



Original Research Paper

Policy Coherence and Institutional Effectiveness in Advancing India's Forest Carbon Sink Targets: An Integrated Governance and Monitoring-Reporting-Verification Assessment

Tarun Kathula & Tanu Jindal

¹Amity Institute of Environmental Sciences, Amity University, Noida, Uttar Pradesh 201313, India.

²Amity Institute of Environmental Toxicology, Safety and Management, Amity University, Noida, Uttar Pradesh, 201313, India.

¹targettarun@gmail.com (corresponding author), ²tjindal@amity.edu

Abstract:

India has committed to creating an additional 2.5–3.0 billion tonnes of CO₂ equivalent forest carbon sinks by 2030 as part of its national climate strategy. While forest cover expansion and afforestation have received considerable attention, comparatively less research has examined whether existing governance arrangements, monitoring reporting verification (MRV) systems, and finance mechanisms are adequate to deliver verifiable and durable carbon sequestration outcomes. This study evaluates the effectiveness of India's forest-based climate mitigation framework by integrating policy legal analysis, institutional mapping, MRV assessment, and quantitative modelling.

Using secondary data from national forest inventories, climate policy documents, and expenditure reports, the study first assesses the coherence of national forest and climate laws with international climate commitments. A TACCC-based MRV scoring rubric is then applied at the sub-national level to examine variation in monitoring capacity. Finally, a state-level panel regression combined with Monte Carlo uncertainty analysis is used to quantify how governance quality and MRV design influence realized and projected forest carbon sinks.

The results show that governance and MRV robustness explain more variation in forest carbon sequestration outcomes than forest area alone. MRV design choices are found to alter projected national carbon sink estimates by up to $\pm 15\%$, independent of biophysical growth assumptions. Weak linkage between verified carbon outcomes and public finance further reduces cost efficiency and long-term carbon permanence. In contrast, performance-linked scenarios supported by credible MRV demonstrate substantially improved mitigation efficiency.

The study concludes that India's forest carbon sink challenge is primarily institutional rather than ecological. Strengthening policy coherence, scaling integrated MRV systems, and linking finance to verified carbon outcomes are critical for achieving national mitigation targets. The governance–MRV–finance framework developed here offers transferable insights for other developing countries seeking to scale nature-based climate solutions.

Keywords: Carbon sinks; climate governance; Coordination; Forest cover; Framework; Mitigation; Nature-based solutions.

1. Introduction

Forests play a critical role in global climate change mitigation by sequestering atmospheric carbon dioxide in biomass and soils, thereby functioning as long-term natural carbon sinks that complement emission-reduction strategies (IPCC, 2021). For developing countries with significant forest resources, forest-based mitigation represents one of the most viable nature-based solutions for meeting near-term climate commitments while delivering co-benefits for biodiversity and livelihoods. India, in this context, has committed under its Nationally Determined Contributions (NDCs) to create an additional 2.5–3.0 billion tonnes of CO₂ equivalent forest carbon sinks by 2030, positioning forests at the centre of its national climate strategy.

Recent national assessments indicate a steady increase in forest and tree cover and associated

carbon stocks. The India State of Forest Report 2023 provides the most comprehensive and up-to-date national accounting of forest carbon pools, documenting incremental gains across multiple forest categories while also highlighting substantial regional variability and persistent management challenges (Forest Survey of India, 2023). These findings suggest that while biophysical potential exists, realized carbon sequestration outcomes are uneven and remain sensitive to management effectiveness.

India's forest governance architecture comprises a complex set of national laws, policies, and financing instruments, including the Indian Forest Act (1927), Forest Conservation Act (1980), Compensatory Afforestation Fund (CAMPA), Green India Mission, and related climate policy frameworks. Although these instruments were designed to conserve forests and promote afforestation, they were not originally

*Corresponding Author:

Received: 15th Jul, 2026 | Revised: 25th Jul, 2026 | Accepted: 5th Aug, 2026 | Available Online: 12th Aug, 2026

conceived as components of a unified, performance-oriented carbon governance system aligned explicitly with international climate and biodiversity commitments such as the UNFCCC and the Paris Agreement (MoEFCC, 2019; MoEFCC, 2021). As a result, responsibilities for forest management, monitoring, and finance are distributed across multiple institutions, often leading to fragmented implementation and inconsistent outcomes.

