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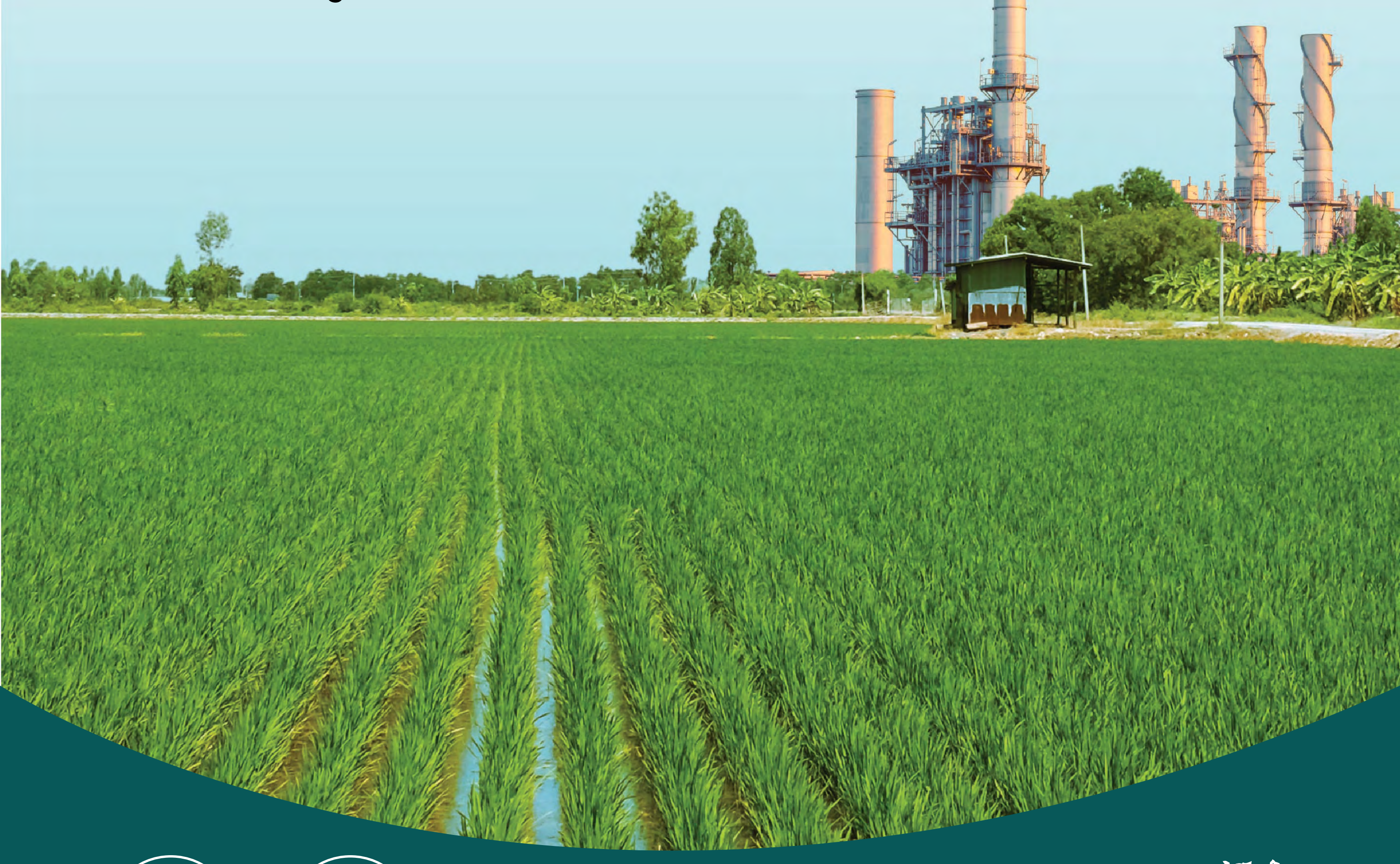
Carbon Credit Opportunities

From Paddy Cultivation

Potential, Challenges, and the Way Forward in Odisha



Carbon Credit Opportunities From Paddy Cultivation: Potential, Challenges, and the Way Forward in Odisha

Yaksana S V

Suresh N S

Center for Study of Science, Technology and Policy (CSTEP)

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Editor: Aparna Thomas

Designer: Bhawna Welturkar

Bengaluru

No. 18, 10th Cross, Mayura Street

Papanna Layout, Nagashettyhalli

RMV Stage 2, Bengaluru 560094

Karnataka (India)

Noida

1st Floor, Tower-A

Smartworks Corporate Park

Sector 125, Noida 201303

Uttar Pradesh (India)

Tel.: +91 (80) 6690 2500

Email: cpe@cstep.in

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Executive Summary

Background

Agriculture, the pillar supporting 54% of India's population, contributes nearly 13% of the country's greenhouse gas (GHG) emissions, estimated at 2.9 Gt carbon dioxide equivalent (CO_{2eq}) in 2020 (MoEF&CC, 2024). Paddy cultivation generates a significant proportion of these agricultural emissions, largely due to methane (CH_4) release from flooded paddy fields.

Odisha is a major paddy cultivator, with kharif and rabi paddy covering 64% and 14% of the total cultivated area, respectively. Paddy cultivation in Odisha accounts for 3% of national agriculture GHG emissions (Directorate of Agriculture and Food Production, Odisha, 2024).

Scaling climate-smart cultivation practices, such as alternate wetting and drying (AWD) and direct-seeded rice (DSR), can significantly reduce emissions from paddy cultivation in the state. These practices reduce methane emissions while improving resource-use efficiency. Integrating these practices with carbon markets can accelerate their adoption while offering farmers additional income opportunities.

Opportunities

Climate-smart agriculture (CSA) practices, such as AWD, DSR, regenerative farming techniques, the use of solar-powered pumping systems, biochar application, and agroforestry, offer significant potential to reduce GHG emissions from agriculture. These emission reductions can be quantified and converted into tradable carbon credits.

This report provides an overview of how carbon markets operate in the context of CSA practices. It explains the functioning of carbon markets; distinguishes between compliance and voluntary systems; and highlights the roles of registries, carbon credits, and monitoring frameworks.

Globally, agricultural carbon credit generation projects have gained greater traction in voluntary carbon markets (VCMs) than in compliance markets. This is because farming systems vary widely in terms of cultivation methods, agricultural inputs, livestock practices, and energy use across farms. Similarly, in India, agricultural carbon credit projects participate primarily in the VCM under standards such as Verra and Gold Standard. Compliance markets, by contrast, are generally structured around defined emission caps for regulated sectors. Agriculture is currently not a focus area of compliance markets due to challenges associated with monitoring, reporting, and verification (MRV).

The report also presents examples of Indian agricultural projects registered in the VCM under Verra standards. In addition, a case study on AWD in Odisha, conducted by CSTEP (in press-b), demonstrates the theoretical potential for substantial methane reductions—approximately one tonne of CO_{2eq} per hectare at the field level, equivalent to one carbon credit.

Current carbon accounting methodologies for paddy cultivation primarily account for emissions at the field level. As a result, several off-field emission sources, such as irrigation power sources, seed production, fertilisers, and other agricultural inputs, are not fully captured. Including these sources could further enhance the overall mitigation potential of CSA practices.

Challenges

The widespread adoption of agricultural carbon sequestration and GHG emission-reduction projects faces several structural barriers. These include fragmented landholdings, limited farmer awareness, high monitoring costs, and weak institutional support. Small and marginal farmers typically operate very small land parcels, which individually generate limited emission reductions. As a result, aggregation models are essential to make carbon projects viable at scale. In addition, the absence of state-level facilitation mechanisms and the need for low-cost MRV systems further constrain participation.

Ensuring fair and viable carbon pricing is another critical factor for delivering equitable benefits to farmers. Addressing these challenges will require a structured framework for generating carbon credits from paddy cultivation in Odisha.

