Developing an Integrated Carbon Accounting Framework for India: A Conceptual Review and Future Research Agenda

ABSTRACT

As India accelerates toward its 2070 net-zero commitment and operationalizes domestic decarbonization mechanisms—most notably the Carbon Credit Trading Scheme (CCTS) under the Energy Conservation (Amendment) Act, 2022, alongside the Securities and Exchange Board of India's (SEBI) Business Responsibility and Sustainability Reporting (BRSR) and BRSR Core mandates—corporate carbon accounting has shifted from peripheral voluntary disclosure to a central pillar of economic governance. Yet India's current carbon accounting landscape remains deeply fragmented across physical greenhouse gas (GHG) inventories, managerial carbon control systems, statutory financial reporting under Indian Accounting Standards (Ind AS), and sustainability assurance. Drawing on a comprehensive conceptual review of international carbon accounting scholarship and India's evolving institutional architecture, this paper synthesizes five competing frames of carbon accounting—physical, political, market-enabling, financial, and social-environmental—and diagnoses the structural misalignments impeding their convergence in an emerging-economy context. To bridge these institutional silos, the paper proposes the Integrated Carbon Accounting Framework for India (ICAF-India), a five-layered conceptual architecture linking operational digital Measurement, Reporting, and Verification (dMRV), carbon management control systems, Ind AS financial integration, harmonized multi-stakeholder reporting, and dual-track independent assurance. The paper further articulates a structured future research agenda spanning standard-setting politics, Scope 3 value-chain digitization for micro, small, and medium enterprises (MSMEs), independent carbon assurance quality, and capital-market valuation effects.

Keywords: *Carbon accounting; Integrated framework; India; BRSR Core; Carbon Credit Trading Scheme (CCTS); Carbon management accounting; Carbon assurance; Conceptual review*

Introduction

Climate change has fundamentally transformed greenhouse gas (GHG) emissions from an unpriced ecological externality into a material financial, strategic, and regulatory variable for corporations worldwide (Hopwood, 2009; Milne &Grubnic, 2011). Over the past two decades, scholarly inquiry into carbon accounting has expanded rapidly—progressing from early compliance debates under the Kyoto Protocol through the voluntary disclosure era of the Paris Agreement and into the contemporary global transition toward mandatory, investor-grade climate-related financial disclosures (He et al., 2021; Amel-Zadeh& Tang, 2025). Despite this intellectual maturation, carbon accounting remains a contested and conceptually fragmented domain. Different epistemic communities—climate scientists, treaty negotiators, carbon market engineers, financial standard-setters, management accountants, and critical sustainability scholars—deploy the term to denote fundamentally different objects of measurement, valuation conventions, and accountability regimes (Ascui& Lovell, 2011; Gulluscio et al., 2020).

Nowhere is this conceptual and institutional fragmentation more consequential than in India. As the world's most populous nation and one of the fastest-growing major industrial economies, India confronts a formidable dual imperative: sustaining rapid infrastructure, manufacturing, and energy

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expansion to lift millions into prosperity while simultaneously fulfilling its updated Nationally Determined Contributions (NDCs), Panchamrit climate pledges, and 2070 net-zero commitment. To operationalize this transition, Indian policymakers have constructed an ambitious yet multi-centric suite of regulatory instruments. The Energy Conservation (Amendment) Act, 2022, and the subsequent Carbon Credit Trading Scheme (CCTS), 2023—administered by the Bureau of Energy Efficiency (BEE) under the Ministry of Power (MoP) in coordination with the Ministry of Environment, Forest and Climate Change (MoEFCC)—establish the Indian Carbon Market (ICM). The ICM transitions India's legacy Perform, Achieve and Trade (PAT) energy-efficiency program into a comprehensive emissions-intensity compliance market alongside a domestic voluntary offset mechanism. Concurrently, the Securities and Exchange Board of India (SEBI) has mandated Business Responsibility and Sustainability Reporting (BRSR) for the top 1,000 listed entities by market capitalization and introduced BRSR Core, imposing phased mandatory reasonable assurance and value-chain (Scope 3) environmental, social, and governance (ESG) disclosures. Meanwhile, the Institute of Chartered Accountants of India (ICAI) and the Ministry of Corporate Affairs (MCA) govern statutory financial reporting through Indian Accounting Standards (Ind AS)—converged with International Financial Reporting Standards (IFRS)—yet without a single, dedicated accounting standard addressing carbon emissions, compliance obligations, or net-zero commitments.

This rapid regulatory proliferation exposes a critical theoretical and practical void. Indian corporations simultaneously navigate domestic compliance targets under CCTS, capital-market disclosure mandates under SEBI BRSR Core, financial audit scrutiny under Ind AS, and cross-border trade pressures such as the European Union's Carbon Border Adjustment Mechanism (EU CBAM) and the International Sustainability Standards Board's (ISSB) IFRS S2 standard. However, corporate practice lacks an integrated conceptual architecture capable of reconciling physical GHG inventories, internal carbon management control systems, financial statement recognition, and externally assured sustainability narratives. International empirical evidence demonstrates that when carbon accounting systems remain decoupled from corporate strategy, budgeting, and financial reporting, external disclosures frequently degenerate into symbolic impression management rather than substantive emissions abatement (Qian&Schaltegger, 2017; Bui et al., 2022; Carrión et al., 2024).

Against this backdrop, this conceptual review pursues three overarching objectives. First, it synthesizes the multidisciplinary international literature on carbon accounting—encompassing physical inventory measurement, internal carbon management accounting, financial reporting, external disclosure, independent assurance, and digital traceability—to establish robust theoretical foundations. Second, it critically evaluates India's emerging regulatory, institutional, and corporate carbon accounting ecosystem, diagnosing structural gaps and competing institutional frames. Third, it develops the Integrated Carbon Accounting Framework for India (ICAF-India) as a multi-layered enterprise blueprint and formulates a prioritized future research agenda tailored to emerging-market institutional realities.

