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**CARBON SEQUESTRATION
PATHWAYS
IN THE INDIAN
AGRICULTURAL SECTOR**



Prepared by:
NatureFIX



NatureFIX

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List of Abbreviations

AI	Artificial Intelligence
AIF	Agriculture Infrastructure Fund
AMI	Agricultural Marketing Infrastructure
AR	Afforestation/Reforestation
BECCS	Bioenergy with Carbon Capture and Storage
CBC	Coastal Blue Carbon
CCM	Compliance Carbon Market
CCU	Carbon Capture and Utilization
CDR	Carbon Dioxide Removal
CH ₄	Methane
CO ₂	Carbon Dioxide
CORCs	CO ₂ Removal Certificates
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRCF	Carbon Removal and Carbon Farming Certification
DAC	Direct Air Capture
DACCS	Direct Air Capture and Storage
DOCCS	Direct Ocean Capture and Storage
e-NAM	(Electronic) National Agricultural Market
ESG	Environmental Social Governance
ETS	Emissions Trading System
ERW	Enhanced Rock Weathering
FDI	Foreign Direct Investment
FOAK	First-of-a-Kind
FPOs	Farmers Producer Organisations
GHG	Greenhouse Gas
GS	Gold Standard
H ₂ CO ₃	Carbonic Acid
H:C	Hydrogen-to-Carbon Ratio
ICAO	International Civil Aviation Organisation
ICM	Indian Carbon Market
IPCC	Intergovernmental Panel on Climate Change
KCC	Kisan Credit Card
MBMs	Market-Based Measures
MRV	Measurement, Reporting, and Verification
N ₂ O	Nitrous Oxide
NABARD	National Bank for Agriculture and Rural Development
NGOs	Non-Governmental Organisations
NICRA	National Innovations on Climate Resilient Agriculture
NMSA	National Mission on Sustainable Agriculture
OAE	Ocean Alkalinity Enhancement
PLI	Production Linked Incentive
PM-AASHA	Pradhan Mantri Annadata Aay Sanrakshan Abhiyan
PMFBY	Pradhan Mantri Fasal Bima Yojana
PMFME	Pradhan Mantri Formalisation of Micro Food Processing Enterprises
PM-KISAN	Pradhan Mantri Kisan Samman Nidhi
PMKMY	Pradhan Mantri Kisan Maan-Dhan Yojana

PMKSY	Pradhan Mantri Krishi Sinchai Yojana
PMKVY	Paramparagat Krishi Vikas Yojana
PPP	Public–Private Partnerships
R&D	Research and Development
SBTi	Science-Based Targets initiative
SCS	Soil Carbon Sequestration
SMAM	Sub-Mission on Agricultural Mechanisation
SOC	Soil Organic Carbon
tCO ₂ e	Tonnes of Carbon Dioxide Equivalent
TRL	Technological Readiness Level
VCM	Voluntary Carbon Market
VVB	Validation and Verification Body

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1. Executive Summary

This report assesses how India's agriculture sector can deliver **durable carbon removal** while strengthening rural livelihoods.

It examines three priority pathways: **Regenerative Agriculture**, **Biochar**, and **Enhanced Rock Weathering (ERW)**, and situates them within India's fast-evolving climate and agricultural policy framework.

Key findings:

- **Policy readiness:** India's multi-layered agri-climate policies (PM-Kisan, NMSA, Indian Carbon Market, etc.) create a strong base for carbon-removal pilots.
- **Market momentum:** Biochar already dominates early removals; ERW and regenerative soil projects are emerging.
- **Financing and scale:** High-integrity CDR credits command premium prices (USD 100–200/tCO₂e). Blended finance, NGO seed funding, and offtake agreements are essential to bridge early-stage costs.
- **Stakeholder landscape:** From farmers to startups and global fashion brands, a diverse coalition is ready to support CDR deployment.

India can leverage abundant biomass, silicate rock resources, and smallholder networks to become a **global leader in nature-based removals**, provided that MRV integrity and farmer incentives remain central.

Opportunities in the Organic Cotton Value Chain

The organic cotton industry presents a natural proving ground for all three carbon-dioxide removal pathways. **Regenerative agriculture** practices such as cover cropping, intercropping, and minimal tillage align with organic standards and enhance soil carbon. **Biochar** provides long-term carbon storage while improving soil fertility and fibre yields without synthetic inputs. **Enhanced Rock Weathering** integrates smoothly into organic systems by applying finely ground silicate rock as a soil amendment, increasing pH and nutrient availability while drawing down atmospheric CO₂.

With global brands demanding **traceable low-carbon fibres**, the organic-cotton supply chain can monetise these interventions through high-integrity carbon credits, creating new revenue streams for farmers and reinforcing India's position as the world's leading producer of organic and conventional cotton.

2. Introduction

India is the **world's leading cotton producer**, supplying roughly **23 percent of global output**. The crop is a mainstay of the national economy and a critical source of income for millions of farming households. Cotton covers about **13.06 million hectares** across the country, compared with a global cultivation area of about **33.1 million hectares**, and supports the livelihoods of nearly **60 million Indians**.

For the **2024–25 season**, India's cotton harvest is projected at **30.225 million bales** (each bale weighing 170 kg). Production in previous years was **32.5 million bales in 2023–24**, **33.6 million in 2022–23**, and **31.1 million in 2021–22**. By the close of the 2024–25 marketing year (ending 30 September 2025), the total supply is expected to reach about **35.744 million bales**, with **exports forecast at around 1.8 million bales**.¹

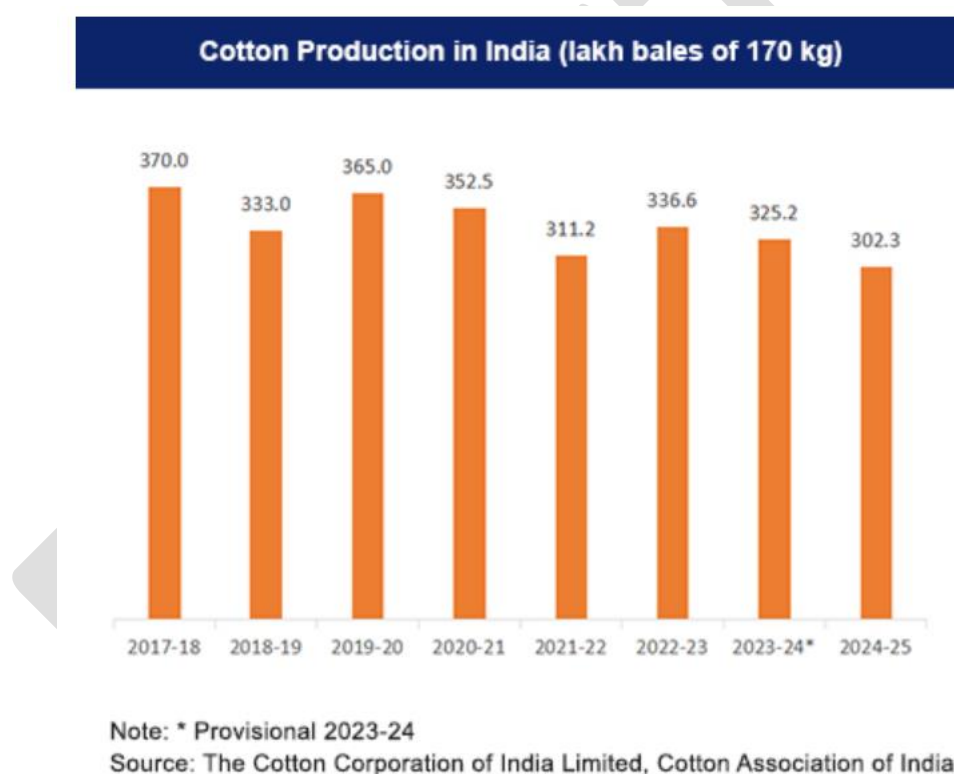


Figure 1: Cotton Production in India

2.1 Regional Production

- **Central Zone** – Encompassing Gujarat, Maharashtra, and Madhya Pradesh, this region leads national output. Gujarat alone contributed **9.49 million bales in 2022–23**, about 70 percent of which came from the Saurashtra area. Within the state, **Amreli district** stands out as the top producer. Maharashtra's key cotton belt is Vidarbha, including districts such as **Yavatmal, Buldhana, Akola, Amravati, Nagpur, Washim, and Wardha**.
- **Southern Zone** – Including Telangana, Andhra Pradesh, Karnataka, and Tamil Nadu, this region accounts for roughly **28.5 percent of India's total cotton**

production. Telangana is the largest producer in the south and ranks third nationally, with an output of about **5.31 million bales**.

The **cotton textile industry** remains India's **second-largest employer after agriculture**, directly supporting around **6.5 million farmers** and anchoring a significant export sector.

2.2 States in India where Cotton is Grown

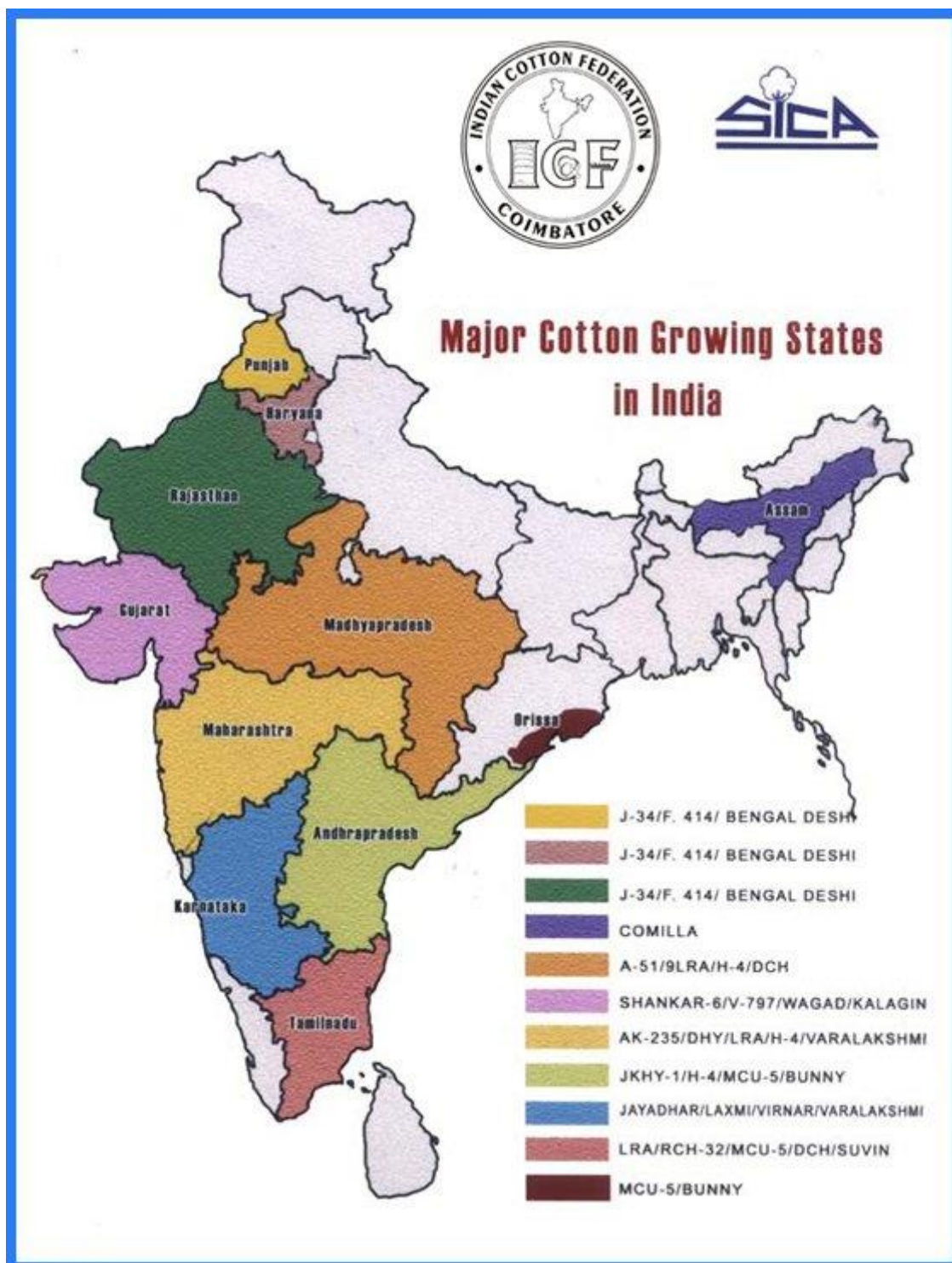


Figure 2: Major Cotton Growing States in India²

This map of India highlights the major cotton-growing states and the main cotton varieties grown in each state. States such as Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu, Odisha and Assam are shown in different colours. A legend at the bottom links each colour to specific cotton varieties like J-34, Bengal Deshi, Shankar-6, MCU-5/Bunny, Suvin and others, indicating the dominant type of cotton cultivated in each region.

3. Indian Agriculture Sector Findings^{3 4}

3.1 Growth and Economic Contribution

Agriculture continues to be a critical pillar of India's economy. It employs around **55% of the country's workforce** and contributed about **18.3% to GDP in 2022–23**. Over the last few years, the sector has maintained a **steady growth rate of ~5% annually (FY17–FY23)** driven by policy support, infrastructure investments, and increasing adoption of modern technologies. Record food grain production is a key highlight, **kharif grains at 1,663.91 LMT** and **rabi grains at 1,645.27 LMT** for 2024–25, with **kharif rice alone reaching 1,206.79 LMT**, a significant increase from the previous year. India also holds top global positions in milk, sugar, eggs, aquaculture, and horticulture, with agri and processed food exports rising to **US\$50.47 billion in FY23**.

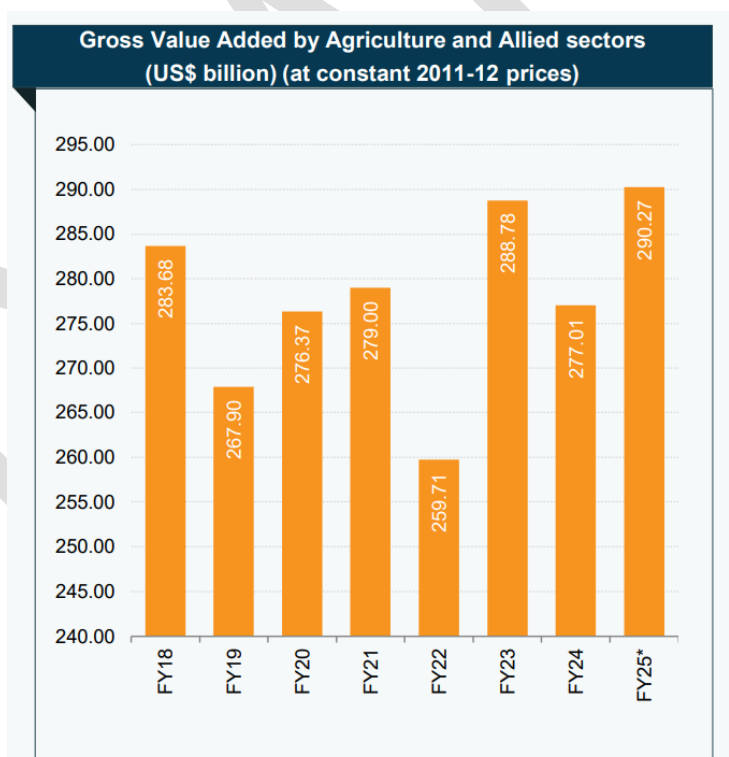


Figure 3: Gross Value Added by Agriculture and Allied Sectors

3.2 Structural Shifts and Diversification

The sector is undergoing a transition from traditional cereal-centric farming toward **horticulture, dairy, poultry, fisheries, and high-value crops**. Government programs

(refer section 3: Policy Frameworks in India) such as **Pradhan Mantri Krishi Sinchai Yojana (PMKSY)** for irrigation, **PM Fasal Bima Yojana (PMFBY)** for crop insurance, **PM-Kisan** income support, and the **push for 'Shree Anna' (millets)** are driving this change. Digital tools and platforms like **e-NAM**, **drone-based monitoring**, and precision agriculture solutions are improving market access, productivity, and efficiency. This shift is creating new income opportunities for farmers and supporting climate-resilient agriculture.

