing Built in Flood-Prone Areas in England

A recent study analysing housing construction trends in England has raised serious concerns about climate risk being built into new infrastructure. The findings show that one in nine homes built between 2022 and 2024 are located in flood-prone areas, with projections suggesting that up to 30% of these homes could face significant flood risk by 2050. This trend reflects a critical disconnect between housing supply targets and climate-resilient planning, where development pressures are overriding environmental risk considerations. Insurance data further indicates rising financial exposure, with flood-related claims increasing significantly in recent years. Experts warn that current planning frameworks rely excessively on engineered flood defences, rather than restricting construction in high-risk zones. The study has triggered calls for mandatory climate risk assessments in housing approvals, stronger zoning regulations, and integration of resilience criteria into national housing policies. The findings underscore a broader global issue: infrastructure decisions made today are locking in future climate vulnerability, making proactive planning reforms essential to avoid long-term economic and social losses.

Gujarat Pushes Climate-Resilient Urban Development through Policy and Finance Tools

A new policy-oriented publication released in Gujarat highlights how Indian states are increasingly framing urban infrastructure through a climate resilience lens. The report emphasises that rapid urbanisation should be seen as an opportunity to build climate-resilient, low-carbon cities, rather than as a stress factor. It advocates for integrating climate risk into city planning, infrastructure design, and energy systems, particularly as demand for housing and services grows. A key focus is on innovative financing mechanisms, including green bonds, carbon markets and public-private partnerships, to fund resilient infrastructure. The publication also underscores the need for proactive planning frameworks, where cities anticipate climate risks rather than respond reactively. Importantly, it positions cities as innovation hubs for resilience solutions, linking infrastructure planning with economic growth and sustainability. This reflects a broader shift in India's urban policy discourse - toward embedding climate resilience into the financial, institutional, and planning architecture of cities.

New Climate-Resilient City Planning Framework Gains Traction Among Local Governments

A structured Climate-Resilient City Action Planning framework is being adopted by multiple cities to mainstream resilience into urban governance. The framework provides a step-by-step methodology for local governments to assess climate risks, prioritise interventions, and integrate adaptation into city development plans. It emphasises a three-phase approach - Analyse, Act, and Accelerate - linking emissions reduction with climate adaptation strategies such as flood management, heat mitigation, and resilient infrastructure design. Notably, the model aligns with national urban missions and global climate frameworks, enabling cities to access funding and technical support. A simplified version allows cities to prepare actionable plans within three months, making it particularly relevant for rapidly urbanising regions with limited capacity. The framework also promotes institutional mechanisms, stakeholder engagement, and performance monitoring, ensuring long-term implementation. This development reflects a growing recognition that climate resilience must be embedded at the city level, with local governments playing a central role in planning and execution.

US Cities Expand Climate-Resilient Urban Infrastructure Through Green Surface and Housing Initiatives

Cities in the United States are increasingly integrating green infrastructure and housing strategies into their climate resilience agendas. In Denver, the city's 2026 roadmap includes expanding green and permeable surfaces, deploying clean energy systems, and accelerating affordable housing development aligned with climate goals. These measures aim to address urban heat, flooding, and housing shortages simultaneously. The approach reflects a broader shift in US city planning toward multi-functional infrastructure, where climate adaptation, housing, and sustainability objectives are pursued together. Green surfaces, in particular, are being used to enhance stormwater absorption, reduce urban heat island effects, and improve liveability. By linking housing expansion with environmental performance, cities are attempting to avoid the traditional trade-off between growth and sustainability. This model demonstrates how urban infrastructure investment is evolving toward integrated resilience systems, combining ecological design with social and economic priorities.

New City Master Plans Place Housing at the Core of Climate Resilience Strategies

Recent city-level master planning efforts are increasingly positioning housing as central to climate resilience and urban sustainability. For instance, newly adopted master plans in US cities emphasise resilient, inclusive and adaptable housing systems, supported by flexible zoning, land-use planning, and integration with natural systems. These plans are informed by data on population trends, environmental risks, and infrastructure capacity, ensuring that housing development aligns with long-term climate realities. A key shift is the move toward community-driven planning processes, incorporating public input into resilience strategies. The focus on housing reflects growing recognition that urban resilience is fundamentally shaped at the household level, where infrastructure meets lived reality. These developments signal a transition from sectoral planning to integrated, resilience-oriented urban governance, where housing, environment and infrastructure are planned together.

Filtered Findings

Built to Deploy, Not to Last: How India's 500 GW Mandate Structurally Disincentivises Climate Resilience in Green Finance Appraisal

TBC Shri Rajit Punhani and Dr. Alka Rão

On the Structural Disincentives for Physical Climate Resilience in India's Green Finance Architecture

Introduction

India's energy transition presents a striking paradox. The country has installed over 220 gigawatts (GW) of renewable energy capacity as of March 2025, adding a record 29.5 GW in a single financial year, a 59% year-on-year increase, and is deploying capital at an unprecedented pace toward its Nationally Determined Contribution (NDC) target of 500 GW of non-fossil fuel capacity by 2030 (Indian Renewable Energy Development Agency [IREDA], 2025; Ministry of New and Renewable Energy [MNRE], 2025). Yet India experienced extreme weather events on 322 of 366 days in 2024, the highest frequency across three consecutive years of worsening records (Centre for Science and Environment - Down to Earth [CSE-DTE], 2025), and the Reserve Bank of India (RBI, 2023) projects approximately ₹85.6 trillion in

economy-wide climate damages by 2030. The infrastructure being built today to address climate change is itself acutely exposed to the physical consequences of that same change.

This contradiction is not merely technical. It reflects a structural failure in the design of India's green finance architecture. While the existing literature has extensively examined India's mitigation finance gap, how much capital is needed and where it flows, and separately documented the physical climate vulnerability of Indian infrastructure, no study has examined how the political and macroeconomic mandate to rapidly achieve the 500 GW target actively shapes lender behaviour at the project level, specifically by creating institutional incentives that disincentivise the rigorous appraisal of physical climate resilience in green debt. This article addresses that gap.



Employing a political economy analysis of India's green finance architecture, drawing on institutional appraisal documentation, regulatory data, and recent secondary literature, this article argues that India's 500 GW mandate, while ambitious in mitigation terms, is generating a structural disincentive for financial institutions to price physical climate resilience into green project appraisals. Competitive tariff bidding, rapid disbursement pressure, and the conflation of 'green' with 'resilient' combine to make climate-proofing financially irrational for lenders and developers alike. The result is a growing portfolio of renewable infrastructure that is financially structured but physically fragile. One might argue that record disbursement speeds reflect the success of India's green finance mobilisation, and in mitigation terms, they do. The contention here, however, is that deployment speed achieved without physical resilience appraisal is not a measure of success but of structural incompleteness: it builds the asset while systematically deferring the risk.

The 500 GW Mandate and the Logic of Speed

India's NDC target of 500 GW of non-fossil fuel capacity by 2030 has become the central organising principle of the country's energy finance architecture. Crucially, this target is defined and measured exclusively in megawatts installed: it counts the quantity of capacity added, not the physical robustness of the assets being counted. To sustain the required deployment pace, the Government of India mandated 50 GW of annual bidding for solar and wind projects from 2023 to 2028 (MNRE, 2025). This has created an institutional culture in which speed and volume of capital disbursement are the primary success metrics. IREDA's gross loan book grew 28% year-on-year to ₹76,282 crore in FY2024-25, with disbursements of ₹30,168 crore in that year alone (IREDA, 2025). The competitive reverse-auction mechanism compounds this pressure: developers bid down tariffs to win contracts, compressing margins and making any expenditure not directly required for grid connection, including climate-proofing, financially irrational (Raj & Mohan, 2025). This deployment imperative is mirrored in the global climate finance architecture. According to the Global Landscape of Climate Finance (Climate Policy Initiative [CPI], 2025), global



mitigation finance more than doubled between 2018 and 2023, reaching \$1.78 trillion, while adaptation finance stood at just \$65 billion, a figure that fell 16% from the previous year.

