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OPINION

A strategic framework to assess causes and consequences of long-term land use change is critical for India

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Greenhouse gas emissions as well as sequestration from land use systems are a critical part of the global and national climate policy debate. Globally, the land-use sector is one of the most important carbon sinks, absorbing nearly one-third of human-induced CO_2 emissions each year [1]. Global research has made major progress in quantifying land-based emissions and sequestration trajectories and their trade-offs within long-term net-zero pathways. Research suggests that large-scale afforestation and reforestation could remove 3.64 $GtCO_2e$ per year by 2050 while broader land sector mitigation options together could deliver up to 15 $GtCO_2e$ annually. However, poorly planned interventions risk reducing global food production and land availability [2]. Similarly, bioenergy with carbon capture and storage (BECCS) could deliver 3.3 $GtCO_2e$ removals annually, but requires 380–700 million hectares of land—an area comparable to one-quarter of global cropland—raising serious concerns for food security and biodiversity [3]. Most importantly, these studies highlight the dual role of land as both a carbon sink and a contested resource where climate mitigation goals intersect with food, water and ecosystem security.

India's climate policy also accords due importance to this sector [4,5]. In 2020, land use offset 17.6% of India's emissions [6] while also sustaining biodiversity, producing food and providing livelihoods critical for society. With 2.4% of global land, India supports 18% of world population and 15% of global livestock which is unmatched by most nations. Within this land mass, India has to feed a growing population (more than 1.4 billion people), add 2.5–3 billion tonnes of CO_2 sinks by 2030 [7], expand to 450 GW of renewable energy capacity through solar parks, wind farms and bioenergy plantations [8], and accommodate the rapid spread of industrial corridors and urbanisation. If unmanaged, these demands are bound to collide. Sectoral studies caution that unplanned afforestation alone could increase the water demand and reduce cropping intensity creating food grain demand–supply gap [9,10]. Similarly, large solar installations in India's desert regions risk displacing farmland and worsening groundwater stress [11]. Given the complex trade-off, India cannot afford fragmented or sectoral approaches to land-use. Every hectare is under intense pressure from competing demands. How India manages this finite resource will determine whether India's 2070 net-zero pledge is viable alongside other developmental goals.

Global assessments, informed by integrated assessment models (IAMs), incorporate a multi-sector view to understand the dynamics around land use. However, India's research on land-use mainly focuses on inventories of current land-use carbon stocks, rather than long-term projections of how land-based emissions and removals will evolve and impact and be impacted by its various development choices. Modelling research in India remains heavily energy-centric [12,13], treating land as residual. This results in a critical blind spot lacking understanding of how competing demands for food, forests, energy and water will reshape India's overall land-use emissions trajectory in future.

The way forward is to carve out a strategy to assess and understand the causes and consequences of land use change, where land should be treated as a strategic resource interacting with multiple sectors rather than a passive sink. The framework to guide this strategy should be based on certain principles which we outline below.

Firstly, the framework should be driven by the best available science, while being aware of uncertainties. Understanding physical behaviour of land use systems, e.g., the carbon sequestration pattern of trees and agricultural soils across a long-time horizon is contested. However, uncertainties shouldn't be viewed as an impediment. Best shouldn't be made the enemy of good. India needs to invest more in understanding the physical as well as socio-economic behaviour of various land use systems to ensure that the best available science informs its land use management choices. At the same time, it should map critical uncertainties and methodically work to reduce these. With time, a robust understanding will emerge even if the beginning appears unconvincing.

Secondly, the strategic motivation should be to understand the long-term implications of various interventions and choices. Implications emerge across decades, not years. A long-term framework guides near-term actions whose strategic implications will unfold across decades. A short-term view would only be counter-productive in the end.

Thirdly, India should adopt a multi-sector assessment approach. Land-use choices are critical not just because land is a carbon sink, but because it also plays a significant role in India's development trajectory. Focusing only on carbon sequestration risks narrowing the debate, when in reality land delivers several major interconnected benefits like food and nutrition security, soil health, livelihoods, greenhouse gas mitigation, bio-economy and resilience (Fig 1).

Fourthly, India has to invest more in robust data collection for multiple variables of interest (like soil carbon). Better and representative data can reduce some key uncertainties. The data should ideally be spatially explicit and open for researchers for them to be able to undertake useful research.

Fifthly, the strategy should focus on asking critical policy relevant questions. How much could India's forest sequester perennially? Could a thriving bio-economy impact food and water security? Can rising industrial wood demand be met through