3.3 Investments, Infrastructure, and Global Integration

Investment flows into agriculture have accelerated sharply. Agriculture credit reached **Rs. 19.28 lakh crore (US\$224.6 billion)** by December 2024, while foreign direct investment in agri-services stood at **US\$3.11 billion**. The government is implementing large-scale storage and processing initiatives, such as the world's **largest cooperative grain storage plan**, mega food parks, and modern cold chains, to reduce post-harvest losses and strengthen value chains. India's export base is also widening, with major buyers for rice, meat, fruits, and processed foods across Asia, Europe, and the Middle East. Together, these measures are positioning India as a **key global agricultural hub**, while enhancing farmer incomes and promoting sustainability.

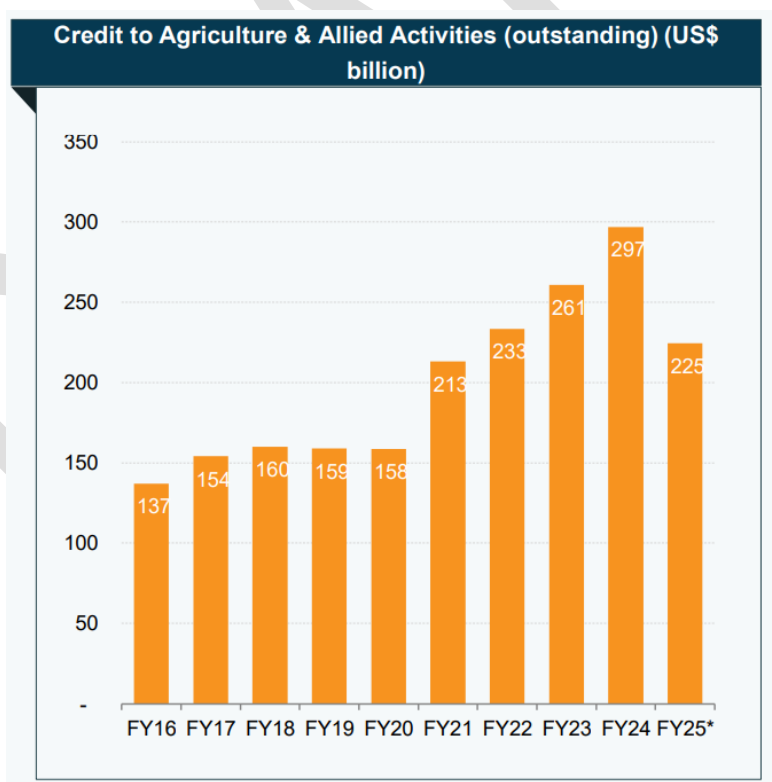


Figure 4: Credit to Agriculture and Allied Activities

4. Policy Frameworks in India^{5 6}

India has steadily built a multi-layered policy environment to make agriculture and carbon removal projects more sustainable, climate-resilient, and market-linked:

4.1 Sustainable Agriculture & Farmer Support

- **PM-Kisan Samman Nidhi (PM-KISAN):** Direct income support to smallholders.
- **PM Fasal Bima Yojana (PMFBY):** Comprehensive crop insurance with low farmer premiums.
- **Pradhan Mantri Krishi Sinchai Yojana (PMKSY):** Expands irrigation and promotes “More Crop per Drop.”
- **Pradhan Mantri Kisan Maan-Dhan Yojana (PMKMY):** Minimum pension for small/marginal farmers.
- **Paramparagat Krishi Vikas Yojana (PKVY):** Cluster-based organic farming to enhance soil carbon.
- **Soil Health Card Scheme:** Science-based nutrient management and fertility improvement.

4.2 Climate-Resilient & Diversified Agriculture

- **National Mission on Sustainable Agriculture (NMSA):** Supports climate-resilient practices and soil health management.
- **National Innovations on Climate Resilient Agriculture (NICRA):** Pilots adaptation technologies.
- **Promotion of ‘Shree Anna’ (millets):** Aligns nutrition security with low-carbon cropping.

4.3 Forestry, Bioenergy & Carbon Markets

- **National Agroforestry Policy (2014):** Integrates trees on farms, aiding afforestation and carbon credit generation.
- **National Afforestation Programme & Green India Mission:** Large-scale re/afforestation with verifiable carbon credits.
- **National Policy on Biofuels (2018):** Supports biomass/bioenergy, complementing biochar initiatives.
- **Indian Carbon Market (ICM):** Now includes removal technologies like biochar and afforestation.

4.4 Market Access & Infrastructure

- **Agriculture Infrastructure Fund (AIF):** Concessional financing for post-harvest infrastructure
- **National Agriculture Market (e-NAM):** Pan-India electronic trading and price discovery

- **Krishi UDAN 2.0:** Subsidised air transport for agri-produce, especially from remote areas
- **Pradhan Mantri Annadata Aay Sanrakshan Abhiyan (PM-AASHA):** Umbrella MSP support

4.5 Innovation & Digital Agriculture

- **Digital Agriculture Mission 2021-25:** Promotes AI, blockchain, drones, and remote sensing
- **Sub-Mission on Agricultural Mechanisation (SMAM):** Supports Custom Hiring Centres for equipment access.

These layered policies together create a supportive environment for carbon-removal and sustainable farming initiatives.

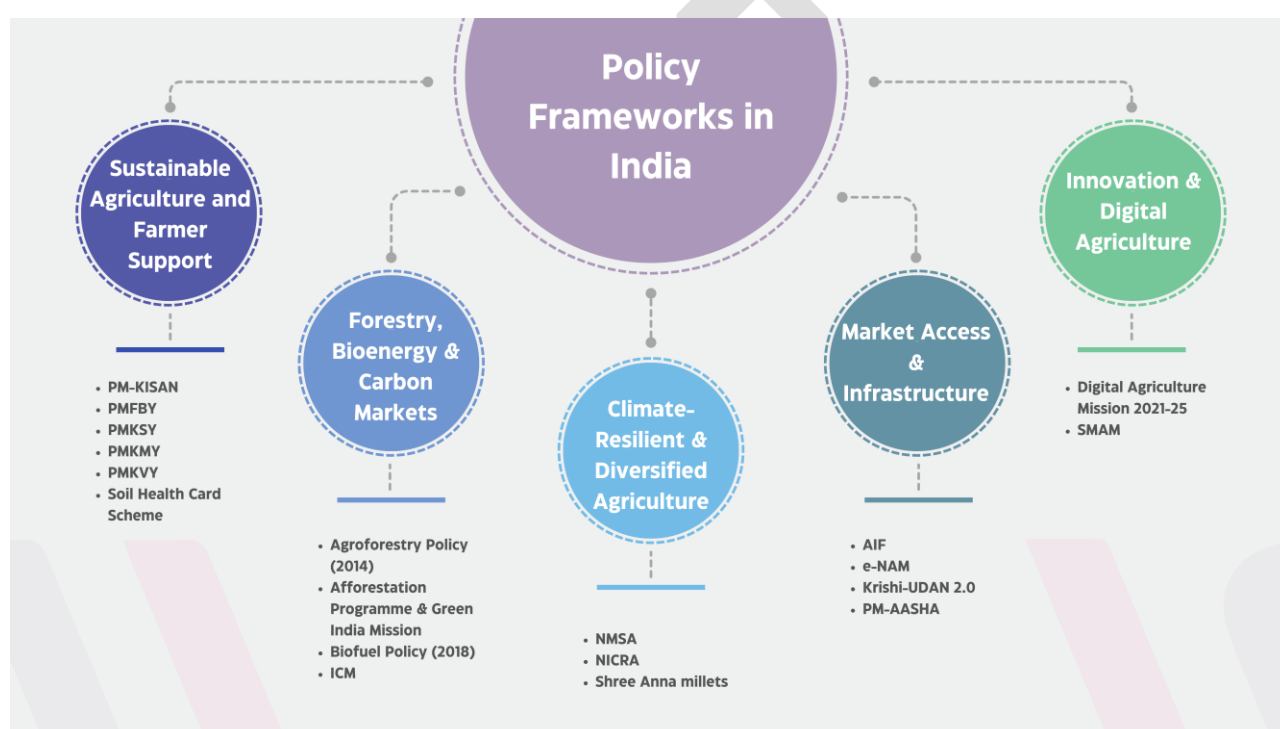


Figure 5: Policy Frameworks in India

India's layered agricultural and climate policies create a solid base for the next step: **actively removing carbon from the atmosphere**. The subsidies, digital tools, and infrastructure described earlier strengthen climate-smart farming, but these primarily reduce or avoid new emissions. Achieving true net-zero requires lowering the existing stock of atmospheric CO₂, a challenge that calls for **carbon-dioxide-**

5. Carbon Dioxide Removals

5.1 About Carbon Dioxide Removals⁷

5.1.1 What are Carbon Dioxide Removals (CDR)?

Carbon dioxide removals (CDR) encompass a range of **technologies, land management practices, and industrial processes that physically draw CO₂ out of the atmosphere and store it for decades to millennia**. Unlike conventional mitigation, which focuses on reducing new greenhouse-gas emissions, CDR targets the **existing stock of atmospheric carbon**, a critical step toward achieving net-zero and, ultimately, net-negative emissions.

There are three primary principles that must be followed when defining whether a method falls under the definition of CDR:⁸

- **Real removal:** measurable transfer of CO₂ **directly** from the atmosphere into a stable reservoir (soils, biomass, rock, or geological formations).
- **Long-term Storage:** CO₂ must be **stored durably** after it has been captured, either in reservoirs such as vegetation, soils, geological formations, or the ocean, or in manufactured products. The CO₂ captured and stored may not be reintroduced to the atmosphere.
- **Additionality:** CDR only constitutes the removal and storage of CO₂, which occurs **through human intervention**, and not the removal of CO₂ via natural means such as natural forestry regrowth.

For India's **cotton and organic cotton industry**, these principles open a direct pathway to both climate impact and **new revenue streams**. Practices such as regenerative soil management, on-farm biochar production, and enhanced rock weathering can be embedded in cotton cultivation to sequester carbon while improving

soil fertility and yields. The resulting high-integrity carbon credits can be sold into voluntary markets often at premium prices, allowing farmers and supply-chain partners to pair **climate-positive fibre production** with verifiable CDR, strengthening India's leadership in sustainable textiles.

5.1.2 Traditional Carbon Offsetting and CDR

Market-Based Measures (MBMs) play a central role in enabling the deployment of carbon abatement strategies, including Carbon Dioxide Removal (CDR). The most common instruments used in MBMs are carbon credits, which can serve both voluntary commitments and regulatory compliance. A carbon credit represents a tradable certificate that corresponds to a verified activity outside an organization's own value chain that avoids, reduces, or removes greenhouse gas emissions. Buyers can purchase these certificates to offset their residual emissions. Because the reduction or removal typically occurs beyond the direct operations of the buyer, they are often described as out-of-sector measures.⁹

Currently, most credits issued in voluntary and compliance markets fall under the category of traditional offsets. These offsets are based on reducing or avoiding emissions rather than physically removing CO₂ from the atmosphere. CDR also falls under the broader umbrella of carbon credits, but the way it functions in practice differs significantly from traditional offsets. This distinction has important implications for how credits are valued and traded, with CDR credits often commanding a higher price.

Traditional offsets generally involve activities that prevent additional emissions from being released. Common examples include building renewable energy projects to replace fossil fuel use, improving industrial energy efficiency, or protecting forests at risk of deforestation. These projects are measured against a **baseline scenario**¹⁰, i.e., a projection of emissions that would have occurred if the project had not been implemented. The difference between the baseline emissions and the actual emissions after the project generates the offset credits, with each credit typically equivalent to one metric tonne of avoided or reduced CO₂.

By contrast, a CDR credit represents one tonne of CO₂ that has been physically captured from the atmosphere and securely stored, often for centuries¹¹. This makes CDR credits technically distinct from avoidance or reduction offsets. The critical difference lies in outcomes: traditional offsets prevent future emissions, while CDR reduces the existing concentration of CO₂ molecules in the atmosphere.

This distinction highlights why CDR is indispensable in climate strategies. While offsets help slow the growth of emissions, they do not create a net reduction. CDR, on the other hand, lowers the overall stock of CO₂ in the atmosphere, addressing both new and historical emissions. In the short term, CDR can help neutralize residual emissions even before net zero is achieved. In the longer term, it becomes essential for offsetting legacy emissions, ensuring that global concentrations of CO₂ are reduced. Because the CDR market is still developing, urgent action is needed to expand its capacity in order to meet the scale of demand expected by 2050.

5.1.3 Importance of Scale-Up

The Intergovernmental Panel on Climate Change (IPCC) has emphasized that achieving global net zero emissions across all sectors will require CDR at gigatonne scale.¹²

Accelerating the scale-up of CDR technologies is therefore critical. Each CDR pathway, whether biochar, regenerative agriculture, or enhanced weathering, offers unique advantages in terms of **Technological Readiness Level (TRL)**¹³ cost, and co-benefits, but also carries distinct risks¹⁴. Early action is essential: the sooner new technologies are piloted and deployed, the faster their costs can come down, first-of-a-kind (FOAK) challenges can be resolved, and commercial-scale adoption can take place. Without immediate investment and rapid scaling, the required CDR capacity will not be available in time to meet global climate goals.

5.1.4 CDR Credits

CDR credits are issued from projects that remove carbon dioxide from the atmosphere and store it securely. These credits can be traded in two types of carbon markets: the **voluntary carbon market (VCM)** and the **compliance carbon market (CCM)**. At present, most CDR credits are transacted in the VCM, where companies and individuals voluntarily purchase credits to offset their emissions. The type and quality of credits differ across CDR approaches, both established and emerging, and are also distinguished by the permanence of carbon storage they achieve. This section outlines how CDR credits are generated, their defining characteristics, and the regulatory and voluntary frameworks that guide their use.

5.1.5 Generation of CDR Credits

Before carbon removal activities can be turned into marketable CDR credits, projects must go through several steps (*refer* Figure 6). A credible methodology must first exist to ensure that the project's activities deliver measurable and verifiable removals. Once a methodology is in place, projects are validated against its requirements and later verified to confirm the actual removals achieved.

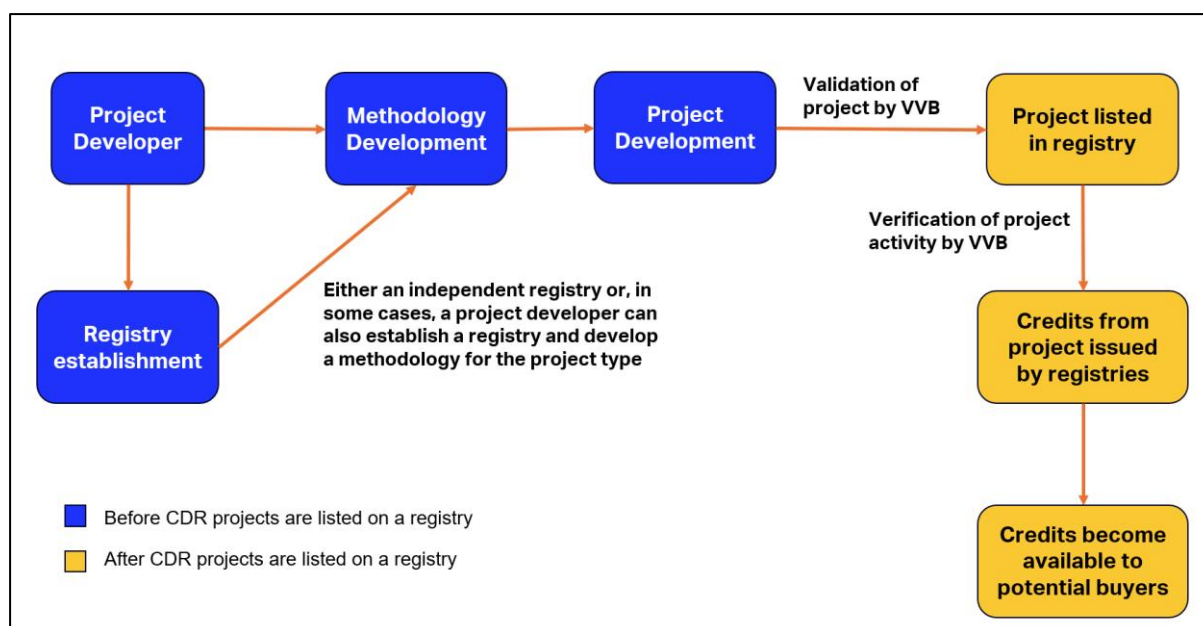


Figure 6: Process of generating CDR credits

Methodology Development

Clear and robust methodologies are fundamental to ensuring the credibility of the CDR market. These methodologies vary across different removal technologies and are typically developed by independent registries, though some project developers may establish their own frameworks to limit conflicts of interest. Projects can be small-scale community initiatives or large commercial operations.