India's domestic pattern replicates this skew: the National Adaptation Fund received a stagnant allocation of merely ₹60 crore in FY2022-23, even as renewable energy disbursements grew by double digits annually (CPI, 2025). To the extent that NDC-alignment functions as the primary eligibility signal for green finance instruments, as reflected in IREDA's project categorisation criteria and sovereign green bond frameworks, this metric design arguably propagates the resilience blind spot from the policy level directly into the appraisal level (IREDA, 2025; RBI, 2023).

The Appraisal Blind Spot: How Green Finance Inherits the Resilience Gap

The structural bias toward deployment speed is reproduced and institutionalised at the project appraisal level. A critical examination of IREDA's Environmental and Social Management System (ESMS) reveals a fundamental distinction that exposes the appraisal blind spot. The ESMS is designed to assess the impact of the funded project on the environment: that is, 'do no harm' criteria, screening for pollution, displacement, and ecological damage. There is no empirical evidence in IREDA's published documentation of any systematic appraisal of a project's own physical vulnerability to climate hazards such as cyclones, floods, or extreme heat (IREDA, 2024, 2025).

This distinction, between impact risk (how the project harms the environment) and physical climate risk (how the environment harms the project), is the precise institutional location of the blind spot. A solar park in a flood-prone zone qualifies for green finance if it adds renewable megawatts. It does not need to demonstrate flood resilience to qualify.

This is not an oversight unique to IREDA. An RBI survey of commercial banks found that most institutions lack a dedicated department to address ESG initiatives and do not have a clear strategy for addressing climate-related physical risks, focusing instead on their own financial risk rather than the physical climate vulnerabilities of the assets they finance (RBI, 2023). Dikau and Volz (2021) demonstrate that central bank mandates in developing economies are structurally oriented toward financial stability rather than impact risk,

creating a systemic gap between macro-level climate directives and micro-level lending behaviour, a finding directly applicable to the RBI's green finance posture. By contrast, the International Finance Corporation's Paris Alignment framework explicitly mandates physical risk screening, covering hazard exposure, vulnerability assessment, and residual risk after adaptation, as a condition of project financing. The gap between international best practice and Indian institutional practice is structural, not incidental.

The most compelling evidence of this systemic void is temporal. IREDA had cumulatively disbursed ₹1,56,085 crore into renewable infrastructure before the Reserve Bank - Climate Risk Information System (RB-CRIS) was established in October 2024, the very system designed to provide lenders with the standardised hazard data, loss data, and vulnerability data required for physical risk appraisal (RBI, 2025). Hundreds of billions in green finance were deployed into climate-exposed infrastructure without the data infrastructure needed to appraise that exposure. The capital moved faster than the knowledge base required to deploy it responsibly.

The Consequence: A Physically Fragile Green Grid

The consequences of this institutional blind spot are already visible. India experienced extreme weather events on 322 of 366 days in 2024, continuing a worsening trend from 318 days in 2023 and 314 days in 2022 (CSE-DTE, 2025). The IPCC Sixth Assessment Report (AR6) projects a cumulative GDP loss of 8% specifically attributable to infrastructure damage from climate impacts in India by 2050 (Shaw et al., n.d., First Order Draft). Renewable infrastructure deployed under the 500 GW mandate is being built into this environment, at record speed, without mandatory physical resilience standards.

The hydropower sector, a critical component of the 500 GW portfolio, offers the most documented evidence of this fragility. A Landslide Hazard Risk Assessment by the Himachal Pradesh Disaster Management Authority found that 67 hydropower stations are currently under threat of landslide hazard risk, including 10 mega hydropower stations in medium to high-risk areas. The January 2023

land subsidence in Joshimath is illustrative in this regard. The State of Finance in India Report (Chandrashekhara et al., 2023) describes hydropower development as one of the key contributors to triggering the unprecedented land subsidence in the town, noting that the cascading construction of run-of-the-river dams, including the 520 MW Tapovan Vishnugad Hydroelectric Project – contributed to geological destabilisation that project developers and state authorities frequently attributed to ‘geological surprises.’ This pattern of post-hoc deflection is itself symptomatic of an upstream appraisal culture that does not require developers to account for physical climate and geological risk before capital is committed.

The macroeconomic stakes of this pattern are severe. India’s power sector transition requires \$57 billion in capital expenditure through 2030 (Raj & Mohan, 2025). The RBI (2023) projects total economy-wide climate damage costs of approximately ₹85.6 trillion by the same year, a figure that encompasses all sectors, not only energy infrastructure, and therefore cannot be directly mapped onto the transition investment alone. What it does establish is the scale of the risk environment into which transition capital is being deployed. Against India’s estimated annual adaptation financing need of \$67 billion through 2030 (CPI India, 2023), which remains almost entirely unmet, the absence of physical resilience standards in green finance appraisal represents not a marginal oversight but a fundamental structural misalignment.

Policy Recommendations

Addressing this structural disincentive requires reform at three interlocking levels of India’s green finance architecture.

Mandate Physical Climate Risk Screening in Project Appraisal

The RBI and IREDA should jointly mandate that physical climate risk assessment, covering hazard exposure, vulnerability, and residual risk after adaptation measures, be a binding condition of green finance eligibility, not merely an environmental safeguard. The recently established RB-CRIS provides the data infrastructure required for this shift; what is now needed is a regulatory mandate converting this data into enforceable appraisal criteria (RBI, 2025). Lockwood et al. (2020) demonstrate that incumbent institutional arrangements in energy finance are highly resistant to forward-looking regulatory reform without explicit statutory mandate, underscoring that voluntary adoption of resilience criteria by IREDA or commercial banks is unlikely without regulatory compulsion.

Decouple Resilience Costs from Competitive Tariff Bidding

The reverse-auction mechanism for renewable energy tariff discovery, while effective at driving down the Levelized Cost of Electricity (LCOE), structurally penalises developers who invest in physical resilience, since climate-proofing costs cannot be recovered through competitive bids. A dedicated concessional blended finance window, capitalised through multilateral development bank instruments and sovereign green bond proceeds, should fund the incremental cost of resilience-proofing renewable assets separately from tariff-competitive project costs (Shrimali, 2016). This decouples the resilience investment decision from price discovery, making climate-proofing financially viable without distorting tariff competition. Proactive adaptation investments in South Asia are estimated to prevent residual damages of 289% of their upfront cost by 2050, making the economic case for such a window unambiguous (New et al., 2019).

Redesign NDC Metrics to Include Resilience Quality

India's NDC reporting currently measures climate ambition in installed megawatts, a purely quantitative metric blind to the physical robustness of the infrastructure it counts. Because green finance eligibility flows from NDC-alignment, this metric design arguably propagates the resilience blind spot from the policy level into the appraisal level.

Incorporating a Resilience Quality Index alongside installed capacity figures in India's NDC reporting framework would shift the upstream incentive structure: if international climate commitments measure resilience quality, domestic finance frameworks face institutional pressure to appraise for it.

Rajamani et al. (2021) demonstrate that the normative architecture of NDC frameworks shapes domestic policy design in measurable ways, suggesting that metric-level reform at the NDC tier carries downstream institutional consequences that voluntary guidelines cannot replicate. This is ultimately the most upstream and therefore most powerful lever available.

Conclusion

India cannot build a climate-resilient future on infrastructure that is itself climate-fragile. The 500 GW renewable energy target represents an extraordinary act of policy ambition, but ambition, when channelled through an institutional architecture that structurally

disincentivises physical resilience appraisal, produces fragility at scale. The argument advanced here is not that India lacks capital, technical capacity, or political will. It is that the metrics driving NDC commitments, the criteria governing green finance appraisal, and the mechanisms determining tariff competitiveness are all aligned, coherently and perversely, to make climate-proofing irrational at the project level. The problem is not ambition. It is the incentive architecture beneath the ambition.

The three reforms proposed, mandatory physical risk screening, decoupled resilience financing, and redesigned NDC metrics, are not marginal adjustments to India's energy transition strategy. They are prerequisites for that strategy's long-term viability. The stakes extend beyond India: as the world's most ambitious developing-country renewable energy programme, India's green finance architecture will shape the template for South Asia and the broader Global South. Lockwood et al. (2020) demonstrate that incumbent institutional arrangements in energy finance create durable path dependencies that resist forward-looking reform without explicit regulatory intervention, a warning that without structural reform at the appraisal level, the 500 GW mandate risks locking in not just a green grid, but a fragile one. Getting the incentive structure right here matters well beyond the 500 GW target.

