India's Net Zero 2070 Trajectory: A Geospatial Analysis a Multisectoral and Spatial Policy Assessment

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Abstract

India's Net Zero 2070 Trajectory: A Geospatial Analysis undertakes a multisectoral and spatially differentiated assessment of the feasibility of India's long-term decarbonization commitment. Framed through a refined Geospatially Differentiated Just Transition Model (GDJTM) and a geospatially extended Kaya Identity, the paper interrogates how mitigation elasticity varies across energy, industry, transport, and land-use systems, and how these sectoral pathways intersect with regional disparities in resource endowments, institutional capacity, and just transition needs. Drawing on recent evidence for baseline emissions growth, peak-year sensitivity under alternative NDC intensification scenarios, and the spatial distribution of emission hotspots, the analysis highlights a pronounced mismatch between coal-dependent production zones in Central and Eastern India and high-renewable transition corridors in the West and South. Particular attention is given to financing architecture, cost-of-capital differentials, macroeconomic multipliers, and the political economy of coal phase-down. The study argues that Net Zero feasibility hinges on region-specific transition compacts that sequence technological deployment, fiscal realignment, and social protection in a spatially targeted and globally competitive manner. It concludes that a geospatially explicit, justice-centred planning architecture—combining advanced earth observation, integrated assessment modelling, and spatially differentiated climate finance—is indispensable if India is to compress its mitigation window between 2040 and 2070 without compromising developmental imperatives.

Keywords: India, Net Zero 2070, Geospatial Analysis, Just Transition, Climate Finance, Energy Transition

Introduction

India's pledge to achieve Net Zero greenhouse gas emissions by 2070 has repositioned the country at the centre of debates on the compatibility of late-industrializing development trajectories with stringent global carbon budget constraints. As the world's third-largest emitter but with per-capita emissions far below the OECD average, India embodies the structural tensions between historical responsibility, current development needs, and future mitigation expectations. Nationally Determined Contributions under the Paris Agreement commit India to reducing the emissions intensity of GDP by 45 percent from 2005 levels by 2030 and to achieving 50 percent of cumulative installed electric power capacity from non-fossil sources; yet these intensity targets leave unresolved whether and how absolute emissions can peak around the 2040s and then decline along a Net Zero-consistent path (NITI Aayog, 2021; 2026).

This paper positions India's Net Zero 2070 trajectory as a fundamentally geospatial problem embedded in a federal political economy. Emissions sources, renewable energy potentials, industrial clusters, and climate vulnerabilities are distributed unevenly across states, districts, and urban regions, generating hotspots of both risk and opportunity. Coal-bearing states in Central and Eastern India underpin national energy security and fiscal revenues but face high transition risk, while the Western and Southern corridors are emerging as renewable and green industrialization hubs (Prajapati et al., 2026). Against this background, the study advances a GDJTM that links decarbonization pathways in power, industry, transport, and land use to region-specific transition capacity, financing conditions, and social equity concerns. The paper seeks to move beyond aggregate national scenarios toward a spatially explicit, justice-oriented assessment of India's Net Zero feasibility and its implications for development planning under climate constraints.

Problem Statement, Knowledge Gaps, and Analytical Framework

India's Net Zero 2070 commitment represents a paradigmatic shift from carbon-intensive developmentalism toward climate-constrained structural transformation. Emissions have grown at a compound rate exceeding four percent between 2001 and 2030 projections, implying a peak around 2040 and an unprecedented mitigation gradient thereafter. The structural problem lies in reconciling accelerated decarbonization with India's developmental imperatives—industrial expansion, poverty alleviation, infrastructure provision, and employment generation. The transition must align with relevant SDGs, particularly SDG 7 (renewable share), SDG 9 (industrial upgrading), SDG 11 (urban sustainability), SDG 12 (resource efficiency), and SDG 13 (climate action). Intensity reductions under current NDCs do not guarantee absolute decline under rapid economic growth (Sharma & Sharma, 2025).

