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AGRICULTURE-BASED OFFSETS FOR VOLUNTARY CARBON MARKETS

Review of current state, Extent of markets, Smallholder and Gender concerns, and Addressing research gaps

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Acronyms

A/R	Afforestation/reforestation
ACCU	Australian Carbon Credit Unit
ACR	American Carbon Registry
AFOLU	Agriculture, Forestry, and Other land Use
BAU	Business as Usual
CAR	Climate Action Reserve
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CDR	Carbon dioxide removal
CER	Certified Emission Reduction Units
CFCs	Chlorofluorocarbons
CH_4	Methane
CIMMYT	International Maize and Wheat Improvement Centre
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide Equivalent
EU ETS	European Union Emissions Trading Scheme
GHG	Greenhouse Gases
$GtCO_2$	Giga tons of Carbon dioxide
$GtCO_2$-eq	Gigatons of CO_2 equivalent
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
IoT	Internet of things
LULUCF	Land use, Land-use Change, and Forestry
MRV	Measuring, Reporting and Verifying
Mt	Mega tons
N_2O	Nitrous oxide
NDC	Nationally Determined Contribution
PES	Payment for Ecosystem Services
REDD+	Reducing Emissions from Deforestation and forest Degradation
SCS	Soil Carbon Sequestration
SDG	Sustainable Development Goal
SF_6	Sulphur hexafluoride
SLM	Sustainable Land Management
SO_2	Sulphur Dioxide
SOC	Soil Organic Carbon
tCO_2-eq	Tons of Carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
USD	US dollar
VCS	Verified Carbon Standard

Abstract

Agriculture and forestry are responsible for 22% of the global greenhouse gas emissions, which makes them crucial for meeting the ambitious carbon reduction targets under the Paris Climate Agreement. While there exist several papers on forestry-based emissions reduction projects, relatively little is known about similar projects in the agricultural sector. Indeed, the last major report on agriculture-based carbon offset projects was published in 2011. We bridge this gap in current knowledge by exploring carbon mitigation efforts in agriculture, especially the growth in the Voluntary Carbon Markets. Our review is based on a careful selection of peer-reviewed literature, international databases, and websites of carbon registries.

Voluntary carbon markets have grown rapidly, transacting 493.1 million tCO2-eq in 2021, valued at nearly $2 billion. Of these, agricultural offsets contributed about 1 million tCO2-eq at an average price of $8.81 per tCO2-eq. There are currently 720 agriculture projects that generated voluntary carbon offsets in the recent past or are still active. Of these, the main ones are methane reduction (331 projects with 16.8 million tCO2-eq emissions reductions), followed by 277 projects on rice cultivation (4 million tCO2-eq). Methane reduction projects have the highest average size of 50,625 tCO2-eq per project, followed by improved irrigation management (28,322 tCO2-eq), solid waste separation (20,322 tCO2-eq), and rice cultivation (14,298 tCO2-eq). Over 90% of projects (648) are 'reduction' projects, while less than 10% (71) combine carbon removal with carbon reduction. China leads with 333 projects, followed by the US (207) and India (59). North America leads in emission reductions (11.1 million tCO2-eq), followed by Asia. Africa has 345,825 tCO2-eq reductions from one project - the Kenya Agricultural Carbon Project. Among carbon registries, 65% of all agricultural offset projects are registered through Verified Carbon Standard, followed by Climate Action Reserve (22%), the Gold Standard (9%), and the American Carbon Registry (4%).

Smallholder farms contribute nearly 32% of agricultural greenhouse gas emissions and are highly susceptible to climate change risks. Carbon offset projects in agriculture have varying local impacts, including positive and negative outcomes. Gender equality is often overlooked in these projects, even though most stakeholders acknowledge its importance. Despite their impressive growth, agricultural carbon offsets represent a small fraction of the overall carbon market, with only 1% of the voluntary and 2.3% of the compliance markets. This is due to the perceived high risks, including concerns about additionality, leakage, permanence, monitoring, and transaction costs. To address these issues, we recommend that projects follow standardized methodologies, collaborate with research institutions, and adopt monitoring innovations. In conclusion, despite its small size, the voluntary carbon market in agricultural offsets plays a vital role by allowing experimentation, enabling participation in jurisdictions without climate regulations, and encouraging smallholders to engage in mitigation efforts.

Keywords: Voluntary carbon markets, agricultural carbon offsets, Smallholders, Gender equality gap, and Sustainability.