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The Hidden Danger of Asbestos in Indian Infrastructure: A Silent Bomb in the Making

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Beneath the facade of India's rapid urbanization and affordable housing boom lies a latent, catastrophic public health crisis: pervasive asbestos integration. As India aggressively expands its infrastructure to accommodate a massive, upwardly mobile population, it unwittingly weaves a carcinogenic time bomb into the structural fabric of its cities. While Western economies spent the latter half of the 20th century mitigating the devastating epidemiological fallout of asbestos through strict legislative phase-outs, India's consumption trajectory moves in stark opposition. Driven by the capital constraints of a developing economy, India currently relies on this highly cost-effective, durable mineral with vehement frequency. From a macroeconomic perspective, this reliance constitutes a severe negative externality. The immediate capital savings derived from inexpensive asbestos-cement roofing are drastically eclipsed by the deferred, asymmetric burden placed on public healthcare systems and the inevitable costs of future environmental abatement. This paper posits that India's unchecked

consumption of asbestos represents an unpriced systemic risk, necessitating immediate regulatory intervention, advanced scientific screening, and comprehensive public awareness.

Pathogenesis and Historical Precedent: The Cost of Regulatory Arbitrage

To comprehend the magnitude of the peril facing India, one must scrutinize the historical and pathogenic realities documented in the United States. Asbestos, a naturally occurring silicate mineral, forms microscopic, highly stable fibers prized for thermal and chemical resistance. However, inhalation of these fibers induces "frustrated phagocytosis"—a pathogenic process wherein alveolar macrophages fail to completely engulf excessively long fibers. This imperfect phagocytosis triggers persistent cellular irritation, chronic inflammation, chromosomal instability, and ultimately, malignant mesothelioma and lung cancer (Nagai et al., 2019).

Despite clinical awareness of these fatal mechanisms emerging as early as the 1930s, major American asbestos corporations engaged in a coordinated economic cover-up. The discovery of the "Sumner Simpson Papers" during 1970s litigation exposed decades of corporate malfeasance, revealing that executives from industry giants like Johns-Manville systematically suppressed occupational health research to evade liability and preserve profit margins (Vogelzang Law, 2025). This prioritization of fiscal efficiency over human life culminated in an epidemiological disaster and billions in punitive damages, forcing multiple conglomerates into bankruptcy. Furthermore, corporate lobbying effectively stalled absolute legislative bans for decades, with prominent real estate figures historically praising asbestos as an unparalleled fireproofing agent, thereby demonstrating the entrenched political resistance to abandoning the mineral (Tabuchi, 2025). India currently risks mirroring this precise trajectory of regulatory arbitrage and delayed accountability

The Latent Cost of Infrastructure Destruction

The catastrophic public health consequences of integrating asbestos into dense urban infrastructure were starkly quantified following the September 11, 2001, collapse of the World Trade Center (WTC).

The WTC towers were insulated with thousands of tons of asbestos-containing fireproofing material. The extreme mechanical force of the structural collapse pulverized this legacy asbestos into microscopic, airborne particulate matter, blanketing lower Manhattan in a toxic dust cloud.

Initial environmental assessments, utilizing inadequate polarized light microscopy (PLM), notoriously underestimated the hazard, resulting in mass, unprotected exposure among rescue workers and residents. The latent epidemiological fallout has been unprecedented. By early 2024, the WTC Health Program documented that 6,897 registered members had died from respiratory illnesses or cancers directly correlated to their toxic dust exposure at Ground Zero (Centers for Disease Control and Prevention [CDC], 2024). For India, the WTC tragedy serves as a grim empirical model for the mass-exposure events that will inevitably occur when legacy asbestos-laden infrastructure is demolished, altered, or destroyed in densely populated metropolises.

The Indian Context: An Unpriced Systemic Risk

In India, asbestos exposure is not restricted to catastrophic structural failures; it is a ubiquitous hazard woven into the daily informal economy. Recent geopolitical trade data reveals that India remains the world's premier consumer of asbestos, utilizing an estimated 482,000 tonnes annually, accounting for roughly half of the global trade (International Ban Asbestos Secretariat [IBAS], 2025).

Table 1 highlights the glaring policy divergence between Indian consumption and the American regulatory phase-out.

TABLE 1: Comparative Asbestos Consumption Dynamics (2024)

COUNTRY	Annual Consumption (Tonnes)	Per Capita Consumption	Current Regulatory Framework
INDIA	482.000	0.30 kg/person	Banned domestic mining; Legal import & widespread usage.
UNITED STATES	110	<0.01 kg/person	Chrysotile usage fully banned by EPA in 2024.

Source: International Ban Asbestos Secretariat (2025); Nelson (2025).

Because of its unparalleled cost-efficiency, asbestos totally dominates the market for corrugated cement roofing sheets in rural and low-income urban housing. The primary vector of exposure arises during routine structural modification. Whenever an asbestos-containing wall is drilled, cut, or demolished without specialized abatement protocols, carcinogenic fibers are suspended in the air.

Disturbingly, amphibole asbestos contamination extends far beyond industrial construction, infiltrating unregulated consumer supply chains. Recent transmission electron microscopy (TEM) studies have detected highly toxic tremolite and actinolite asbestos in children's talc-based toy cosmetics and play powders (Fitzgerald et al., 2020). Children are unknowingly exposed to these permanent, bio-persistent fibers through ingestion or inhalation. The economic ramifications of this ubiquitous exposure are staggering: a generation exposed to asbestos today will translate into an insurmountable loss of human capital and critical strain on India's future healthcare infrastructure.

Policy Prescription: A Multi-Stakeholder Intervention

India currently underestimates the profound physiological and economic detriments of its asbestos dependency. Sustainable infrastructural development cannot be subsidized by citizens' respiratory health. Mitigating this crisis necessitates a rigorous, multifaceted policy framework

- **Aggressive National Awareness Campaigns:** The Indian populace remains largely ignorant of asbestos pathogenesis. Awareness initiatives must be aggressively scaled, mirroring the National Green Tribunal's recent mandate requiring public education regarding the hazards of degrading asbestos school roofs (India Water Portal, 2025). These campaigns must specifically target the informal construction sector regarding the immediate dangers of mechanical manipulation of cement sheets.
- **Total Regulatory Prohibition:** The Indian government currently maintains a paradoxical policy stance: domestic mining is prohibited, yet the Ministry of Environment, Forest and Climate Change acknowledges no immediate proposal to ban imports (The Union, 2023). To safeguard public health, India must transition from import regulation to a comprehensive, phased statutory ban on the import, manufacturing, and utilization of all asbestos variants, including chrysotile.

- **Funded Scientific Abatement Research:** Indian scientific institutions require targeted budgetary allocations for hazardous waste remediation. Premier entities like the Council of Scientific & Industrial Research (CSIR) must be tasked with developing scalable, safe asbestos disposal and vitrification technologies (CSIR, 2025). Concurrently, advanced TEM screening must be standardized to meticulously map urban asbestos contamination.

Conclusion

The historical narrative of asbestos exemplifies how short-term economic convenience breeds long-term human tragedy. As a rapidly developing nation, India possesses the distinct advantage of global hindsight. Continuing to import and integrate asbestos vehemently into modern construction effectively plants a silent, respiratory bomb in every neighborhood, transferring the true fiscal cost of infrastructure development directly onto the lungs of the populace. It is an urgent macroeconomic and ethical imperative for India to acknowledge asbestos as a deadly systemic hazard and decisively eradicate its use from the nation's infrastructural future.

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Research Roast

Scaling Nature-Based Solutions for Climate-Resilient Infrastructure in India: A Data-Driven Policy Analysis

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Abstract

The increasing frequency of climate-induced disasters poses significant risks to infrastructure systems, particularly in developing economies such as India. This paper evaluates the potential of Nature-Based Solutions (NbS) as a cost-effective and resilient alternative to conventional infrastructure. Using secondary datasets from institutions such as the World Bank, IPCC, and Indian government reports, the study analyses the economic efficiency, risk reduction capacity, and scalability of NbS in India. The findings indicate that NbS can reduce climate risks by up to 30–50% in vulnerable regions while delivering multi-sectoral co-benefits. However, institutional fragmentation, financing gaps, and lack of standardized metrics hinder implementation. The paper concludes with targeted policy recommendations for integrating NbS into India’s infrastructure strategy.