Way forward

Odisha can position itself as an early mover in integrating carbon markets with CSA practices. Policies that build institutional readiness, promote digital MRV tools, and support farmer producer organisation (FPO)–based aggregation models can help unlock this potential.

This report provides an overview of carbon markets and their relevance for key stakeholders, including government agencies, agritech companies, FPOs, and farmers. It outlines participation mechanisms and highlights the potential for carbon credit generation from sustainable agricultural practices.

It also aims to inform Odisha’s efforts to integrate low-carbon agricultural practices within its broader state climate resilience strategy and the State Action Plan on Climate Change.

These efforts can also be viewed in the context of emerging national-level frameworks in India. The Green Credit Programme (GCP) and the Carbon Credit Trading Scheme (CCTS) are administered by the Ministry of Environment, Forest and Climate Change and the Ministry of Power, respectively. The CCTS focuses on compliance-oriented carbon markets, while the GCP incentivises environmental actions through non-fungible green credits. Given this institutional separation, direct integration or fungibility between GCP and CCTS credits is unlikely in the near term.

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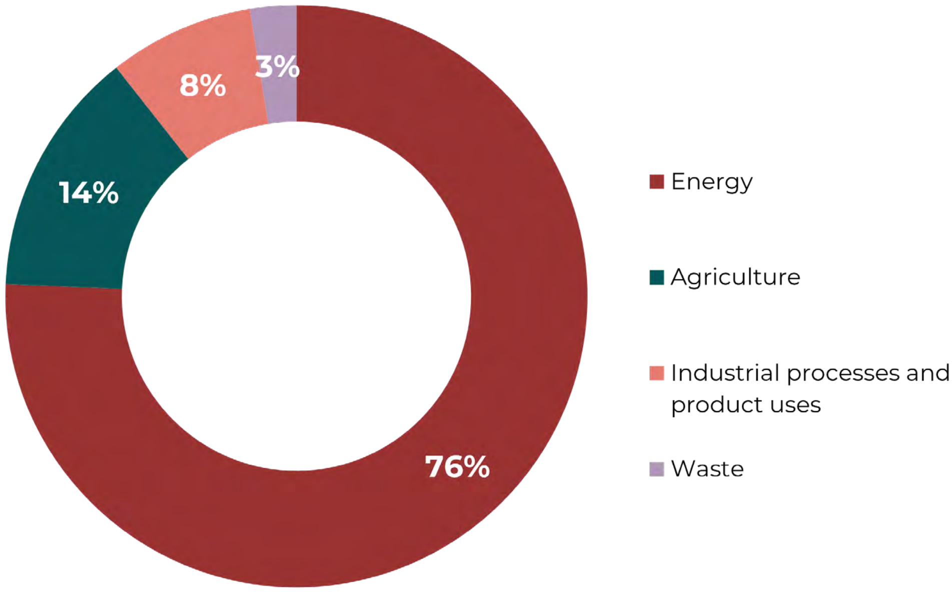
Abbreviations

Abbreviation	Definition
ACR	American Carbon Registry
AFOLU	Agriculture, Forestry, and Other Land Use
AWD	Alternate wetting and drying
BEE	Bureau of Energy Efficiency
BUR	Biennial Update Report
CAR	Climate Action Reserve
CCTS	Carbon Credits Trading Scheme
CO_{2eq}	Carbon dioxide equivalent
CRA	Climate-resilient agriculture
CSA	Climate-smart agriculture
CZAFIL	Crop Zone Agro Forestry Limited
DA&FE	Department of Agriculture & Farmers' Empowerment
DSR	Direct-seeded rice
ETS	Emission trading system
FPO	Farmer producer organisation
GCP	Green Credit Programme
GHG	Greenhouse gas
Gt	Gigatonne
ha	Hectare
MRV	Monitoring, reporting, and verification
MT	Million tonnes
NGO	Non-governmental organisation
SAPCC	State Action Plan on Climate Change
SRI	System of rice intensification
t CO_{2eq}	tonne of carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
VCM	Voluntary carbon market
VCS	Verified Carbon Standard

1. Introduction

India's total greenhouse gas (GHG) emissions stood at 2.9 gigatonnes of carbon dioxide equivalent (Gt CO_{2eq}) in 2020 (MoEF&CC, 2024). Figure 1 shows the sectoral distribution of these emissions, with agriculture and allied sectors contributing approximately 14% (~380 Mt CO_{2eq}).

***Figure 1:** India's GHG emissions across sectors*

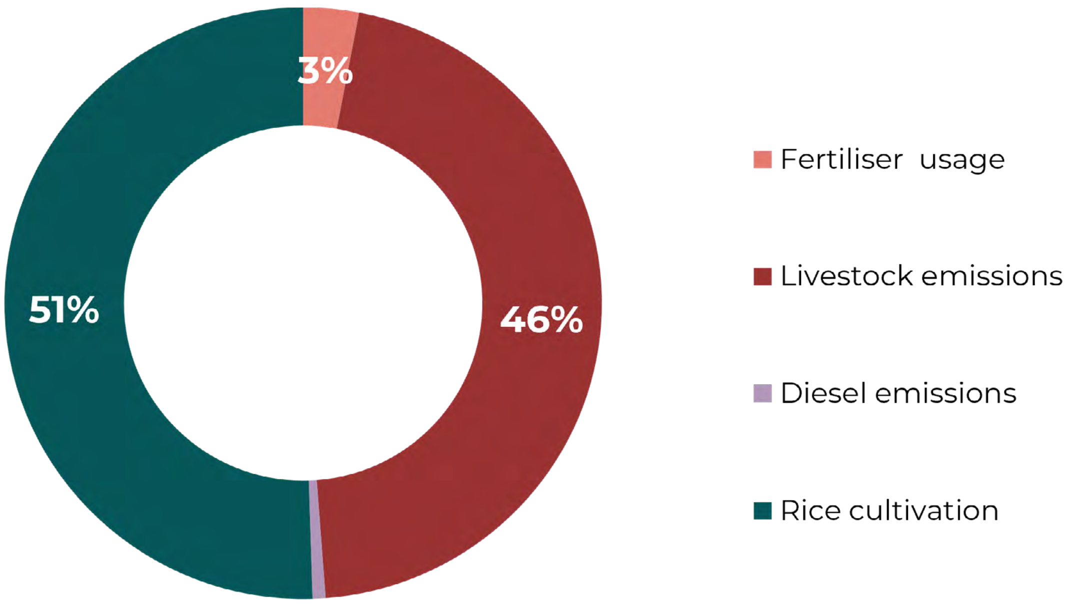


Among agricultural sources, paddy cultivation is a major contributor to GHG emissions. Methane, a GHG approximately 21 times more potent than carbon dioxide based on national emissions reporting estimates (Ministry of Environment, Forest and Climate Change, 2024), is released from standing water in transplanted paddy fields due to the anaerobic activity of methanogenic bacteria in the soil. Given the widespread cultivation of rice, these emissions make paddy cultivation a significant source of agricultural GHG emissions.

Odisha is one of the country's agriculture-dependent states where rice is extensively cultivated. Agriculture contributes approximately 19% to the state's gross value added. During the kharif season, paddy accounts for 64% of the total cultivated area, followed by pulses (10%), other cereals (9%), and oilseeds (3.8%). In the rabi season, pulses occupy 52% of the cultivated area, followed by vegetables (16%), rice (14%), and oilseeds (12%) (Directorate of Agriculture and Food Production, Odisha, 2024).

The Center for Study of Science, Technology and Policy (CSTEP, 2025) estimated the state's Agriculture, Forestry, and Other Land Use (AFOLU) emissions at 24.25 Mt CO_{2eq} in 2023. Figure 2 presents the category-wise emission share of the AFOLU sector in Odisha. At the same time, agriculture and allied sectors have recorded an average growth rate of 7% between 2019–20 and 2024–25 (Directorate of Economics and Statistics & Planning and Convergence Department, 2025).