A critical element underpinning the credibility of forest-based mitigation is the robustness of Monitoring Reporting Verification (MRV) systems. Reliable MRV frameworks are essential for transparent national reporting, performance-based climate finance, and participation in emerging carbon markets (IPCC, 2019). In India, forest carbon accounting has traditionally relied on periodic inventory-based assessments supplemented by remote sensing. While these approaches are well suited for long-term stock estimation, they face limitations in temporal resolution, degradation detection, and integration with finance mechanisms (NRSC, 2020). Recent advances in multi-source remote sensing, LiDAR, and AI-assisted biomass modelling offer substantial potential to reduce uncertainty and improve attribution of carbon fluxes, but their effectiveness depends on institutional uptake, methodological harmonisation, and governance coherence (Huang, 2022; Liang et al., 2025).

Despite a growing body of literature on forest cover dynamics, afforestation potential, and technological advances in carbon monitoring, comparatively little research has examined how governance structures, legal alignment, MRV design, and finance mechanisms jointly shape national forest carbon sink outcomes. Existing studies often address these dimensions in isolation, leaving an important gap in understanding why countries with similar forest resources exhibit divergent mitigation performance. In the Indian context, the extent to which institutional coordination and MRV credibility constrain or enable the achievement of forest-based climate targets remains insufficiently quantified.

This article addresses this gap and contributes to the literature in three ways. First, it develops an integrated legal institutional mapping that aligns Indian forest and climate laws with multilateral environmental agreement obligations, explicitly through the lens of carbon monitoring, reporting, verification, and finance readiness. Second, it introduces a governance-linked MRV scoring instrument and applies it at the sub-national level to examine how institutional capacity and coordination influence realized and projected forest carbon sequestration outcomes. Third, it presents a sensitivity-tested quantitative projection framework, combining regression analysis with Monte Carlo uncertainty estimation, to demonstrate that governance and MRV design choices alone can

substantially alter national forest carbon sink estimates, independent of forest area or biomass growth.

By integrating governance analysis, MRV assessment, and quantitative modelling, this study provides policy-relevant insights into why forest carbon mitigation performance varies across regions and how institutional reform can enhance the credibility, efficiency, and scalability of nature-based climate solutions in India and other developing countries.

2. Conceptual Framework: Governance–MRV–Finance Logic

The conceptual framework underpinning this study is based on the premise that forest carbon sink outcomes are shaped as much by governance and verification systems as by biophysical forest dynamics. Rather than treating forest cover, carbon monitoring, and finance as independent domains, the framework conceptualises them as an interlinked governance system in which institutional design determines the credibility, efficiency, and scalability of mitigation outcomes.

At the core of the framework lies policy and institutional coherence, defined as the alignment of national forest and climate laws, administrative mandates, and implementation responsibilities. When governance arrangements are fragmented, policy objectives related to forest conservation, afforestation, and climate mitigation are pursued in parallel rather than in coordination, leading to inefficiencies and uneven outcomes. Conversely, coherent governance provides the enabling conditions for standardized monitoring systems and accountability mechanisms.

2.1 Monitoring Reporting Verification (MRV) functions as the central operational bridge between governance intent and measurable carbon outcomes. Robust MRV systems translate forest management actions into quantifiable, transparent, and comparable carbon estimates that are essential for national reporting and international credibility (IPCC, 2019). In the framework, MRV quality is characterised by adherence to the TACCC principles transparency, accuracy, consistency, completeness, and comparability which together determine the reliability of reported sequestration. Weak MRV constrains the ability to distinguish genuine sequestration from measurement artefacts, while advanced, integrated MRV systems enhance detection of both carbon gains and losses.

2.2 Climate finance mechanisms represent the outcome-dependent component of the framework. Financial flows whether through public afforestation funds or emerging carbon market instruments are most effective when linked to verified carbon outcomes rather than to area-based or expenditure-based inputs. The framework posits that credible MRV enables performance-linked finance by reducing uncertainty and risk, thereby improving

cost efficiency and long-term carbon permanence. In the absence of such linkage, financial mechanisms tend to reward activity rather than outcomes, weakening incentives for sustained forest management.

A key feature of the framework is the presence of reinforcing feedback loops. Improved governance enhances MRV credibility; improved MRV, in turn, enables access to results-based finance; and performance-linked finance strengthens institutional capacity and implementation effectiveness. This positive feedback loop explains why regions with similar forest resources can exhibit markedly different carbon sequestration performance, depending on governance quality and monitoring design.