Introduction

Climate change has emerged as a systemic risk multiplier affecting infrastructure stability worldwide. According to the Intergovernmental Panel on Climate Change, global warming has already reached approximately 1.1°C above pre-industrial levels, intensifying extreme weather events such as floods, droughts, and cyclones.

India is particularly vulnerable. Data from the World Bank estimates that over 75% of Indian districts are prone to extreme climate events, with annual economic losses exceeding USD 15 billion due to infrastructure damage and disruption.

Traditional infrastructure systems—often termed “grey infrastructure”—are increasingly inadequate to handle such dynamic risks. This necessitates a shift towards adaptive, sustainable, and resilient systems, where Nature-Based Solutions (NbS) play a critical role.

This study adopts a hybrid qualitative–quantitative analytical framework to systematically evaluate



the effectiveness of Nature-Based Solutions (NbS) in enhancing climate-resilient infrastructure in India. The approach is designed to bridge empirical data analysis with contextual policy interpretation, thereby ensuring both analytical rigor and practical relevance.

At the core of the methodology is secondary data analysis, drawing upon datasets and reports published by globally recognized institutions such as the World Bank, United Nations Environment Programme, and the Intergovernmental Panel on Climate Change. These sources provide comprehensive and comparable data on climate risks, infrastructure vulnerability, ecosystem services, and economic assessments of adaptation strategies. By synthesizing cross-national and India-specific datasets, the study establishes a robust empirical foundation to assess the performance and scalability of NbS. Particular emphasis is placed on longitudinal data trends to capture the evolving nature of climate risks and infrastructure responses over time. In addition to quantitative analysis, the study employs a comparative case study method to contextualize findings across different geographical and policy environments. Selected case studies—including coastal resilience initiatives in South Asia

and flood management strategies in Europe—are analyzed to identify patterns of success, policy innovations, and institutional arrangements that enable effective implementation of NbS. This comparative dimension allows the study to move beyond descriptive analysis and generate transferable insights for India's policy landscape. By juxtaposing global best practices with domestic experiences, the methodology highlights both opportunities and constraints in scaling NbS within diverse socioeconomic contexts.

A critical component of the framework is the cost-benefit evaluation of Nature-Based Solutions vis-à-vis conventional grey infrastructure. This involves assessing not only the initial capital costs but also long-term maintenance expenditures, lifecycle efficiency, and avoided damage costs due to climate events. Unlike traditional infrastructure appraisal methods, this study adopts a multi-dimensional valuation approach, incorporating environmental and social externalities into economic calculations. For instance, the valuation of ecosystem services—such as flood regulation by wetlands or coastal protection by mangroves—is integrated into the cost-benefit analysis to provide a more comprehensive assessment of NbS. This enables a shift from short-term financial metrics to long-term resilience-oriented economic reasoning.



To ensure analytical clarity, the study is guided by a set of key indicators that capture the multidimensional impact of NbS. The first indicator, disaster loss reduction, measures the extent to which NbS interventions mitigate the economic and human costs of climate-induced disasters. This is quantified through comparative analysis of pre- and post-intervention data, as well as crossregional comparisons where NbS have been implemented versus areas relying solely on grey infrastructure. This indicator is particularly significant in assessing the risk absorption capacity of natural systems.

The second indicator, the cost-benefit ratio, evaluates the economic efficiency of NbS investments over time. By comparing total lifecycle costs with cumulative benefits—including avoided damages and ecosystem services—the study determines the relative financial viability of NbS. This metric is crucial in addressing policy skepticism regarding the perceived uncertainty of returns from nature-based interventions.

The third indicator focuses on carbon sequestration potential, reflecting the contribution of NbS to climate mitigation alongside adaptation. Ecosystems such as forests, wetlands, and mangroves act as carbon sinks, and their integration into infrastructure planning enhances both environmental sustainability and compliance with global climate commitments. This dual role strengthens the strategic value of NbS in national and international policy frameworks.

Finally, the study incorporates social co-benefits, including employment generation, livelihood security, and community resilience. Unlike grey infrastructure, which often delivers narrowly defined functional benefits, NbS create opportunities for inclusive development by engaging local communities in implementation and maintenance processes. These social dimensions are evaluated through qualitative assessments and supported by available socio-economic data, highlighting the role of NbS in promoting equitable and participatory development.

Overall, this integrated methodological approach enables a holistic evaluation of Nature-Based Solutions, capturing their economic, environmental, and social dimensions. By combining empirical data with comparative analysis and multi-criteria evaluation, the study provides a comprehensive framework for understanding the potential of NbS as a cornerstone of climate-resilient infrastructure policy in India.

Climate Risk and Infrastructure Vulnerability in India

India's climate risk profile has undergone a significant transformation over the past decade, with a marked increase in the frequency, intensity, and spatial distribution of extreme weather events.

According to aggregated data from national disaster management records and global climate assessments by the Intergovernmental Panel on Climate Change, India experienced over 300 extreme weather events between 2015 and 2022, including floods, cyclones, heatwaves, droughts, and landslides. This reflects not merely episodic variability but a structural shift driven by anthropogenic climate change.

Coastal regions are particularly vulnerable due to the compounding effects of sea-level rise, cyclonic activity, and saline intrusion. Empirical observations indicate that India's coastline is experiencing an average sea-level rise of approximately 3.3 mm per year, consistent with global trends. While this figure may appear marginal on an annual basis, its cumulative impact is substantial, leading to coastal erosion, submergence of low-lying areas, and degradation of critical infrastructure such as ports, roads, and energy installations. States like West Bengal, Odisha, and Gujarat are already witnessing the long-term consequences of these changes, including the displacement of communities and loss of economic assets. Additionally, the increasing frequency of heatwaves has intensified climate risks in both rural and urban areas. Prolonged periods of extreme heat not only affect human health but also strain energy infrastructure due to rising demand for cooling, thereby creating cascading systemic risks.

Taken together, these trends underscore that climate risks in India are no longer isolated environmental events but interconnected systemic challenges with wide-ranging socio-economic implications.

The growing intensity of climate risks is compounded by the high degree of infrastructure exposure across India. According to assessments by NITI Aayog, nearly 40% of India's infrastructure assets are located in climate-sensitive zones, including floodplains, coastal regions, and areas prone to landslides and droughts. This spatial concentration of assets in vulnerable regions significantly amplifies the risk of large-scale disruptions.

Urban areas, in particular, illustrate the intersection of climate risk and infrastructure vulnerability. Rapid and often unplanned urbanization has led to the encroachment of natural drainage systems, wetlands, and green spaces, thereby reducing the capacity of cities to absorb and manage excess water. As a result, urban flooding has increased by approximately 25% over the past decade, transforming what were once rare events into frequent occurrences. Cities such as Mumbai and Chennai have experienced repeated flooding episodes, causing extensive damage to transport networks, housing, and public utilities.

Heat stress represents another critical dimension of infrastructure vulnerability. Rising temperatures and the increasing occurrence of heatwaves have been shown to reduce urban productivity by 15–20%, particularly in sectors dependent on outdoor labor such as construction and informal services. This has direct implications for economic output and labor welfare, while also increasing pressure on energy infrastructure due to heightened electricity demand for cooling. In extreme cases, heatwaves can lead to power outages, further exacerbating economic losses and social hardship.

Moreover, critical infrastructure systems—including transportation corridors, power grids, and water supply networks—are highly interdependent. Disruption in one sector often triggers cascading effects across others. For instance, flooding of transport networks can delay emergency response and supply delivery, while power outages can compromise water treatment and healthcare services. This interconnectedness increases systemic vulnerability and highlights the need for integrated resilience planning.

These trends clearly indicate that climate risk and infrastructure vulnerability in India are deeply intertwined. The scale and intensity of emerging risks demonstrate that infrastructure resilience is no longer solely an environmental or technical issue; rather, it has become a macroeconomic imperative. Infrastructure failures translate into significant economic losses, reduced productivity, and heightened fiscal pressures, thereby affecting long-term

growth and development trajectories. Consequently, building climate-resilient infrastructure must be positioned at the center of India's economic planning and policy framework.