Figure 2: *Category-wise emission share in the AFOLU sector in Odisha (CSTEP, 2025)*



Strategic interventions can reduce GHG emissions, improve resource-use efficiency, and strengthen climate resilience without compromising crop productivity. Climate-smart agriculture (CSA) interventions should be selected based on crop type, agroclimatic zone, terrain, irrigation conditions, and prevailing farming practices.

Suitable CSA interventions for paddy cultivation include direct-seeded rice (DSR), alternate wetting and drying (AWD), and natural farming approaches. For non-paddy crops and vegetables, micro-irrigation and mulching are effective interventions. These practices help reduce GHG emissions through more efficient use of inputs and lower energy consumption for pumping. In paddy systems, DSR and AWD also enhance soil aeration, thereby suppressing methane formation.

CSTEP (in press-b) conducted a life cycle emissions analysis and found that natural farming, DSR, and AWD have the potential to reduce GHG emissions by 36%, 14%, and 25%, respectively, compared with conventional farming practices in Odisha. Practices such as agroforestry and the use of biochar offer opportunities for carbon sequestration and enhancement of soil organic carbon, respectively.

To accelerate the adoption of CSA practices, it is essential to develop market-based mechanisms that incentivise emission reductions and sustainable practices while supplementing farmers' primary income streams. Carbon markets provide one such mechanism. Emission reductions achieved through CSA practices can be converted into tradable carbon credits, where each carbon credit represents one tonne of GHG emissions reduced or avoided (Bureau of Energy Efficiency [BEE], n.d.). The forthcoming Carbon Credit Trading Scheme (CCTS), introduced by the Government of India, is expected to establish structured pathways for emission trading across sectors, creating new opportunities for the agriculture sector.

Odisha's policy landscape provides an enabling environment for scaling climate-smart agricultural practices and for exploring the state's carbon market readiness. The State Action Plan on Climate Change (SAPCC) 2021–2030 outlines a strong commitment to building climate resilience across several sectors, including agriculture. The plan emphasises sustainable land and water management, promotion of climate-resilient agriculture (CRA), and the mainstreaming of low-carbon practices to safeguard livelihoods. While the SAPCC primarily refers to CRA in the context of adaptation, this brief adopts the broader concept of CSA, which integrates resilience with GHG emissions reduction and carbon market opportunities.

Complementary policy initiatives aim to enhance productivity while reducing environmental impacts. These include the Odisha Agriculture Policy (Vision 2035), the Odisha Integrated Irrigation Project for Climate Resilient Agriculture, and the ongoing Gates Foundation–funded project.

Odisha is well positioned to benefit from early engagement with carbon markets, given its high share of rice cultivation and the significant mitigation potential of water- and energy-efficient practices. Private-sector carbon buyers and agritech aggregators are increasingly interested in sourcing credits from nature-based and smallholder-driven projects. This trend highlights the need for Odisha to build institutional, data, and policy readiness to participate in carbon markets.

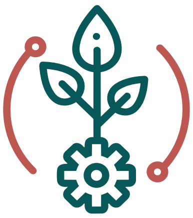
2. Objective

This report examines carbon markets and their relevance to the agriculture sector. It aims to inform the development of a carbon credit framework for Odisha that enhances farmers' secondary income; promotes sustainable, resource-efficient practices; and reduces GHG emissions.

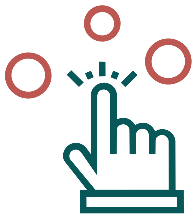
The specific objectives are as follows:

To **examine** carbon market mechanisms and global emission trading systems, particularly those that include agriculture and allied sectors within their compliance frameworks

To **analyse** the landscape of India's carbon markets with a focus on the agriculture sector



To **identify** suitable CSA interventions and institutional models that can be scaled to generate carbon credits effectively



To **provide** actionable insights for developing a carbon credit framework tailored to Odisha's agriculture sector, including a case study estimating the potential carbon credits achievable through a CSA intervention

3. Carbon Markets

Carbon markets are trading systems that enable the buying and selling of carbon credits, where each credit represents one tonne of GHG emissions reduced or removed from the atmosphere, measured in CO_{2eq}. Entities that reduce or remove GHG emissions can sell the quantity of CO_{2eq} removed as carbon credits. Organisations or individuals can purchase these credits to compensate for their GHG emissions.

3.1. Carbon market mechanism

Carbon markets are broadly classified into two main types: compliance markets and voluntary markets. The details of these mechanisms are discussed below.

3.1.1. Compliance market

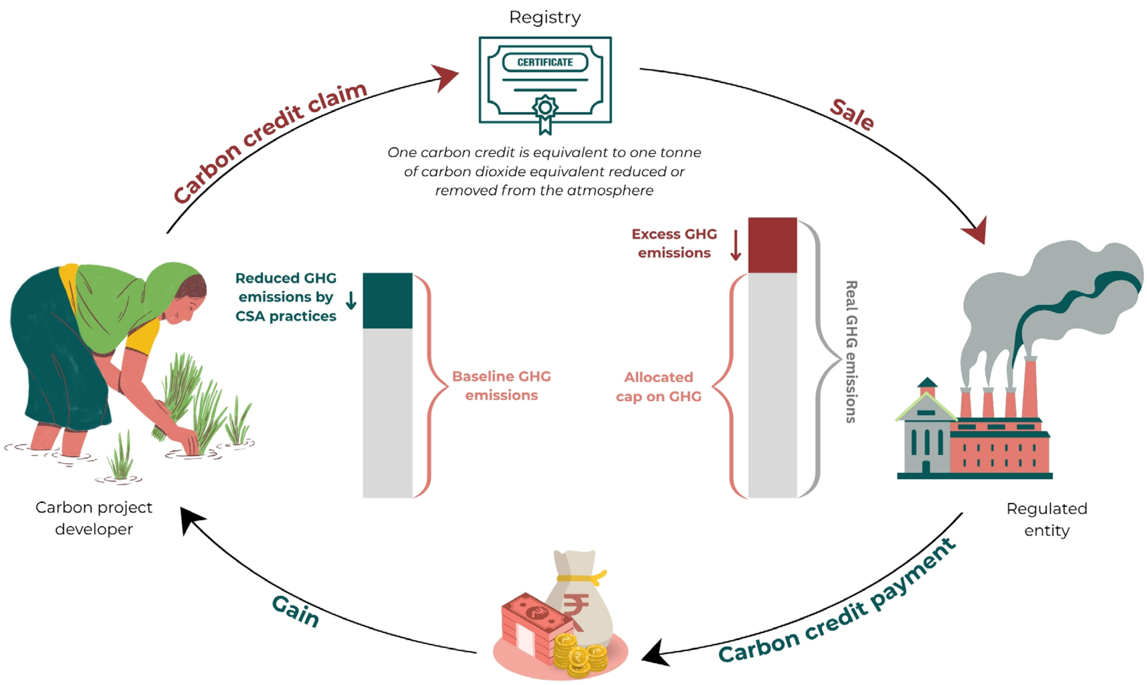
Figure 3 presents the functioning mechanism of a compliance market.

- Compliance markets are mandated by governments to meet national or regional climate targets.
- A cap is set on the total GHG emissions that can be emitted by a sector or across the economy.
- The total emissions cap is gradually reduced over time, lowering the amount of emissions allowed.
- Regulated entities are issued or must purchase allowances, each representing the right to emit a specific amount of CO_{2eq} (typically 1 tonne per allowance).
- These allowances are either auctioned or allocated free of cost. Entities can buy or sell allowances, thereby creating a market price for carbon.

At the end of each compliance period,

- entities are required to surrender allowances equal to their verified emissions
- if emissions are below their allocated allowances, entities can sell the surplus allowances or bank them for future use.