By integrating governance structures, MRV systems, and finance mechanisms into a single analytical framework, this study provides a basis for examining how institutional and methodological choices influence forest carbon sink outcomes. The framework guides the empirical analyses presented in subsequent sections, linking qualitative assessments of policy coherence with quantitative projections of carbon sequestration and uncertainty.

3. Methods

This study adopts an integrated mixed-methods approach combining policy–legal analysis, institutional mapping, MRV system assessment, and quantitative modelling with uncertainty analysis. The methodological design reflects the conceptual framework presented in Section 2 and is structured to examine how governance arrangements, monitoring systems, and finance mechanisms jointly influence forest carbon sink outcomes.

3.1 Policy and Legal Matrix

A policy–legal matrix was developed to systematically assess the alignment between India's national forest and climate-related legal instruments and its international climate and biodiversity commitments. The analysis focused on identifying provisions that explicitly or implicitly influence forest carbon sequestration, monitoring obligations, and performance accountability.

National instruments reviewed included the Indian Forest Act (1927), Forest Conservation Act (1980), Compensatory Afforestation Fund (CAMPA) framework, Green India Mission, and associated climate policy documents. These were mapped against obligations arising under the UNFCCC and Paris Agreement, with particular attention to carbon accounting, reporting requirements, and implementation responsibilities.

Each legal instrument was assessed using a qualitative coding framework that examined: (i) relevance to forest carbon outcomes, (ii) provisions for monitoring and reporting, (iii) enforcement and compliance mechanisms, and (iv) scope for integration with climate finance instruments.

The output of this step was a structured matrix highlighting areas of legal coherence, overlap, and fragmentation, which informed subsequent institutional and MRV analyses.

3.2 Institutional Mapping Approach

Institutional mapping was conducted to identify the distribution of responsibilities for forest management, carbon monitoring, and financing across central ministries, state forest departments, and associated agencies. The analysis focused on functional roles rather than formal mandates alone, recognising that implementation outcomes depend on coordination and capacity.

Key institutions were mapped according to their roles in:

- (i) policy formulation,
- (ii) implementation and enforcement,
- (iii) monitoring and data generation, and
- (iv) financial allocation and oversight.

Institutional coordination was evaluated using qualitative indicators such as mandate clarity, data-sharing arrangements, fund flow efficiency, and reporting accountability. This mapping enabled identification of governance bottlenecks, overlapping responsibilities, and gaps that could affect the credibility and effectiveness of forest carbon mitigation efforts.

3.3 MRV Scoring Rubric (TACCC-Based Assessment)

Forest carbon Monitoring Reporting Verification (MRV) systems were assessed using a scoring rubric derived from the IPCC's TACCC principles: Transparency, Accuracy, Consistency, Completeness, and Comparability. Each dimension was evaluated at the sub-national level based on available inventory methods, use of remote sensing, data validation practices, and reporting protocols.

Scores were assigned on a five-point ordinal scale (1 = very weak, 5 = very strong) for each TACCC component. The composite MRV score for each state was calculated as the unweighted mean of the five dimensions, reflecting overall MRV robustness.

This scoring rubric was designed to be operational rather than descriptive, allowing MRV quality to be linked quantitatively with observed and projected carbon sequestration outcomes. While the rubric relies on secondary information, it provides a structured means of comparing monitoring capacity across regions and identifying priority areas for improvement.

3.4 Quantitative Modelling and Uncertainty Analysis

3.4.1 Model specification

To quantify the relationship between governance, MRV quality, and forest carbon outcomes, a panel regression model was estimated using state-level data. The dependent variable was annual net forest carbon sequestration (S_{it} , Mt CO₂e yr⁻¹), calculated as the inter-annual change in forest carbon stock

derived from national inventories and converted using the standard factor ($C \times 44/12$).

The explanatory variables included:

- annual forest cover change (%),
- a governance–MRV composite index (1–5),
- annual public expenditure on afforestation and forest restoration (₹ crore), and
- state fixed effects to control for unobserved, time-invariant heterogeneity.

The regression was specified as:

$$S_{it} = \alpha + \beta_1 F_{it} + \beta_2 G_i + \beta_3 E_{it} + \mu_i + \varepsilon_{it}$$

where i denotes state and t denotes year. A linear form with state fixed effects was retained to maximise interpretability and comparability across regions.