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2. Conceptual Foundations and Multidisciplinary Literature Synthesis

2.1 Competing Frames and Definitional Pluralism in Carbon Accounting

A persistent obstacle in carbon accounting scholarship and practice is the absence of a universally accepted definition. Ascui and Lovell (2011) famously conceptualized this ambiguity through the metaphor of 'colliding frames,' demonstrating that carbon accounting spans at least five overlapping yet frequently conflicting frames of reference: (1) physical carbon accounting, concerned with scientific quantification of atmospheric GHG fluxes; (2) political carbon accounting, governing national inventory rules that compare sovereign emissions against international treaty commitments; (3) market-enabling carbon accounting, establishing baseline-and-credit or cap-and-trade conventions that commensurate heterogeneous greenhouse gases into fungible tradable commodities; (4) financial carbon accounting, focusing on monetary recognition, valuation, and presentation of carbon assets, compliance liabilities, and abatement costs within GAAP or IFRS financial statements; and (5) social and environmental carbon accounting, emphasizing broad stakeholder accountability and democratic scrutiny of corporate climate impacts.

Foundational scholarship by Bebbington and Larrinaga-González (2008) underscored that climate risk and emissions trading cannot be adequately captured through conventional financial accounting alone; non-financial reporting is indispensable for rendering organizational accountability visible under conditions of scientific, regulatory, and market uncertainty. Hopwood (2009) similarly contended that accounting is never a neutral technical mirror of ecological reality, but an active institutional technology that determines how environmental crises are framed, rendered calculable, and acted upon inside corporations. Yet, as Asdal (2011) cautioned, numerical inscriptions simultaneously produce institutional authority and epistemic fragility whenever underlying calculation boundaries, counterfactual baselines, and emission factors remain contested.

Comprehensive literature reviews trace how the discipline has evolved across distinct regulatory eras. Gulluscio et al. (2020) systematically mapped climate change accounting and reporting scholarship, revealing a pronounced structural imbalance: while external corporate carbon disclosure studies dominate academic output, internal carbon management accounting, financial statement integration, and emerging-economy institutional contexts remain severely underrepresented. He et al. (2021) reviewed corporate carbon accounting research spanning the Kyoto Protocol to the Paris Agreement, organizing the field into five interrelated streams: carbon measurement, carbon disclosure, carbon management systems, carbon assurance, and capital-market valuation consequences. More recently, Amel-Zadeh and Tang (2025) documented the structural inflection point represented by the global shift from voluntary disclosure frameworks (such as CDP and GRI) to mandatory climate-related financial reporting anchored by the ISSB's IFRS S2. They argue that carbon accounting must now evolve toward audit-grade precision, internal control rigor, and financial-statement connectivity comparable to traditional financial accounting.

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2.2 Internal Carbon Management Accounting (CMA) and Control Systems

Although external reporting dominates public policy debates, tangible decarbonization occurs inside organizations through capital allocation, energy procurement, industrial process redesign, and supply-chain coordination. Burritt et al. (2011) conceptualized Carbon Management Accounting (CMA) as a specialized branch of environmental management accounting encompassing both monetary carbon information (such as internal shadow carbon pricing, marginal abatement cost curves, compliance cost budgeting, and green capital investment appraisal) and physical carbon information (such as facility-level fuel flows, captive power heat rates, and Scope 1–3 emissions inventories). They structured CMA across past-oriented versus future-oriented and routine versus ad hoc managerial decision horizons.

Subsequent management accounting scholarship has investigated how carbon metrics integrate into broader Management Control Systems (MCS). Hartmann et al. (2013) identified critical research challenges in embedding carbon key performance indicators (KPIs) into divisional performance measurement, budgeting, and executive remuneration, warning that poorly calibrated carbon metrics can provoke short-term gaming or organizational resistance. Empirical investigations reinforce the strategic importance of coupling carbon accounting with governance mechanisms. Bui and de Villiers (2017) demonstrated that regulatory uncertainty acts as a decisive constraint inhibiting organizations from moving beyond reactive compliance toward proactive carbon management accounting. Complementing these findings, Bui and Fowler (2017) illustrated how carbon accounting plays an active mediating role in translating evolving national climate policies into concrete strategic and operational responses.

Cross-national empirical evidence further validates the performance impact of mature internal systems. Analyzing global CDP disclosures, Bui et al. (2022) established that comprehensive carbon accounting systems positively moderate the relationship between corporate carbon strategy and realized carbon performance—confirming that ambitious net-zero rhetoric fails to yield emissions reductions unless supported by granular internal measurement and control infrastructure. Luo and Tang (2020) corroborated this governance nexus, showing that strong corporate governance improves carbon performance via proactive carbon strategies and heightened board-level climate risk awareness, while Luo and Tang (2021) highlighted that national cultural orientations systematically influence corporate carbon performance across jurisdictions. Furthermore, Mahmoudian et al. (2021) argued that effective CMA demands both intra-organizational integration (bridging finance, plant engineering, procurement, and sustainability departments) and inter-organizational stakeholder arrangements across upstream and downstream value chains. Yet translating long-horizon net-zero pledges into day-to-day operational accounting continues to confront severe technical granularity gaps (Carrión et al., 2024).