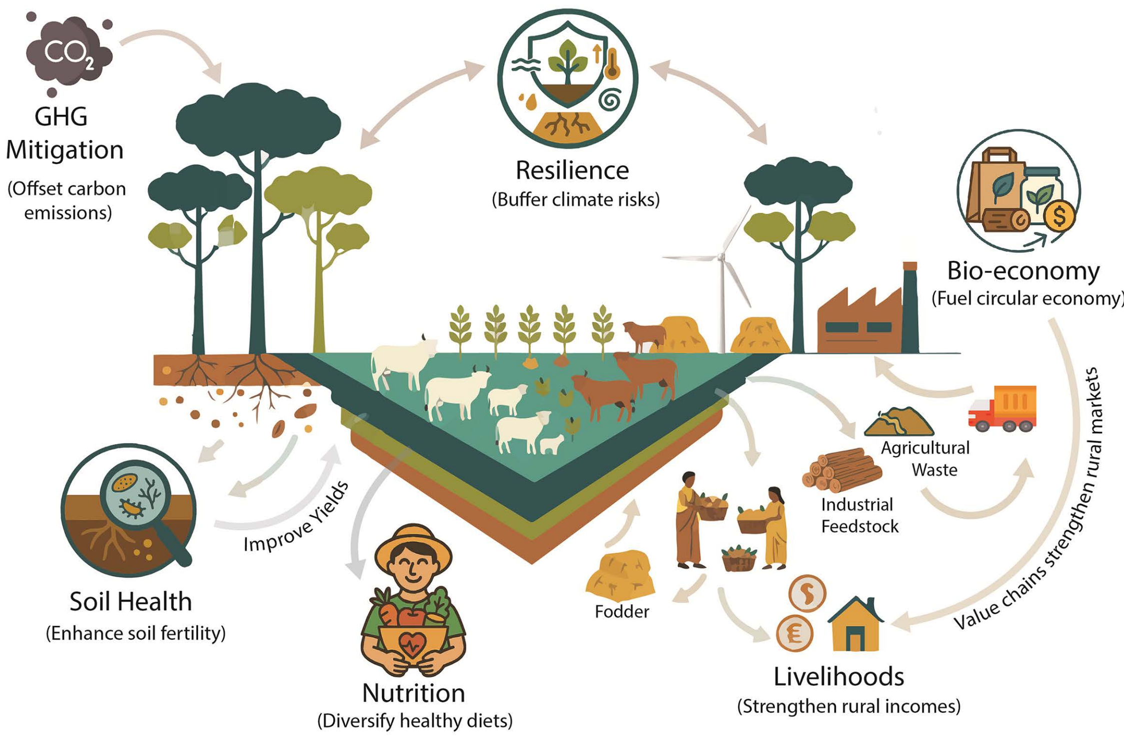

Fig 1. The illustrative figure shows that sustainable land-use choices generate several interconnected co-benefits (i.e., greenhouse gas mitigation, soil health, nutrition, livelihoods, bio-economy and resilience) that collectively shape India's climate and development trajectory.

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agroforestry? Can bio-energy be a crucial part of India's long-term emissions mitigation strategy? Are nutrition security and farmers livelihoods at odds with each other? These and many more would be critical to cement the science-policy interface.

Finally, the strategy should embrace perspectives from various stakeholders in India's land use debate- the on-field experience of farmers, policy experience of government representatives, private sectors expertise on markets, as well as analytical lens of researchers. A multi-sector framework has to be complemented by multi-stakeholder perspective to inform India's land use policy.

IAMs have been used extensively to inform policy [14,15] and can be used effectively as a platform to operationalise these principles. Given the complexities within the land use system, IAM is not optional—it is essential. India must pursue studies that integrate emissions, food security, biodiversity and livelihoods into a unified system. Such a strategy would ensure that every hectare is treated as a strategic resource supporting India's development goals along with its net-zero ambition.

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References

1. IPCC. Climate change 2022: mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report. Cambridge: Cambridge University Press; 2022.
2. Roe S, Streck C, Obersteiner M. Contribution of the land sector to a 1.5 °C world. Nat Climate Change. 2019;9:817–28.
3. Smith P, Davis SJ, Creutzig F. Biophysical and economic limits to negative CO_2 emissions. Nat Climate Change. 2016;6:42–50.
4. Government of India, Ministry of Environment, Forest and Climate Change. India's intended nationally determined contribution: working towards climate justice. UNFCCC; 2015.
5. Government of India, Ministry of Environment, Forest and Climate Change. India's Long-Term Low-Carbon Development Strategy. UNFCCC; 2022.
6. Government of India. India's Fourth Biennial Update Report (BUR-4) to the UNFCCC. New Delhi: Ministry of Environment, Forest and Climate Change; 2024.
7. Government of India. India's updated first nationally determined contribution under the Paris agreement. New Delhi: Ministry of Environment, Forest and Climate Change; 2022.
8. Ministry of New and Renewable Energy. Annual report 2024–2025. New Delhi: Government of India; 2025.
9. Clark B, DeFries R, Krishnaswamy J. India's commitments to increase tree and forest cover: consequences for water supply and agriculture production within the central Indian highlands. Water. 2021;13(7):959. https://doi.org/10.3390/w13070959
10. Jain M, Fishman R, Mondal P, Galford GL, Bhattarai N, Naeem S, et al. Groundwater depletion will reduce cropping intensity in India. Sci Adv. 2021;7(9):eabd2849. https://doi.org/10.1126/sciadv.abd2849 PMID: 33627418
11. Centre for Financial Accountability. Solar power in India: a case study of the Bhadla Solar Power Park. New Delhi: CFA; 2024.
12. Spencer T, Dubash NK. Scenarios for different 'Future Indias': sharpening energy and climate modelling tools. Clim Policy. 2021;22(1):30–47. https://doi.org/10.1080/14693062.2021.1973361
13. Chaturvedi V, Malyan A. Implications of a net-zero target for India's sectoral energy transitions and climate policy. Oxford Open Clim Change. 2022;2(1). https://doi.org/10.1093/oxfclm/kgac001
14. Braunreiter L, van Beek L, Hajer M, van Vuuren D. Transformative pathways—using integrated assessment models more effectively to open up plausible and desirable low-carbon futures. Energy Res Soc Sci. 2021;80:102220. https://doi.org/10.1016/j.erss.2021.102220
15. Stehfest E, van Zeist W-J, Valin H, Havlik P, Popp A, Kyle P, et al. Key determinants of global land-use projections. Nat Commun. 2019;10(1):2166. https://doi.org/10.1038/s41467-019-09945-w PMID: 31092816