Validation

Project developers submit an application to a registry, demonstrating compliance with the relevant methodology. An independent validation and verification body (VVB) reviews the project documentation, such as project design documents and ownership records, while the registry may also open a public consultation phase. If successful, the registry approves the project and lists it officially.

Verification

Once a project has been validated, the actual removals it achieves must be verified before credits are issued. Project operators prepare verification reports that detail and quantify the CO₂ removed, which are then independently reviewed by a VVB. Following approval, the registry issues credits and records them in its system. Verification usually occurs at regular intervals and must always follow validation. Both steps may occur together at the project outset, but verification cannot precede validation¹⁵.

5.1.6 Characteristics of CDR Credits

CDR credits are derived from diverse methods of removing CO₂, ranging from direct air capture technologies to biological sequestration approaches such as biomass growth or ocean-based enhancement. Before issuance, credits are assessed for factors such as **additionality**, **social and environmental impacts**, and most

importantly, **durability of CO₂ storage** as it distinguishes CD from traditional offset credits¹⁶.

Durability of CO₂ Storage¹⁷

Durability, or permanence, refers to how long carbon can remain securely stored and whether there is a risk of reversal¹⁸. Different technologies vary significantly in their permanence. Geological storage can lock carbon away for tens of thousands of years, while biological or soil-based approaches may last decades to centuries. Registries calculate credits based on the net CO₂ removed across the project lifecycle, adjusting for potential reversal risks. If carbon is re-emitted, registries are expected to adjust credit issuance accordingly, with liability typically falling on the project owner, registry, or an insurer, not the buyer.

5.1.7 Regulatory Framework and Voluntary Use

CDR credits are relevant in both **compliance schemes** and **voluntary markets**.

Regulatory Applications:

- **CORSIA (International Aviation):** The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is the first global MBM applied to a sector. Since 2019, it has required airlines in participating states emitting over 10,000 tonnes of CO₂ annually to report emissions, with the target of keeping them below **85%** of 2019 levels. CDR credits can be used to meet these obligations as out-of-sector offsets¹⁹. However, as of mid-2025, only two registries have approved CDR methodologies for CORSIA's first phase²⁰, and both CDR and traditional offsets are currently treated the same.
- **United Kingdom:** In 2024, the UK proposed integrating CDR into its Emissions Trading System (ETS). This would allow removals to contribute to compliance obligations under the UK cap-and-trade system²¹.
- **European Union:** The EU ETS does not yet incorporate CDR, but by 2026 the European Commission is expected to recommend pathways for including durable removals.²² The EU has already introduced the **Carbon Removal and Carbon Farming Certification (CRCF)** framework for voluntary markets.
- **Japan:** Japan launched its GX-ETS in 2023, initially voluntary but with the potential to evolve into a compliance scheme. The system currently accepts CDR credits from **Direct Air Capture and Storage (DACCS)**, **Bioenergy with Carbon Capture and Storage (BECCS)**, and coastal blue carbon projects that meet approved international standards.²³

5.1.8 Voluntary Actions

Most CDR credits today are purchased voluntarily, often by organizations aiming to meet internal climate commitments or align with initiatives such as the **Science-Based Targets initiative (SBTi)**. Voluntary demand signals are crucial for building confidence in the market and encouraging investment²⁴. However, stronger policy clarity and incentives will be needed to expand voluntary purchases into a mature, large-scale market.

5.2 Status of the CDR Market

Although still in its early stages, the carbon dioxide removal (CDR) market is clearly expanding, as shown by rising purchase volumes and deliveries of credits. Broadly, the market can be split into two segments: **conventional CDR** and **novel CDR**.

- **Conventional CDR** covers long-established practices with widespread commercial use, such as afforestation/reforestation (AR) and soil carbon sequestration (SCS). These methods have traditionally been in steady demand at relatively low prices.
- **Novel CDR**, by contrast, refers to emerging technologies still in the development or pilot phase such as Direct Air Carbon Capture and Storage (DACCS), Bioenergy with Carbon Capture and Storage (BECCS), and Enhanced Rock Weathering (ERW).²⁵ These approaches remain costlier and have fewer credits available on the market today.

The sections below highlight the present situation of mainly novel CDR pathways, which hold the greatest potential for scale-up but need stronger support from stakeholders.

5.2.1 Demand and Supply

Most current demand for CDR credits is from the voluntary carbon market (VCM). In 2023, buyers purchased about 20 Mt of conventional CDR credits versus just 5 Mt of novel CDR ²⁶credits. Yet interest in novel CDR is accelerating purchases almost doubled from 4.6 Mt of CO₂ in 2023 to nearly 8 Mt in 2024²⁷.

BECCS accounted for the largest share, mainly because of a single major purchase but also due to its comparatively lower prices and more diverse credit supply. DACCS purchases are primarily structured as offtake or pre-purchase agreements. By contrast, biochar credits tend to be bought on the spot market because a sizable pool of issued credits is already available after sequestration has occurred²⁸.

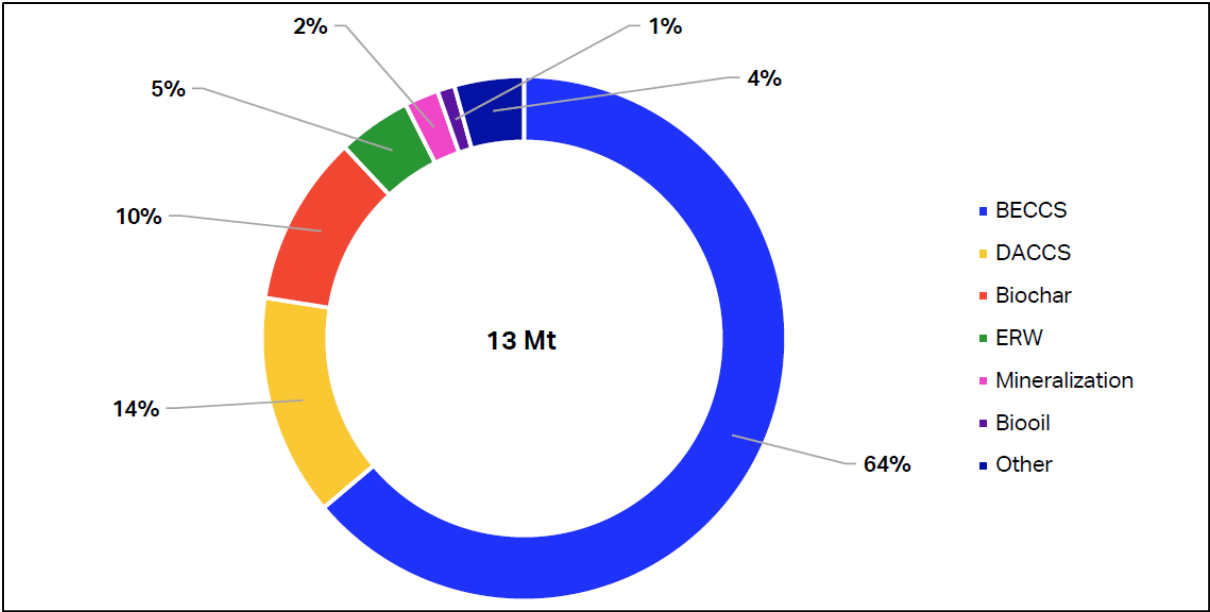


Figure 7: Purchases of novel CDR credits (tonnes of CO2) by technology since 2023 and 2024^{29 30 31 32 33 34}

5.2.2 Deliveries

Deliveries show how many credits are reaching the buyers. For most novel CDR types, near-term delivery volumes remain low because projects are still under development and credits are sold through long-term agreements. Even so, deliveries of novel CDR credits climbed from 145 kt in 2023³⁵ to 319 kt in 2024.

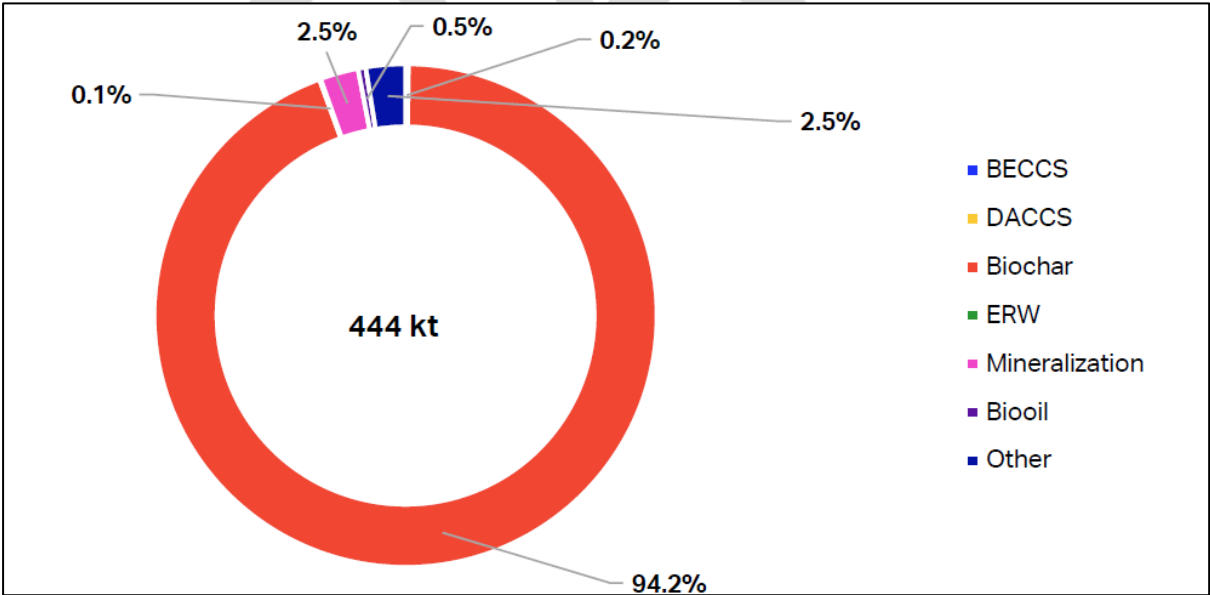


Figure 8: Deliveries of Novel CDR credits (tonnes of CO2) by Technology in 2023 and 2024^{36 37 38 39 40 41}

Biochar dominates actual deliveries because it is a more commercially mature method, allowing suppliers to fulfil same-year orders. Conversely, BECCS and DACCS have high purchase volumes but very low near-term deliveries, only about 301 t of DACCS credits have been delivered since 2023, with none yet for BECCS. Many buyers of

these technologies will purchase CDR credits, with an expected delivery date beyond the current year, even as far away as 2035.⁴²

5.2.3 Pricing Trends

Prices for CDR credits are generally higher than for traditional offsets. Even conventional CDR averaged USD 12–16/tCO₂ in 2023, roughly triple the price of a typical offset credit in the same year.⁴³ Novel CDR prices ranged widely from USD 95 to USD 1,200/tCO₂ in 2024, depending on technology and contract type (spot, offtake, or pre-purchase)⁴⁴.

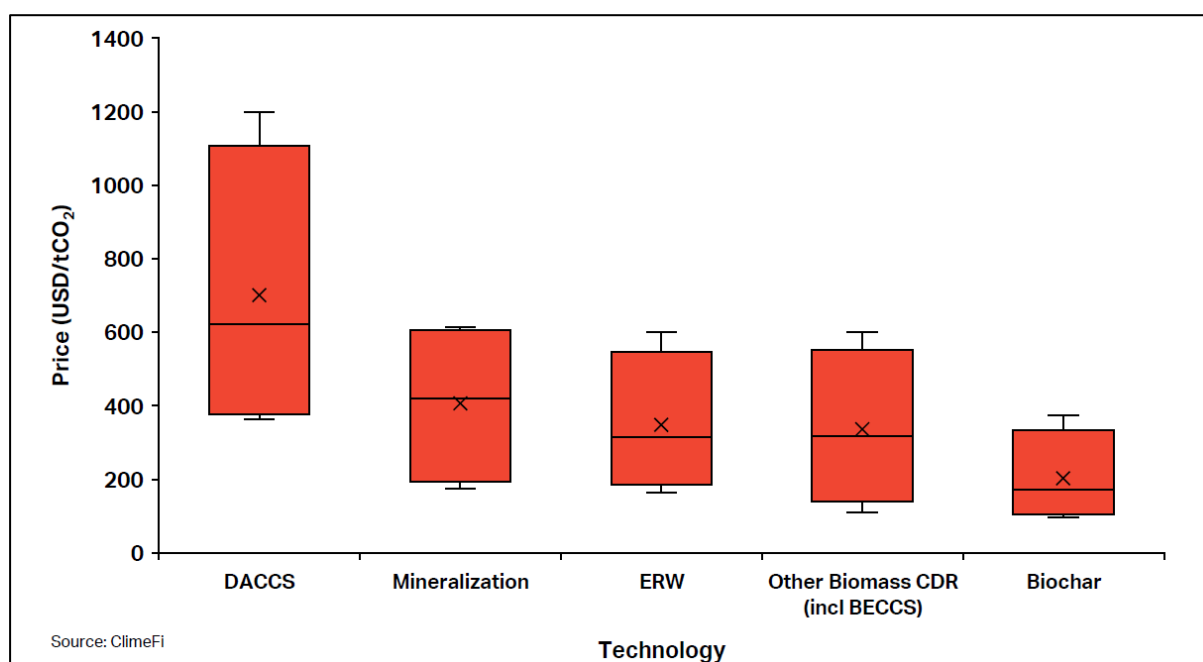


Figure 9: Estimated range of price per tonne of CO₂ removed by CDR Novel Technology in 2024⁴⁵

Biochar prices mainly reflect spot transactions thanks to abundant supply, while DACCS prices mirror long-term offtake agreements due to limited spot availability. Ocean-based CDR credits are still hard to price because of low commercialization and technological readiness, but early market data suggests an average of about USD 803/tCO₂⁴⁶.

Analysts such as the Boston Consulting Group estimate that average prices will need to fall below USD 200/tCO₂ to spur large-scale demand from high-emission industries⁴⁷. This will require substantial public funding in the early stages to reduce risk for private investors, followed by increased private capital as technologies mature and scale up⁴⁸. Pre-purchasing and offtake deals are critical for helping developers secure financing and de-risk projects until economies of scale drive costs down⁴⁹.

5.3 India's Carbon Removal Market – Current Status and Outlook⁵⁰

India's carbon-dioxide-removal (CDR) sector is moving beyond its traditional focus on avoidance projects such as renewable energy and into technologies that remove and

store CO₂. Analysts expect 2025 to bring more projects, larger volumes and a gradual increase in demand for high-durability credits.

5.3.1 Shift from Avoidance to Removals

Historically, almost all credits generated by Indian projects in the voluntary carbon market came from avoidance activities. That pattern is starting to change. Biochar projects dominate the emerging removal space, and enhanced rock weathering (ERW) and direct-air-capture (DAC) initiatives are now appearing, though at smaller scale. To date, Indian projects have retired about **267 million credits**, of which **~98% come from avoidance**. The remainder are removals, dominated by nature-based solutions. India's climate, large areas of farmland and abundant biomass feedstock give it an advantage for these pathways.