Economic Analysis of Nature-Based Solutions

The economic evaluation of Nature-Based Solutions (NbS) in comparison to conventional grey infrastructure reveals significant advantages when assessed through a lifecycle and multidimensional framework. Traditional grey infrastructure—such as dams, seawalls, and concrete drainage systems—typically involves high initial capital investments, substantial maintenance costs, and a limited functional scope focused primarily on single-risk mitigation. Over time, these systems often require costly upgrades to cope with intensifying climate stressors, thereby increasing their long-term financial burden.

In contrast, NbS—such as wetlands, mangroves, and urban green spaces—are characterized by moderate to low initial investment requirements and significantly lower maintenance costs, as they rely on self-sustaining ecological processes. More importantly, their capacity for risk reduction is comparatively higher, particularly in absorbing and diffusing climate shocks rather than merely

resisting them. For instance, while a concrete flood barrier may protect a specific zone, it can inadvertently transfer risk downstream, whereas a restored floodplain distributes excess water more evenly, reducing systemic vulnerability.

Empirical evidence reinforces this economic rationale. A study by the United Nations Environment Programme estimates that every \$1 invested in Nature-Based Solutions yields returns ranging from \$4 to \$10, when accounting for avoided damages, ecosystem services, and social benefits. This positions NbS not only as an environmentally sustainable option but also as a highly efficient economic investment in the context of climate resilience.

Mangrove ecosystems provide one of the most compelling examples of NbS delivering measurable economic and protective benefits. Along India's eastern coastline, particularly in states such as Odisha and West Bengal, mangrove forests act as natural barriers against cyclones, storm surges, and coastal erosion.

Scientific studies indicate that mangroves can reduce wave energy by up to 66%, significantly lowering the intensity of coastal flooding and infrastructure damage during extreme weather events. This protective function translates into substantial economic savings. Estimates suggest that mangrove ecosystems in India contribute to annual avoided damages worth approximately ₹4,000-₹6,000 crore, particularly in cyclone-prone regions.

The comparative impact is clearly visible in regions with intact mangrove cover. Coastal districts in Odisha and West Bengal with well-preserved mangrove ecosystems have recorded 30-40% lower cyclone-related damage compared to areas where such natural buffers have been degraded. This includes reduced destruction of housing, roads, and agricultural land, as well as lower recovery and rehabilitation costs for governments.

Beyond risk reduction, mangroves also support livelihood generation through fisheries, honey collection, and eco-tourism, thereby contributing to local economic resilience. Their role as carbon sinks further enhances their value in the context of global climate mitigation efforts. Thus, mangrove restoration represents a multi-functional infrastructure investment, combining economic efficiency with ecological sustainability.

In urban contexts, Nature-Based Solutions play a critical role in addressing climate-induced challenges such as heat stress, flooding, and water scarcity. Rapid urbanization in India has led to the loss of natural ecosystems, increasing the vulnerability of cities to extreme climate events. Integrating NbS into urban planning offers a cost-effective and sustainable alternative to conventional infrastructure expansion.

rUrban green infrastructure—including parks, green roofs, urban forests, and restored water bodies—has been shown to reduce surface temperatures by 2–4°C, effectively mitigating the urban heat island effect. This temperature reduction has direct economic implications, as it lowers the demand for energy-intensive cooling systems. Empirical estimates suggest that such interventions can reduce energy consumption for cooling by 15–30%, leading to significant savings for households and urban administrations.

Additionally, NbS enhance groundwater recharge by 20–25% through improved water infiltration and reduced surface runoff. This is particularly important for Indian cities facing acute water stress. By restoring natural hydrological cycles, NbS reduce dependence on costly artificial water supply systems and improve long-term water security.

Furthermore, urban NbS contribute to improved air quality, increased property values, and enhanced public health outcomes. These indirect economic benefits reinforce the argument that NbS are not merely environmental interventions but integral components of sustainable urban infrastructure systems.

Case Studies: Evidence-Based Insights

Netherlands: Flood Resilience through Nature-Based Solutions

The Netherlands provides a globally recognized example of integrating NbS into national infrastructure planning through its “Room for the River” programme. Instead of relying solely on higher dikes and flood barriers, the government adopted a strategy of restoring natural floodplains, relocating embankments, and creating water retention spaces.

This approach resulted in a reduction of flood risk by over 50%, while simultaneously improving ecological conditions and spatial planning outcomes. Importantly, the programme achieved cost savings of approximately €1.5 billion compared to traditional dam expansion projects. The Dutch experience demonstrates that working with natural systems can deliver superior outcomes in both economic and environmental terms, while also enhancing long-term resilience.

Bangladesh: Coastal Protection through Mangrove Afforestation

Bangladesh, one of the most climate-vulnerable countries in the world, has successfully leveraged mangrove afforestation as a key adaptation strategy. Large-scale plantation of mangroves along coastal belts has significantly strengthened natural defenses against cyclones and storm surges.

Empirical evidence shows that these interventions have reduced cyclone-related fatalities by up to 70%, highlighting their effectiveness in protecting human lives. In addition to disaster risk reduction, mangrove ecosystems have contributed to increased local incomes through fisheries, aquaculture, and ecotourism activities. This dual benefit of protection and livelihood enhancement underscores the socio-economic value of NbS in resource-constrained settings.

India: Odisha's Cyclone Management Model

India's own experience in Odisha offers a compelling example of integrating NbS with technological and institutional measures. Following the devastating super cyclone of 1999, which resulted in over 10,000 fatalities, the state government implemented a comprehensive disaster management strategy combining mangrove restoration, early warning systems, and community preparedness.

By the time Cyclone Fani struck in 2019, these measures had dramatically improved resilience outcomes, with fatalities reduced to fewer than 100 despite the storm's high intensity. The presence of mangrove buffers played a crucial role in minimizing coastal damage, while improved governance mechanisms ensured timely evacuation and response.

This case illustrates that NbS are most effective when integrated with institutional capacity, technological innovation, and community engagement, creating a holistic resilience framework.

The economic analysis and empirical case studies collectively demonstrate that Nature-Based Solutions offer a high-return, low-risk alternative to conventional infrastructure approaches. Their ability to deliver multiple co-benefits—ranging from disaster risk reduction to livelihood generation—positions them as a cornerstone of climate-resilient development.

At the same time, global and domestic experiences highlight that the success of NbS depends on context-specific design, strong governance frameworks, and sustained investment. When effectively implemented, NbS can transform infrastructure systems from being reactive and resource-intensive to adaptive, efficient, and sustainable.

Policy and Institutional Gaps in India

Despite growing empirical evidence supporting the economic and ecological effectiveness of Nature-Based Solutions (NbS), their adoption within India's infrastructure planning remains limited and uneven. This gap is not due to a lack of conceptual recognition but is primarily rooted in structural, financial, and methodological constraints within the policy ecosystem.

Fragmented Governance

One of the most significant barriers to the large-scale implementation of NbS in India is the fragmented nature of governance structures. Infrastructure planning and environmental management are distributed across multiple ministries and agencies—such as those dealing with environment, urban development, water resources, and rural development—each operating with distinct mandates, priorities, and regulatory frameworks. This institutional compartmentalization often leads to policy incoherence and duplication of efforts, where ecological considerations are either sidelined or treated as secondary to economic and infrastructural goals.

For instance, urban development authorities may prioritize rapid construction and land-use conversion, while environmental agencies focus on conservation, resulting in conflicting policy outcomes. The absence of an integrated decision-making framework prevents the mainstreaming of NbS into infrastructure planning. Moreover, coordination challenges between central, state, and local governments further complicate implementation, particularly in federal contexts where jurisdictional overlaps are common. Consequently, NbS projects often remain pilot initiatives rather than being scaled into systemic policy instruments.

Financing Constraints

Financial limitations constitute another critical impediment to the expansion of NbS. According to estimates by the World Bank, India

will require approximately USD 2.5 trillion in investments for climate-resilient infrastructure by 2030. However, despite this substantial requirement, NbS currently receives less than 3% of total climate finance, reflecting a significant mismatch between potential and actual investment.

The economic analysis and empirical case studies collectively demonstrate that Nature-Based Solutions offer a high-return, low-risk alternative to conventional infrastructure approaches. Their ability to deliver multiple co-benefits—ranging from disaster risk reduction to livelihood generation—positions them as a cornerstone of climate-resilient development.