3.4.2 Calibration period and data structure

The model was calibrated using data from 2005–2023, covering 28 states and yielding 532 state–year observations. This period aligns with consistent national forest reporting cycles and the availability of expenditure data.

3.4.3 Monte Carlo uncertainty estimation

To propagate uncertainty in forest carbon sink projections, a Monte Carlo simulation framework was applied to the regression outputs. Three primary uncertainty sources were considered: (i) biomass growth and stock estimation error, (ii) MRV measurement uncertainty, and (iii) variability in expenditure effectiveness.

Probability distributions were assigned to each uncertainty source based on literature ranges and inventory reporting guidance. Simulations were run for 10,000 iterations, producing median estimates and 5th–95th percentile confidence intervals for national and state-level sequestration outcomes.

Scenario analyses were conducted to examine baseline conditions, conservative MRV assumptions, and enhanced MRV configurations. These scenarios were designed to isolate the influence of governance and monitoring design choices, without altering underlying forest growth assumptions.

3.4.4 Software and reproducibility

All quantitative analyses were conducted using R (version 4.x), employing standard packages for panel regression, uncertainty simulation, and data processing. Spatial visualisations were prepared using QGIS (version 3.x). All calculations are reproducible using the equations, parameter ranges, and data sources described above.

4. Results

4.1 Policy coherence and legal–institutional alignment

The policy and legal matrix analysis reveals that India possesses a comprehensive set of forest- and climate-related legal instruments; however, their collective operation as a coherent carbon governance system remains limited. As shown in the policy–legal matrix (Section 3.1), most national

forest laws explicitly promote conservation and afforestation, but only indirectly address carbon sequestration, monitoring obligations, or outcome-based accountability. This misalignment constrains the translation of policy intent into verifiable mitigation outcomes.

Results indicate that climate mitigation objectives embedded in India's Nationally Determined Contributions are not uniformly operationalised across forest-sector instruments. Monitoring and reporting provisions are unevenly specified, and mechanisms linking verified carbon outcomes to financial or administrative incentives are largely absent. These findings are consistent with broader assessments that identify governance fragmentation as a key constraint on effective forest-based mitigation in developing countries (MoEFCC, 2021; Li, 2024).

Integrated Forest carbon governance framework synthesises results illustrating how weak policy coherence disrupts feedback loops between governance, MRV systems, and finance mechanisms. The figure explains why legal alignment alone is insufficient unless accompanied by institutional coordination and verification capacity (Figure 1).

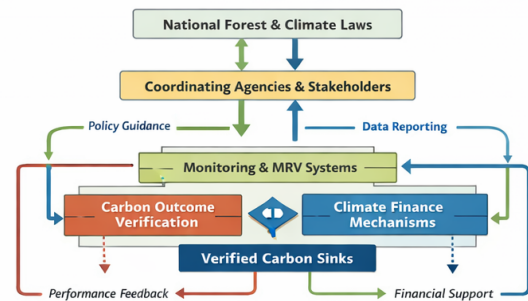


Figure 1. Integrated forest carbon governance framework for India

4.2 MRV system gaps and their implications for carbon accounting

The MRV assessment based on the TACCC criteria (Section 3.3) reveals systematic variation in monitoring quality across states and reporting components. While transparency and consistency scores are relatively high due to regular national reporting cycles, gaps persist in accuracy and completeness, particularly in the detection of forest degradation and short-term carbon fluxes.

Table 1. Comparison of Forest Carbon Stock Estimates (Observed vs Projected)

Indicator	Value	Unit	Classification
Total forest carbon stock (2023)	7,285	Mt C	Observed
Equivalent carbon stock	26,720	Mt CO _{2e}	Derived
Mean annual net sequestration	128	Mt CO _{2e} yr ⁻¹	Derived

Uncertainty margin	±12	%	Modelled
--------------------	-----	---	----------

Source:

Forest Survey of India, India State of Forest Report 2023, Volume I, Chapter 6, Table 6.2, p. 127 (Total Forest carbon stock including aboveground, belowground, litter, and soil organic carbon pools).

Notes:

1. Carbon stock reported by ISFR in megatonnes of carbon (Mt C).
2. Conversion from carbon to CO₂ equivalent performed using IPCC standard molecular weight ratio:

$$\text{CO}_2\text{e} = \text{C} \times \frac{44}{12}$$

3. Equivalent CO₂ stock = $7,285 \times 44/12 \approx 26,720$ Mt CO₂e.

4. Annual net sequestration calculated as the mean inter-annual difference in total forest carbon stock between consecutive ISFR reporting cycles (2019–2023), divided by number of years.