Agriculture-Based Offsets for Voluntary Carbon Markets

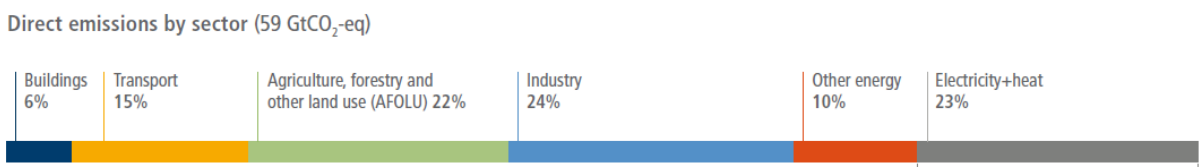
1. Introduction

Natural ecosystems, such as tropical forests, and managed ecosystems, such as agricultural lands, are categorized as the agriculture, forestry, and other land uses (AFOLU) sector under the international climate change negotiations. AFOLU is critical for managing climate change; it is an essential source of GHG emissions and a significant sink for reducing atmospheric emissions (figure 1). In 2019, AFOLU (managed land) contributed 22% of the global GHG emissions (13 $GtCO_2$-eq), placing it third after the energy supply sector (34%) and industry (24%). On the mitigation side, when sustainably managed, AFOLU can generate emission reductions of 8–14 GtCO2-eq per year between 2020 and 2050 (IPCC 2022). Out of this, agriculture (including soil carbon management in croplands and grasslands, agroforestry, and biochar) alone can reduce 1.8–4.1 Gt CO_2-eq per year. These emission reductions will be critical for the global community to keep the average temperature increase below 2^0C or even 1.5^0C, as envisaged under the Paris Climate Agreement (Roe et al. 2019).

While there exist global and even regional reviews of forestry-based emission reduction activities (Jindal et al. 2008; Bayrak et al. 2016; Chagas et al. 2020), such reviews for agriculture-based projects to address climate change are relatively rare. Indeed, the last major paper on emission reduction activities from agriculture was published in 2012 (González-Ramírez et al. 2012). This paper addresses this gap through a comprehensive review of agriculture-based carbon mitigation activities, primarily via the Voluntary Carbon Market (VCM). The main aim is to review current literature (post-Paris Agreement of 2015) on:

"*Voluntary Carbon Markets (VCMs), focusing on agriculture - based carbon credits and how they relate to gender, poverty reduction for smallholders, and other co-benefits.*"

Figure 1: Sectoral Division of GHG Emissions (2019)



Source: IPCC 2022

The rest of the paper is organized as follows: in section 2, we explain our methodology, followed by an introduction to carbon markets in section 3. Section 4 introduces types of agriculture-based carbon offset projects, followed by a more detailed review in section 5. Section 6 focuses on smallholder and gender concerns related to voluntary carbon offset projects. Section 7 discusses the challenges associated with the quality and sustainability of voluntary carbon offsets from agriculture and forestry projects. Section 8 concludes the paper after discussing some crucial aspects of the voluntary carbon markets.

2. Literature Review

Literature on carbon offsets/credits to mitigate GHG emissions is expanding quickly in peer-reviewed papers and as reports and fact sheets published by international clearinghouses. For example, scientific literature on conservation agriculture exists on portals like the Web of Science and research organizations like the International Maize and Wheat Improvement Centre (CIMMYT). However, information on voluntary projects that have sold carbon offsets is available primarily from international organizations such as Ecosystem Marketplace and the World Bank Carbon Finance Group. To systematically review the available literature, the research team identified four key themes for deeper exploration.

2.1 Voluntary Carbon Market (VCM)

VCM is a large and growing collection of sub-markets related to trading offsets from different emission reduction activities, with forestry and land use being the most prominent among them. In 2021, for example, the total value of VCM was about $2 billion, out of which $1.3 billion was transacted in the form of forestry and land use offsets at an average price of $5.80 per ton of CO_2 (Ecosystem Marketplace 2022). The literature for VCM is in the form of peer reviews and reports available through several portals (table 1).

Table 1: Identifying Relevant Studies for Literature Review

Theme	Portals/Repositories	Key Search Items	Additional Inclusion Criteria
1. Voluntary Carbon Market (VCM)	Google Scholar World Bank Carbon Finance Group United Nations CGIAR System (FAO, CIFOR)	“Voluntary”, and “Carbon”, and “Offsets”	Date: 2015 onwards Land use Forests Review papers
2. Smallholder and Gender Issues	Google Scholar Web of Science Scopus Semantic Scholar United Nations CGIAR System (FAO, CIMMYT)	“Gender”, and “Carbon”, and “Offsets”	Date: 2015 onwards Voluntary Agriculture
3. VCM Project Database	Ecosystem Marketplace Plan Vivo Foundation Verified Carbon Standard	“Voluntary”, and “Carbon”, and “Offsets”	Forestry Agriculture
4. Agricultural Carbon Offsets	Google Scholar Web of Science Scopus Semantic Scholar United Nations CGIAR System (ICRAF, CIMMYT)	“Agriculture”, and “Carbon”, and “Offsets”	Date: 2015 onwards Voluntary Wheat Maize Rice Smallholder