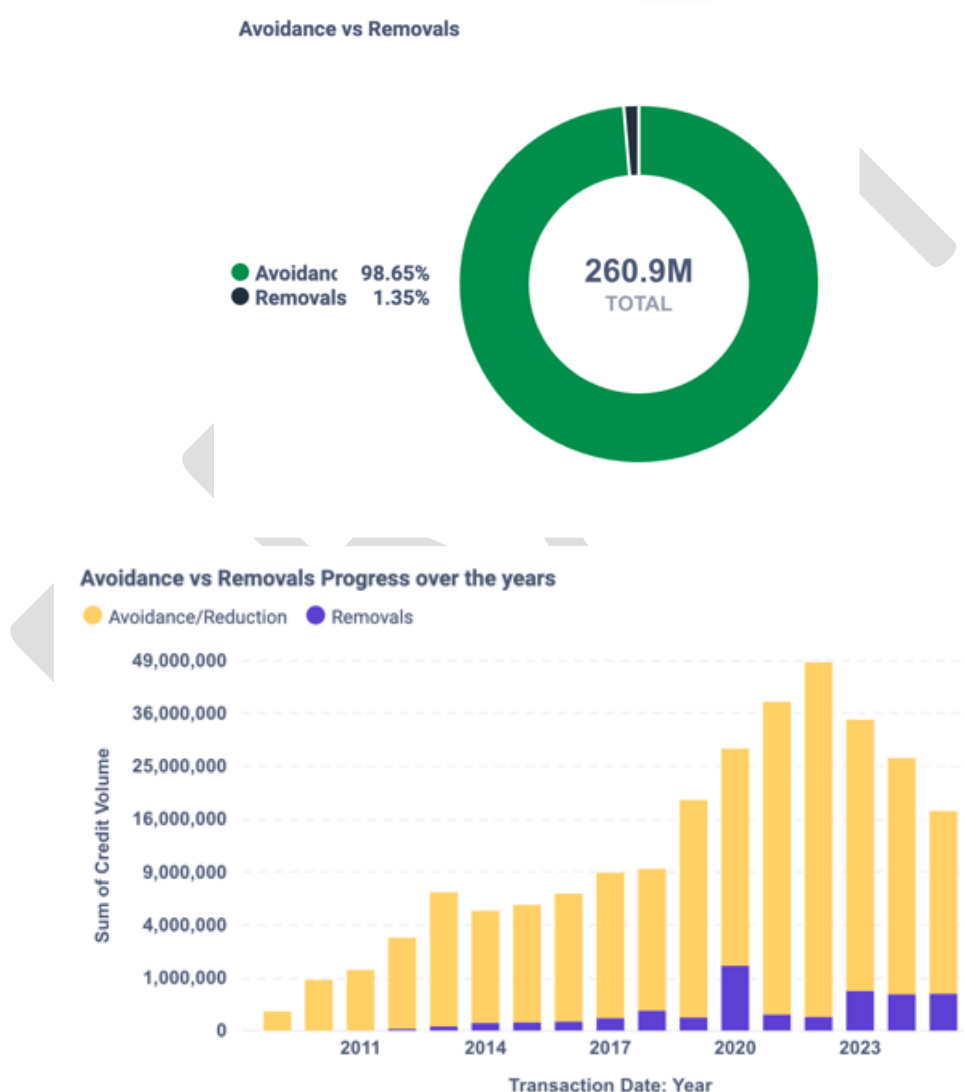


Figure 10: Avoidance vs removals in India's Carbon Market, Showing 98% Avoidance Dominance and Gradual Growth in Removals⁵¹

5.3.2 Project Pipelines and Supply Trends

As of mid-2025 there are roughly **49 CDR initiatives under development in India**, including about two-thirds technology-based projects and one-third nature-based efforts.

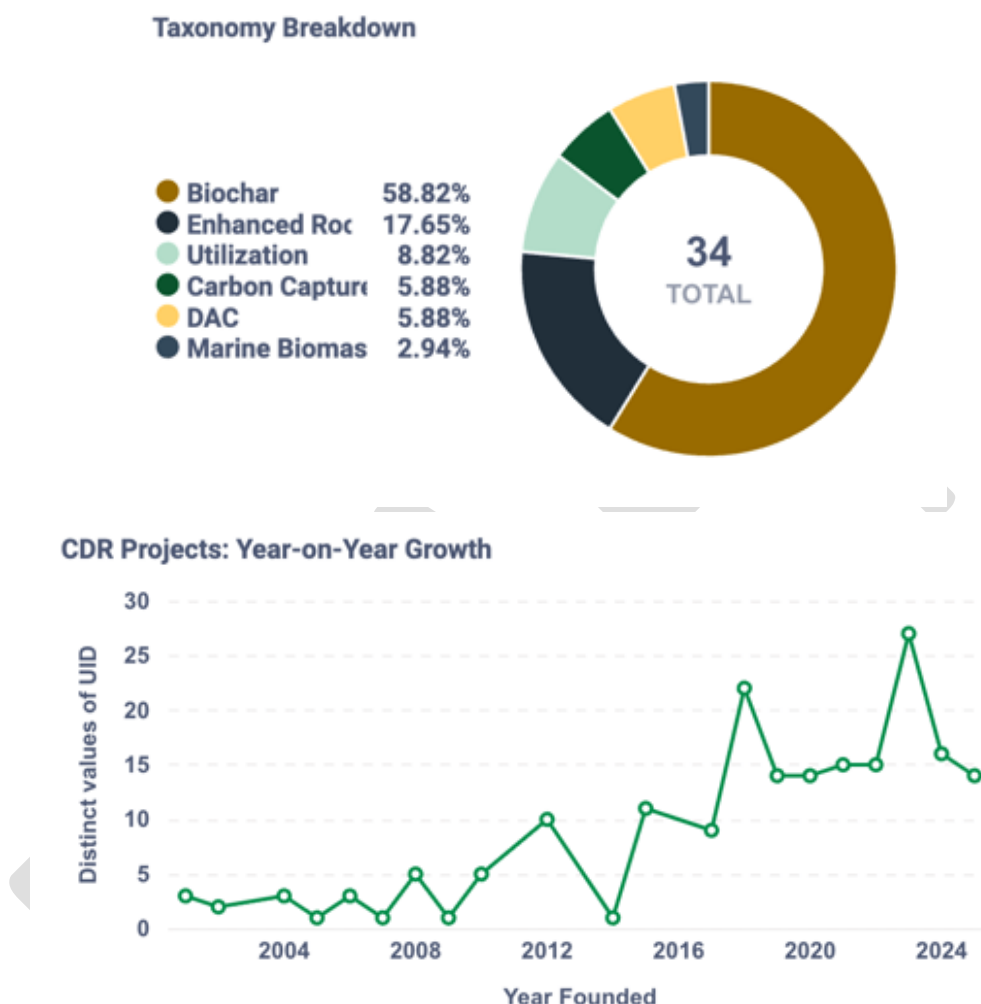


Figure 11: Growth and Composition of India's Carbon Removal Projects, Highlighting Biochar Dominance and Rising Activity Over Time⁵²

Verified issuances from tech-based projects have topped 200,000 credits, with offtake agreements approaching **114,000 credits**, mostly from biochar and ERW. The largest suppliers include Varaha, Carboneers, Mash Makes and Alt Carbon, with biochar accounting for around **95 %** of issued credits.

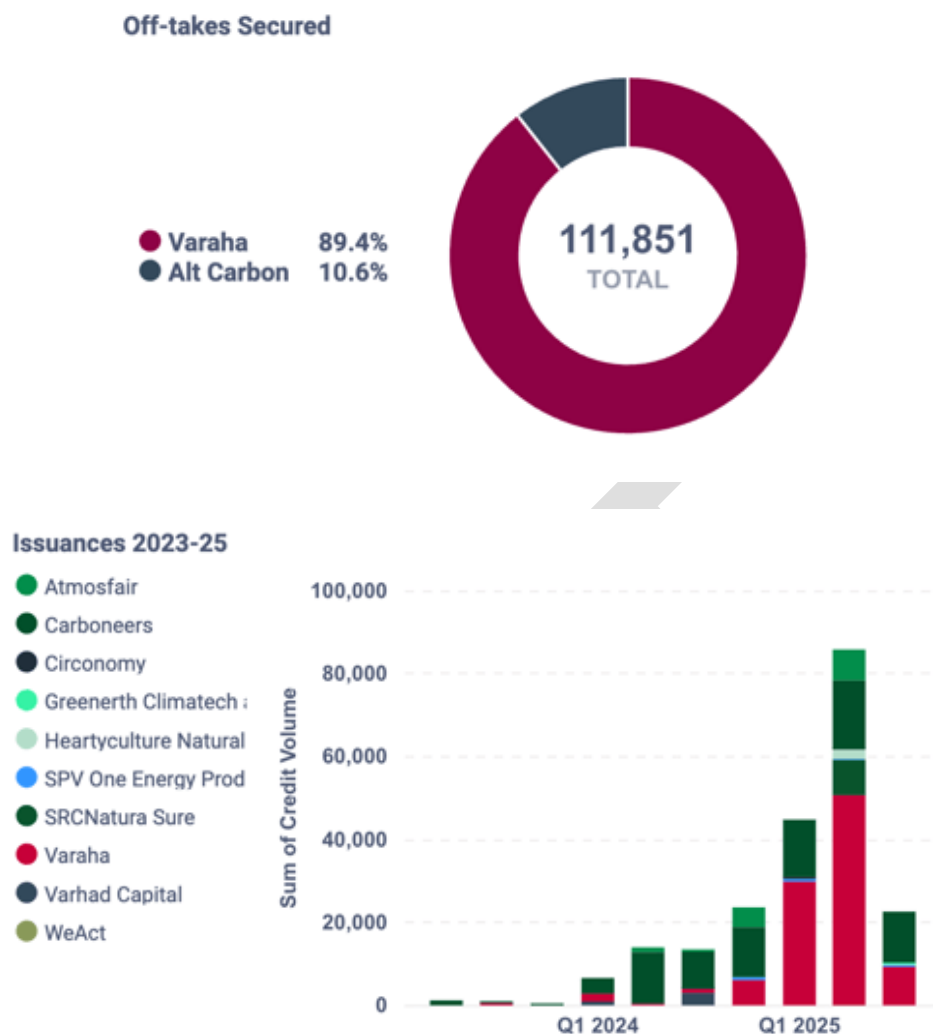


Figure 12: Offtakes and Issuances of Indian Carbon Removal Credits, led by Varaha and Alt Carbon with Rising Volumes Since 2023⁵³

5.3.3 Buyers – International vs Domestic

Foreign buyers dominate demand for Indian removal credits. Google's offtake agreement with Varaha is the most high-profile, followed by purchases from Mitsui O.S.K., Frontier and NextGen CDR.

On the domestic side, companies have mostly retired nature-based removal credits. Sterling and Wilson Solar and Delhi International Airport are among the top Indian retirees. Only one company, **Omega Healthcare** has so far purchased small quantities of technical CDR credits (from CarbonCure).

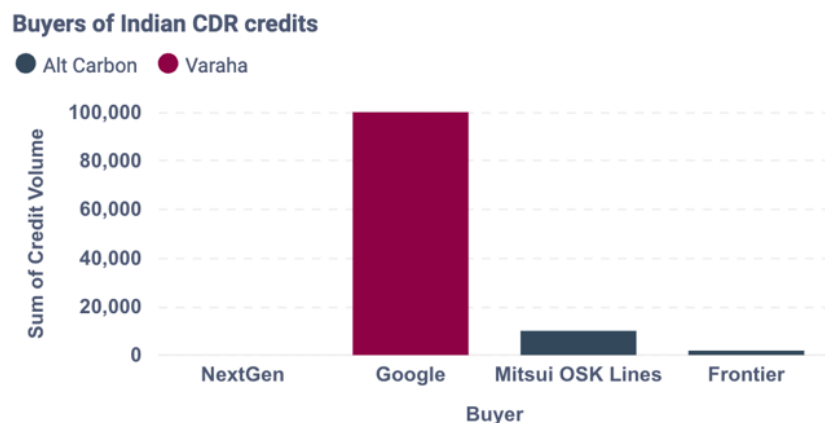


Figure 13: Buyers of Indian Carbon Removal Credits, led by Google with Additional Purchases from Mitsui OSK Lines, Frontier, and NextGen⁵⁴

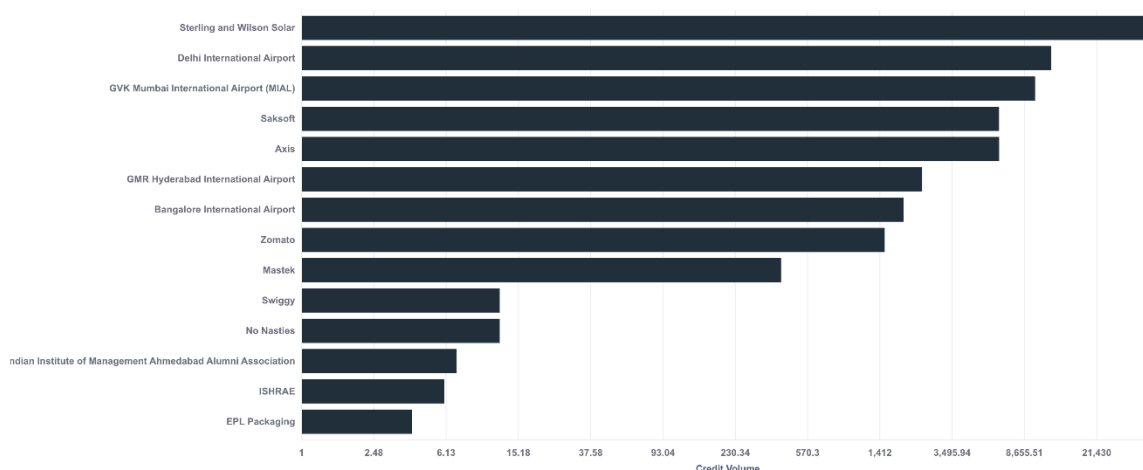


Figure 14: Indian Corporate Carbon Removal Retirements, led by Sterling and Wilson Solar, and Delhi International Airport⁵⁵

5.3.4 Outlook- Towards Durable Removals

Corporate awareness of sustainability is increasing, and the Indian government has identified **10 sectors for its planned domestic offset mechanism**, including biochar and afforestation. Although biochar currently dominates, ERW and direct air capture (DAC) are slowly gaining ground. Together, these developments signal a gradual move toward more **durable, technology-driven** removals in India.

The discussion of individual CDR technologies shows that India's agricultural landscape can do more than feed people like it can also serve as a durable carbon sink. Translating these scientific pathways into real-world impact now hinges on market mechanisms, financing models, and stakeholder collaboration. The next section moves from the "how" of removal to the "how to scale," examining the carbon removal technologies such as **Regenerative Agriculture, Biochar, and**

6. Regenerative Agriculture⁵⁶

Regenerative agriculture is an **outcome-oriented** production system designed to:

- Rebuild soil structure and organic matter
- Capture and store carbon in the ground
- Protect water quality and conserve scarce resources
- Strengthen farm profitability and climate resilience

It is not a single prescription, but a toolkit of practices adapted to each farm's conditions and ecosystem.