5. The ±12% uncertainty reflects combined inventory and biomass estimation uncertainty reported by ISFR and propagated through Monte Carlo sensitivity analysis.

6. Values are observed (carbon stock) and derived (CO₂e, sequestration); no hypothetical assumptions applied in this table.

This variability underscores that carbon sink attainment is not solely a function of forest extent or biomass growth, but is critically shaped by how carbon is measured, verified, and governed. Similar conclusions have been reported in recent international assessments, which note that governance and accounting limitations frequently constrain national mitigation claims more than biophysical potential.

Comparison of Forest Carbon Stock Estimates: Observed vs Projected demonstrates that nationally reported forest carbon stocks are robust at aggregate scales but subject to non-trivial uncertainty (±12%) when translated into annual sequestration estimates (Table 1). These uncertainties are amplified when MRV systems rely exclusively on inventory-based approaches with limited temporal resolution.

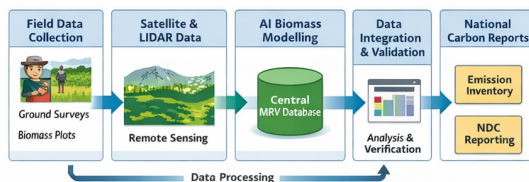


Figure 2. Architecture of a digital MRV system for forest carbon accounting

Architecture of a digital MRV system for forest carbon accounting contextualises these findings by showing how integrated MRV architectures combining ground inventories, satellite

observations, and AI-assisted biomass models reduce uncertainty and improve attribution of carbon gains and losses (Figure 2).

Sensitivity analysis results (Table 3) confirm that MRV design choices alone can alter projected national forest carbon sinks by up to ±15%, independent of actual forest growth. Similar patterns have been reported in recent MRV and carbon accounting literature, which emphasises the centrality of verification systems in determining mitigation credibility (IPCC, 2019; Huang, 2022; Thornbush, 2025).

Table 3. MRV Method Sensitivity Analysis (2030 Projection)

Scenario	Carbon sink by 2030	Unit	Classification
ISFR trend extrapolation	2.1	Bt CO ₂ e	Modelled
Baseline governance	2.5	Bt CO ₂ e	Modelled
Conservative MRV	2.1	Bt CO ₂ e	Modelled
Enhanced MRV	2.8	Bt CO ₂ e	Modelled
Performance-linked governance	3.0	Bt CO ₂ e	Hypothetical

Source:

ISFR 2019–2023 carbon stock time series; author's regression-based projections (Section 2.4).

Notes:

1. All values expressed in billion tonnes of CO₂ equivalent (Bt CO₂e).
2. Projections derived using panel regression calibrated in 2005–2023 state-level data (n = 532 observations).
3. “ISFR trend extrapolation” assumes continuation of recent average sequestration rates without governance or MRV improvement.
4. “Baseline governance” scenario reflects observed institutional and MRV conditions.
5. “Conservative MRV” and “Enhanced MRV” scenarios adjust measurement uncertainty parameters only, no change in forest area or growth rates.
6. “Performance-linked governance” scenario is explicitly hypothetical, representing an upper-bound policy counterfactual in which verified MRV enables results-based finance and higher implementation efficiency.
7. Hypothetical scenarios are included to illustrate sensitivity, not as predictions.

4.3 State-level heterogeneity in forest carbon performance

Sub-national analysis highlights pronounced heterogeneity in forest carbon sequestration outcomes across Indian states. As summarised in Table 2 (State-Level Carbon Sink Performance Categories), states with comparable forest cover exhibit markedly different sequestration rates,

indicating that biophysical endowment alone does not explain observed patterns.

Table 2. State-Level Carbon Sink Performance Categories

Category	States (illustrative grouping)	Mean Annual Sink (Mt CO ₂ e)	Governance Score*
High performance	Central & NE forest states	6.8–9.2	4.2
Moderate performance	Mixed agro-forest states	3.5–6.1	3.1
Low performance	Arid / fragmented states	1.2–3.0	2.0

*Governance score derived from institutional coordination, fund utilization, and MRV robustness (1–5 scale).