Current scholarship remains fragmented across sectoral, financial, and political economy domains (Islam & Mohna, 2025). Emissions modelling often relies on aggregate national projections, insufficiently capturing subnational heterogeneity across coal-bearing states, industrial corridors, and methane-intensive agrarian regions. Financial studies estimate total investment needs—ranging from 10 to 12 trillion USD—but rarely integrate weighted average cost of capital, concessional finance leverage ratios, or macro-fiscal sustainability analysis. Few analyses link Net Zero trajectories with SDG indicator trade-offs, and limited work integrates NDC-aligned intensity targets with post-2030 absolute reduction pathways. Political economy dimensions—state revenue dependence on coal royalties, stranded asset exposure, and labour transition risk—remain under-modelled. Emerging methodological tools such as satellite-derived methane detection (Chauhan & Raval, 2025), machine-learning demand forecasting (Jain & Gupta, 2024), and regionally calibrated Integrated Assessment Models (Briera & Lefèvre, 2024) have not been systematically incorporated into India-focused transition studies.

The analytical foundation integrates four interrelated bodies of literature: energy transition theory, political economy of decarbonization, sustainable finance, and development under climate constraint. The IPCC (2022) underscores that limiting warming to 1.5°C requires rapid, deep, and sustained reductions across all sectors. Sustainable finance literature emphasizes the scale of capital reallocation required, with emerging economies facing disproportionately higher capital costs (Bhattacharya et al., 2022). Traditional growth models assume carbon-intensive industrialization; emerging economies must now pursue leapfrogging strategies that bypass fossil-intensive stages (Aklin & Mildenberger, 2020; Shen et al., 2025). The study's central hypothesis posits that India's Net Zero feasibility is a function of mitigation elasticity—defined as the responsiveness of emissions decline to coordinated investment in renewable capacity, industrial electrification, and green hydrogen deployment within region-specific transition compacts. Front-loaded capital expenditure in grid flexibility, storage, and hydrogen infrastructure lowers marginal abatement cost over time, producing dynamic efficiency gains consistent with endogenous growth theory.

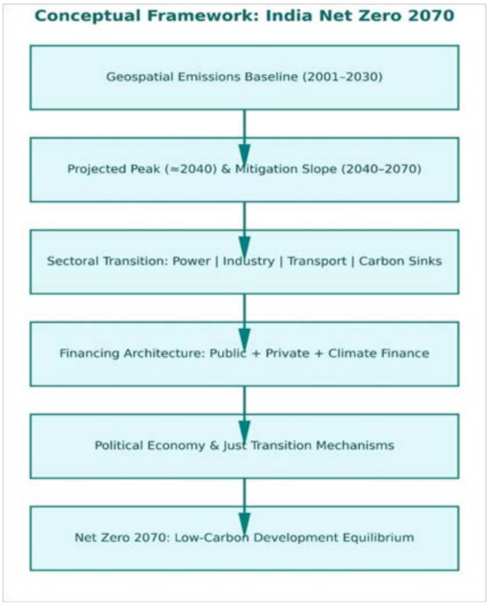

Figure 1 Conceptual Framework: India Net Zero 2070

Figure 1 presents the Geospatially Differentiated Just Transition Model (GDJTM), outlining the analytical pathway from geospatial emissions baseline through sectoral transitions and financing architecture to a low-carbon development equilibrium by 2070.

Baseline Emissions Growth and Mitigation Gradient

As of 2022, India emitted approximately 3.9 billion tonnes of CO_2-equivalent annually, making it the third-largest emitter globally, yet its per-capita emissions remain roughly one-third of the global average (IEA, 2023). A geospatial decomposition reveals stark regional heterogeneity: the coal-belt states of Chhattisgarh, Jharkhand, Odisha, and Madhya Pradesh collectively account for over 40% of energy-sector emissions despite hosting less than 15% of the national population (Garg et al., 2021). Solar-rich states such as Rajasthan, Gujarat, and Tamil Nadu exhibit negative-to-near-zero marginal abatement costs for renewable energy deployment, owing to high irradiance levels combined with declining module costs that have fallen below INR 2 per kWh in competitive auctions (Tongia & Gross, 2019). In contrast, Gangetic plain states with dispersed agricultural emissions and limited grid connectivity face mitigation costs exceeding USD 60 per tonne CO_2-equivalent (Sapkota., et.al.2019).