6.1 Guiding Principles and Core Practices

6.1.1 *Minimize Soil Disturbance*

- Techniques: no-till or low-till planting
- Benefits: prevents erosion, maintains soil carbon, and improves water retention

6.1.2 *Keep the Soil Covered Year-Round*

- Techniques: cover crops, double cropping, perennial plantings
- Benefits: shields soil from heat, adds organic matter, and supports moisture balance

6.1.3 *Diversify Crops in Time and Space*

- Techniques: crop rotation, intercropping, relay planting, agroforestry belts
- Benefits: reduces pests, replenishes nutrients, and nurtures a richer soil microbiome

6.1.4 *Optimize and Reduce Chemical Inputs*

- Techniques: precision agriculture, soil sensors, targeted nutrient management, biological alternatives
- Benefits: lowers fertilizer and pesticide use while sustaining yields

6.1.5 *Integrate Livestock Where Feasible*

- Techniques: managed grazing of cover crops or crop residues

- Benefits: recycles nutrients, improves soil fertility, and enhances pasture health

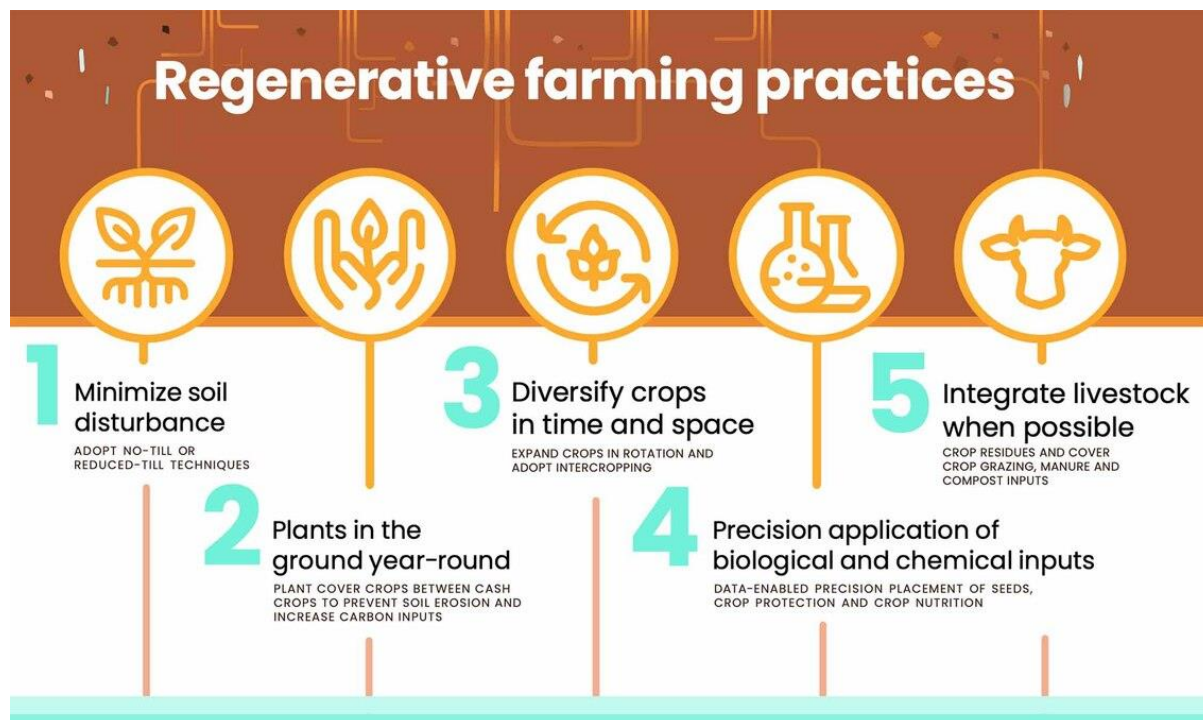


Figure 15: Regenerative Agriculture Practices

6.2 Environmental and Social Benefits

6.2.1 Climate Action

Healthy soils act as powerful carbon sinks. Widespread adoption of regenerative methods could sequester hundreds of millions of tons of carbon dioxide annually, offsetting a significant share of global emissions.

6.2.2 Biodiversity Gains

Below ground, microbes, fungi, and invertebrates flourish when soils are undisturbed. Above ground, field borders, hedgerows, and diverse rotations create habitat for pollinators, birds, and beneficial insects.

6.2.3 Water Security

Improved soil structure increases infiltration and water-holding capacity, helping crops survive drought and reducing runoff during heavy rains.

6.2.4 Farmer Livelihoods

Over time, farmers often see lower input costs, higher resilience to extreme weather, and access to premium markets for sustainably produced crops.

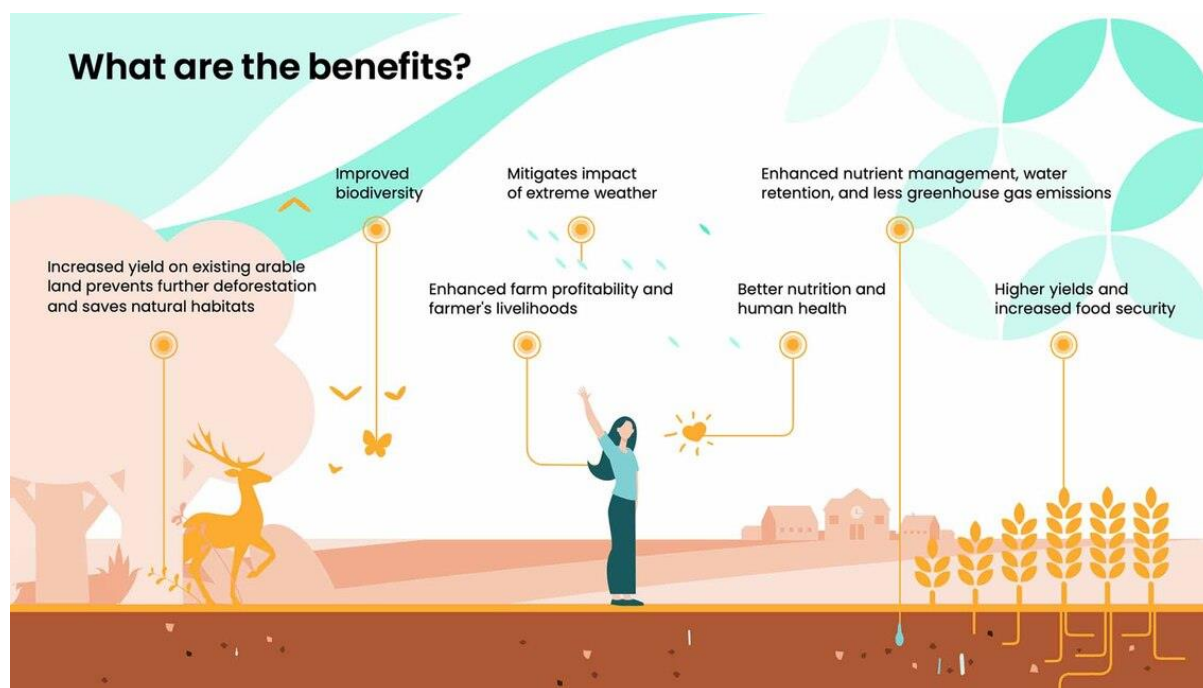


Figure 16: Benefits of Regenerative Agriculture

6.3 Role of Technology and Innovation

Digital tools such as satellite mapping, soil-health sensors, and AI-driven decision platforms allow farmers to apply fertilizers or crop-protection products precisely where needed.

Advances in drought-tolerant seeds, bio-fertilizers, and biological pest controls further reduce reliance on synthetic inputs.

6.4 Scaling Up and Financing the Transition

6.4.1 Public Policy

Governments can accelerate adoption by restructuring subsidies, offering carbon credits, and funding soil-health programs.

6.4.2 Private Sector and Food Companies

Major brands and agribusinesses are pledging to source raw materials from farms using regenerative practices, creating new markets and premium pricing for growers.

6.4.3 NGOs and Farmer Networks

Non-profits provide training, cost-sharing grants, and connections to global climate funds, lowering the financial barriers for smallholders.

6.5 Global Examples and Partnerships

Collaborations between technology firms, food processors, and farmer cooperatives demonstrate that regenerative systems can succeed at scale from maize intercropping in East Africa to large-scale no-till operations in North America. **PepsiCo**, the second largest, committed to regenerative practices across 7 million acres by 2030. Other

companies with regenerative agriculture commitments include **Cargill**, **General Mills**, **McCain** and **Walmart**.

6.6 Outlook

Regenerative agriculture is not a quick fix but a long-term strategy for transforming food systems.

By blending time-tested indigenous knowledge with modern science, it offers a credible path to restore ecosystems, secure food supplies for a growing population, and turn agriculture into a **net solution** to climate change.

7. Biochar

7.1 What is Biochar?

Biochar is a carbon-rich, charcoal-like material produced when biomass, such as crop residues, wood chips, or manure, is heated in a low-oxygen environment (**pyrolysis**). Unlike open burning, which quickly returns plant carbon to the atmosphere, pyrolysis transforms biomass into a stable form of black carbon that can persist in soils for hundreds to thousands of years, effectively locking away CO₂.

7.2 Scientific Foundations

Carbon Sequestration

- **Mechanism:** Plant material captures CO₂ during growth. Pyrolysis converts that biomass into a solid matrix of aromatic carbon rings resistant to microbial decomposition, so the carbon remains stored long-term.
- **Permanence:** Modern standards require proof that >70–80 % of the carbon remains after 100 years. Hydrogen-to-carbon (H:C) ratios <0.7 (or <0.4 for the most conservative standards) are used as a proxy for long-term stability.
- **Global Potential:** Modelling studies estimate biochar could offset up to 6 % of annual global CO₂ emissions if produced and applied at scale.

Soil and Agronomic Effects

USDA-ARS research shows biochar improves⁵⁷:

- **Soil structure & water holding capacity**, increasing drought resilience.
- **Cation exchange capacity**, enhancing nutrient retention of N, P, and K.
- **Microbial diversity**, which supports long-term soil fertility.

Responses are site-specific: some trials show yield gains >2×⁵⁸, while others see neutral or negative effects if biochar quality or application rates are mismatched to soil type.

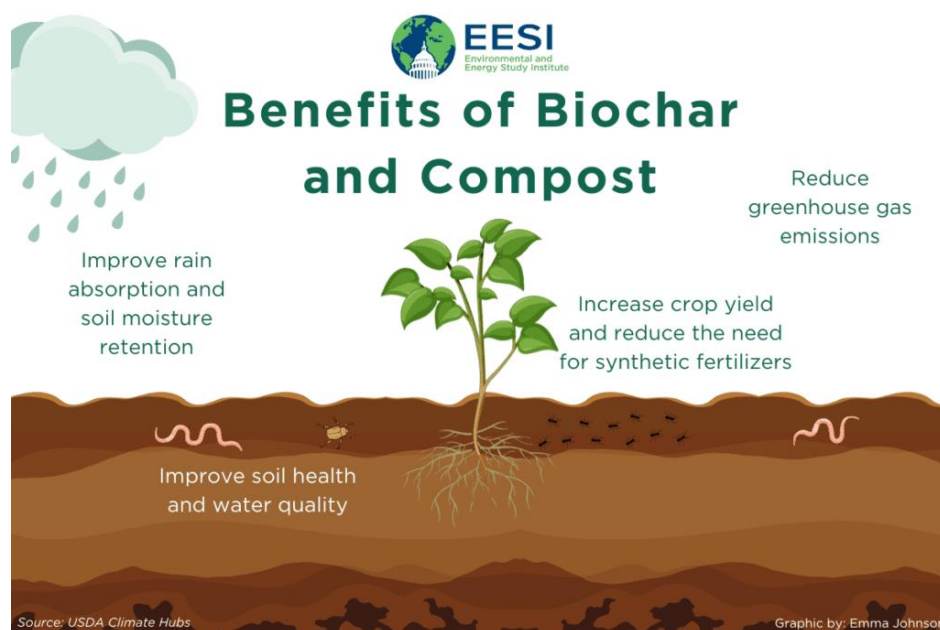


Figure 17: Benefits of Biochar and Compost

7.3 Feedstock and Technology Variability

- **Feedstock:** Carbon content can range from ~10 % (e.g., sewage sludge) to >80 % (wood at high pyrolysis temperature).
- **Production:** *Slow pyrolysis* favours higher char yield; *fast pyrolysis* produces more bio-oil and syngas. *Gasification* operates at higher temperatures, giving less char but more usable energy.
- **Cost:** Artisanal kilns can operate at minimal expense, while industrial pyrolysis plants may cost **USD 220–580 per tonne** of biochar produced.

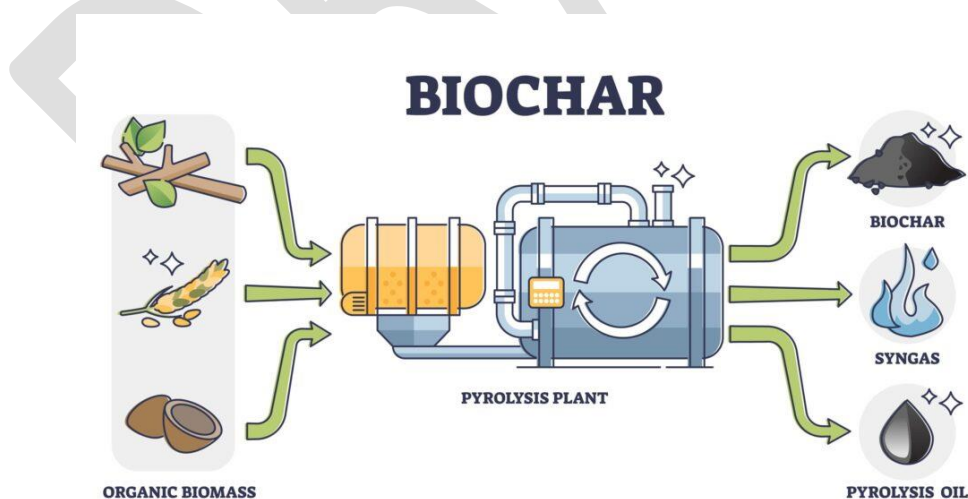


Figure 18: Biochar Production Technologies

7.4 Applications and Co-Benefits

- **Agriculture:** Enhances soil fertility, reduces need for fertilizers and irrigation, and can increase crop yields (e.g., cotton biomass and yield gains reported in Indian trials).
- **Waste Management:** Turns crop residues that might otherwise be burned, releasing methane and particulates into a valuable product.
- **Energy:** Co-products such as syngas and bio-oil can provide on-site renewable energy for self-sufficient operations.

7.5 Carbon Markets & Certification

Biochar is a leading technology on the voluntary carbon market, responsible for ~94 % of durable carbon removal credits issued in 2023.

Key certification pathways include:

Standard	Geographic Scope	Highlights
Puro Standard (Puro.earth)	Global	First widely adopted biochar crediting methodology; issues CO ₂ Removal Certificates (CORCs) after independent third-party audit and durability verification.
Verra VCS (VM0044)	Global	Covers both soil and non-soil biochar applications; requires detailed life-cycle GHG accounting and strict monitoring for permanence.
Isometric Biochar Methodology	Global	Digital-first platform that uses continuous data and automated MRV to quantify carbon removal; early-stage but gaining high-integrity buyer interest.
Carbon Standards International (CSI)	Global	Offers two tailored methodologies: Global Biochar C-Sink for industrial projects and Global Artisan C-Sink for smallholder/community scale.
Climate Action Reserve (CAR)	U.S. & Canada	Biochar Protocol designed for North American projects; emphasizes conservative carbon accounting and regional feedstock sustainability.
Riverse	Europe	Biochar and BECCS methodology suited to industrial-scale operations; aligned with EU regulatory requirements and voluntary carbon market demand.

All require:

- Full life-cycle analysis of emissions (CO_2 , CH_4 , N_2O).
- Proof of sustainable feedstock sourcing.
- Tracking and reporting of end-use to ensure >100-year carbon storage.

7.6 Example: Cotton Sector in India

India generates ~740 million tons of farm residue annually, a significant fraction of which is burned, releasing CO_2 and methane. Converting cotton stalks into biochar:

- **Avoids open-burn emissions.**
- **Improves degraded soils** suffering from over-fertilization and salinity.
- **Raises farmer income** through yield gains and potential carbon credit sales.

7.7 Limitations and Research Needs

- **Site-Specific Performance:** Outcomes depend on soil type, climate, and biochar properties.
- **Economic Viability:** Without carbon credit revenue, direct field application may be only marginally profitable.
- **Knowledge Gaps:** Long-term ecological effects and interactions with soil microbiomes are still being studied.

Biochar represents a scientifically validated, **high-durability carbon sink** that simultaneously enhances soil health and creates new revenue streams through the voluntary carbon market. Successful projects hinge on rigorous feedstock selection, controlled pyrolysis, and adherence to recognized certification standards to monetize the climate benefits.