Figure 3: *Compliance market mechanism*



Government bodies manage the Emission Trading System (ETS), in which regulated entities participate. Emission allowances are allocated based on overall emission caps and sectoral benchmarks, and entities can trade these allowances to meet their compliance obligations (BEE).

3.1.2. Voluntary carbon market

Companies, investors, and individuals may choose to purchase carbon credits to offset their emissions through the voluntary carbon market (VCM). This market relies on independent standards that set rules for project development and issue credits, such as Verra, Gold Standard, Climate Action Reserve (CAR), the American Carbon Registry (ACR), and Puro.earth. These standards help ensure consistency, transparency, and credibility in the issuance of carbon credits.

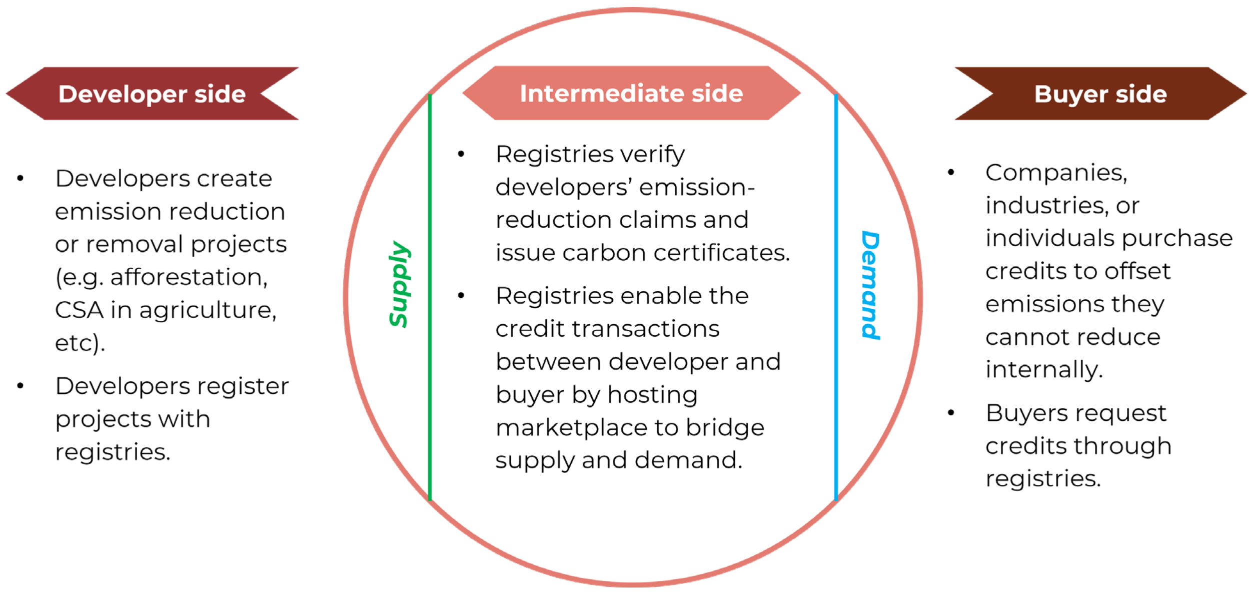
The VCM enables organisations to offset emissions by funding certified mitigation projects. The market functions through the interaction of project developers (supply), buyers (demand), and intermediaries such as platforms/brokers.

Unlike compliance markets, VCMs are driven by corporate responsibility and self-imposed climate goals. Independent standards and non-governmental organisations enable entities to voluntarily offset their emissions by purchasing carbon credits from projects that reduce or remove GHG emissions.

Figure 4 presents the functioning mechanism of VCMs.

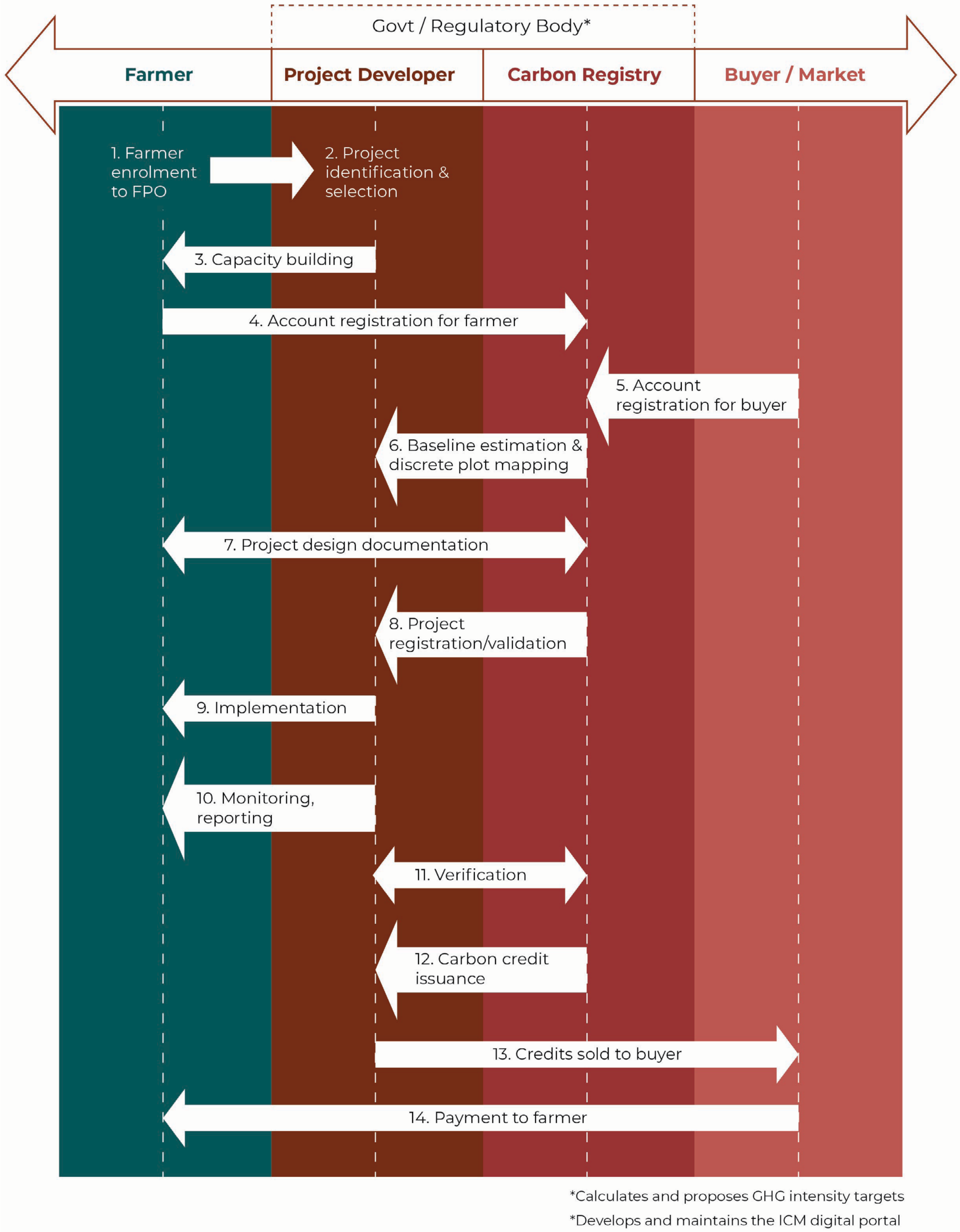
- The project developer proposes a nature-based or technology-based project that reduces or removes GHG emissions to FPO.
- Next, they select a registry (e.g. Verra, ACR, or CAR) for the issuance of credits.
- The registry estimates the amount of CO_{2eq} removed or reduced relative to a baseline scenario (i.e. emissions that would have occurred if the project had not been implemented).
- After project implementation, data on emission reductions or removals are collected for a defined monitoring period (typically one year).
- An accredited third-party verifier reviews the collected data to verify the reported emission reductions or removals.
- Following successful verification, the chosen standard issues carbon credits to the project's account in the registry.