India's current emissions profile is characterized by a decoupling of GDP growth from carbon intensity, yet absolute emissions continue to rise due to industrial expansion and urbanization. Baseline emissions are modelled using the Kaya Identity: $F = P \times (G/P) \times (E/G) \times (F/E)$, where F is total CO_2 emissions, P is population, G/P is GDP per capita, E/G is energy intensity of GDP, and F/E is carbon intensity of energy (Kaya & Yokobori, 1997). Based on historical data, the compound annual growth rate from 2001 to 2030 is approximately 4.24% per annum (E_{2001} = 1.20 $GtCO_2e$; E_{2030} = 4.00 $GtCO_2e$ projected). Assuming a peak year of 2040, $E_{2040} \approx$ 6.06 $GtCO_2e$, and the required linear reduction rate to reach Net Zero by 2070 is approximately 0.202 $GtCO_2e$ per year. The Net Zero 2070 target implies an economy-wide decarbonization rate of approximately 5–7% per year in emissions intensity beginning no later than 2030, steepening considerably after 2050 (Dubash et al., 2021). Achieving the 2070 target would require cumulative abatement of roughly 65–75 $GtCO_2$-equivalent, distributed unevenly across states and sectors (Chaturvedi etal., 2024).

Peak-Year Sensitivity and Spatial Distribution of Emission Hotspots

The timing of India's emissions peak is among the most consequential variables for global temperature stabilization. Under current NDC commitments, the peak-year ranges from 2035 to 2052 depending on modelling assumptions about GDP growth, structural economic change, technology cost trajectories, and policy implementation fidelity (Shukla et al., 2022). Sensitivity analysis across three scenarios illuminates this uncertainty. Under a Business-as-Usual Intensification scenario, the emissions peak occurs around 2048 at approximately 6.8 $GtCO_2$-equivalent. A Moderate Acceleration scenario—characterized by a 65% renewable share in the electricity mix by 2035 and a moratorium on new coal power plant approvals after 2030—brings the peak forward to approximately 2041 at 5.9 $GtCO_2$-equivalent (Rao & Bhatt, 2017). A Radical Transformation scenario premised on 80%

renewable electricity by 2035 and coal-based power phase-out by 2045 models the peak as early as 2034 at approximately 5.2 $GtCO_2$-equivalent.

The geospatial dimension is critical. States with high economic dynamism such as Maharashtra, Karnataka, and Telangana are projected to decouple economic growth from emissions growth by 2030, exhibiting sub-national peaks earlier than the national aggregate. Conversely, states whose fiscal revenues are heavily dependent on coal royalties—notably Chhattisgarh, Odisha, and West Bengal—show emissions peaks delayed well into the 2040s absent substantial structural support (Dubash et al., 2021; Garg et al., 2021). Integrated assessment models must therefore incorporate subnational heterogeneity rather than treating India as a monolithic emitter.

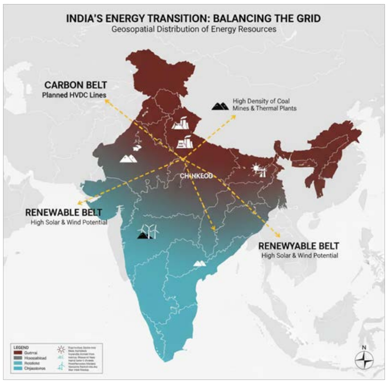

Figure 2 India's Energy Transition: Balancing the Grid — Geospatial Distribution of Energy Resources

Mapping India's emission hotspots at the district and state level using satellite-derived NO_2 column density data from the Sentinel-5P TROPOMI instrument reveals that approximately 50 high-emission districts collectively contribute nearly 60% of national industrial and energy-sector GHG output (Hammer et al., 2020). These hotspot districts cluster around three spatial archetypes: the Vindhyan coal belt spanning northern Madhya Pradesh and southern Uttar Pradesh; the Odisha–Jharkhand–Chhattisgarh mineral-industrial corridor; and the Indo-Gangetic industrial clusters in Haryana, Punjab, and western Uttar Pradesh. Regional transition capacity—a composite of renewable energy potential, workforce education levels, infrastructure quality, access to capital, and institutional governance strength—varies dramatically. In 2023, Karnataka, Gujarat, and Tamil Nadu scored above 70 on the CEEW State-Level Climate Policy Index, while Jharkhand, Chhattisgarh, and Bihar scored below 30 (CEEW, 2023). This inverse correlation between emission intensity and transition capacity represents the central spatial challenge of India's Net Zero trajectory.

