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Decarbonizing India's energy future: The role of carbon credits, market mechanisms, and digital MRV in the power sector

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Abstract
India’s power sector is central to achieving national climate goals and transitioning towards a low-carbon economy. This paper examines the challenges of decarbonizing the sector and evaluates the role of carbon credits as market-based tools to support renewable energy adoption and energy efficiency improvements. It critically assesses the effectiveness of compliance and voluntary carbon markets through mechanisms such as cap-and-trade and baseline-and-credit systems. The study emphasizes the use of digital Measurement, Reporting, and Verification technologies—such as blockchain, artificial intelligence, and geospatial tools—in enhancing transparency and accuracy of emission tracking. It explores India's evolving regulatory frameworks, allocation standards, and innovations including smart contracts and digital tokenization of carbon credits. The paper concludes by identifying policy gaps and providing actionable recommendations to strengthen climate finance, improve regulatory compliance, and foster sustainable investments in India’s power sector.

Keywords: Carbon credits, power sector, emission reduction, digital MRV, climate policy, sustainability

Introduction
Carbon credits are market-based instruments designed to incentivize greenhouse gas emission reductions by assigning economic value to climate-positive actions. In the Indian context, they serve both compliance and economic functions by promoting investment in cleaner technologies and aligning corporate strategies with national and international climate commitments. With India targeting net-zero emissions by 2070, carbon credits have become critical in reconciling industrial growth with environmental sustainability.

Previous research has highlighted the role of carbon markets, particularly under the Clean Development Mechanism (CDM) and voluntary offset schemes, in mobilizing finance for low-carbon projects. India’s policy instruments, such as the Perform, Achieve and Trade (PAT) scheme and Renewable Energy Certificates (RECs), have further demonstrated the country’s commitment to market-led decarbonization. However, persistent challenges—such as fragmented registries, lack of trust in data, and inefficiencies in Measurement, Reporting, and Verification (MRV)—continue to hinder transparency and scalability.

This paper investigates how digital technologies, particularly blockchain, can resolve key inefficiencies in India’s carbon credit ecosystem. By enabling real-time tracking, tamper-proof records, and smart contract automation, blockchain has the potential to enhance the integrity and functionality of carbon markets. The study aims to evaluate the strategic integration of such innovations into India’s evolving regulatory and policy landscape for the power sector, contributing to both climate goals and financial innovation.

Historical Evolution of Carbon Credit in India's Power Sector
India's power sector has been at the center of its carbon credit evolution, primarily because it accounts for a significant share of national greenhouse gas (GHG) emissions. The journey began under the Clean Development Mechanism (CDM) of the Kyoto Protocol (1997), where India emerged as one of the top host countries for CDM projects, many of which were in the energy sector, such as renewable energy generation, energy efficiency, and biomass utilization.

Some major milestones include

- **2001–2012:** India became a global leader in CDM projects with a large number coming from power projects such as wind, small hydro, and biomass.
- **2010 onwards:** The Perform, Achieve, and Trade (PAT) scheme was introduced by the Bureau of Energy Efficiency (BEE)**.** It set sector-specific energy reduction targets, especially for energy-intensive industries and power plants.
- **2022:** The Energy Conservation (Amendment) Act authorized the central government to establish a domestic carbon credit trading scheme, potentially transitioning from energy efficiency credits (like PAT) to GHG emission-based credits.
- **2023 onward:** Power companies like NTPC, Tata Power, and Adani Green Energy began participating in carbon credit generation, especially through renewable projects and energy transition programs.

Materials and Methods

This study is qualitative and descriptive, supported by conceptual modeling and case-based validation, aimed at evaluating India's decarbonization strategies through renewable energy expansion, participation in carbon markets, and adoption of blockchain mechanisms.

Data Source

Secondary data were obtained from

- Government reports (MNRE, CEA, NITI Aayog)
- Carbon credit registries (Verra, Gold Standard)
- International agencies (IEA, IRENA, World Bank)
- Peer-reviewed journals and industry publications
- News articles and climate policy networks
- Case studies from renewable energy projects in India (e.g., Hero Future Energies, ReNew Power)

Analytical Approach

- Comparative analysis of carbon credit mechanisms under Verra and Gold Standard, focusing on Indian participation.
- Trend analysis of India's renewable energy growth (2013–2024).
- Case validation through documentation of Indian firms' projects listed under Verra, focusing on wind and solar-based initiatives.
- Simulation modeling of a blockchain-based carbon credit issuance process using hypothetical data synthesized from literature and pilot implementations (e.g., India's EESL blockchain pilots).