Figure 4: *Voluntary carbon market mechanism*



Typical projects eligible under the VCM include improved cookstoves, biochar projects, tree plantation, sustainable agricultural practices, and soil carbon sequestration. Figure 5 illustrates the step-by-step process by which farmers can participate in VCMs through CSA interventions.

Figure 5: A step-by-step project implementation, registration, and issuance process for CSA practices under an offset mechanism



For smallholder agriculture projects, carbon credit generation typically occurs through aggregated project models, often led by farmer producer organisations (FPOs). The following steps illustrate a typical project cycle for CSA-based carbon credit generation:

Step 1: Farmer enrolment

Smallholder farmers participate in the carbon project through an existing FPO. The FPO acts as the aggregator for farmer groups and manages the documentation required for project enrolment.

Step 2: Project identification and selection

The FPO, in consultation with technical experts, identifies suitable carbon mitigation interventions, such as water-saving practices in rice cultivation or improved livestock management. Technical feasibility, financial viability, and monitoring, reporting, and verification (MRV) requirements guide the selection process.

Step 3: Capacity building

The FPO conducts training and capacity-building programmes for enrolled farmers. These activities ensure that farmers understand project requirements, data recording protocols, compliance responsibilities, and expected benefits.

Step 4: Account registration for farmers

The FPO registers the aggregated project on the relevant carbon registry or government portal. Registration formally initiates the project cycle, similar to the account registration step described under offset mechanisms.

Step 5: Account registration for buyers

Prospective carbon credit buyers register with the relevant carbon registry or trading platform. Registration enables buyers to participate in carbon credit transactions and maintain ownership records.

Step 6: Baseline estimation and discrete plot mapping

The project developer defines the precise geographical boundaries of the project through discrete plot mapping, ensuring that the project land area is accurately delineated for monitoring and verification. The baseline scenario is also established by validating assumptions, calculations, and methodological justifications.

Step 7: Project design documentation

The FPO prepares and submits the Project Design Document or equivalent documentation, often with support from institutions such as the Indian Agricultural Research Institute. This document outlines baseline conditions, mitigation practices, expected GHG reductions, monitoring methodologies, and implementation timelines.

Step 8: Project validation and registration

Following verification, the FPO submits the required documentation for validation or project registration under the chosen carbon standard or compliance mechanism. Registration confirms the project's eligibility for carbon credit issuance.

Step 9: Implementation

Farmers implement the agreed-upon mitigation practices in the field, with support from the FPO and technical partners. The FPO oversees compliance and provides technical assistance during implementation.

Step 10: Monitoring and reporting

Project performance data are collected in accordance with the approved monitoring plan. The FPO compiles monitoring reports documenting project activities and achieved emission reductions.

Step 11: Verification

An independent accredited verification body reviews the monitoring reports and verifies the reported GHG emission reductions. Verification confirms compliance with the applicable methodology and programme requirements.

Step 12: Carbon credit issuance

Upon completion of the verification and approval process, the registry or administrator issues carbon credits to the project. These credits represent the verified GHG emission reductions achieved during the monitoring period.

Step 13: Credit sale to buyers

The issued carbon credits are transferred or sold to registered buyers through the registry or marketplace. Transaction records are maintained within the registry system to ensure transparency and traceability.

Step 14: Payment to farmers

Revenue from the sale of carbon credits is distributed to participating farmers through the FPO under the agreed benefit-sharing arrangement, with a portion retained to cover project administration and operational costs.

Table 1 presents the differences between compliance markets and VCMs relevant to agriculture.

Table 1: *Key differences between compliance and voluntary carbon markets*

Feature	Compliance market	Voluntary market
Regulatory body	Government or regulatory authority (e.g. BEE; Indian Council of Forestry Research and Education for the Green Credit Programme [GCP]; United Nations Framework Convention on Climate Change [UNFCCC] for international compliance mechanisms)	Independent standards or non-governmental organisations, such as Verra, Gold Standard, American Carbon Registry, and Climate Action Reserve
Mandatory/voluntary	Mandatory participation to meet national or regional climate targets	Voluntary participation driven by corporate climate commitments or individual initiatives
Purpose	Achieve legally binding emissions targets across regulated sectors	Enable voluntary offsetting of emissions and support CSA practices
Examples in agriculture	Limited participation globally; pilot discussions under schemes such as the New Zealand ETS pilot	Projects involving AWD in rice cultivation, agroforestry, system of rice intensification (SRI), improved land management, soil carbon sequestration (Verra, Gold Standard)
Relevance to agriculture	Currently limited but may expand with inclusion under schemes such as India's CCTS	High relevance; enables farmers to generate additional income through CSA interventions and carbon credit generation

3.2. Global overview of carbon markets in agriculture

Globally, agriculture's participation in carbon markets is gradually expanding. Carbon registries play a vital role in verifying projects and issuing credits to project developers. International registries such as Verra, Gold Standard, Plan Vivo, and the ACR have developed methodologies for activities including soil carbon sequestration, AWD in rice cultivation, and agroforestry.

However, participation of the agriculture sector in compliance carbon markets remains limited. This is largely due to concerns regarding carbon leakage or re-release, such as during deforestation, as well as the challenges associated with accurately measuring agricultural GHG emissions. Nevertheless, several countries have shown growing interest in including agricultural projects within ETSs. The following examples illustrate global developments.

a. California Cap-and-Trade Program (USA)

- Agricultural offset protocols are recognised under this compliance programme.
- Rice cultivation projects that reduce methane emissions through practices such as AWD are eligible to generate carbon credits. These credits can be used by regulated entities to meet compliance obligations (California Air Resource Board, n.d.).

b. New Zealand Emissions Trading Scheme (NZ ETS)

- Agriculture has been removed from the NZ ETS. Between 2011 and 2024, agricultural processors were subject to reporting obligations under the NZ ETS, with plans to transition to full compliance between 2025 and 2027. However, legislation passed in 2024 repealed these requirements, formally excluding agriculture from the ETS.
- The government plans to introduce a dedicated system for pricing agricultural emissions, replacing the He Waka Eke Noa partnership with a new Pastoral Sector Group. Implementation is targeted for 2030, with the aim of measuring and pricing farm-level emissions such as methane, nitrous oxide, and carbon dioxide (International Carbon Action Partnership, 2022).

3.3. India's carbon market in agriculture

3.3.1. Voluntary carbon market in India

The VCM has emerged as the primary avenue for agricultural mitigation projects in India. Agricultural emission-reduction and carbon-sequestration projects are currently registered under international standards such as Verra's Verified Carbon Standard (VCS) and the Gold Standard.

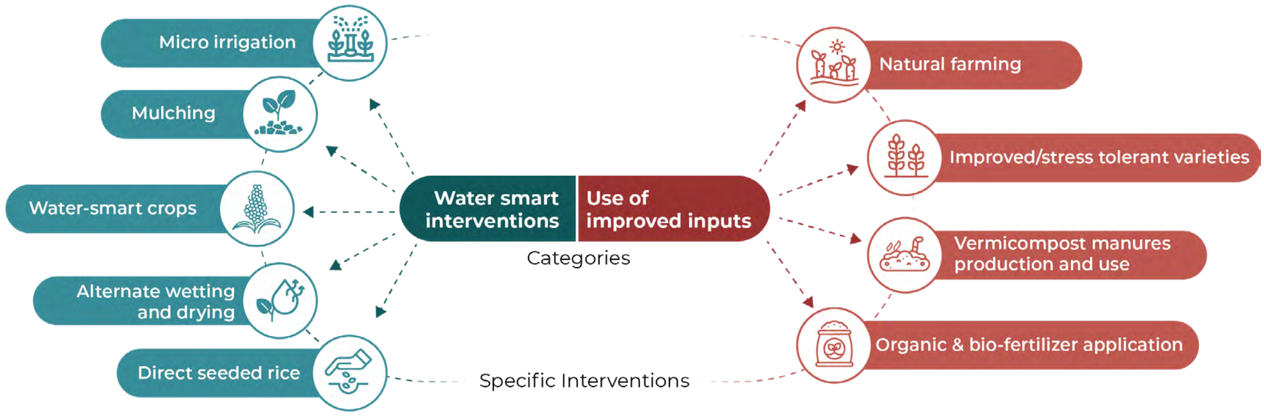
Participation in VCMs plays a transitional role. It helps build institutional capacity, develop methodologies, and strengthen MRV systems that may support the sector's eventual integration into compliance markets.