Geospatial cluster analysis yields five distinct transition typology zones. Pioneer zones in southern and western coastal states are poised for rapid decarbonization with commercial financing. Supported transition zones in central India require targeted public investment in grid extension and workforce retraining. Managed decline zones in the coal belt need dedicated just transition financing and alternative livelihood programs. Agricultural transformation zones in the Gangetic plain require integrated approaches addressing methane, nitrous oxide, and land-use emissions. Finally, fragile periphery zones in the Northeast and Himalayan states require adaptation-first strategies.

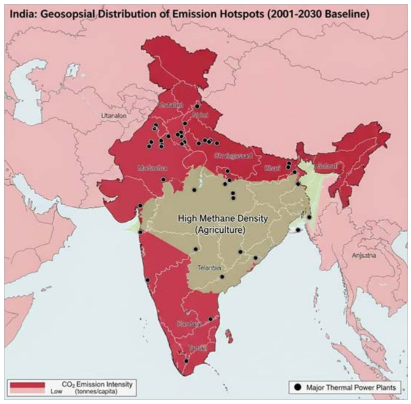

Figure 3 India: Geospatial Distribution of Emission Hotspots (2001–2030 Baseline)

Sectoral Transition Architecture

Power Sector Decarbonization and Grid Flexibility

The power sector is the single largest contributor to India's GHG emissions, accounting for approximately 1.1 $GtCO_2$ in 2022 (roughly 28% of the national total), and remains the anchor of Net Zero strategy (IEA, 2023). India's installed capacity has grown from 250 GW in 2014 to over 420 GW by 2023, with renewable energy contributing approximately 185 GW. The government's target of 500 GW non-fossil capacity by 2030 requires the addition of approximately 40–50 GW of renewable capacity annually. As variable renewable energy (VRE) share approaches 60–70% of annual generation, the need for balancing resources, pumped hydro storage, battery energy storage systems (BESS), demand response, and flexible gas peakers increases non-linearly (Heptonstall & Gross, 2021). Geospatial optimization of battery storage deployment suggests that approximately 100–150 GW of battery storage would be required by 2040 to maintain grid stability at 70% VRE penetration, at an estimated cost of USD 60–80 billion. The retirement of approximately 210 GW of coal-based generation—concentrated in Vidarbha, Singrauli, and the Damodar Valley—must be managed to avoid stranded asset losses while ensuring energy security during the transition (Shukla et al., 2022).

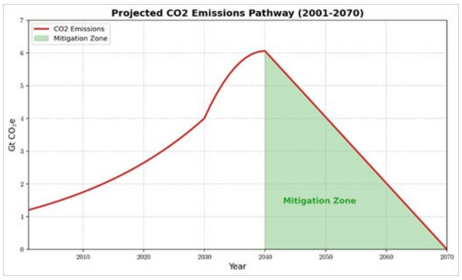

Figure 4 Projected CO_2 Emissions Pathway (2001–2070)

Industrial Electrification and Green Hydrogen

India's industrial sector contributes approximately 29% of national GHG emissions and presents some of the most technically complex decarbonization challenges, given the prevalence of high-temperature process heat requirements that cannot be easily electrified (Ahuja & Bhatt, 2020). Integrated steel plants cluster in Jharkhand, Odisha, and Chhattisgarh; cement production concentrates in Rajasthan, Andhra Pradesh, and Madhya Pradesh; and the petrochemical complex anchors in Gujarat. India's National Green Hydrogen Mission targets 5 million tonnes per annum of green hydrogen production by 2030 (Ministry of New and Renewable Energy, 2023). The levelized cost of green hydrogen currently ranges from USD 4–6 per kilogram, with techno-economic modelling projecting costs declining to USD 1.5–2.5 per kilogram by 2030—a threshold at which green hydrogen becomes competitive with grey hydrogen (IRENA, 2022). The spatial economics of production are governed by the co-location of low-cost renewable electricity and water availability; Greater potential for offshore wind energy exists in Goa, Karnataka, Kerala, Tamil Nadu, and Andhra Pradesh (Upadhyaya etal., 2024), while coastal Gujarat, Rajasthan, Andhra Pradesh and Tamil Nadu offer a favourable combination of offshore wind resources and desalination feasibility (Upadhyaya, et.al. 2024; Madhuri etal., 2025). Green hydrogen's pathways for net zero sustainability in India were assessed via green chemistry, circular economy, Life Cycle Analysis and SDGs, in terms of efficiency, emissions, and resources by Kundu etal.(2026). They concluded that no single pathway meets all sustainability criteria; targeted deployment, integration, regional optimization, green chemistry, and synchronised policy are vital for a resilient, and equitable hydrogen economy.