8. Enhanced Rock Weathering (ERW)

8.1 What is ERW?

Enhanced Rock Weathering (ERW) speeds up a geological process, weathering, that normally removes about **1.1 gigatonnes of CO_2 per year**⁵⁹.

8.2 Natural Weathering Chemistry

- **Carbonic Acid Formation:** CO_2 in the air dissolves in rainwater, forming weak carbonic acid (H_2CO_3).
- **Silicate Reaction:** When this slightly acidic water contacts silicate rocks containing calcium or magnesium, a reaction converts CO_2 into dissolved bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions.
- **Long-Term Storage:** These ions wash into rivers and oceans, where they help counter ocean acidification and lock carbon away for thousands of years as solid carbonates or stable dissolved bicarbonate.

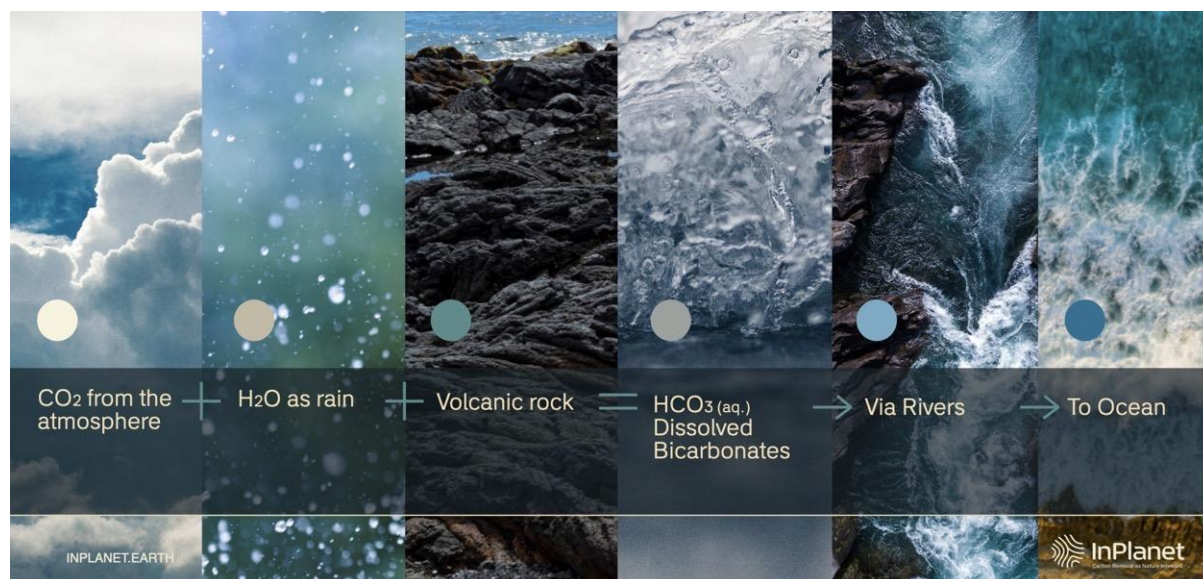


Figure 19: Carbon's Journey to the Sea

8.3 Acceleration Through ERW

InPlanet⁶⁰ and other developers **grind silicate rocks to a fine powder** and spread them on cropland.

The increased surface area, like how granulated sugar dissolves faster than a cube, **speeds the same reaction from millennia to years or decades**. Moist soils and warm, humid climates further enhance reaction rates.

8.4 Agricultural and Ecological Co-Benefits

- **Nutrient Release:** As minerals weather, they release calcium, magnesium, and trace elements, improving soil structure and fertility.
- **Water Retention:** Finer soil particles hold more moisture, increasing drought resilience.
- **Reduced Fertilizer Need:** Added base cations can buffer soil acidity and reduce reliance on synthetic inputs.

8.5 Verified Carbon Removal and Market Pathway

- **Puro.earth Methodology:** The first global carbon-credit standard for ERW defines how to measure, monitor, and verify the captured carbon.
- **CO₂ Removal Certificates (CORCs):** Projects that meet these criteria can issue tradable credits through the **Puro Registry**, giving companies a way to finance and claim durable, 1,000-year carbon removal.

8.6 Scalability and Permanence

- **Abundant Feedstock:** Silicate rocks and existing farmland are widely available; crushing and spreading use established mining and agricultural equipment.

- **Circular Resource Use:** Residual rock from quarries or industrial processes can be repurposed, turning waste into a carbon sink.
- **Stable Storage:** Once converted to bicarbonate or carbonate, the carbon remains sequestered for geologic timescales.

9. Carbon Market for Removal Activities

9.1 Standards and Methodologies

The following tables list the **leading international standards and methodologies** that currently allow projects to generate **verified carbon credits** from three priority carbon-dioxide-removal (CDR) approaches: **Regenerative Agriculture, Biochar, and Enhanced Rock Weathering (ERW)**.

Each standard sets out eligibility rules, monitoring and reporting requirements, and verification procedures to ensure that every tonne of CO₂ claimed is real, measurable, and durable. Including the links to the official methodology documents enables project developers, investors, and buyers to review the most up-to-date technical guidance.

9.1.1 Regenerative Agriculture

Frameworks such as Verra's VM0042 and the Gold Standard Soil Organic Carbon (SOC) methodology certify projects that increase soil-organic-carbon stocks through practices like cover cropping, reduced tillage, and improved nutrient management.

Standard/Methodology	Link
VERRA VM0042- Improved Agricultural Land Management (IALM)	https://verra.org/methodologies/vm0042-improved-agricultural-land-management-v2-1/
Gold Standard – Soil Organic Carbon Framework	https://globalgoals.goldstandard.org/documents/methodology/

9.1.2 Biochar

Methodologies from Verra (VM0044), Puro.earth, and Isometric define how to quantify and verify carbon sequestered when biomass is converted into stable biochar and applied to soils or other long-term storage sites.

Standard/Methodology	Link
Verra VM0044 – Biochar Utilization (Soil & Non-Soil)	https://verra.org/methodologies/vm0044-biochar-utilization-in-soil-and-non-soil-applications-v1-2/

Puro.earth – Biochar Methodology	https://7518557.fs1.hubspotusercontent-na1.net/hubfs/7518557/Puro%20Biochar%20Methodology%20-%20Edition%202025%20-%20Approved%20Version%20-%20Pending%20Copy%20Edit.pdf
Isometric – Biochar Production & Storage	https://registry.isometric.com/protocol/biochar/1.0

9.1.3 Enhanced Rock Weathering (ERW)

Methodologies from Puro.earth and Isometric outline how spreading finely ground silicate rock on farmland can accelerate natural chemical weathering, lock away CO₂ for millennia, and generate tradable removal credits.

Standard/Methodology	Link
Puro.earth – ERW Methodology	https://puro.earth/enhanced-rock-weathering#specialform
Isometric – ERW Methodology	https://registry.isometric.com/protocol/enhanced-weathering-agriculture/1.1/ctn_1JBF3A2JY1S0Z7MA

9.1.4 Summary Table

CDR Technology	Standard/Methodology
Regenerative Agriculture	VERRA VM0042- Improved Agricultural Land Management (IALM)
	Gold Standard – Soil Organic Carbon Framework
Biochar	Verra VM0044 – Biochar Utilization (Soil & Non-Soil)
	Puro.earth – Biochar Methodology
	Isometric – Biochar Production & Storage
ERW	Puro.earth – ERW Methodology
	Isometric – ERW Methodology

Together, these standards provide the **rules of the market** covering project design, measurement, reporting, and verification (MRV), that Indian developers and organic-

cotton growers will need to follow to access premium carbon-credit prices and diversify their farm income.

9.2 Comparative Analysis

The following three tables summarise the **main international standards and methodologies** that allow Indian projects to generate verified carbon credits from **Regenerative Agriculture, Biochar, and Enhanced Rock Weathering (ERW)**.

Each table sets out:

- **Eligibility & Key Criteria** – who can participate, and the practices or feedstocks allowed.
- **MRV & Timeline** – how monitoring, reporting, and verification (MRV) is performed and how often credits can be issued.
- **Indicative Costs** – typical development, monitoring, and issuance expenses.
- **Typical Buyers / Market** – the kinds of companies purchasing these credits.
- **Seller / Project Requirements** – the documentation and on-ground evidence needed to qualify.

9.2.1 Regenerative Agriculture

This table compares the **Verra VM0042** and **Gold Standard Soil Organic Carbon Framework**, the two most widely used methodologies for rewarding soil-carbon gains. It highlights that Verra emphasises rigorous baseline sampling and modelling, while Gold Standard places stronger requirements on stakeholder consultation and sustainable-practice criteria. Both require periodic soil re-sampling and long-term land-tenure proof.

REGENERATIVE AGRICULTURE

Standard/Methodology	Eligibility & Key Criteria	MRV & Timeline	Indicative Costs	Typical Buyers/ Market	Seller / Project Requirements
Verra VM0042 – Improved Agricultural Land Management (IALM)	Cropland or grassland with measurable soil-organic-carbon (SOC) increase through practices like cover cropping, residue retention, reduced/no tillage, optimized fertilizer use.	Baseline soil sampling, modelling and field verification; credits issued annually; full re-sampling every 2–5 years.	Project development ~USD 5–10 per acre; verification & issuance ~USD 0.2–0.5 per tCO ₂ e.	Global corporate net-zero programmes; agrifood supply chains.	Land-tenure proof, documented practice change, soil-carbon lab data, long-term monitoring plan.
Gold Standard – Soil Organic Carbon Framework	Agricultural land or pasture showing verifiable net SOC gain; must meet GS additionality and sustainable practice criteria.	Annual activity monitoring, third-party verification every 1–3 years; credits issued after each verification.	GS registration + issuance ~USD 0.1–0.3 per tCO ₂ e; development costs project-specific.	ESG-focused corporates, food & beverage majors, carbon buyers.	Farm-level stakeholder data collection, consultation, sustainable land-management plan.

9.2.2 Biochar

Here the focus shifts to permanent carbon storage through pyrolyzed biomass. The table outlines three recognised standards: **Verra VM0044**, **Puro.earth Biochar**, and **Isometric**, noting their permanence criteria (e.g., hydrogen-to-carbon ratios), the

higher production costs (USD 120–150 per tonne of biochar), and the premium market prices (USD 140–160 per tCO₂e) paid by tech firms and other buyers seeking high-durability removals.

BIOCHAR

Standard/Methodology	Eligibility & Key Criteria	MRV & Timeline	Indicative Costs	Typical Buyers/Market	Seller / Project Requirements
Verra VM0044 – Biochar Utilization (Soil & Non-Soil)	Sustainable biomass feedstock; hydrogen-to-carbon (H:C) ratio < 0.7; evidence of >100-year permanence.	Batch-level tracking, laboratory carbon analysis; credits issued at production or final application.	Production ~USD 120–150 per t biochar; verification/issuance ~USD 0.3–0.5 per tCO ₂ e.	Tech firms and industrial emitters seeking high-durability credits.	Chain-of-custody documentation, full life-cycle GHG accounting, third-party audit.
Puro.earth – Biochar Methodology	Similar feedstock and permanence criteria; H:C ≤ 0.4; char stored or applied to soil.	Continuous MRV; CO ₂ Removal Certificates (CORCs) typically issued after 12 months.	Verification & registry ~USD 0.3 per tCO ₂ e; market prices often USD 140–160 per tCO ₂ e.	Frontier carbon-removal buyers (e.g., Microsoft, Shopify, Stripe Climate).	Independent lab tests, proof of storage/application, sustainability screening.
Isometric – Biochar Production & Storage	Industrial or community-scale biochar with traceable supply chain.	Digital MRV platform with automated issuance; frequent data uploads.	Platform service fee per tonne (varies by contract).	Early-stage but attracting high-integrity voluntary buyers.	Sensor-based monitoring, digital data sharing, feedstock traceability.

9.3.3 Enhanced Rock Weathering (ERW)

This table compares the **Puro.earth** and **Isometric** approaches to verifying carbon drawdown through the application of finely ground silicate rock. It shows that both require baseline soil chemistry and long-term monitoring, but Isometric leans heavily on digital MRV and remote sensing, while Puro.earth uses more traditional soil-sampling protocols. Pilot projects report credit prices in the USD 150–200 per tCO₂e range.

ENHANCED ROCK WEATHERING

Standard/Methodology	Eligibility & Key Criteria	MRV & Timeline	Indicative Costs	Typical Buyers/Market	Seller / Project Requirements
Puro.earth – ERW Methodology	Cropland or grassland with measurable soil-organic-carbon (SOC) increase through practices like cover cropping, residue retention, reduced/no tillage, optimized fertilizer use.	Baseline soil sampling, modelling and field verification; credits issued annually; full re-sampling every 2–5 years.	Field/lab monitoring ~USD 5–10 per tCO ₂ e; pilot credit prices reported ~USD 150–200 per tCO ₂ e.	Global corporate net-zero portfolios; agrifood supply chains.	Land-tenure proof, documented practice change, soil-carbon lab data, long-term monitoring plan.
Isometric – ERW Methodology	Same mineral criteria; designed for digital MRV and remote sensing.	Continuous digital monitoring with automated reporting and credit issuance.	Platform & verification fees per tonne (contract-based).	Tech-sector net-zero portfolios, early-adopter corporates.	Digital data integration, baseline soil chemistry, consent from landholders.

9.2 Carbon Project Development Process

The development of a carbon-credit project follows a structured ten-step pathway designed to ensure transparency, scientific rigor, and market integrity. The main actors

are the **carbon-dioxide removal (CDR) project developer**, the **registry** (such as Verra, Gold Standard, or Puro.earth among others), and **independent third-party auditors**.

1. Request and Initial Submission – The CDR supplier (for example, a biochar producer) submits a request to list the project on a recognised registry and provides preliminary documentation.

2. Pre-Listing Review – The registry examines the initial submission to confirm that it meets basic eligibility requirements.

3. Project Design Document – The developer submits a complete project description and proof of a validation contract, outlining technology, baseline emissions, monitoring plans, and expected removals.

4. Completeness Check – The registry verifies that all required information is present and updates the project's status.

5. Validation of Project Design – Independent auditors review the design to ensure it complies with the chosen methodology and satisfies additionality and permanence criteria.

6. Registration Submission – Following successful validation, the developer submits final documentation for registration.

7. Registration Review – The registry conducts a final



Figure 20: Project Development Process

assessment and formally registers the project.

8. Monitoring and Measurement – Once operational, the developer monitors carbon-removal performance, gathers field data, and prepares a monitoring report.

9. Verification of Monitoring Report – Third-party auditors confirm the accuracy of the monitoring data and the quantity of CO₂ removed.

10. Credit Issuance – After successful verification, the registry issues verified carbon units (VCUs, CORCs, or equivalent) that can be sold on voluntary or compliance markets.

This sequence provides a clear chain of custody from project conception to the issuance of marketable carbon credits, ensuring that every tonne of CO₂ claimed is real, measurable, and permanent.

10. Dynamics of the CDR Market

10.1 Purchasing Mechanisms⁶¹

CDR credits can be purchased through three main mechanisms:

1. **Spot Purchases:** Credits are paid for and transferred immediately, with retirement occurring as soon as they are delivered. Retirement removes the credit from the registry to prevent double counting. This option is only available for removals that have already been completed.
2. **Pre-purchases:** Buyers agree in advance on a price and volume of credits, which will be delivered and retired at a future date once the removals take place. Payment is made partially or fully before the sequestration occurs.
3. **Offtake Agreements:** Buyers commit upfront to purchasing credits for a specific year (vintage)⁶² or on a recurring annual basis. Credits are transferred and retired once the associated CO₂ removals are verified.

In all cases, once credits are issued and delivered, they may be traded before being retired.

10.2 Purchasing Options

Buyers have multiple pathways to acquire CDR credits:

- **Direct Purchase:** Credits can be obtained directly from project developers, either through a registry or via resellers.
- **Marketplace/Retailers:** Platforms that aggregate and display a broad selection of CDR credits, allowing buyers to access different projects without needing to approach each supplier individually.
- **Portfolio Managers:** Independent advisors who help clients navigate the CDR market. They provide customized guidance, curate portfolios that combine

credits from various technologies, ensure due diligence, and handle negotiations with suppliers. Their services are usually compensated through a commission fee.