This underinvestment can be attributed to several factors. First, NbS are often perceived by investors as high-risk and low-return projects, primarily due to their longer gestation periods and the difficulty of monetizing ecosystem services. Unlike traditional infrastructure, which generates direct and predictable revenue streams (such as tolls or tariffs), NbS deliver benefits that are often indirect, diffuse, and realized over extended time horizons. This creates a bias in favor of conventional infrastructure within both public and private financing mechanisms.

Second, there is a lack of dedicated financial instruments and policy incentives tailored to NbS. While mechanisms such as green bonds and climate funds are emerging, their application to NbS remains limited due to inadequate project pipelines and insufficient technical capacity to design bankable proposals. Additionally, regulatory uncertainties and the absence of clear valuation frameworks further discourage private sector participation. As a result, NbS continue to be underfunded despite their demonstrated cost-effectiveness and long-term benefits.

Lack of Standardized Metrics

A fundamental challenge in scaling NbS lies in the absence of standardized metrics and evaluation frameworks to assess their performance. Unlike grey infrastructure, where outputs such as capacity, durability, and return on investment can be quantitatively measured with relative ease, NbS involve complex ecological processes that are inherently dynamic and context-specific. The lack of clear indicators makes it difficult to systematically measure:

- Ecological benefits, such as biodiversity enhancement, carbon sequestration, and ecosystem restoration
- Economic returns, including avoided disaster costs and long-term savings
- Resilience outcomes, particularly the capacity of systems to absorb and adapt to climate shocks over time

This measurement gap creates challenges for policymakers, investors, and planners, who require quantifiable evidence to justify large-scale investments. It also limits the ability to compare NbS with traditional infrastructure on a standardized basis, thereby reinforcing institutional inertia. Without robust data and monitoring systems, NbS risk being perceived as experimental rather than as mainstream infrastructure solutions.

Integrating NbS into India's Infrastructure Strategy

Addressing these structural gaps requires a comprehensive and forward-looking strategy that embeds Nature-Based Solutions into the core of India's infrastructure and development planning. This integration must occur across policy, finance, and technological domains to ensure scalability and long-term sustainability.

Policy Integration

The first step towards mainstreaming NbS is their systematic integration into existing national policy frameworks. India already possesses a range of policy instruments that can serve as entry points for NbS, including the *National Action Plan on Climate Change (NAPCC)*, the *Smart Cities Mission*, and the *Disaster Management Act*. However, these frameworks often treat environmental considerations as peripheral rather than central components of infrastructure planning.

To address this, NbS must be explicitly incorporated into policy guidelines, planning standards, and regulatory requirements. For example, urban development policies under the Smart Cities Mission can mandate the inclusion of green infrastructure—such as urban forests, wetlands, and permeable surfaces—as part of city planning. Similarly, disaster management strategies can prioritize ecosystem-based approaches, such as mangrove restoration and watershed management, as first-line defenses against climate hazards.

Institutional reforms are also necessary to promote inter-agency coordination and integrated governance. Establishing dedicated NbS units or task forces at national and state levels can facilitate policy alignment and ensure that ecological considerations are embedded across sectors. Such integration would enable a shift from fragmented, project-based interventions to a holistic and systems-based approach to infrastructure development.

Financial Innovation

Scaling NbS requires the development of innovative financing mechanisms that can mobilize both public and private capital. Traditional funding models, which rely heavily on government expenditure, are insufficient to meet the scale of investment required for climate resilience.

One promising avenue is the expansion of green bonds, which can be specifically earmarked for NbS projects such as afforestation, wetland restoration, and sustainable urban infrastructure. Additionally, blended finance models—which combine public funds with private investment—can help reduce perceived risks and attract institutional investors. By leveraging concessional financing from public sources, these models can make NbS projects more financially viable.

Multilateral institutions such as the World Bank and the Asian Development Bank can play a crucial role by providing technical assistance, risk guarantees, and long-term funding for NbS initiatives. Furthermore, the creation of dedicated climate funds and incentive structures, such as tax benefits and subsidies, can encourage private sector participation and accelerate project implementation.

Technology and Data Utilisation

The effective implementation of NbS depends on the strategic use of technology and data-driven decision-making tools. Advances in geospatial technologies and data analytics provide new opportunities to design, monitor, and evaluate NbS interventions with greater precision.

For instance, Geographic Information Systems (GIS) can be used to map climate risks, identify vulnerable regions, and determine the most suitable locations for NbS interventions. This spatial analysis enables policymakers to prioritize investments based on evidence rather than assumptions.

Similarly, artificial intelligence (AI)-driven risk assessment tools can model future climate scenarios and assess the potential impact of different infrastructure strategies. These tools enhance predictive capacity and support proactive planning, allowing governments to anticipate risks rather than merely respond to them.

In addition, satellite monitoring technologies play a crucial role in tracking ecosystem changes, measuring vegetation cover, and assessing the effectiveness of restoration projects over time. Such real-time data not only improves transparency and accountability but also provides the empirical basis needed to refine policies and attract investment.

The limited adoption of Nature-Based Solutions in India is not a reflection of their ineffectiveness but rather a consequence of institutional fragmentation, financial constraints, and methodological gaps. Addressing these challenges requires a coordinated and multi-dimensional strategy that integrates NbS into the mainstream of infrastructure planning.

By aligning policies, innovating financial mechanisms, and leveraging technology, India can unlock the full potential of NbS as a scalable, cost-effective, and sustainable solution to climate risks. Such a transition is essential not only for environmental resilience but also for ensuring longterm economic stability and inclusive development.

International Relations and Strategic Dimensions

Nature-Based Solutions (NbS) extend beyond domestic environmental policy and occupy an increasingly important space within global governance and international relations. In the context of a rapidly evolving climate regime, NbS offer India an opportunity to align its development priorities with its strategic and diplomatic objectives, thereby reinforcing its position as a responsible and influential global actor.

First, NbS enhance India's role in climate diplomacy by providing a practical and scalable model of climate adaptation that is particularly relevant for developing countries. Unlike capital-intensive technological solutions, NbS are relatively low-cost, locally adaptable, and socially inclusive, making them highly suitable for countries across the Global South. By championing NbS in international forums, India can position itself as a norm entrepreneur, shaping global discourse on sustainable infrastructure and climate resilience.

Second, NbS directly support India's commitments under the Paris Agreement. While the Agreement primarily emphasizes mitigation through emission reductions, it also underscores the importance of adaptation and resilience. NbS contribute to both dimensions simultaneously—through carbon sequestration (mitigation) and ecosystem-based adaptation (resilience). This dual functionality enables India to meet its Nationally Determined Contributions (NDCs) more effectively while maintaining developmental flexibility.

Third, NbS play a crucial role in strengthening South-South cooperation, a key pillar of India's foreign policy. Many developing countries in Asia, Africa, and Latin America face similar climate vulnerabilities, including coastal erosion, water stress, and biodiversity loss. By sharing expertise, technology, and best practices related to NbS, India can foster collaborative partnerships that enhance collective resilience. Such cooperation not only builds diplomatic goodwill but also reinforces India's leadership in representing the interests of the Global South in climate negotiations.

India can further leverage its participation in key multilateral platforms to institutionalize NbS within global policy frameworks. For instance, the International Solar Alliance, although primarily focused on renewable energy, provides a platform for integrating broader sustainability initiatives, including ecosystem-based approaches.

Similarly, India's leadership within the G20 offers an opportunity to mainstream NbS into discussions on infrastructure financing, climate adaptation, and sustainable development. By advocating NbS as a global public good, India can promote their adoption across diverse geopolitical contexts while aligning environmental sustainability with economic and strategic interests.

Policy Recommendations

To unlock the full potential of Nature-Based Solutions in India, a comprehensive set of policy interventions is required, addressing regulatory, financial, institutional, and social dimensions.

A critical first step is the mandatory integration of NbS into infrastructure planning. This can be achieved by requiring all infrastructure projects above a specified financial threshold to include a NbS component as part of their design and approval process. Such a mandate would ensure that ecological considerations are not treated as optional add-ons but as core elements of infrastructure development, thereby institutionalizing sustainability within planning frameworks

In addition, there is a need to establish a National NbS Mission that provides a centralized and coordinated framework for implementation. This mission should define clear targets, timelines, and performance indicators, while

facilitating coordination across ministries and levels of government. By creating a dedicated institutional mechanism, the government can move from fragmented pilot projects to a systematic and scalable approach.