2.3 Carbon Disclosure, Legitimacy, Assurance, and Capital-Market Effects

An expansive body of empirical accounting research explores the determinants, credibility, and economic consequences of corporate carbon disclosures. Theoretical explanations predominantly draw upon legitimacy theory, institutional theory, stakeholder theory, and signaling theory (Daddi et al., 2018;

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Borghei, 2021). Early critical assessments by Andrew and Cortese (2011) interrogated voluntary self-regulation through CDP and the GHG Protocol, warning that discretionary methodological choices permit corporations to construct self-serving legitimacy narratives while entrenching market-centric norms. Qian and Schaltegger (2017) revisited the enduring tension between legitimacy-driven symbolic disclosure and management-driven substantive improvement, finding that while expanded carbon disclosure can catalyze subsequent emissions reductions, this positive feedback loop weakens markedly in high energy-intensive industrial sectors.

To counteract greenwashing and mitigate carbon information asymmetry between corporate insiders and capital-market participants, independent carbon assurance has emerged as a vital governance mechanism. Fan et al. (2021) provided compelling international evidence that independent carbon assurance significantly reduces carbon information asymmetry—and crucially, that conventional financial statement auditing cannot substitute for specialized carbon assurance. Extending this literature, Luo et al. (2023) demonstrated that corporate carbon assurance substantially elevates overall carbon disclosure quality, with quality gains scaling proportionally with the percentage of reported emissions assured and the rigor of the assurance engagement (reasonable versus limited assurance).

Capital-market valuation studies confirm that investors increasingly price corporate carbon exposures and disclosures across both developed and emerging economies. Jiang et al. (2021) investigated the value relevance of voluntary carbon disclosure across the United States and BRIC nations (including India), establishing that carbon disclosures supply incremental decision-useful information to equity markets beyond conventional financial statements, although domestic institutional maturity moderates pricing efficiency. Anwar et al. (2020) similarly demonstrated that national carbon pricing policies exert coercive institutional pressure that elevates corporate environmental disclosures globally. Synthesizing contemporary developments, Syam et al. (2024) showed that integrating carbon accounting into corporate sustainability reporting reshapes both financial statement interpretation and long-term enterprise risk management.

2.4 Digital Technologies, Blockchain, and Scope 3 Value-Chain Accounting

The foremost technical frontier of modern carbon accounting centers on Scope 3 (indirect value-chain) emissions, which routinely represent more than 70% of an industrial enterprise's total carbon footprint yet suffer from acute primary data scarcity, over-reliance on coarse spend-based secondary emission factors, and double-counting vulnerabilities across multi-tier supply networks. Emerging operations and accounting research highlights the transformative role of digital Measurement, Reporting, and Verification (dMRV) and distributed ledger architectures. Chen et al. (2025) demonstrated that blockchain technologies significantly enhance the traceability, immutability, and credibility of Scope 3 carbon disclosures across complex supply chains, with these gains amplified by complementary data-processing technologies such as Internet of Things (IoT) telemetry and automated analytics. Likewise, Zhu et al. (2024) modeled focal firms' blockchain adoption strategies in the context of carbon emission

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reduction technology innovation, identifying the economic thresholds under which distributed verification incentivizes upstream suppliers to invest in substantive decarbonization.

Table 1: Evolution and Typology of Carbon Accounting Dimensions in International Scholarship

Carbon Accounting Dimension	Primary Purpose & Focus	Dominant Metrics & Units	Key Theoretical Lenses	Core Limitations / Tensions	Representative Literature
Physical / Inventory Accounting	Quantifying direct (Scope 1) and indirect (Scope 2 & 3) GHG emissions across organizational boundaries	Metric tonnes of CO2e (activity-based, spend-based, and hybrid factors)	Framing theory; Scientific commensuration	Boundary ambiguity; Scope 3 estimation errors; uncertainty ranges	Ascui& Lovell (2011); Milne &Grubnic (2011); Chen et al. (2025)
Carbon Management Accounting (CMA)	Internal decision support, abatement costing, budgeting, capital allocation, and performance control	Marginal abatement cost (INR/tCO2e), internal carbon price, energy intensity KPIs	Contingency theory; Management control theory	Decoupling of net-zero targets from operational budgets; regulatory uncertainty	Burritt et al. (2011); Hartmann et al. (2013); Bui & de Villiers (2017); Carrión et al. (2024)
Financial Carbon Accounting	Recognizing, measuring, and disclosing carbon assets, compliance liabilities, and expenses in GAAP/Ind AS	Monetary currency (INR / USD); Fair value, historical cost, NRV, impairment	Positive accounting theory; Institutional standard-setting	Absence of dedicated IFRS/Ind AS standard; asset-liability mismatch	Bebbington& Larrinaga-González (2008); Warwick & Ng (2012); Black (2013); Kim et al. (2022)
External Disclosure & Assurance	Communicating climate risks, governance, and emissions performance to investors and regulators	Standardized ESG templates (BRSR, IFRS S2, CDP); Limited vs. reasonable assurance	Legitimacy theory; Signaling theory; Institutional theory	Impression management; comparability gaps; assurance capacity constraints	Andrew &Cortese (2011); Qian&Schaltegger (2017); Borghei (2021); Fan et al. (2021); Luo et al. (2023)
Market-Enabling Carbon Accounting	Creating, verifying, registering, and retiring tradable compliance allowances and offset credits	Serialized Carbon Credit Certificates (CCCs), 1 CCC = 1 tCO2e	Economic sociology; Market framing; Regulatory governance	Baseline counterfactual subjectivity; additionality and permanence risks	Bebbington& Larrinaga-González (2008); de Aguiar (2017); Milanés Montero et al. (2020)

3. India's Evolving Regulatory and Institutional Carbon Accounting Landscape

India's corporate climate governance architecture has undergone a rapid structural transformation over the past decade—evolving from voluntary corporate social responsibility (CSR) narratives toward a dense, multi-layered statutory regime. However, because regulatory mandates have emerged sequentially across distinct ministries and statutory agencies, Indian corporate practitioners confront an

intricate mosaic of overlapping organizational boundaries, verification methodologies, and reporting calendars.