Transport Electrification and Urban Air-Quality Co-Benefits

India's transport sector accounts for approximately 14% of national GHG emissions and virtually all of the country's petroleum import dependency, with crude oil imports amounting to USD 120 billion in 2022–23 (Ministry of Petroleum and Natural Gas, 2023). Delhi, Mumbai, Kolkata, and Chennai consistently rank among the world's most polluted cities, with $PM_{2.5}$ concentrations exceeding 60–80 μg/m³—five to eight times the WHO guideline of 15 μg/m³ (WHO, 2021). Electrification of urban bus fleets, three-wheelers, and two-wheelers in the ten most polluted cities would reduce transport-attributable $PM_{2.5}$ exposure by 30–45%, yielding monetized health benefits exceeding USD 20 billion annually. A network of approximately 500,000 public charging stations across 600 districts—at an investment of USD 8–12 billion—would eliminate range anxiety as a barrier to EV adoption by 2030 (Rao & Bhatt, 2017). Oil import substitution savings from full transport electrification by 2050 are estimated at USD 250–320 billion cumulatively (Chaturvedi et al., 2024).

Carbon Sink Expansion and Land-Use Trade-offs

India's NDC incorporates land-based carbon sinks targeting an additional 2.5–3 billion tonnes of CO_2-equivalent through enhanced forest and tree cover by 2030 (Forest Survey of India, 2021). Geospatial analysis indicates that India's current forested area of approximately 71 million hectares could potentially be expanded to 80–90 million hectares by 2070 through natural regeneration, afforestation on degraded lands, and agroforestry integration. Approximately 25–30 million hectares of degraded wasteland could be targeted for carbon sink enhancement without conflicting with food production or biodiversity conservation objectives. However, these lands are disproportionately located in tribal and forest-dependent communities, raising critical questions of tenure rights and free prior informed consent. Afforestation aligned with SDG 15 and SDG 13 can simultaneously advance SDG 6 (Clean Water), SDG 1 (No Poverty), and SDG 3 (Good Health), while large-scale monoculture plantations can undermine SDG 2 (Zero Hunger) through groundwater depletion.

Financing Architecture and Macroeconomic Implications

Achieving Net Zero by 2070 will require India to mobilize approximately USD 160 billion per year in clean energy investment by the late 2020s, rising to USD 300 billion per year by 2040—compared with current annual investment levels of approximately USD 60–70 billion (IEA, 2023). The cumulative investment gap over the 2024–2070 period is estimated at USD 3.5–5 trillion. The cost of capital differential remains a fundamental structural barrier: renewable energy projects in India face a weighted average cost of capital approximately 4–6 percentage points higher than equivalent projects in Germany or the United States, owing to currency risk, regulatory uncertainty, and perceived macroeconomic instability (Naran et al., 2022). Multilateral development bank interventions through first-loss guarantees, currency hedging facilities, and blended finance structures can narrow this differential, but their current scale falls far short of what is required.

The financing architecture must integrate multiple capital streams: domestic public finance through development financial institutions and sovereign green bonds; international concessional finance through the Green Climate Fund and bilateral mechanisms; private capital through green bond markets; and innovative instruments such as debt-for-climate swaps (Bhattacharya et al., 2022). Concessional finance should be prioritized for coal-dependent states with limited fiscal space, while commercial instruments can be deployed in renewable-ready states with stronger credit profiles.
Macroeconomic modelling suggests that well-designed decarbonization pathways could generate a GDP premium of 1.5–2.5% above baseline by 2040, primarily through reduced fossil fuel import bills and the emergence of clean technology export sectors (Ghosh et. al., 2021). The macroeconomic multipliers for renewable energy investment are estimated at 1.8–2.4 for GDP and 3.5–5.0 for employment, significantly higher than for fossil fuel investments. Approximately 1.5 million workers are directly employed in coal mining and coal-based power generation, with an estimated 5–7 million in indirect support industries (Just Transition Research Collective, 2021).