10.3 Revenue Streams and Financing Options^{63 64}

A wide range of financing mechanisms and income opportunities can underpin agriculture-based carbon removal and climate-smart projects.

10.3.1 Government-Backed Finance

- **Agriculture Infrastructure Fund (AIF):** Over ₹52,000 crore sanctioned for post-harvest and climate-smart projects.
- **PM Formalisation of Micro Food Processing Enterprises (PMFME):** Priority sector lending and credit-linked subsidies.
- **Production Linked Incentive (PLI) Scheme for Food Processing:** Incentives for value-added products and exports.
- **Kisan Credit Card (KCC):** Enhanced loan limits (₹5 lakh) with interest subvention.
- **NABARD & Agricultural Marketing Infrastructure (AMI):** Subsidies up to 33% for storage and value-add projects.

10.3.2 Carbon & Ecosystem Markets

- **Indian Carbon Market (ICM):** Compliance and voluntary credits from afforestation, biochar, soil carbon projects.
- **International Article 6 Markets:** Opportunities for cross-border carbon credit trading.

10.3.3 Private & Blended Finance

- **Foreign Direct Investment (FDI):** 100% automatic route in food processing and agri-services.
- **Public–Private Partnerships (PPP):** For mega food parks, cold chains, and bioenergy projects.
- **Impact/Climate Funds:** Growing interest from ESG and carbon funds in nature-based solutions.

10.3.4 Export and Value-Addition Revenues

- **Agri-Exports:** India's agri and processed food exports exceeded US\$50 billion in FY23 and continue to grow.
- **High-Value Crops & Organics:** Premium markets for certified organic produce and resilient crops like millets.
- **Food Processing & Ready-to-Eat Products:** Fast-growing domestic and export markets create new income streams

10.3.5 NGO and Philanthropic Participation

- **Project Co-Financing & Grants:** International and Indian NGOs (e.g., CottonConnect⁶⁵) often provide seed funding or matching grants for pilot

carbon-removal projects (e.g., biochar or agroforestry) and for farmer-producer organisations to access carbon markets.

- **Capacity Building & Technical Assistance:** NGOs help farmers aggregate into cooperatives/FPOs, reducing transaction costs and improving creditworthiness, making them attractive to institutional lenders like NABARD.
- **Outcome-Based or Results-Based Funding:** Philanthropic donors increasingly back “pay-for-performance” models, wherein verified carbon sequestration or biodiversity outcomes trigger disbursements.
- **Blended Finance Platforms:** NGOs frequently act as intermediaries, blending concessional funds from foundations with private capital to de-risk investments in smallholder-focused climate projects.
- **Access to International Climate Funds:** Many NGOs are accredited to channel finance from the Green Climate Fund or Adaptation Fund, which can complement domestic schemes.

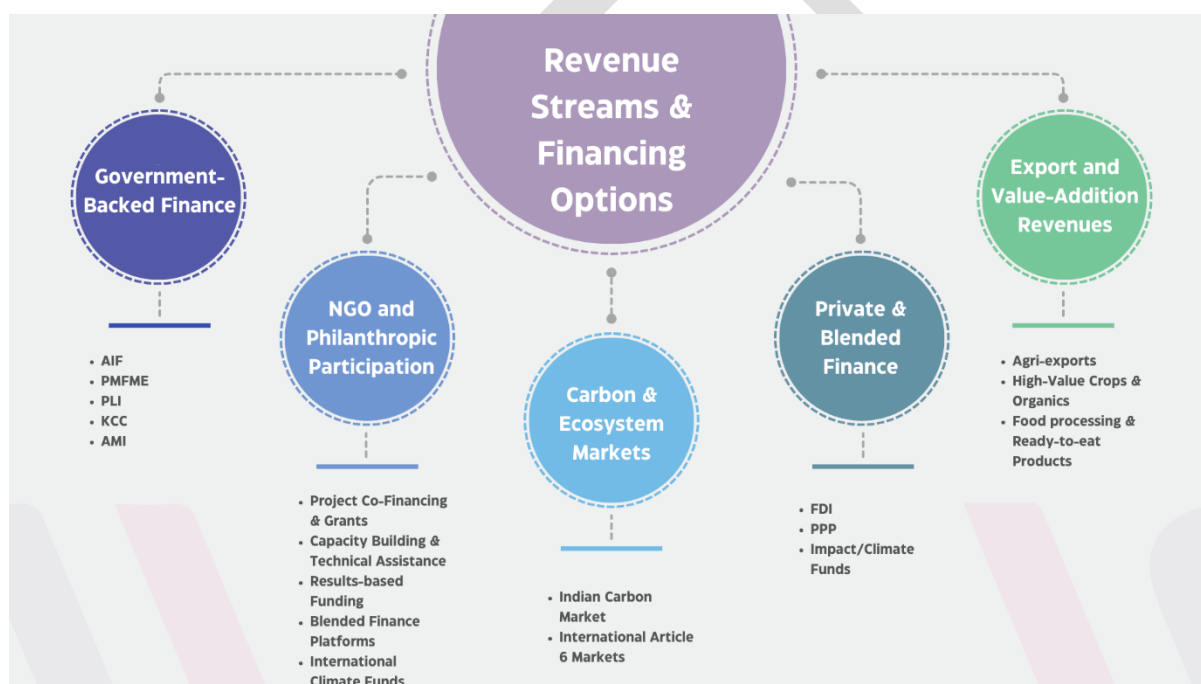


Figure 21: Revenue Streams and Financing Options

These instruments provide both direct income (through carbon credits, exports, value addition) and capital access (credit, subsidies, FDI) to scale sustainable agriculture and carbon-removal initiatives.

11. Stakeholders Supporting the CDR Industry

A wide range of actors contribute to the growth of the CDR market even if they do not directly trade credits. Their roles span education, collaboration, policy support, and financing. Many stakeholders perform multiple functions, making them vital for strengthening the sector.

11.1 Ensuring CDR Credit Integrity

Measuring, Reporting, and Verification (MRV)

Organizations developing MRV standards are central to quantifying the real climate benefits of CDR projects. They help verify that project developers' claims are accurate and provide a foundation for directing policy incentives toward proven technologies. Registries also play a trust-building role by preventing over-crediting and ensuring credits reflect genuine removals, particularly important for emerging solutions like DACCS⁶⁶.

Carbon Credit Rating Agencies

Because protocols differ across registries, credit comparability can be difficult. Rating agencies have emerged to evaluate the likelihood that one credit truly equals one tonne of CO₂ removed or avoided. These agencies score projects, both traditional offsets and CDR, using standardized criteria, helping buyers assess quality and credibility. A higher project rating indicates a stronger probability that each issued credit genuinely represents the reduction or removal of one tonne of CO₂⁶⁷.

Governance Standards

Independent governance bodies set benchmarks for what qualifies as a “high-quality” carbon credit. By defining criteria such as additionality and permanence, they ensure environmental integrity and transparency.⁶⁸ In voluntary markets, registries are typically accredited by such governance bodies, while in compliance markets the oversight may come from international or state authorities, such as ICAO through CORSIA.

11.2 Additional Supporting Stakeholders

Financiers

Access to capital is essential for scaling CDR. Funding sources include venture capital, private equity, institutional investors, philanthropic organizations, banks, and public programs such as tax credits or grants⁶⁹. Demand coalitions that aggregate purchases also help accelerate investment. Financing is particularly critical for early-stage technologies still in R&D or pilot phases.

Educators and Research Institutions

Knowledge-sharing organizations such as think tanks, non-profits, and universities, help close awareness gaps among the public, policymakers, and investors. They produce market and policy analyses, conduct techno-economic studies, and advance research to refine existing technologies and develop new ones.

11.3 Role of Startups and Fashion Companies

Startups have emerged as key drivers in the development and scaling of carbon dioxide removal (CDR) solutions. Their agility, innovative business models, and ability to leverage new technologies position them at the forefront of advancing practices such as regenerative agriculture, biochar production, and enhanced rock weathering.

Many startups are developing low-cost MRV systems, portable pyrolysis units for crop residues, or AI-enabled platforms that connect farmers with carbon markets. By bridging technology gaps and accelerating deployment, these enterprises are creating new revenue opportunities for smallholder farmers and supporting the credibility of the wider carbon market.

Some startups working in these areas:

Low-cost MRV (Monitoring, Reporting & Verification) systems

- **Carbonfuture (Germany)**⁷⁰: provides a digital MRV platform to track biochar and other CDR credits across the value chain.
- **Pachama (US)**⁷¹: uses satellite imagery and AI to verify forest carbon projects, reducing the cost and time of MRV.
- **Sylvera (UK)**⁷²: offers independent carbon credit ratings and AI-powered MRV tools for buyers and policymakers.

Portable pyrolysis units for crop residues

- **Takachar (India/US)**⁷³: develops small-scale, low-cost portable machines that convert agricultural waste into biochar and fuel.
- **PyroCCS (Germany)**⁷⁴: works on decentralized pyrolysis units to sequester CO₂ in biochar while producing renewable energy.

AI-enabled platforms connecting farmers with carbon markets

- **Agreena (Denmark)**⁷⁵: offers a digital platform to help farmers transition to regenerative agriculture and monetize carbon credits.
- **Boomitra (India/US)**⁷⁶: uses satellites and AI to measure soil carbon sequestration, linking farmers (especially smallholders) to carbon markets.

The fashion industry is increasingly exploring carbon capture and removal as a pathway to decarbonization. McKinsey research shows that the sector was responsible for some **2.1 billion metric tons** of greenhouse-gas (GHG) emissions in 2018, about 4 percent of the global total⁷⁷. Instead of relying on fossil fuels or large tracts of farmland, new technologies are enabling textiles to be produced from CO₂ taken directly from the air. This shift holds the potential to create sustainable and even carbon-negative fibres. Europe is leading much of this progress, supported by ambitious climate goals, renewable energy investments, and strong R&D ecosystems.

11.3.1 Startups as Catalysts in the CDR Space

Startups are at the forefront of innovation in carbon dioxide removal (CDR), especially in agriculture-driven methods. A prime example is **Varaha**, an Indian carbon removal enterprise that has deployed a range of projects, ranging from regenerative agriculture and afforestation to biochar production and enhanced rock weathering across India, Nepal, Bangladesh, and Kenya. It has mobilized over 100,000 smallholder farmers and achieved a removal of more than 2 million tonnes of CO₂e.⁷⁸ Notably, Varaha

made history by issuing India's first industrial biochar-based CDR credits under the Puro.Earth registry⁷⁹, and struck a landmark agreement to sell 100,000 credits to Google, making it Google's first major CDR purchase in India⁸⁰.

Another standout is **Boomitra**, which recently executed India's first issuance of soil organic carbon credits through its URVARA Project⁸¹, employing AI-powered MRV tools to verify carbon removals across 6,000 smallholder farmers and issuing over 47,000 credits, with expectations to scale further.

11.3.2 Fashion Industry's Engagement in Regenerative CDR Pathways⁸²

Fashion companies also play an influential role, particularly in cotton and natural fibre value chains. Global brands are increasingly recognizing the importance of decarbonizing their supply chains and improving the sustainability of raw material sourcing.

How it works:

The process begins with Direct Air Capture (DAC), which extracts CO₂ from the atmosphere using chemical solvents or solid absorbents. Once captured, the CO₂ can be transformed into fibres through:

- **Chemical conversion** into polymers,
- **Biological conversion** using microbes to create biomass, or
- **Mineralization** to produce solid materials that can be spun or applied to textiles.

Applications:

These CO₂-based fibres could substitute for polyester, nylon, or even cotton, and may be used in clothing, sportswear, footwear, packaging, or trims. Their versatility allows designers to develop high-performance fabrics while reducing reliance on petroleum-based inputs.

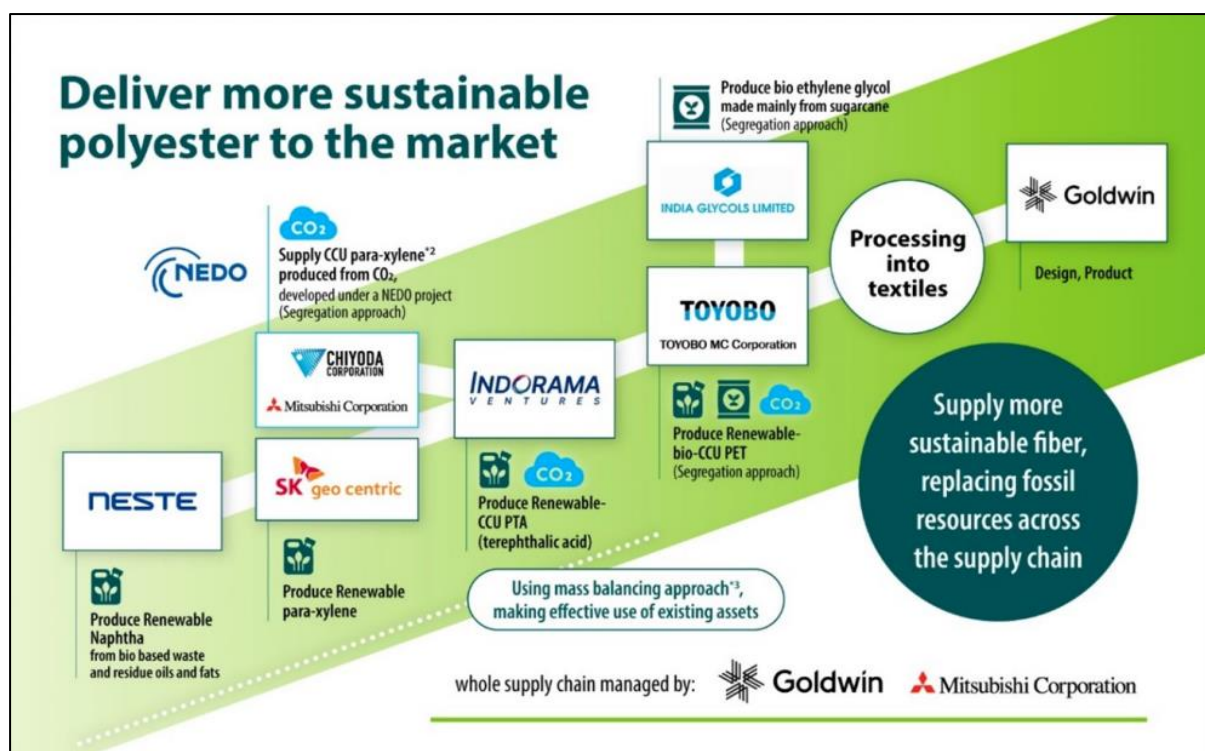


Figure 22: Full supply chain visualized to achieve sustainable polyester⁸³

Key Research Initiatives:

- The **Fraunhofer Institutes** (Germany) are developing algae-based CO₂ capture technologies, in partnership with Adidas, to create polymers that can be woven into fabrics for footwear.
- **SINTEF** (Norway/Sweden) and **TNO** (Netherlands) are advancing a range of CCU (carbon capture and utilization) technologies through large-scale international collaborations.

Startups to Watch:

- **LanzaTech:** Converts captured industrial emissions into polyester and foam, collaborating with brands like **Lululemon** and **On**.
- **Fairbrics:** Uses molecular chemistry to turn waste CO₂ into polyester yarn, currently scaling up production in Belgium.
- **CleanO₂:** Transforms captured CO₂ from heating systems into pearl ash, used in soaps and cleaning products.

Apparel and fashion brands are emerging as strong demand drivers for CDR-aligned solutions by integrating regenerative agriculture and carbon offsetting into their supply chains:

- **H&M** launched a summer capsule crafted from Regenerative Organic Certified cotton⁸⁴. As part of the *Regenerative Production Landscape Collaborative* (RPL Collaborative), H&M supports over 140,000 Indian smallholder farmers to adopt regenerative practices, improving both ecological resilience and yield.