3.1 Transition from Perform, Achieve and Trade (PAT) to the Indian Carbon Market (CCTS)

Historically, India's flagship industrial decarbonization policy was the Perform, Achieve and Trade (PAT) scheme established under the Energy Conservation Act, 2001. PAT targeted specific energy consumption reductions among designated consumers (DCs) in energy-intensive industrial sectors—including thermal power generation, iron and steel, cement, aluminum, fertilizers, chlor-alkali, textiles, railways, and pulp and paper—through tradable Energy Saving Certificates (ESCerts) denominated in metric tonnes of oil equivalent (MTOE). While PAT achieved notable energy-efficiency gains, its reliance on energy-intensity metrics rather than direct greenhouse gas metrics limited its alignment with international carbon pricing regimes.

The enactment of the Energy Conservation (Amendment) Act, 2022, empowered the Central Government to establish a comprehensive domestic carbon market. Pursuant to this statutory mandate, the Carbon Credit Trading Scheme (CCTS), 2023—overseen by a National Steering Committee chaired by MoEFCC and administered operationally by BEE—instituted the dual-segment Indian Carbon Market (ICM). First, the Compliance Mechanism assigns legally binding sector-specific GHG emission intensity targets (measured in tCO2e per unit of physical output) to obligated entities in hard-to-abate sectors. Entities outperforming their assigned intensity trajectories earn tradable Carbon Credit Certificates (CCCs), whereas underperforming entities must purchase CCCs on power exchanges regulated by the Central Electricity Regulatory Commission (CERC) or face statutory financial penalties. Second, the Offset Mechanism enables non-obligated entities—such as renewable energy developers, green hydrogen producers, afforestation projects, and waste-to-energy plants—to register mitigation activities under BEE-approved methodologies to generate verified offset CCCs for domestic voluntary buyers or authorized international transfers under Article 6 of the Paris Agreement. From a carbon accounting perspective, transitioning from PAT's energy-metric to CCTS's GHG-intensity metric substantially heightens technical measurement complexity, requiring facility-level process emissions accounting, accredited carbon verification agencies (ACVAs), and centralized registry reconciliation.

3.2 Capital-Market Transparency: SEBI's BRSR, BRSR Core, and Value-Chain Mandates

In parallel with MoP and MoEFCC's industrial compliance architecture, SEBI has spearheaded capital-market sustainability transparency. Replacing the legacy Business Responsibility Report (BRR), SEBI mandated the Business Responsibility and Sustainability Reporting (BRSR) framework for the top 1,000 listed companies by market capitalization beginning FY 2022–23. Recognizing global investor demands for decision-useful, auditable ESG metrics, SEBI subsequently introduced BRSR Core, delineating a focused set of nine quantitative ESG attributes—explicitly encompassing Scope 1 and Scope 2 GHG footprints, energy intensity, water footprint, and circular waste management—adjusted for purchasing power parity (PPP) to facilitate global comparability. Crucially, SEBI instituted a phased statutory rollout of mandatory reasonable assurance (and assessment) for BRSR Core among top listed entities, paired

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with phased ESG disclosure mandates covering material upstream and downstream value-chain partners. This value-chain requirement directly transmits Scope 3 carbon accounting pressures onto India's vast MSME ecosystem, which supplies major listed conglomerates yet predominantly lacks digital ERP systems, standardized emission factor repositories, or dedicated sustainability accounting personnel.

3.3 Financial Accounting Patchwork UnderInd AS and ICAI Guidance

Within statutory financial reporting governed by the Companies Act, 2013, Indian listed and large companies prepare financial statements under Ind AS (notified by MCA upon recommendation of ICAI and oversight of the National Financial Reporting Authority, NFRA). Currently, no standalone Ind AS addresses greenhouse gas emissions, carbon credit holdings, compliance surrender obligations, or corporate net-zero commitments. Consequently, preparers rely on an ad hoc patchwork of general accounting standards—Ind AS 2 (Inventories), Ind AS 20 (Accounting for Government Grants), Ind AS 36 (Impairment of Assets), Ind AS 37 (Provisions, Contingent Liabilities and Contingent Assets), Ind AS 38 (Intangible Assets), Ind AS 113 (Fair Value Measurement), and Ind AS 115 (Revenue from Contracts with Customers)—supplemented by ICAI's legacy 2012 Guidance Note on Accounting for Self-generated Certified Emission Reductions (CERs), originally drafted during the Kyoto Clean Development Mechanism (CDM) era. As international empirical evidence from the European Union and South Korea demonstrates, applying generic accounting standards to carbon instruments in the absence of a dedicated standard produces severe cross-company divergence in balance-sheet classification, income-statement volatility, and footnote transparency (Warwick & Ng, 2012; Black, 2013; Kim et al., 2022).

3.4 Global Trade Pressures and ISSB Interoperability

Beyond domestic statutory mandates, export-oriented Indian industries—particularly iron and steel, aluminum, cement, fertilizers, and information technology services—confront rapidly tightening transnational carbon accounting regimes. The European Union's Carbon Border Adjustment Mechanism (EU CBAM) requires Indian exporters in covered sectors to measure, verify, and report granular product-level embedded direct and indirect GHG emissions according to EU verification protocols, with financial certificate liabilities tied directly to carbon price differentials. Simultaneously, global institutional investors increasingly benchmark Indian equities against the ISSB's IFRS S1 and IFRS S2 climate disclosure standards and Science-Based Targets initiative (SBTi) validation criteria. Without systematic interoperability between India's domestic reporting templates (CCTS and BRSR Core) and international frameworks (IFRS S2 and EU CBAM), Indian enterprises risk escalating compliance duplication and double verification costs.