Political Economy, Governance, and CBAM Exposure

Coal-producing states derive approximately INR 50,000–60,000 crore annually from royalties, surface rents, and district mineral foundation levies, which in some cases represent 25–35% of own-source revenue in states like Jharkhand, Chhattisgarh, and Odisha (Coal India Limited, 2023). Any credible transition strategy must incorporate robust fiscal compensation mechanisms. An India-specific just transition fund, capitalized at INR 2–3 lakh crore over 20 years and financed through a combination of cess on coal production, international climate finance, and reallocation of fossil fuel subsidies, could support community resilience in transition zones. Approximately 80–100 parliamentary constituencies in central and eastern India have significant coal employment concentrations, creating cross-party political sensitivity that explains India's insistence on common but differentiated responsibilities in international climate negotiations (Sharma et al., 2020).

India's federal architecture creates complex governance coordination challenges, with energy, environment, land, water, and labour all subjects on which both central and state governments hold concurrent or shared jurisdiction. The absence of a unified national climate governance architecture means that policy coherence depends heavily on informal inter-ministerial coordination mechanisms. The establishment of Regional Climate Transition Councils, corresponding to the five regional grids, could provide a spatially coherent platform for coordinating renewable energy planning, grid investment, just transition financing, and adaptation planning across state boundaries.

The European Union's Carbon Border Adjustment Mechanism (CBAM), which will impose definitive carbon charges from 2026 onward, represents a significant external structural factor. India exported approximately EUR 8–10 billion in CBAM-covered goods to the EU in 2022; under full CBAM implementation, Indian exporters could face additional costs of EUR 1.5–2.5 billion annually by 2030 (Mehling et al., 2019). Steel-producing clusters in Jharkhand and Odisha face the highest tariff exposure, with emission intensities of 2.0–2.4 tonnes CO_2 per tonne of steel compared to the EU benchmark of approximately 0.8 tonnes (Elango etal., 2023). India's strategic response must include accelerating domestic industrial decarbonization, advocating in multilateral forums for CBAM design modifications, and exploring a domestic carbon pricing instrument that could be credited against CBAM obligations.

Future Perspectives and Conclusions

Low-carbon technologies such as coal gasification coupled with carbon capture, utilization, and storage (CCUS), Underground Coal Gasification (UCG), and renewables would enable continued fossil fuel use to meet India's rising energy needs while bridging to Net Zero by 2070 (Singh et al., 2024; Ding et al., 2025). Nuclear power, currently 3% of electricity, targets 22,480 MW by 2031 through Fast Breeder Reactors, Advanced Heavy Water Reactors, and Small Modular Reactors (Christopher Selvam et al., 2025). However, contentious issues around regulatory streamlining, R&D investment, private engagement, and the inappropriate applicability of larger nuclear power plant frameworks to SMR demand resolution (Nriezedi-Anejionu, 2024).

While robust funding and strategic planning are universally recognized as necessary conditions for just energy transitions in the Global South, equal attention must be paid to institutional, technical, financial, and social dimensions (Gather et al., 2025; Narassimhan et al., 2025). India has prioritized a renewable energy transition pathway, but its legacy of fossil fuel dependence remains a significant barrier (Das & Malik, 2025).

This paper has argued that India's Net Zero 2070 feasibility is not merely a technological question but a spatially differentiated political-economic challenge. A geospatially explicit, justice-centred planning architecture—combining advanced earth observation, integrated assessment modelling, and spatially differentiated climate finance—is indispensable if India is to compress its mitigation window between 2040 and 2070 without compromising developmental imperatives. Region-specific transition compacts that sequence technological deployment, fiscal realignment, and social protection are a precondition for a transition that is both environmentally credible and socially sustainable.

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