Addressing financing gaps requires the creation of a dedicated climate finance mechanism focused on NbS. Given that NbS currently receive less than 3% of climate finance, there is a need to significantly increase this share to at least 15%. This can be achieved through a combination of public investment, private sector participation, and international funding. Policy instruments such as green bonds, viability gap funding, and tax incentives can help mobilize resources and make NbS projects more attractive to investors.

Equally important is capacity building within institutions responsible for infrastructure planning and implementation. Policymakers, engineers, and urban planners need to be trained in ecosystem-based approaches to understand the design, benefits, and maintenance of NbS. Without adequate technical expertise, even well-designed policies may fail at the implementation stage.

The development of standardized data and measurement frameworks is another essential requirement. Establishing national indicators for resilience, ecosystem services, and economic returns will enable evidence-based decision-making and improve accountability. Such data systems can also facilitate comparison between NbS and traditional i

nrastructure, thereby strengthening the case for their adoption. Finally, the success of NbS depends heavily on community participation and local governance. Since many NbS interventions—such as afforestation, wetland restoration, and watershed management—are location-specific, involving local communities in planning and implementation is crucial. Strengthening institutions such as Panchayati Raj bodies and urban local governments can ensure that NbS are not only effective but also socially inclusive and sustainable over the long term.

Conclusion

The empirical and analytical evidence presented in this study clearly demonstrates that NatureBased Solutions are not merely environmental alternatives but economically viable and strategically significant infrastructure strategies. With estimated returns ranging from four to ten times the initial investment, NbS offer a compelling pathway to address India's growing climate risks while simultaneously advancing sustainable development goals.

However, the transition from potential to practice requires a fundamental shift in policy and governance frameworks.

Realizing the full benefits of NbS necessitates institutional reform to overcome fragmentation, financial innovation to mobilize adequate resources, and data-driven governance to ensure effective planning and evaluation. Without these enabling conditions, NbS will remain underutilized despite their proven advantages.

Integrating NbS into national infrastructure planning presents India with a unique opportunity to achieve multiple policy objectives simultaneously—including climate resilience, economic efficiency, and social inclusivity. Moreover, by embedding NbS within its domestic and international strategies, India can position itself as a global leader in climate governance, contributing not only to national development but also to the broader goal of building a sustainable and resilient world order.

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Guest Blends

Fortifying Food Safety Infrastructure Against Climate Volatility

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Abstract

This article examines the strategic fortification of national food safety systems in response to climate-induced systemic risks. The analysis focuses on four pillars: industrial circularity, ecological standards, mobile diagnostics, and laboratory modernization. With a large investment in testing systems and an authorized annual recycled plastic capacity of 64,740 metric tonnes (MT), India has developed a risk-resilient ecosystem capable of protecting public health while fostering sustainable markets.

Industrial Circularity

Packaging acts as the primary defense against heat-induced spoilage, yet reliance on virgin polymers increases carbon intensity and exposure to volatile energy markets. National standards now provide a scientific pathway for using food-grade recycled materials. Currently, five authorized manufacturing lines have established a verified annual capacity of 64,740 metric tonnes (MT) of food-safe recycled plastic. This initiative is strictly aligned with the MoEFCC

Plastic Waste Management Rules, which mandate a 40% recycled content threshold for the 2026-27 cycle. This "whole-of-government" approach internalizes material loops and reduces greenhouse gas emissions, which the UNEP Food Waste Index (2024) notes contribute to 8-10% of global emissions. By securing the supply chain against resource scarcity, India is positioning itself to meet the high-value export standards of international markets that increasingly prioritize circularity.

Ecological Standards

Ecological standards are vital for resource-efficient food systems. The FSS (Vegan Foods) Regulations, 2022 and FSS (Organic Foods) Regulations, 2017 provide the legal clarity required for sustainable dietary transitions. According to the OECD-FAO Agricultural Outlook, shifting consumer preferences toward plant-based proteins are a key global trend for climate mitigation.



The domestic organic market has reached USD 2.3 billion in 2025 (APEDA, 2024). This growth is anchored by the National Programme for Organic Production (NPOP) and landmark Mutual Recognition Arrangements (MRA), such as the 2025 agreement with Australia and ongoing similar arrangements with EU. These MRAs enabled USD 665.96 million in organic exports in the 2024-25 fiscal year. As documented in the FAO/FiBL/IFOAM "World of Organic Agriculture" reports, such systems enhance soil organic carbon and water retention, acting as a biological buffer against extreme weather.

Testing Mobility

In a large, climatically diverse country, centralized laboratories can be a single point of failure during climate-induced disasters. To bridge this gap, a network of 305 mobile units has been deployed to decentralize diagnostic capacity. These units test for over 40 safety parameters, including thermophilic pathogens and pesticide residues. In the 2024-25 fiscal year, this mobile "safety grid" conducted approximately 87,000 training sessions and tested 46,000 samples. By utilizing rapid diagnostic kits for immediate results, the system minimizes the "waste window"—the interval where unsafe food stays in circulation—thereby protecting public health and reducing the economic losses caused by spoilage during extreme heat or floods.

Laboratory Modernization

To maintain testing accuracy as climate risks evolve, the national laboratory network has been modernised under the SOFTS scheme. This network currently includes 72 state laboratories, 16 referral centers, and 131 NABL-accredited units. A critical reform is the mandatory requirement for all state laboratories to maintain dedicated Microbiology Facilities. This infrastructure is a direct response to the rise of heat-resistant and waterborne pathogens—a trend highlighted by the FAO Food Price Index reports which monitor supply disruptions. By ensuring that every region has the technical capacity to detect emerging biological threats, the government maintains a consistent standard of safety that remains resilient despite regional environmental fluctuations.

Conclusion

Building climate resilience requires long-term investment in technology and unified regulations. India's transition toward proactive risk management is validated by the expansion of sustainable food sectors, the verified scale of the recycling industry, and the growth of mobile diagnostics. Coordination between health, environmental, and trade authorities ensures that the food system remains durable and adaptive. These structural investments are vital for securing national food security and



maintaining economic stability as global environmental conditions become increasingly unpredictable.

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Global Pour

Critical Minerals Diplomacy and Clean Energy Infrastructure: How India Can Lead a Just Transition in the Global South

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Abstract

The global clean energy transition has spawned a new geopolitical contest — one centred not on oil fields but on critical mineral supply chains. China's dominant control over lithium, cobalt, rare earth elements (REEs), and solar photovoltaic manufacturing creates systemic vulnerabilities for emerging economies pursuing decarbonisation. This article argues that India is uniquely positioned to lead a just and resilient energy transition in the Global South by leveraging its geological endowments, diplomatic capital, and industrial policy ambitions. Drawing on data from the International Energy Agency (IEA, 2025), the United States Geological Survey (USGS, 2024), and India's National Critical Mineral Mission (2024), this study employs a supply chain vulnerability index and a diplomatic positioning framework to assess India's strategic options. Findings suggest that a trilateral strategy — combining domestic mineral processing, multilateral supply chain diversification through the Quad and I2U2, and South-South technology transfer — can reduce India's critical mineral import dependency by 35-45% by 2035, while positioning New Delhi as an indispensable partner for Global South nations seeking climate-resilient infrastructure.

Introduction

The geopolitics of energy is undergoing its most profound transformation since the 1973 OPEC oil embargo. The clean energy transition — once conceived primarily as a climate imperative — has become a theatre of great power competition. At its centre lies a stark dependency: the technologies that underpin solar panels, wind turbines, electric vehicle batteries, and grid storage systems all depend on a narrow set of critical minerals whose extraction and processing are overwhelmingly concentrated in a handful of states. China today controls approximately 60% of global rare earth element production and over 85% of their processing capacity (IEA, 2025). In cobalt, the Democratic Republic of Congo supplies over 70% of global output, much of it processed in China. For lithium — the cornerstone of battery technology — China refines nearly 60% of global supply. This concentration is not accidental; it reflects decades of deliberate industrial policy, overseas investment, and strategic acquisition.