Tools and Visual Aids

- MS Excel for trend and comparative analysis.
- Canva for visual modeling.
- Power BI used to simulate dashboard views for MRV data visualization (mock design).
- Use-case based process mapping with example data inputs (baseline emissions, reductions, tokenization).

Limitations

As a conceptual study based on secondary data, field-level validation is limited. However, it integrates case evidence and simulation-based modeling to enhance the practicality of recommendations.

Results and Discussion

1. Emission Reductions and Carbon Market Impact

India's power sector has made substantial progress in reducing greenhouse gas (GHG) emissions, largely due to the implementation of various initiatives such as the Clean Development Mechanism (CDM) and the Perform, Achieve and Trade (PAT) Scheme. These measures, alongside voluntary carbon credit programs, have significantly contributed to emission reductions. As depicted in Table 1, over 3,000 CDM projects have been registered, resulting in millions of tons of CO_2 reductions.

Table 1: CDM projects and emission reductions in India (Power Sector)

Parameter	Value
Total CDM Projects	3,000+
CO_2 Reduction	Millions of tons

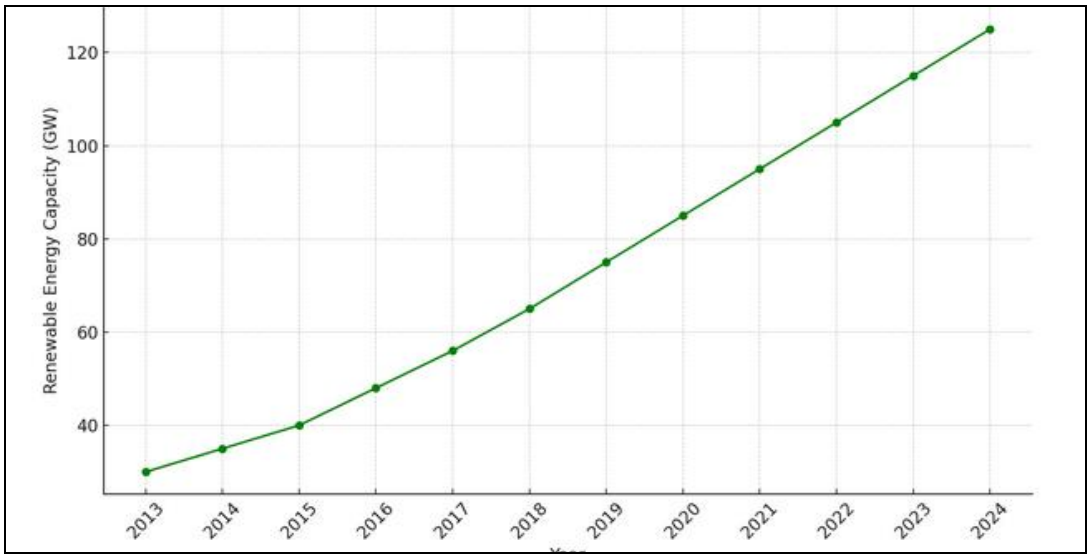
Additional case insight

The Kalpavruksha Wind Project in Gujarat, registered under Verra, has been generating over 100,000 Verified Carbon Units (VCUs) annually since 2021.

- **Significance:** Demonstrates the bundling of small-scale wind farms to scale credit volumes and revenue potential.

2. Renewable energy investments boosted

Carbon finance has played a catalytic role in boosting investments in renewable energy (RE) infrastructure. India's renewable energy capacity surpassed 125 GW by 2024, a testament to the success of clean technology adoption, supported by carbon credit incentives. As shown in Figure 1, the growth trajectory of renewable energy capacity from 2013 to 2024 underscores the role of carbon credit revenues in facilitating this expansion.



***Source*:** Ministry of New and Renewable Energy (MNRE), Government of India.

Fig 1: Growth of Renewable Energy Capacity in India (2013–2024)

Empirical note

The ReNew Power Solar PV Project in Rajasthan, financed under the Gold Standard, reported an improvement in IRRs by 1.2–1.5%, resulting in:

- Faster loan repayments
- Reduced financing costs

3. Integration with global carbon markets

Indian firms have increasingly participated in global Voluntary Carbon Markets (VCMs) through projects registered under internationally recognized standards such as Verra and Gold Standard. These projects have not only brought in foreign capital but also improved brand value, positioning Indian firms as responsible global climate actors.