One notable example is the Maharashtra Methane Mission, which demonstrates emerging opportunities for livestock-based mitigation within the VCM (Verified Carbon Standard, n.d.). Registered under Verra, the initiative targets enteric methane reductions in dairy cattle through feed-based interventions combined with digital MRV systems. The project highlights how aggregation models and technology-enabled monitoring can facilitate carbon credit generation within fragmented smallholder farming systems.

In agriculture, particularly in rice cultivation, farmers can earn additional income by adopting climate-smart and regenerative practices that reduce emissions or enhance carbon sequestration. These practices include improved water and fertiliser management, organic inputs, and regenerative soil practices.

Figure 6 illustrates potential CSA interventions for paddy cultivation that could qualify as offset projects under the VCM. While agroforestry also offers significant mitigation potential, the scope of this report is limited to mitigation activities within paddy-based systems. The identified interventions are broadly classified into water-smart practices and improved seed and organic input use. These practices contribute to better soil health, enhanced resource-use efficiency, and reduced methane emissions.

Figure 6: *CSA interventions in paddy cultivation with potential for carbon markets*



At present, Verra and Gold Standard have developed GHG estimation methodologies primarily for rice cultivation practices (Gold Standard, 2023; Verified Carbon Standard, 2025). This reflects both the maturity of rice-based mitigation approaches and the need to expand methodologies to other agricultural systems.

Industries can support the scaling of CSA practices by purchasing carbon credits generated from agricultural interventions, thereby linking corporate climate commitments with on-the-ground agricultural transformation.

According to the Verra registry, India currently hosts eight registered agricultural land management projects. Together, these projects claim emissions reductions of approximately 6 million tonnes CO_{2eq} annually (Department of Agriculture and Farmers' Empowerment, 2024; Verra registry, n.d.). These initiatives include interventions such as tree plantations, intercropping, and vermicomposting.

A recent example from Telangana highlights the scalability of CSA-based mitigation. Approximately 35,000 farmers adopted AWD in paddy cultivation across nearly one lakh acres, resulting in methane emission reductions of 6–7 tonnes per hectare per year and the generation of 37,405 carbon credits. The project was implemented in collaboration with Kosher Climate and Sow & Reap Agro (Kurmanath, 2025). Other key initiatives include projects on agroforestry and biochar production from agri-waste, financed by the Asian Development Bank's ReNew Carbon Credits Financing Project.

3.3.2. Green Credit Programme

In addition to carbon markets, India introduced complementary incentive mechanisms such as the GCP, launched during COP28. The programme promotes environmental actions including voluntary tree plantation on degraded lands, water conservation initiatives, and watershed development, implemented through state forest departments (Ministry of Environment, Forest and Climate Change, n.d.). Importantly, BEE has clarified that green credits generated under the Green Credit Rules, 2023, are independent of carbon credits issued under the CCTS, 2023. As a result, the GCP functions as a parallel incentive mechanism rather than a market-based carbon credit system.

3.3.3. Carbon Credit Trading Scheme

India is in the process of establishing the CCTS as a national compliance carbon market. It is expected to be operationalised by 2026. Agriculture has been included in Phase 1 of the offset mechanism under the scheme (BEE) as part of the voluntary offset market. Approved agricultural activities under this mechanism currently include SRI, biochar application, and agroforestry, indicating early recognition of agriculture's mitigation potential within the compliance framework. The next chapter provides a case study with a numerical example illustrating how carbon credits can be generated from CSA practices based on the emissions abated.

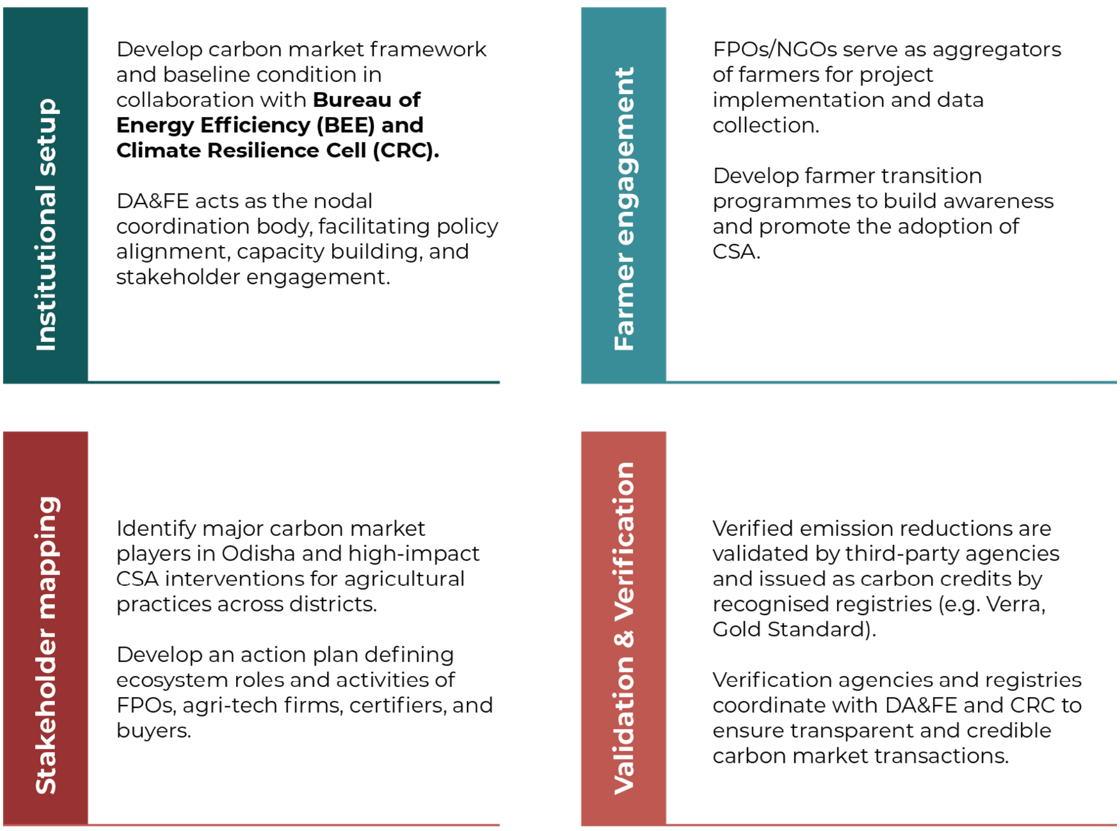
4. Case Study: Carbon Credit Framework for Odisha

4.1. Framework for sustainable rice cultivation in paddy fields in Odisha

Adopting sustainable practices, such as AWD, DSR, and natural farming can significantly reduce GHG emissions from paddy cultivation. However, a comprehensive framework is required to accurately assess, measure, and verify these emission reductions.

This section presents a model (Figure 7) focusing on methane emission reduction from paddy cultivation. Rice-based systems form the backbone of rural livelihoods in Odisha and account for a substantial share of the state's agricultural methane emissions. To illustrate how this model can translate into measurable emission reductions and potential carbon credits, the case study in the next section examines the adoption of AWD in paddy cultivation.