For India — a rapidly industrialising democracy with an ambitious 500 GW renewable energy target by 2030 and net-zero commitments by 2070 — this dependency represents both a strategic vulnerability and a diplomatic opportunity. This article examines how India can transform the critical minerals challenge into leadership capital, forging a just transition pathway for itself and the broader Global South.

The Critical Minerals Landscape: Vulnerabilities and Stakes

India's clean energy infrastructure ambitions require massive and sustained inputs of critical minerals. The National Critical Mineral Mission (Government of India, 2024) identifies 30 minerals as strategically essential, including lithium, cobalt, nickel, graphite, manganese, titanium, and six platinum group elements. Current domestic production meets less than 10% of projected demand for most of these minerals by 2030 (Ministry of Mines, 2024).

Every solar panel, every EV battery, every grid storage system embeds a geopolitical choice — the question is whether India makes that choice deliberately or by default.

The economic stakes are significant. A supply chain disruption scenario modelled using the IEA's Critical Minerals Security Index suggests that a 30-day export restriction on Chinese REEs — analogous to Beijing's October 2024 export controls — could delay India's renewable energy deployment by 18–24 months and increase clean energy infrastructure costs by 22–28% (IEA, 2025; USGS, 2024). For a country aiming to install 50 GW of solar capacity annually, the fiscal implications run into hundreds of billions of rupees.

Yet India is not without assets. The Geological Survey of India has confirmed significant deposits of lithium in Jammu & Kashmir (5.9 million tonnes), rare earths in Andhra Pradesh and Odisha, and titanium along its eastern coastline. Critically, India's thorium reserves — the largest in the world at an estimated 846,000 tonnes — position it as a future leader in advanced nuclear fuel cycles. The challenge is translating geological potential into a processed, deployment-ready supply.

India's Diplomatic Architecture for Mineral Security

3.1 The Quad and Mineral Supply Chain Diversification

The Quadrilateral Security Dialogue (Quad) — comprising India, the United States, Australia, and Japan — has emerged as the most consequential multilateral framework for critical mineral supply chain diversification. Australia holds the world's largest lithium, nickel, and cobalt reserves; Japan brings advanced battery and processing technology; the United States provides capital markets access and regulatory architecture. India contributes a large skilled workforce, a growing refining base, and strategic geography.

The Quad's Critical and Emerging Technology Working Group, established in 2022 and expanded in 2024, has begun to operationalise joint mineral mapping, harmonised standards for battery-grade lithium processing, and co-investment vehicles for mine development in partner countries. India's role in this architecture — as both a consumer and a potential processor — is central to its long-term diplomatic leverage (White House, 2024).

3.2 The I2U2 Framework: Energy Infrastructure in West Asia

The India-Israel-UAE-USA (I2U2) grouping, though younger, offers a complementary vector for India's critical mineral diplomacy. The UAE's sovereign wealth funds have committed over USD 75 billion to global clean energy investments, including battery storage and solar manufacturing.

Joint I2U2 projects in hybrid renewable energy corridors — linking Indian solar manufacturing with UAE finance and Israeli agri-tech — create a template for integrated clean infrastructure that serves both energy and food security goals (I2U2 Joint Statement, 2023).

3.3 South-South Leadership: The BASIC and G77 Dimension

Perhaps India's most distinctive opportunity lies in leading a Global South coalition on critical mineral governance. Countries across Africa, Latin America, and Southeast Asia hold substantial mineral reserves but lack the processing infrastructure, technology access, and capital to capture value from their endowments. India — itself a middle-income country with a credible development narrative — can offer a non-extractive partnership model that contrasts sharply with both Chinese Belt and Road investments and traditional Western conditionality. A proposed India-led Critical Minerals Partnership for the Global South (CMPGS) — modelled on India's International Solar Alliance — could provide joint geological mapping, capacity building in mineral processing, technology transfer, and blended finance access to 40+ developing nations. This would simultaneously secure India's supply chains and expand its diplomatic footprint.

Industrial Policy: Closing the Processing Gap

Diplomatic access to mineral deposits is necessary but insufficient. The value — and the strategic leverage — lies in processing. India currently sends most of its rare earth ore overseas for processing, capturing only the lowest value-added segment of the supply chain. The National Critical Mineral Mission's USD 2.5 billion allocation for domestic processing infrastructure is a start, but independent analysis suggests a minimum investment of USD 8-12 billion is required to achieve meaningful processing self-sufficiency by 2030 (CEEW, 2024).

Three policy interventions are essential. First, production-linked incentive (PLI) schemes must be extended beyond solar panels and batteries to cover the upstream processing of battery-grade lithium carbonate, cobalt sulphate, and REE oxides. Second, India must accelerate the operationalisation of the Khanij Bidesh India Limited (KABIL) joint venture — mandated to acquire overseas mineral assets — with a target portfolio of 15 strategic mines across Africa, Latin America, and Central Asia by 2028. Third, a National Mineral Processing Technology Mission should fund public-private R&D to develop indigenous hydrometallurgical and pyrometallurgical processing capabilities, reducing technology import dependency.

India's critical minerals strategy must evolve from reactive procurement to proactive industrial statesmanship — building processing depth at home while forging supply security through principled multilateralism abroad.

Justice, Sustainability and the Minerals Extraction Challenge

Any discussion of critical minerals leadership must confront the social and environmental costs of extraction. Lithium mining in the Atacama region has displaced indigenous communities and depleted water tables; cobalt mining in the DRC involves documented child labour and severe ecological degradation. India's own mineral extraction history carries comparable legacies in tribal and forest-dwelling communities.

A credible just transition framework — one that India can advocate globally — must embed free, prior, and informed consent (FPIC) protocols for affected communities; enforce binding environmental impact assessments aligned with international standards; mandate gender-disaggregated social impact analysis; and establish dedicated community benefit-sharing funds from mineral royalties. India's Forest Rights Act (2006) and Panchayat (Extension to Scheduled Areas) Act provide a domestic institutional template that, if rigorously enforced, could serve as a Global South model for rights-respecting extraction governance.

Policy Recommendations

Launch an India-led Critical Minerals Partnership for the Global South (CMPGS), modelled on the International Solar Alliance, to provide joint geological mapping, processing technology transfer, and blended finance to developing nations.

Scale PLI schemes to upstream critical mineral processing with an additional INR 30,000 crore allocation, targeting domestic production of battery-grade lithium and REE oxides by 2028. Mandate FPIC protocols and community benefit-sharing funds in all KABIL overseas acquisition agreements, establishing India as a standard-setter for ethical mineral diplomacy. Establish a Quad Mineral Security Fund of USD 5 billion in co-investment capital targeting 10 priority mineral corridors across Africa, Latin America, and the Indo-Pacific by 2027. Embed critical mineral resilience metrics into India's National Infrastructure Pipeline project assessment criteria, ensuring that all clean energy infrastructure projects above INR 500 crore demonstrate supply chain due diligence.

Conclusion

The transition to clean energy is simultaneously the most consequential climate imperative and the most complex geopolitical realignment of the 21st century. For India, the critical minerals challenge is not merely a supply chain problem — it is a test of strategic vision. A nation that imports its energy dependencies rather than transforming them will

remain a price-taker in both fossil fuel and clean energy markets. But the inverse is equally true: a nation that marshals its geological assets, diplomatic relationships, and industrial policy with coherence and conviction can shape the terms of the global energy transition — not merely adapt to them. India's civilisational tradition of Vasudhaiva Kutumbakam — the world as one family — offers a normative framework for a critical minerals diplomacy that is both strategically astute and genuinely just. The Global South does not need a new hegemon in clean energy. It needs a partner with the credibility, capacity, and commitment to build supply chains that serve development, not domination. That is the leadership role India is positioned — and obligated — to claim.

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What's Up @NEF?



We had the opportunity to host Ma'am Charu Malhotra, Member of NEF's Advisory Board and Co-Founder at Primus Partners, for our podcast NEF Charcha in an invigorating discussion with Yash Kapur on A.I. in Education.



It was a privilege to meet Ashish Sood, Hon'ble Minister in the Government of Delhi. We presented him the January and February issues of NEF Brew, the policy insights publication of the National Economic Forum. The interaction included valuable insights on Delhi's initiatives in education and urban development.




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