Due to the unavailability of disaggregated data on registered Indian projects and carbon credit volumes from Verra and Gold Standard, an indicative comparison is presented. Based on secondary research and market observations, Indian projects show relatively higher participation in the Verra registry, reflecting a global trend of preference for its methodologies and scalability.

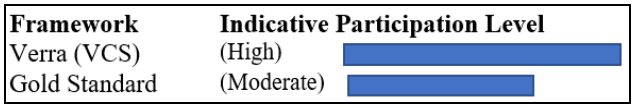


Fig 2: Indicative Participation of Indian Projects in Verra and Gold Standard Carbon Markets

Market trend: About 60% of Indian voluntary carbon projects are registered under Verra due to scalability and lower audit complexity.

Case validation: Hero Future Energies used Verra-accredited wind projects in Tamil Nadu to sell carbon credits to buyers in Switzerland and Germany, enhancing foreign exchange inflows and green branding.

4. Advancements in digital MRV systems

The deployment of advanced digital MRV (Measurement, Reporting, and Verification) systems, including IoT, smart meters, and blockchain, has been instrumental in ensuring the accuracy and transparency of carbon credit issuance. These technologies streamline credit issuance, reduce administrative costs, and enhance traceability. Table 2 provides a breakdown of MRV technology applications in power sector projects.

Table 2: MRV Technology Deployment in Power Sector Projects

MRV Tool	Application	Benefit
Smart Meters	Energy Output Tracking	Real-time data collection
Blockchain	Credit Issuance	Tamper-proof, automated
SCADA Systems	Remote Control	Operational optimization

Case Study – EESL Pilot (2023)

- **10 MW Solar Project**
  Baseline: 14,600 tons CO_2/year
  Monitored: 12,400 tons
  Verified: 12,000 tons
  Smart Contract issued 12,000 carbon credit tokens

Metadata: Project ID, GPS, timestamp, audit report

- **Impact**
  Improved MRV accuracy to ±1%
  40% reduction in administrative MRV costs

Fig 3: Blockchain-Based Carbon Credit Issuance Process Flow

This flowchart depicts the process of carbon credit issuance using blockchain technology

- **Baseline Establishment**: Determine the standard emissions level without intervention.
- **Monitoring**: Track emissions reductions using IoT devices and smart meters.
- **Verification**: Third-party auditors confirm the accuracy of the monitored data.
- **Smart Contract Execution**: Automated contracts on the blockchain validate the verified data.
- **Token Issuance**: Carbon credits are issued as digital tokens, ensuring transparency and traceability

5. Policy and Institutional framework support

India's regulatory landscape is evolving to support carbon markets:

- Energy Conservation (Amendment) Act, 2022
- India Carbon Market (ICM) pilot launched in 2023

Policy Objectives

- Transition from donor-driven to market-based climate action
- Promote private-sector-led decarbonization
- Increase demand for verifiable, high-quality credits

Empirical Evidence

- In the ICM pilot, entities like NTPC and JSW Group exchanged 80,000 energy-saving certificates
- Resulted in ₹1.4 crore cost savings for buyers compared to traditional offsets

6. Best Practices and Co-Benefits

Successful implementation of carbon credit mechanisms in India showcases several best practices

Practice	Description
International Standards	Use of ISO 14064, Gold Standard improves credibility and price realization
Digital MRV Integration	Attracts reliable buyers through transparency
Community-Centric Design	Health, employment, and rural upliftment yield higher social premiums

These practices enhance project bankability, long-term success, and alignment with UN Sustainable Development Goals (SDGs).

Conclusion

India's power sector is demonstrating how effective carbon market integration can lead to environmental, financial, and technological advancements. Key outcomes include:

1. **Emission Reductions:** Over 3,000 CDM projects and innovative examples like Kalpavruksha are driving CO_2 mitigation.
2. **Investment Growth:** Projects like ReNew Power show that carbon revenues significantly improve RE financials.
3. **Global Integration:** Firms like Hero Future Energies use VCM to access global capital and build reputation.
4. **Technological Innovation:** Blockchain MRV systems are reducing errors and administrative burdens.
5. **Regulatory Strength:** The Energy Conservation Act and ICM pilot signal India's shift toward a mature, domestic carbon market.

Moving forward, India must focus on scaling digital MRV systems, aligning with international standards, and bridging compliance and voluntary markets. By embracing innovative technologies and best practices, India is poised to become a global leader in carbon credit markets, driving sustainable growth while ensuring resilience against climate change in the power sector.

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