Figure 7: *Model for integration of carbon markets into Odisha's agriculture*



4.2. Case study: Scenario for potential carbon credits through a CSA intervention

Current scenario: This case study evaluates the potential emission reductions and carbon credit generation from adopting AWD in a typical borewell-irrigated paddy cultivation system.

This scenario is particularly relevant to the Puri and Balangir districts of Odisha, where water-intensive paddy cultivation is prevalent and there is significant potential for emission reduction through optimised irrigation management.

Emissions associated with paddy cultivation are classified into two categories:

- On-field emissions: These include methane emissions from flooding, soil drainage, fertiliser and manure application, and fuel consumption.
- Off-field emissions: These include seed production, fertiliser production, and energy use for irrigation.

Most current carbon credit methodologies under VCM frameworks primarily account for on-field emissions. Interventions suitable for this include water management practices such as AWD. Some interventions, such as natural farming, can tackle both on-field and off-field emissions.

4.3. Method for estimating carbon credits from CSA interventions

Table 2 provides the basis for estimating carbon credits generated through the adoption of AWD in paddy cultivation. The emission values are obtained from an earlier study by CSTEP (in press-b). The table also indicates that AWD can reduce emissions by approximately 25% compared to conventional flooded cultivation.

This reduction occurs because AWD uses 25% less water, allowing periodic soil aeration. Improved aeration suppresses methane production (ICAR, 2021).

***Table 2:** Inputs and CSA intervention considered for carbon credits estimation*

Parameter	Flooded cultivation	AWD
Principle	Fields remain continuously flooded. Stagnant water prevents soil aeration, leading to anaerobic microbial respiration that decomposes organic matter and releases methane.	Fields are flooded intermittently, allowing periods of soil aeration. Microbial activity alternates between anaerobic (wet) and aerobic (dry) phases, which suppresses methane production.
Water savings		25% reduction compared to conventional flooded irrigation
Total emissions (kg CO_{2eq}/acre)	4,460	3,325
Overall emission mitigation potential	–	25%

4.3.1. Assumptions

- AWD is practised for one crop cycle (150 days) annually.
- India's Fourth Biennial Update Report to the UNFCCC (BUR-4, 2024) (Ministry of Environment, Forest and Climate Change, 2024) adopts a methane GWP value of 21 kg CO_{2eq}, following earlier Intergovernmental Panel on Climate Change guidelines for national emissions reporting. This analysis adopts a GWP of 33 kg CO_2eq, based on the CSTEP life cycle assessment conducted in SimaPro (CSTEP, in press-b), reflecting a broader accounting of methane's climate impacts.

Methane emissions from AWD fields are lower because periodic drainage allows soil aeration, reducing the anaerobic activity of methanogenic bacteria. This results in significantly lower emissions per acre of paddy field practising AWD. Additionally, the lower electricity requirement for irrigation contributes to lower emissions per acre. The potential on-field emission reduction achieved through AWD is presented in Table 3.

Currently, VCM frameworks consider only on-field GHG emissions when issuing carbon credits. The potential carbon credits generated are calculated based on the tonnes of CO_{2eq} abated. Carbon credit estimates may vary across voluntary carbon market methodologies, as they may use different GWP values for methane. Accordingly, the estimates presented here should be interpreted as indicative.

Table 3: *Potential carbon credits through AWD*

Total GHG emissions under AWD (per acre)	3,325 kg CO_{2eq}
On-field GHG emissions from flooded cultivation (per acre)	1,032 kg CO_{2eq}
On-field GHG emission under AWD (per acre)	611 kg CO_{2eq}
On-field GHG emission reduction through AWD (per acre)	420 kg CO_{2eq}
On-field GHG emission reduction through AWD (per hectare)	1,037 kg CO_{2eq}
Potential carbon credits (per hectare)	1 credit/hectare (on-field emissions only)

Note: Carbon credits are issued in whole units, where 1 credit = 1 tonne of CO_2eq reduced or removed. If emission reductions amount to 1.7 tonnes CO_2eq, the project can claim only 1 credit, while the remaining 0.7 tonne may be carried forward or accounted for in subsequent monitoring cycles, depending on registry rules. For meaningful carbon credit generation, aggregation of land is required. In Table 4, this has been demonstrated by quantifying carbon credits per hectare.

In Puri district, approximately 84,740 hectares of land are cultivated under paddy during the kharif season and 35,420 hectares during rabi. Of these, 28,096 hectares are considered suitable for AWD adoption. If AWD were adopted across this area, approximately 35,500 m^3 of water could be saved and 28,000 carbon credits could be generated annually (CSTEP, in press-a). At current market prices (INR 1,200–2,500), this could translate into annual revenue of INR 3.4–7 crore from carbon credit sales (Department of Agriculture and Farmers' Empowerment, 2024).

The above numbers represent a theoretical reduction of GHG emissions; post-MRV, 80%–90% could potentially be eligible to be availed as carbon credits.

4.3.2. Uncertainty of emissions in field plots

The emission conversion factors used in this analysis are based on BUR-4 (Ministry of Environment, Forest and Climate Change, 2024).

Actual field-level outcomes may vary depending on factors such as soil type, irrigation frequency, crop variety, and local management practices. To validate these estimates and refine region-specific factors, pilot studies across representative agro-climatic zones of Odisha are recommended. These pilots should incorporate real-time monitoring of soil moisture, irrigation energy use, and methane flux to strengthen the MRV framework.

Insights from such pilots can help design scalable, data-driven carbon credit projects for the state.

4.4. Challenges in voluntary carbon markets for the agriculture sector

One of the key challenges in scaling carbon markets in agriculture is the limited adoption of CSA practices among farmers. Many farmers have limited awareness of CSA practices and the potential financial benefits available through carbon markets.

The GHG emissions reduced by an individual farmer are typically low. Most smallholders operate on 1–2 acres, where annual emission reductions per farmer may fall below 1 tonne of CO_{2eq}. If the removed GHG is less than a tonne, no credits can be reaped, making individual participation in carbon markets unviable.

Aggregation models, such as FPOs, clusters, or community-based projects, are therefore essential to achieve marketable volumes of carbon credits.

Farmers or aggregators often need to pay external agencies for verification of emissions reduction through CSA practice, which can be costly. Without government subsidies, carbon funds, or private buyers, these verification costs remain a barrier.

Odisha currently lacks a state-level nodal body or registry to facilitate aggregation, verification, and sale of agricultural carbon credits.

The registration and implementation of VCS projects in India can be time-consuming.

According to the Verra registry database, only 4% of AFOLU projects from India successfully achieved VCS registration.

Manual monitoring of GHG emissions is costly and inconsistent. Developing digital MRV platforms that integrate satellite imagery, internet of things (IoT) sensors, and blockchain-based registries could significantly streamline validation and credit issuance (Cariappa & Krishna, 2025).

Therefore, building carbon market in agriculture will require a coordinated approach involving farmer aggregation, institutional support, and the scaling of CSA practices.

4.5. Co-benefits of GHG reduction in agriculture

GHG mitigation practices in rice cultivation offer several advantages that extend beyond emissions reduction. When farmers adopt CSA practices, such as AWD, DSR, or improved nutrient management, irrigation demand decreases, pumping costs reduce, and soil aeration improves.

These changes also enhance soil quality by increasing soil organic matter, improving water retention, and strengthening overall soil structure. Under AWD, improved soil aeration accelerates organic matter decomposition and enhances nutrient uptake, which supports stronger root growth and improved crop productivity (Nongmaithem et al., 2019; Vetri Selvi et al., 2025).

Higher levels of soil organic carbon and improved soil porosity increase the soil's capacity to retain moisture and nutrients. This reduces dependence on synthetic fertilisers while maintaining or even increasing yields. Such improvements in soil physical and chemical properties help sustain productivity in water-scarce districts such as Nuapada, Balangir, Mayurbhanj, Malkangiri, and Ganjam.