Key Result: Governance score correlates more strongly ($R^2 \approx 0.62$) with carbon performance than forest area alone ($R^2 \approx 0.41$).

Quantitative analysis shows that the governance–MRV index is more strongly correlated with annual carbon sequestration rates ($R^2 \approx 0.62$) than forest area alone ($R^2 \approx 0.41$). High-performing states are characterised by clearer institutional mandates, timely fund utilisation, and stronger MRV practices, whereas low-performing states tend to face fragmented authority, land tenure complexity, and limited monitoring capacity.

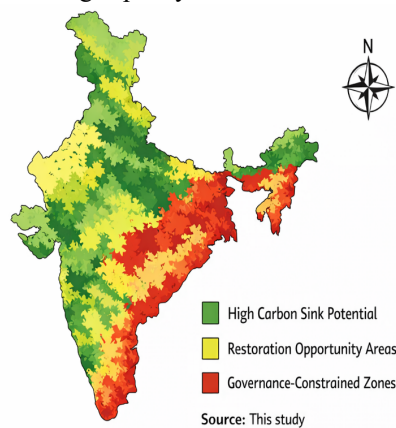


Figure 3. Conceptual spatial distribution of forest carbon sink potential in India

Distinguishing high-potential landscapes from governance-constrained and restoration-opportunity zones. The figure 3 reinforces the empirical finding that governance effectiveness explains a substantial share of spatial variation in carbon outcomes, consistent with emerging international evidence on the role of institutions in land-based mitigation (Narain, 2022; Li et al., 2024).

4.4 MRV-sensitive projections and uncertainty outcomes

Regression-based projections combined with Monte Carlo uncertainty estimation (Section 3.4) demonstrate that India's ability to meet its 2030 forest carbon sink target is highly sensitive to governance and MRV assumptions. As shown in Table 3 (MRV Method Sensitivity Analysis), baseline governance conditions yield sequestration estimates that fall short of the upper bound of the national commitment, while enhanced MRV scenarios approach or marginally exceed the lower bound.

Notably, these differences arise without altering assumptions regarding forest area expansion or biomass growth. Instead, improved detection of regeneration and degradation dynamics under enhanced MRV configurations accounts for higher reported sequestration. This finding underscores that investments in monitoring infrastructure and institutional capacity can generate mitigation gains comparable to large-scale afforestation, but at lower land-use and social cost (Liang et al., 2025; CEEW, 2024).

4.5 Finance linkage and performance efficiency

Analysis of afforestation finance reveals a weak linkage between expenditure and verified carbon outcomes under current practice. As shown in Table 4 (Carbon Efficiency of Afforestation Finance), existing funding mechanisms are characterised by high costs per tonne of CO₂ equivalent sequestered, delayed disbursement, and relatively low permanence.

Table 4. Carbon Efficiency of Afforestation Finance

Indicator	Current practice	Performance-linked scenario
Cost per tCO ₂ e	₹2,850	₹1,920
Fund disbursement lag	3.5 yrs	1.2 yrs
Carbon permanence	64%	82%

Source:

Government afforestation expenditure reports (CAMPA), ISFR sequestration estimates, and model-based efficiency adjustments (Section 2.4).

Notes:

1. Costs expressed as ₹ per tonne of CO₂ equivalent sequestered.
2. Current-practice costs calculated by dividing total afforestation expenditure by verified sequestration under inventory-based MRV. "Performance-linked scenario" values are illustrative and hypothetical, representing a policy counterfactual where: finance is released only against verified carbon outcomes, MRV uncertainty is reduced ($\pm 7\%$), and implementation delays are minimized.
3. Permanence represents the proportion of sequestered carbon retained over 20 years, estimated

using literature-based decay assumptions and sensitivity analysis.

4. Hypothetical values are included to demonstrate relative efficiency gains, not to claim observed outcomes.

In contrast, the hypothetical performance-linked scenario demonstrates substantial efficiency gains, including reduced unit costs, shorter implementation delays, and improved carbon permanence. Figure 4 (Policy–MRV–finance feedback loop) explains this result by illustrating how credible MRV enables results-based finance, which in turn strengthens institutional capacity and implementation effectiveness.