Table 2: Mapping India's Fragmented Carbon Governance and Reporting Architecture

Institutional Pillar	Nodal Regulator / Body	Primary Mandate & Instrument	Target Entities	Measurement & Verification Basis	Key Integration Gaps

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Institutional Pillar	Nodal Regulator / Body	Primary Mandate & Instrument	Target Entities	Measurement & Verification Basis	Key Integration Gaps
Industrial Compliance & Carbon Market	MoEFCC, MoP, BEE, CERC	Energy Conservation (Amendment) Act, 2022; CCTS, 2023; CERC CCC Regulations	Obligated entities (energy-intensive sectors) & voluntary offset project developers	Facility-level GHG emission intensity (tCO2e/output); Accredited Carbon Verification Agencies (ACVAs)	ICM Registry data not automatically linked to corporate financial ledgers or SEBI BRSR filings
Capital-Market Sustainability Reporting	SEBI	BRSR (Top 1,000 listed firms) & BRSR Core (Reasonable assurance + Value Chain)	Top listed equities and their material upstream/downstream value-chain partners	Organizational Scope 1, 2, and phased Scope 3 disclosures; intensity adjusted for PPP	Divergent boundaries vs. CCTS facility targets; acute MSME data gaps for Scope 3
Statutory Financial Reporting	MCA, ICAI, NFRA	Companies Act, 2013; Ind AS (2, 20, 36, 37, 38, 113, 115); Legacy 2012 CER Guidance Note	All Ind AS / AS reporting Indian corporate entities	Monetary recognition and measurement under general financial reporting principles	No unified Ind AS for CCCs or climate liabilities; disconnect between financial P&L and Carbon P&L
International Trade & Global Investor Alignment	Ministry of Commerce / Global Buyers	EU CBAM, ISSB (IFRS S2), CDP, Science-Based Targets initiative (SBTi)	Export-oriented Indian steel, aluminum, cement, fertilizer, and IT/manufacturing firms	Embedded product-level GHG intensity; TCFD/ISSB financial materiality	High compliance duplication; risk of double verification costs for exporters

4. Proposed Conceptual Framework: Integrated Carbon Accounting Framework for India (ICAF-India)

4.1 Theoretical Grounding and Design Principles

To resolve the colliding frames identified by Ascui and Lovell (2011) and bridge the institutional silos mapped in Table 2, this study proposes the Integrated Carbon Accounting Framework for India (ICAF-India). Grounded in institutional theory, contingency-based management control theory, and socio-technical systems design (Burritt et al., 2011; Hartmann et al., 2013; Mahmoudian et al., 2021; Bui et al., 2022; Amel-Zadeh& Tang, 2025), ICAF-India conceptualizes corporate carbon accounting not as an isolated year-end compliance exercise, but as a five-layered, closed-loop enterprise architecture. The framework rests on four core design principles: (1) Single-Source Data Integrity, ensuring that plant-level physical measurements feed both managerial controls and financial ledgers without manual spreadsheet re-keying; (2) Financial-Physical Connectivity, translating tCO2e exposures transparently into monetary Ind AS impacts; (3) Multi-Stakeholder Interoperability, enabling a 'collect once, report

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many' digital reporting workflow across BEE, SEBI, ISSB, and CBAM; and (4) Dual-Track Assurance, harmonizing engineering GHG verification with financial/sustainability audit standards.

4.2 Five-Layered Enterprise Architecture of ICAF-India

Layer 1: Physical Activity & Digital MRV Foundation. At the operational base, enterprises establish unified organizational and operational boundaries that systematically reconcile equity-share and operational-control approaches across entity-wide SEBI BRSR reporting and facility-level BEE CCTS obligations. Primary activity data—covering coal and natural gas combustion, captive thermal generation, grid electricity mixes, industrial chemical process emissions, and fleet logistics—are captured continuously through IoT telemetry, SCADA meters, and Enterprise Resource Planning (ERP) integrations. For Scope 3 value-chain emissions involving resource-constrained Tier-1 and Tier-2 Indian MSMEs, Layer 1 deploys a tiered hybrid calculation protocol: initiating with nationalized, India-specific secondary emission factors hosted on an open public repository, and progressively migrating toward primary supplier data authenticated via permissioned blockchain or API-based digital MRV platforms (Zhu et al., 2024; Chen et al., 2025).

Layer 2: Carbon Management Accounting (CMA) & Strategic Control Core. Verified physical GHG flows from Layer 1 feed directly into internal managerial decision-making and strategic control (Burritt et al., 2011; Bui et al., 2022). Corporations operationalize internal carbon pricing—combining shadow carbon prices for long-term capital expenditure appraisal with implicit carbon prices benchmarked against live ICM CCC spot prices—construct dynamic Marginal Abatement Cost Curves (MACCs), and embed divisional carbon budgets into quarterly variance analysis (Hartmann et al., 2013). Crucially, Layer 2 resolves the 'net-zero translation gap' documented by Carrión et al. (2024) by linking multi-decade decarbonization pathways directly to annual operating budgets, procurement scorecards, and executive incentive compensation.