- The **Unlock Programme**⁸⁵, established by *The Fashion Pact* and consultancy 2050, is aimed at decarbonizing cotton production through collective financing. Within its 2023 pilot phase, it achieved reductions of 200–600 kg CO₂ per hectare in India and is set to scale to over 10,000 enrolled farmers thus, potentially channelling up to €1.2 million in payments to growers in 2024.
- **Levi's (Levi Strauss & Co.)**⁸⁶ is also engaging in regenerative sourcing through participation in RPL Collaborative in India, linking its supply chain to sustainable land-use practices that contribute to carbon sequestration.

Industry Partnerships:

Global collaborations are underway, such as the consortium led by **Goldwin** and **Indorama Ventures**, which is developing CO₂-derived polyester for **The North Face** sports uniforms.

Policy Support:

The **EU Green Deal**, **Circular Economy Action Plan**, and major funding programs like **Horizon Europe** and the **EU Innovation Fund** are catalysing investment and research. Europe's renewable energy leadership is also key to powering these technologies sustainably.

The collaboration between startups and fashion companies is mutually reinforcing: startups provide technological solutions and carbon market access, while fashion companies bring large-scale demand signals, long-term offtake agreements, and investment capital. Together, they can help accelerate the commercialization of CDR in agriculture and textiles, create resilient supply chains, and position India as a leader in sustainable fibre production.

11.4 Examples of Companies in Regenerative Agriculture, Biochar, and ERW

11.4.1 Regenerative Agriculture / Soil Carbon

- **Boomitra India**⁸⁷— Satellite-based MRV and soil-carbon credit platform, active with farmer producer organisations (FPOs) in Rajasthan, Madhya Pradesh and Gujarat.
- **SustainPlus**⁸⁸— Works with smallholders across multiple states in India to introduce low-tillage, cover cropping and composting practices for soil-carbon gains.
- **Samunnati**⁸⁹— Agri-value-chain financier supporting FPOs that adopt regenerative practices and aggregate carbon credits for sale.

11.4.2 Biochar

- **Takachar**⁹⁰— Delhi-based clean-tech startup developing small, portable pyrolysis units so farmers can convert crop residues into biochar and avoid stubble burning.

- **Varaha Climate**⁹¹– Bengaluru startup operating multiple biochar projects across Punjab, Haryana, and Maharashtra; among the first Indian developers to issue Puro.earth credits.
- **Carbon Craft Design**⁹²– Mumbai social enterprise turning biochar and other carbon residues into building tiles and soil amendments.

11.4.3 Enhanced Rock Weathering (ERW)

- **Mati Carbon**⁹³– Conducting on-farm trials in Chhattisgarh using locally sourced basalt dust to boost soil health and sequester carbon, reporting yield gains of around 20% while reducing chemical inputs.
- **Alt Carbon**⁹⁴– A Bengaluru-based company, Alt Carbon applies a proprietary mix of organic inputs and silicate-rich amendments to agricultural land. This process mineralizes CO₂ and is shown to improve soil quality, increase crop yields, and generate carbon credits.
- **Varaha** – Varaha focuses on partnering with smallholder farmers to capture greenhouse gases through projects like ERW. They apply fine basalt rock to acidic fields to balance pH, capture carbon, and work with communities for on-ground implementation.

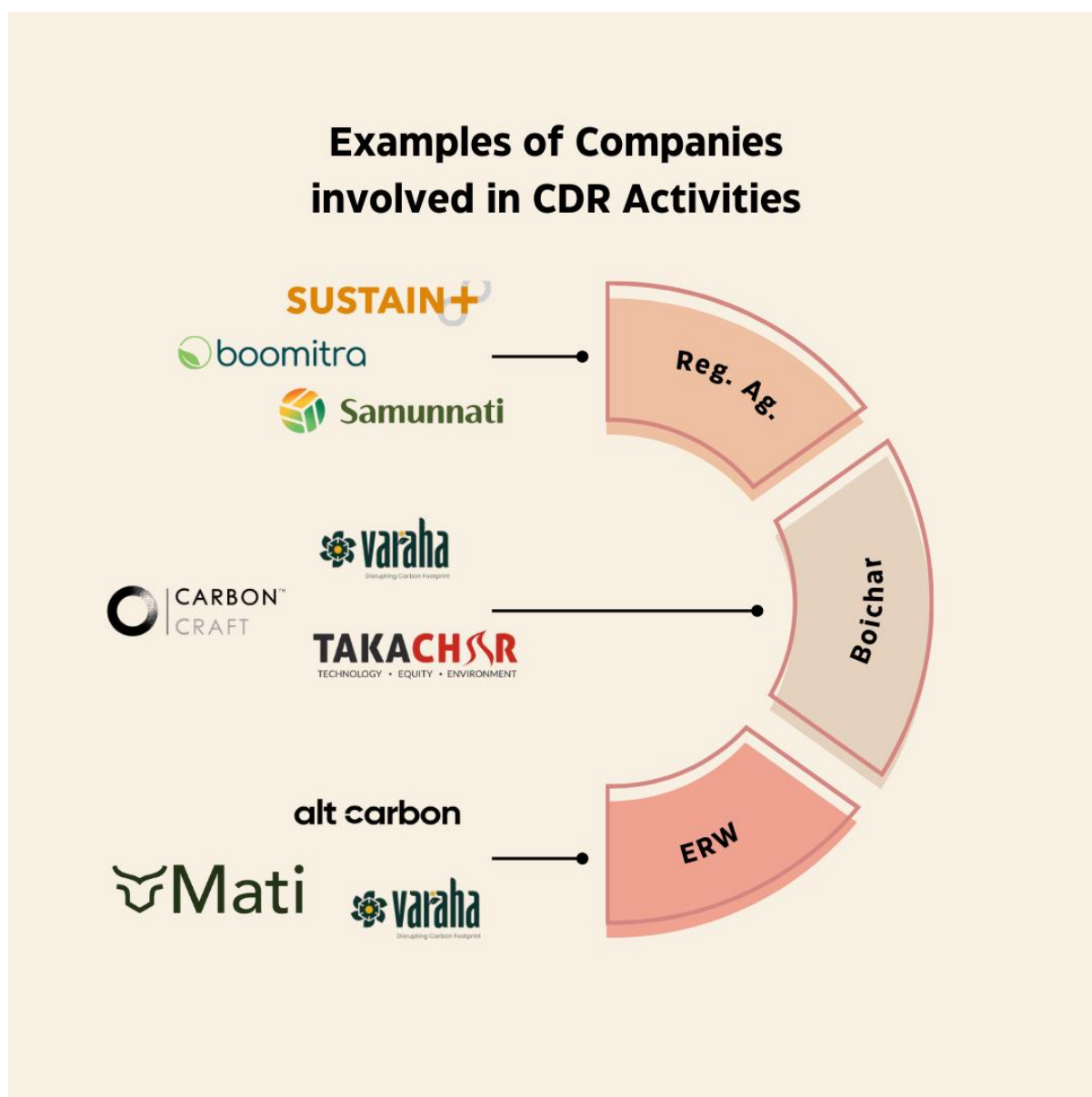


Figure 23: Companies Involved in CDR Activities in India

11.5 Possible Partner Companies for Pilio

For piloting or scaling durable carbon removal in India, Pilio could consider partnerships such as:

11.5.1 Biochar Implementation Partners

- **Takachar** – Portable pyrolysis and farmer-level biomass collection.
- **Varaha Climate** – Turn-key project development and Puro.earth registration.

11.5.2 ERW Partners

- **Mati Carbon** – Community outreach and basalt-dust field trials.
- **Alt Carbon** – Access to silicate rock feedstock and logistics.

11.5.3 Regenerative Agriculture Partners

- **Boomitra India** – Digital MRV platform and carbon credit issuance.
- **Samunnati** – Financing and aggregation of farmer producer organisations.

11.5.4 Finance / Market Access

- **Indian Carbon Market (ICM)** – Domestic compliance and voluntary credit platform.
- **NABARD & Small Industries Development Bank of India (SIDBI)** – Blended finance for farmer-led CDR pilots.

12. Suggestions for Scale

12.1 Opportunities and Challenges

Capturing carbon dioxide to produce textile fibres offers a dual benefit: it lowers reliance on fossil-based feedstocks and helps free agricultural land for uses such as food production or ecological restoration. It also supports circular-economy goals by turning an industrial greenhouse gas into a valuable raw material.

Scaling this innovation, however, is not without obstacles. Current CO₂-to-fibre processes are energy-intensive and require dependable access to low-carbon power to deliver a true climate benefit. Infrastructure investments, from carbon-capture facilities to specialised fibre-production plants, remain capital-heavy. In addition, CO₂-derived fibres must consistently meet the durability, comfort, and performance standards of conventional textiles to gain acceptance among manufacturers, brands, and consumers.

12.2 Outlook

Despite these challenges, carbon-capture technologies for textiles present a significant pathway toward climate-neutral, and potentially climate-negative fashion. Continued R&D can improve conversion efficiency and reduce energy demands, while supportive policies such as green-product incentives and carbon-removal credits can lower financial barriers. Collaboration across the value chain, start-ups developing the chemistry, established fibre producers, apparel brands, and end consumers, will be essential to build market confidence and demand.

If these elements align, CO₂-based fibres could move from niche pilot projects to mainstream production, transforming the fashion sector into a contributor to global decarbonization targets rather than a source of emissions.

Appendix⁹⁵

List of common CDR technologies and their typical CO₂ storage characteristics

Technology	Description ⁹⁶	Storage Type ⁹⁷	Durability in Years ⁹⁸
Enhanced Rock Weathering (ERW)	Acceleration of the natural geologic weathering process through the spreading of finely ground alkaline materials in agricultural, urban, or forest soils, where it reacts with CO ₂ and water to produce dissolved inorganic carbon	Ocean Reservoirs	10,000+
Direct Air Carbon Capture and Storage (DACCS)	Using engineered system to pull ambient air from the atmosphere and capturing CO ₂ via chemical interactions with a suitable sorbent/solvent, which is then stored in geological reservoirs or mineralized.	Geological formations, minerals	10,000 +
Mineralization	Enhancing the natural capacity of alkaline feedstock to passively react with atmospheric CO ₂ – through crushing, grinding, spreading, heating, or other physical and chemical means – to form carbonate materials.	Minerals	10,000 +
Bioenergy with Carbon Capture and Storage (BECCS)	Thermal conversion of biomass (either dedicated feedstock or waste) to generate electricity/fuels that produces CO ₂ , which is captured with point-capture CCS technology and stored in geological reservoirs or mineralized.	Geological formations, minerals	10,000 +
Direct Ocean Capture and Storage (DOCCS)	Electrochemical processes that split water from oceans, lakes or other bodies of water into acid and base streams, then use the acid stream to push dissolved CO ₂ out of the water to be captured, and finally, recombine the acid and base streams to re-neutralize the water and return it to the source.	Geological formations/ocean reservoirs	10,000 +
Artificial Upwelling/Dowelling	Upward/downward transfer of surface and deep ocean water to stimulate growth of	Marine sediment	100s to 1,000s

Technology	Description ⁹⁶	Storage Type ⁹⁷	Durability in Years ⁹⁸
	phytoplankton on the surface that removes CO ₂ from the atmosphere and pushes CO ₂ -rich surface water to the deep ocean		
Ocean Alkalinity Enhancement (OAE)	Direct addition of alkaline materials to lakes, oceans, rivers, wastewaters, or other bodies of water to increase the alkalinity of the water and its capacity to absorb CO ₂	Ocean reservoirs	10,000 +
Biochar	Thermal conversion of biomass while excluding oxygen, optimized to produce solid char in open or controlled environments	Soil and sediments	100s to 1000s
Afforestation/Reforestation (AR)	Deliberate establishment of forest ecosystems on previously degraded or unforested land to act as natural CO ₂ sinks.	Vegetation, buildings, soils	10s to 100s
Coastal Blue Carbon (CBC)	Deliberate establishment of marine vegetation and organisms to act as natural CO ₂ sinks.	Vegetation	10s to 100s
Soil Carbon Sequestration (SCS)	Implementation of agricultural practices that build up organic soil carbon content	Soil and sediments	10s to 100s

Glossary⁹⁹

Carbon Avoidance/Reduction: The negative change in greenhouse gas emissions caused by an intervention relative to the intervention's baseline scenario.

Carbon Removal Credits: Carbon credits issued from technologies, practices or approaches that remove and durably store CO₂ from the atmosphere.

Credit Delivery: When the carbon credits issued by a registry are transferred to and reaches the account of purchaser of the carbon credits.

Credit Issuance: The instruction by the relevant authority in a carbon crediting program to create and serialize a specified quantity of carbon credits in a registry account.

Credit Retirement: The permanent removal of a carbon credit in an electronic registry, after a party has claimed the associated avoided/reduced or removed emissions. This is done to prevent another party from claiming the same avoided or removed emissions again.

Durability: duration in years for which carbon dioxide is securely stored in a reservoir without risk of reversal.¹⁰⁰

In-sector decarbonization measures: A measure applied to a process within the value chain of the company/entity to reduce or remove CO₂ emissions.

Insetting: Interventions along a company's value chain that are designed to generate GHG emission reductions and carbon storage, and at the same time create positive impacts for communities, landscapes and ecosystems.¹⁰¹

Leakage: An unintentional increase in emissions or decrease in removals caused by an intervention, relative to the intervention's baseline scenario, which typically occurs at sources or sinks physically separate from the location where the intervention is implemented.

Market based measures (MBMs): Provide financial incentives and disincentives to regulated entities towards desired behaviour, e.g. lowering emissions. These measures can be implemented to reduce damage to the environment¹⁰².

Net-zero emissions: net-zero emissions are achieved when anthropogenic emissions of greenhouse gases to the atmosphere are balanced by anthropogenic removals over a specified period.

Out-of-sector decarbonization measures: A measure applied to a process outside of the value chain of the company/entity to reduce to remove CO₂ emissions.

Project developer: The project developer refers to the legal entity requesting the registration of a crediting project and issuance of carbon credits. The crediting project developer may be a public or private entity.

Registry: A standard-setting organization that registers carbon-crediting projects and issues carbon credits. They have a means to register, track, and make publicly available information on carbon crediting projects, issue carbon credits and enable the transfer of carbon credits between different accounts, and cancel or retire them.

Reversal: The occurrence of an event in which some of the stored carbon resulting from a CDR project are subsequently re-released into the atmosphere.

Traditional Carbon Offsets: Carbon credits which are issued based on avoidance or reduction of greenhouse gas emissions.

Validation: The process by which auditors confirm that a carbon crediting project meets all eligibility criteria for registering with a registry.

Value-chain emissions: A company's scope 1,2 and 3 emissions as defined by the GHG Protocol Corporate Accounting and Reporting Standard.¹⁰³

Verification: The process by which auditors confirm that a carbon crediting project has been properly monitored, and that avoided/reduced emissions or removals achieved by the crediting project have been properly quantified in accordance with registry rules and standards.

Vintage year: It can either refer to the year in which the emissions reduction or removal associated with the carbon credit occurred or was issued as a credit.

¹ <https://ibef.org/exports/cotton-industry-india>

² <https://www.icfcotton.in/cotton-map/>

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⁸ Riahi et al. (n.d.). SPM 295 3 Mitigation Pathways Compatible with Long-term Goals Coordinating Lead Authors: Lead Authors: Contributing Authors: Review Editors: Chapter Scientists. [online] DOI: <https://doi.org/10.1017/9781009157926.005>.

⁹ <https://climate.mit.edu/explainers/carbon-offsets>

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¹¹ Smith et al. (2024). The State of Carbon Dioxide Removals 2024 - 2nd Edition. [online] Available at: <https://www.stateofcdr.org/>.

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¹³ According to TRL is a measurement system used to assess the maturity of a particular technology, with TRL 1 being the lowest level of technological readiness and TRL 9 being the highest, indicating technological maturity

¹⁴ Carbon Dioxide Removal (CDR) Technologies. (n.d.). Available at: <https://www.iata.org/globalassets/iata/publications/sustainability/carbon-dioxide-removal-cdr-technologies-facts.pdf> [Accessed 4 Jul. 2025].

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¹⁷ <https://isometric.com/writing-articles/raising-the-bar-for-carbon-credits>

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- ³² <https://www.cdr.fyi/blog/2024-q1-durable-cdr-market-update-blossoming-biochar>
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