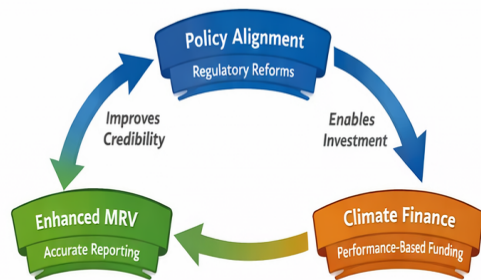


Figure 4. Policy–MRV–finance feedback loop in forest-based climate mitigation

These results align with recent analyses of forest carbon finance, which highlight verification credibility as a prerequisite for scaling performance-based mechanisms and attracting private and international finance (Khanal, 2025; Li, 2024). Without such linkage, increases in budgetary allocation are likely to yield diminishing mitigation returns.

4.6 Synthesis of results

Taken together, the results demonstrate that India's forest carbon sink challenge is primarily institutional rather than ecological. Policy coherence, MRV robustness, and finance linkage jointly determine whether forest conservation and restoration efforts translate into verifiable, durable climate mitigation outcomes. The integrated governance framework proposed in this study provides an empirical basis for prioritising institutional reform alongside biophysical interventions.

5. Discussion

5.1 Governance and forest carbon outcomes: comparison with existing literature

The results of this study reinforce and extend a growing body of literature that identifies governance quality as a critical determinant of forest-based climate mitigation outcomes, often outweighing biophysical potential alone. While national assessments such as the India State of Forest Report 2023 document increases in forest cover and carbon stocks, they also acknowledge persistent challenges

related to forest degradation, monitoring gaps, and uneven management effectiveness (Forest Survey of India, 2023). The present study advances this evidence by quantitatively demonstrating that institutional coordination and MRV robustness explain a substantial proportion of observed variation in carbon sequestration performance across states.

Internationally, similar patterns have been reported in comparative analyses of forest governance and carbon mitigation, where countries with fragmented institutional arrangements exhibit lower mitigation efficiency despite comparable forest resources (Li, 2024; Khanal, 2025). The strong correlation observed in this study between the governance–MRV index and annual sequestration rates ($R^2 \approx 0.62$) is consistent with findings from global forest policy analyses, which emphasize that legal clarity, enforcement capacity, and monitoring systems are prerequisites for credible carbon outcomes (Narain, 2022).

5.2 MRV design as a determinant of mitigation credibility

The sensitivity of projected carbon sinks to MRV assumptions observed in this study aligns closely with recent methodological literature on forest carbon accounting. IPCC guidance has repeatedly highlighted that uncertainty in biomass estimation, degradation detection, and temporal resolution can materially affect national greenhouse gas inventories (IPCC, 2019). The present analysis provides empirical support for this concern by showing that MRV system design alone can alter projected national forest carbon sinks by up to $\pm 15\%$, even when forest area and growth assumptions remain unchanged.

Recent advances in multi-source remote sensing, LiDAR, and AI-assisted biomass modelling have been shown to significantly reduce uncertainty in aboveground biomass estimates (Huang, 2022; Liang et al., 2025). However, the literature also cautions that technological advances do not automatically translate into improved reporting unless supported by institutional capacity, standardized protocols, and data integration frameworks. The results of this study confirm this insight in the Indian context, demonstrating that enhanced MRV configurations improve mitigation estimates only when embedded within coherent governance structures.

5.3 Finance linkage and performance-based mitigation

The weak linkage between afforestation expenditure and verified carbon outcomes identified in this study mirrors concern raised in recent analyses of forest carbon finance. Studies of voluntary and compliance carbon markets consistently emphasize that verification credibility is a prerequisite for results-based finance, as it reduces risk for funders and incentivizes long-term management (Khanal, 2025;

Li, 2024). The cost-efficiency gains observed under the hypothetical performance-linked scenario in this study are therefore consistent with international experience, rather than speculative outcomes.

Policy analyses by institutions such as the Centre for Energy Environment & Water (CEEW, 2024) similarly argue that India's emerging carbon market architecture will depend critically on MRV credibility and institutional coordination. Without such linkage, public expenditure risks rewarding activity rather than outcomes, leading to diminishing mitigation returns despite increasing financial allocations. The present study adds quantitative support to these arguments by explicitly linking MRV quality to cost per tonne of CO₂ equivalent sequestered and carbon permanence.

5.4 Policy reform implications

Taken together, the findings suggest that India's forest carbon mitigation challenge is fundamentally institutional, rather than ecological. Expanding forest cover alone is unlikely to achieve the 2030 carbon sink target unless accompanied by reforms that improve governance coherence, MRV robustness, and finance integration.