Layer 3: Financial Accounting &Ind AS Integration Engine. Layer 3 translates physical emission obligations, abatement capital investments, and carbon market transactions into monetary financial statement impacts under Ind AS. It establishes standardized chart-of-accounts mapping for self-generated and purchased CCCs (under Ind AS 2 or Ind AS 38 based on holding intent), accrues compliance shortfall provisions (Ind AS 37), incorporates climate transition risk into impairment testing of carbon-intensive stranded assets (Ind AS 36), applies Ind AS 113 fair-value hierarchies to market-traded carbon instruments, and generates a supplementary Carbon Profit & Loss (Carbon P&L) reconciliation linking audited financial expenses to environmental abatement expenditures and climate risks (Bebbington& Larrinaga-González, 2008; Syam et al., 2024).

Layer 4: Harmonized Multi-Stakeholder Reporting & Interoperability Hub. Leveraging a 'collect once, report many' digital XBRL taxonomy architecture, Layer 4 maps validated internal physical and monetary data simultaneously to four distinct external reporting regimes: (a) BEE's ICM Registry for statutory CCTS compliance and offset issuance; (b) SEBI's BRSR and BRSR Core disclosures for domestic capital markets; (c) global investor frameworks including ISSB IFRS S2 and CDP; and (d) product-level embedded

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emissions declarations required for cross-border trade mechanisms such as the EU CBAM. This layer eliminates redundant reporting workflows and prevents contradictory public disclosures across regulatory filings.

Layer 5: Governance, Independent Assurance, and Institutional Feedback Loop. Governing all four technical layers is board-level climate oversight—anchored jointly in the Audit Committee and ESG/Sustainability Committee—coupled with dual-track independent assurance that reconciles technical facility-level GHG verification conducted by BEE-accredited ACVAs with statutory financial audits and SEBI BRSR Core reasonable assurance performed by Chartered Accountants (Luo& Tang, 2020; Fan et al., 2021; Luo et al., 2023). Findings from external assurance audits, regulatory inspections, and capital-market investor feedback loop continuously back into Layers 1 and 2 to recalibrate internal controls, emission factors, and strategic abatement targets.

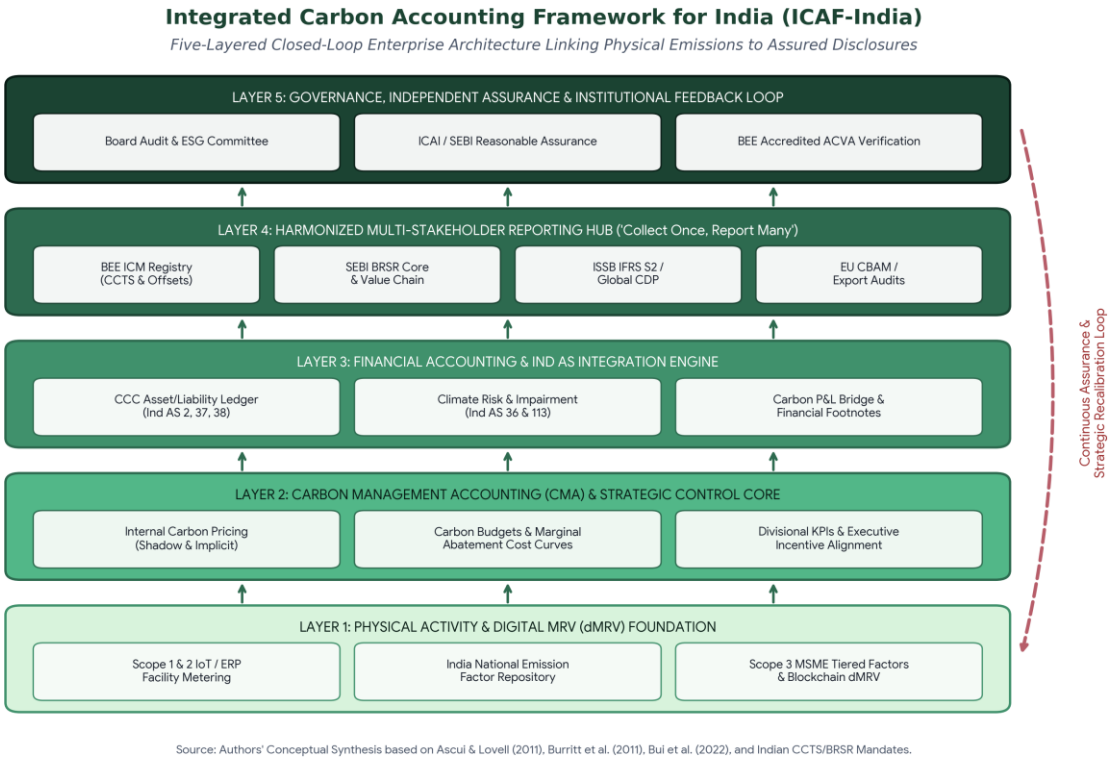

Figure 1: Multi-Level Conceptual Architecture of the Integrated Carbon Accounting Framework for India (ICAF-India)

4.3 Operationalizing Data Integrity: The dMRV-to-Assurance Feedback Loop

A chronic operational vulnerability in emerging-market corporate carbon accounting is data discontinuity: physical emissions tracked by plant engineers frequently reside in unlinked desktop spreadsheets that never reconcile with the ERP general ledger maintained by corporate finance teams or the ESG narrative assembled by sustainability departments. This discontinuity severely undermines auditability and exposes firms to misstatement risks under SEBI BRSR Core reasonable assurance. Figure 2 delineates the operational data governance and dual-track assurance workflow embedded within

ICAF-India. By routing plant telemetry, supply-chain MSME inputs, and ICM Registry transaction feeds into a unified enterprise carbon data lake, the architecture automatically generates synchronized physical (tCO2e) and monetary (Ind AS) ledgers, enforces automated inter-ledger reconciliation prior to external verification, and provides transparent audit trails to both ACVA technical verifiers and statutory financial/BRSR Core assurance practitioners.