Research indicates that AWD combined with organic amendments can boost nutrient availability and soil carbon levels, resulting in better soil health and higher water use efficiency without yield loss (Haque et al., 2021).

When smallholders aggregate through FPOs, cooperatives, or producer organisations, they can access additional revenue from carbon credits while also benefitting from training, improved technologies, and digital MRV systems. The resulting financial incentives encourage long-term adoption of CSA practices, diversify household income sources, and improve farmers' ability to withstand climate and market shocks.

With adequate policy support and inclusive institutional arrangements, such collectives can also promote social and gender inclusion in agriculture. Examples from Uganda and India show that cooperatives that train women farmers to adopt CSA practices have successfully reduced emissions (Sadiq, 2025).

Thus, carbon mitigation measures in rice and livestock systems can create a virtuous cycle of productivity gains, resource conservation, and economic resilience for farming communities.

5. Conclusion

5.1. Context and key findings

India's agricultural sector plays a crucial role in supporting livelihoods and ensuring food security, but it also contributes substantially to national GHG emissions. Evidence from multiple studies indicates that sustainable practices such as AWD, DSR, and regenerative farming can significantly reduce emissions while enhancing resource-use efficiency. These practices also create opportunities for farmers to generate additional income through carbon markets. However, the integration of agriculture into carbon markets remains at an early stage and is largely confined to VCMs.

The Odisha case study on AWD adoption by CSTEP serves as an exploratory exercise, offering quantitative insights into the potential benefits of carbon market participation. The analysis suggests that AWD can reduce approximately one tonne of CO_{2eq} per hectare per cropping season, translating to around one carbon credit.

While CSA practices demonstrate measurable mitigation potential, their conversion into carbon credits remains constrained by methodological and structural barriers, particularly in smallholder-dominated farming systems.

The experience of the Maharashtra Methane Mission illustrates how technology-enabled MRV platforms can support the monetisation of emission reductions in smallholder systems. Similar digital MRV approaches could be adapted for crop-based CSA practices in Odisha to improve measurement accuracy, reduce transaction costs, enhance transparency in carbon credit generation, and expand farmer participation across diverse agro-climatic zones.

5.2. Implications for carbon markets in agriculture

Agricultural carbon markets rely on three interdependent components: the mitigation potential of agricultural practices; VCMs as a mechanism for monetising emission reductions; and enabling systems that include farmer aggregation, credible MRV frameworks, and supportive institutional arrangements.

Achieving this transition requires targeted policy support, effective farmer aggregation mechanisms, and strong institutional coordination to develop scalable and credible agricultural carbon markets.

5.2.1. Institutional readiness roadmap for Odisha

To operationalise agricultural carbon markets in the state, the following actions are recommended:

- Design a digital MRV system tailored to smallholder conditions, integrating remote sensing, IoT technologies, and data verification tools.
- Facilitate farmer aggregation through FPOs or cooperatives to achieve the scale required for carbon credit generation.
- Promote policy convergence with the DA&FE to streamline project registration, verification, and benefit-sharing mechanisms through technical and financial assistance to farmers.

5.2.2. Pilot recommendations

Pilot projects could be initiated across contrasting agro-climatic zones, such as coastal saline zones and irrigated rice belts, to capture diverse field conditions and establish district-level carbon credit frameworks. These pilots would help validate emission factors, refine institutional coordination mechanisms, and serve as demonstration models for scaling carbon credit projects across the state.

5.2.3. Way forward for agricultural carbon markets in Odisha

Odisha's experience demonstrates that policymakers should view agriculture not only as a source of emissions but also as a strategic sector for climate action. Unlocking its full potential will require a comprehensive framework that integrates the following:

- carbon markets tailored to agricultural contexts,
- widespread CSA adoption, and
- programmes such as the GCP that incentivise sustainable land-use practices.

With effective policy innovation and strong farmer engagement and adequate technical and financial assistance, the state's agriculture sector can improve resource efficiency, reduce emissions, and generate new income opportunities through carbon credit markets.

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7. Annexure

Key Terminology in Carbon Markets

- **Additionality**: A key principle for carbon-offset projects, requiring that the emission reductions achieved are additional to those that would have occurred in the absence of the project. If the project would have been implemented even without carbon finance or policy initiatives, the resulting carbon offsets would not represent genuine emission reductions.
- **Cap-and-Trade (or Emissions Trading System [ETS])**: Under a compliance system, the government or a regulatory body sets an upper limit (cap) on the total amount of greenhouse gases that can be emitted by certain sectors or industries within a specific period, as explained in section 3.1.1. This cap represents the maximum permissible emissions. Companies receive or purchase emission allowances, each corresponding to a portion of the total cap (UNFCCC, n.d.-a). Entities that emit less than their allotted allowances can sell the surplus to others who have exceeded their limits, thereby creating a market for emissions trading.
- **Carbon allowance**: A permit to emit a specific quantity of CO_2 equivalent (CO_{2eq}), issued under a compliance carbon market such as an ETS (UNEP, 2022).
- **Carbon border tax**: A climate-related tariff imposed on imported goods to account for the carbon emissions associated with their production. Such mechanisms aim to ensure that imported products reflect their true carbon cost, thereby protecting domestic industries subject to carbon pricing from unfair competition. An example is the Carbon Border Adjustment Mechanism implemented by the European Union (World Bank, 2025).
- **Carbon credit**: A tradable certificate representing one tonne of CO_{2eq} removed, reduced, or avoided from the atmosphere (UNFCCC, n.d.-d).
- **Carbon leakage**: Carbon leakage occurs when industries relocate their production to countries or regions with less stringent climate policies or when goods and fuels are imported from regions without carbon pricing systems. Although carbon pricing policies aim to reduce global greenhouse gas (GHG) emissions, leakage can shift the emissions from regions with stricter regulations to those with weaker policies. To address this issue, mechanisms such as Carbon Border Adjustment Tax, introduced by the European Union, have been proposed to prevent carbon leakage. Other approaches include providing temporary exemptions for industries at risk of carbon leakage and promoting international cooperation on emission reduction policies.
- **Carbon offset**: An activity that reduces, removes, or avoids GHG emissions and is used to compensate for emissions produced elsewhere (UNFCCC, n.d.-d).
- **Carbon pricing**: Placing a price on carbon emissions to provide financial incentives for businesses and sectors to invest in low-carbon technologies. Two primary approaches are carbon taxation and ETS, also known as cap-and-trade mechanisms (World Bank Group, n.d.). In the agriculture sector, carbon pricing can encourage the adoption of low-emission and climate-smart practices by rewarding farmers and agribusinesses for measurable reductions in GHG emissions and carbon sequestration.
- **Carbon tax**: A carbon tax is imposed on the carbon content of fossil fuels, such as coal, oil, and natural gas. Assigning a price on carbon emissions from these fuels encourages businesses to reduce their carbon footprint and adopt cleaner technologies, renewable energy, and offset mechanisms. The tax is calculated based on the amount of carbon dioxide released when the fuel is combusted. Governments may use the revenue

generated from carbon taxes to fund or subsidise clean energy initiatives (UNFCCC, n.d.-b).

- **Registry**: A database or digital platform that issues carbon credits after verification, tracks their life cycle, and retires them after use (UNFCCC, n.d.-c). Prominent registries include Verra and Gold Standard.
- **Retirement of credits**: When a credit is used (to offset emissions), it is permanently 'retired' from the registry to prevent double-counting.

CSTEP

Center for Study of Science, Technology & Policy

Bengaluru

#18, 10th Cross, Mayura Street, Papanna Layout,

Nagashettyhalli (RMV II Stage),

Bengaluru – 560094, Karnataka, India

Noida

1st Floor, Tower-A, Smartworks

Corporate Park, Sector-125,

Noida-201303, Uttar Pradesh, India

www.cstep.in +91-8066902500 cpe@cstep.in