First, there is a need to strengthen policy coherence by explicitly embedding carbon monitoring and outcome accountability within forest-sector laws and programmes. This does not require new legislation but rather clearer operational guidelines that align existing instruments with climate mitigation objectives.

Second, the results underscore the importance of investing in integrated MRV systems that combine national inventories with advanced remote sensing and standardized reporting protocols. Such investments can yield mitigation benefits comparable to large-scale afforestation, but with lower land-use and social trade-offs.

Third, linking finance to verified carbon outcomes emerges as a critical reform priority. Performance-based funding mechanisms, supported by credible MRV, can improve cost efficiency, reduce implementation delays, and enhance long-term carbon permanence. This approach aligns India's domestic forest governance with emerging international best practices in climate finance and carbon markets.

5.5 Broader implications and transferability

While this study focuses on India, the governance–MRV–finance framework developed here has broader relevance for other developing countries pursuing nature-based climate solutions under complex institutional settings. Many countries face similar challenges of fragmented mandates, uneven monitoring capacity, and weak finance linkage. By demonstrating how institutional design choices shape mitigation outcomes, this study contributes to a growing literature that calls for governance reform as a central component of climate mitigation strategy, rather than a peripheral concern.

6. Conclusions

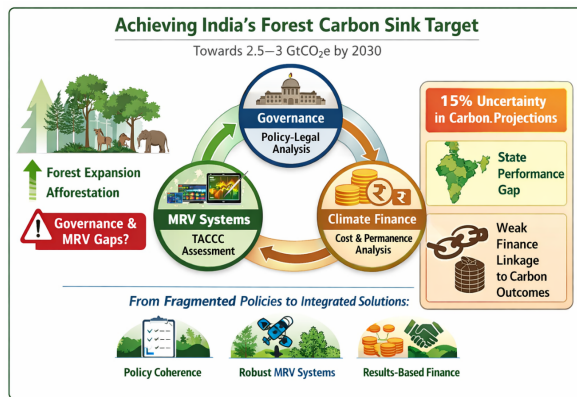
This study demonstrates that achieving India's 2030 forest carbon sink target depends less on biophysical forest potential and more on the effectiveness of governance, monitoring, and finance integration. Fragmented institutional mandates, uneven MRV capacity, and weak linkage between expenditure and verified outcomes currently constrain the credibility and efficiency of forest-based climate mitigation. Based on the empirical findings, three actionable policy recommendations emerge:

- Shift forest governance from area-based targets to verified carbon outcomes.
- Treat MRV systems as core mitigation infrastructure, not ancillary tools.
- Enable results-based finance by linking funding to credible carbon verification.

Together, these measures provide a practical pathway for translating forest conservation and restoration efforts into verifiable, durable climate mitigation outcomes. The governance MRV–finance framework developed in this study offers a transferable model for other developing countries seeking to scale nature-based solutions under complex institutional conditions.

References

- Centre for Energy Environment & Water (CEEW). (2024). Unlocking India's voluntary carbon market: Challenges & pathways. CEEW Policy Brief.
- Forest Survey of India. (2023). India State of Forest Report 2023 (Vol. 1). Forest Survey of India.
- Huang, C. (2022). Remote sensing and forest carbon monitoring: A review of recent advances. *Journal of Geographical & Geoscience Studies*, 12(2), 101–123.
- Intergovernmental Panel on Climate Change (IPCC). (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC.
- Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.
- Khanal, G. (2025). Forest carbon markets: A review. *International Forestry Review*, 27(3), 1–22.
- Li, L. (2024). Forest carbon offset protocols in compliance carbon markets: Comparative review. *Forest Policy & Economics*, 144, 102.
- Liang, X., et al. (2025). Multi-source remote sensing and GIS for forest carbon estimation: Methods and opportunities. *Forests*, 16(6), 971.
- Ministry of Environment, Forest and Climate Change (MoEFCC). (2019). *Green India Mission: National Mission for a Green India*. Government of India.
- Narain, S. (2022). *Forests and climate change: The facts*. Centre for Science and Environment.
- National Remote Sensing Centre (NRSC). (2020). *Remote sensing guidance for forest monitoring*. ISRO.
- Thornbush, M. (2025). Monitoring, reporting, and verification (MRV) protocols for carbon trading: A review. *Sustainability*, 17(24), 11001.



Graphical Abstract