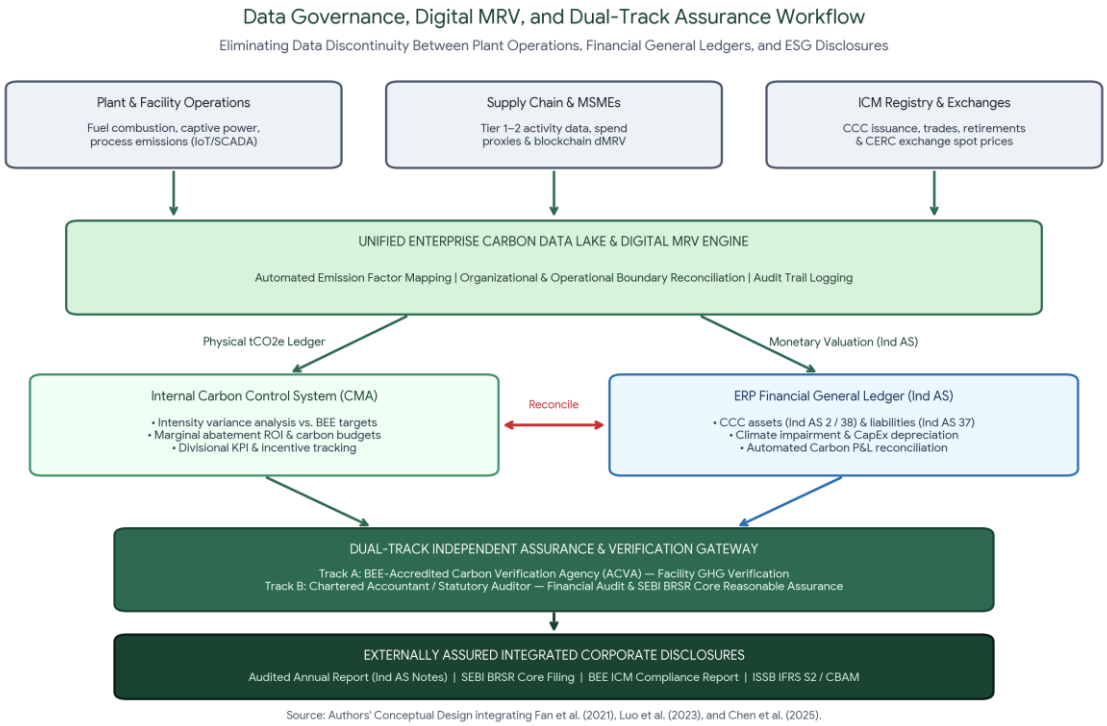

Figure 2: Data Governance, Digital MRV, and Dual-Track Assurance Workflow Connecting Operational Emissions to Financial & BRSR/ISSB Disclosures

5. Structural Challenges, Institutional Tensions, and Sectoral Realities in India

Translating ICAF-India from conceptual design to nationwide corporate adoption confronts four deeply rooted structural tensions inherent in India's political economy, industrial structure, and regulatory governance.

5.1 Regulatory Fragmentation and Jurisdictional Overlap

India's climate governance spans multiple central ministries and statutory regulators—MoEFCC, MoP, BEE, CERC, SEBI, MCA, ICAI, and NFRA—each operating under distinct legislative mandates, policy priorities, and reporting cycles. International evidence from Europe and South Korea demonstrates that regulatory fragmentation fosters reporting omission strategies, inconsistent accounting policies, and corporate compliance fatigue unless standard-setters institutionalize coordinated multi-agency governance (Milanés Montero et al., 2020; Kim et al., 2022). Without a formally harmonized national carbon data taxonomy bridging BEE's facility-level intensity metrics and SEBI's entity-level absolute

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emissions metrics, Indian conglomerates face duplicative verification fees and confusing reconciliations for global investors.

5.2 The MSME Value-Chain Bottleneck in Scope 3 Accounting

India's manufacturing and export base depends heavily on over 60 million micro, small, and medium enterprises (MSMEs) that constitute the backbone of upstream Scope 3 supply chains for large listed corporations. While SEBI's BRSR Core value-chain mandate and global standards such as IFRS S2 rightly emphasize full value-chain transparency, imposing rigorous primary GHG inventory mandates on resource-constrained MSMEs without technical capacity-building and digital public infrastructure risks two adverse outcomes: either widespread reliance on crude spend-based emission proxies that mask actual decarbonization efforts, or the progressive exclusion of smaller domestic suppliers from globalized value chains (Mahmoudian et al., 2021; Chen et al., 2025).

5.3 Assurance Expectations Gap and Multidisciplinary Capacity Constraints

Independent carbon assurance is indispensable for curbing greenwashing and lowering capital-market information asymmetry (Fan et al., 2021; Luo et al., 2023). Yet India's emerging assurance ecosystem exhibits an institutional bifurcation: engineering-trained ACVAs accredited by BEE specialize in plant-level physical GHG measurement and thermodynamic mass-balance verification, whereas Chartered Accountants regulated by ICAI specialize in financial internal controls, materiality judgments, and BRSR Core assurance. Bridging this interdisciplinary divide requires joint competency frameworks, harmonized assurance materiality thresholds, and rigorous regulatory quality oversight to prevent an 'assurance expectations gap' among domestic and foreign institutional investors.

5.4 Symbolic Legitimacy Versus Substantive Decarbonization in Hard-to-Abate Sectors

Consistent with international empirical findings (Qian&Schaltegger, 2017; Borghei, 2021), a substantial risk persists that Indian enterprises—particularly in coal-intensive thermal power, integrated blast-furnace steel, and clinker-heavy cement sectors—treat BRSR Core disclosures and headline net-zero announcements as symbolic legitimacy exercises rather than catalysts for internal capital reallocation. In hard-to-abate Indian sectors where decarbonization requires multi-billion-dollar investments in green hydrogen direct reduced iron (DRI), carbon capture utilization and storage (CCUS), and grid-scale renewable storage, carbon accounting drives substantive abatement only when tightly coupled with internal carbon pricing, capital budgeting hurdle rates, and executive incentive structures (Bui et al., 2022; Carrión et al., 2024).

6. Future Research Agenda and Policy Roadmap

6.1 Prioritized Research Themes and Methodological Directions

To advance both theoretical scholarship and evidence-based policymaking in India's transitioning carbon economy, Table 3 synthesizes a prioritized future research agenda organized across five thematic

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domains, mapping key research questions to appropriate theoretical lenses and rigorous empirical methodologies.

Table 3: Future Research Agenda for Integrated Carbon Accounting in India

Thematic Domain	Priority Research Questions	Recommended Theoretical Lenses	Suggested Methodological Approaches
1. Institutional Harmonization & Standard-Setting	How do institutional power dynamics among ICAI, SEBI, BEE, and MoEFCC shape the convergence of Ind AS, BRSR Core, and CCTS reporting? What lessons from Korea's K-ETS standard-setting apply to India?	Institutional theory; Regulatory capture; Framing theory (Ascui& Lovell, 2011; Kim et al., 2022)	Longitudinal policy analysis; elite interviews with standard-setters; public comment-letter content analysis
2. Internal CMA & Net-Zero Translation	How do Indian energy-intensive firms integrate internal carbon pricing and CCTS intensity targets into capital budgeting and managerial incentive systems? Does CMA maturity moderate actual abatement?	Contingency theory; Management control theory (Burritt et al., 2011; Bui et al., 2022; Carrión et al., 2024)	Multi-site longitudinal case studies in steel/cement; survey-based structural equation modeling (SEM)
3. Scope 3 Digitization & MSME Inclusion	How can Digital Public Infrastructure (DPI), India-specific emission factor databases, and blockchain-enabled dMRV lower Scope 3 compliance costs for Tier-1 and Tier-2 Indian MSMEs?	Transaction cost economics; Socio-technical systems (Mahmoudian et al., 2021; Chen et al., 2025)	Design-science research; field experiments with industrial clusters; cost-benefit econometric modeling
4. Carbon Assurance & Information Asymmetry	Does mandatory BRSR Core reasonable assurance reduce equity cost of capital, debt spreads, and analyst forecast dispersion for Indian listed firms? How do CA-led vs. engineering-led assurance teams differ?	Agency theory; Signaling theory; Information asymmetry (Fan et al., 2021; Luo et al., 2023)	Difference-in-differences (DiD) quasi-natural experiments exploiting SEBI's phased BRSR Core rollout
5. Capital-Market Valuation & Trade Spillovers	How do Indian equity and green-bond markets price corporate carbon intensity, CCTS compliance exposure, and EU CBAM vulnerability under mandatory versus voluntary disclosure regimes?	Value-relevance modeling; Market efficiency; Legitimacy theory (Jiang et al., 2021; Anwar et al., 2020)	Panel regressions; capital-market event studies around CCTS, BRSR Core, and CBAM regulatory announcements

6.2 Actionable Policy Implications for Regulators, Standard-Setters, and Industry

Translating the insights of this conceptual review into institutional reform yields three concrete policy imperatives for India's climate and financial regulators:

- **Establish a Joint Inter-Regulatory Carbon Accounting Taskforce:** MCA, ICAI, NFRA, SEBI, BEE, and MoEFCC should convene a permanent statutory taskforce to harmonize organizational versus facility-level reporting boundaries, publish an authoritative open-access India National Emission Factor Database, and promulgate a dedicated Ind AS on Pollutant Pricing Mechanisms aligned with IFRS S2.
- **Deploy Digital Public Infrastructure (DPI) for MSME Scope 3 Carbon Accounting:** Leveraging India's globally acclaimed DPI architecture (analogous to UPI and GSTN), policymakers should sponsor an open-

protocol, low-cost digital carbon ledger allowing MSMEs to calculate, verify, and securely share Scope 1–2 data with large corporate buyers without prohibitive ERP expenditures.

- **Co-Develop Multidisciplinary Carbon Assurance Standards:** ICAI and BEE should establish joint technical standards and multidisciplinary accreditation pathways integrating Chartered Accountants and ACVA engineers, ensuring that facility-level GHG verification and entity-level BRSR Core reasonable assurance reinforce one another seamlessly.

7. Conclusion

Developing an integrated carbon accounting framework is far more than a technical compliance upgrade; it constitutes foundational institutional infrastructure for India's low-carbon economic transformation. By synthesizing international carbon accounting scholarship and diagnosing the structural fragmentation across India's CCTS, SEBI BRSR Core, and Ind AS regimes, this conceptual review demonstrates why siloed physical GHG inventories, managerial controls, financial statements, and sustainability reports fail to deliver credible, decision-useful accountability. The proposed Integrated Carbon Accounting Framework for India (ICAF-India) offers a coherent, five-layered enterprise architecture unifying operational digital MRV, carbon management accounting, financial statement integration, harmonized multi-stakeholder reporting, and dual-track independent assurance. Executing this integration—supported by coordinated inter-regulatory reform and rigorous empirical scholarship along the proposed research agenda—will empower Indian corporations, capital markets, and policymakers to transition decisively from fragmented compliance toward transparent, economically efficient decarbonization.

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