2.2 Smallholder and Gender Issues

Agriculture continues to be the primary source of livelihood for rural populations across most developing countries, where the farmers are primarily smallholders. Moreover, women play a massive role in the agricultural sector, which often goes unrecognized (Agarwal et al. 2021). Hence, any review of agriculture-based carbon projects will be incomplete without discussing smallholder and gender concerns, including exploring both positive and negative local impacts of carbon offset projects. Moreover, the effects of climate change are not gender-neutral. Although the literature on gender aspects of agriculture carbon credits is still sparse, we identified studies that have raised or addressed different aspects of this vital theme.

2.3 VCM Project Database

The carbon offset project database is growing rapidly, making it difficult for the peer-reviewed literature to carry the most updated details. Hence, information clearing houses such as Ecosystem Marketplace (https://www.ecosystemmarketplace.com/carbon-markets/), carbon aggregators such as Plan Vivo (www.planvivo.org), and carbon certifiers such as Verified Carbon Standard (https://verra.org/programs/verified-carbon-standard/) are better sources.

2.4 Agriculture Carbon Offsets

An all-encompassing theme, there were two essential issues to consider: (i) While numerous studies assess the feasibility of selling carbon offsets from agriculture, few are based on the actual sale of carbon offsets. (ii) When categorizing sources of carbon offsets, agriculture is often combined with forestry and land use as the AFOLU sector. Within AFOLU, agriculture is still a tiny part of the voluntary carbon market. To address these issues, we first 'cast out net wide' to identify a large set of papers and reports that met our review criteria (see table 1 above), followed by:

(i) **Review of 720 agriculture-based carbon offset projects:** by exploring the extensive database of the Berkeley Carbon Trading Project. Using the database, we identified the main characteristics of agricultural carbon offset projects, their challenges, and potential alternatives to address these challenges. We combine this review with a section on carbon standards that are used globally to address issues regarding the quality of voluntary carbon offsets.

(ii) **Exploration of technological innovation in climate-smart agriculture:** Within the agricultural sector, soil carbon sequestration, improved rice cultivation, and agroforestry are among the main activities with the highest emission reduction potential globally (IPCC 2022). Consequently, there is extensive experimentation and development of new technologies to carry out carbon mitigation using climate-smart agriculture effectively. Although peer-reviewed, most literature in this area pertains to the potential for these technologies in generating carbon offsets rather than the actual generation and sale of offsets in the carbon market. Keeping this gap in mind, we highlight some of the recent work focusing on presenting their main results. We try to balance breadth and depth in the scope of these studies.

The result is one of the most extensive reviews of agriculture-based voluntary carbon offsets worldwide. As far as we know, this is the first such review in more than ten years, the last two global studies on agriculture-based carbon offsets being Foucherot and Bellassen (2011), and González-Ramírez et al. (2012), while a more recent review (Lokuge and Anders 2022) considers only developed countries, such as Canada and Australia.

3. The Paris Agreement and Carbon Markets

The Paris Climate Agreement was adopted in December 2015 under the United Nations Framework Convention on Climate Change (UNFCCC) to keep the increase in the global temperature well below 2 °C above pre-industrial levels and even to attempt to limit the temperature increase to 1.5 °C above pre-industrial levels (Harper et al. 2018). The Paris Agreement is a continuation of global efforts to combat climate change that began with adopting the Kyoto Protocol in 1997 (and through its subsequent ratification in 2005). Currently, 194 parties (193 countries and the European Union) have joined the Paris Agreement, making it one of the most widely adopted international agreements ever.

The Kyoto Protocol and the Paris Agreement include provisions supporting the use of carbon markets to reduce GHG emissions. These markets operate like any other market, with buyers and sellers competing to sell a good or a service and market forces determining the equilibrium price, except that in carbon markets, the good being exchanged is a carbon credit or an offset (right to emit a ton of CO_2- equivalent) (Espelage et al. 2022). While the Kyoto Protocol introduced the Clean Development Mechanism (CDM) through which industrialized countries could finance carbon offset projects in developing countries, the Paris Agreement allows countries to achieve their nationally determined contributions (NDCs) towards emission reductions through internationally transferred mitigation outcomes (IPCC 2022)[1]. As a result, there has been a flurry of activity resulting in carbon markets of various kinds and at different scales of operation, ranging from transnational to national and more localized markets.

3.1 Typology of Carbon Markets

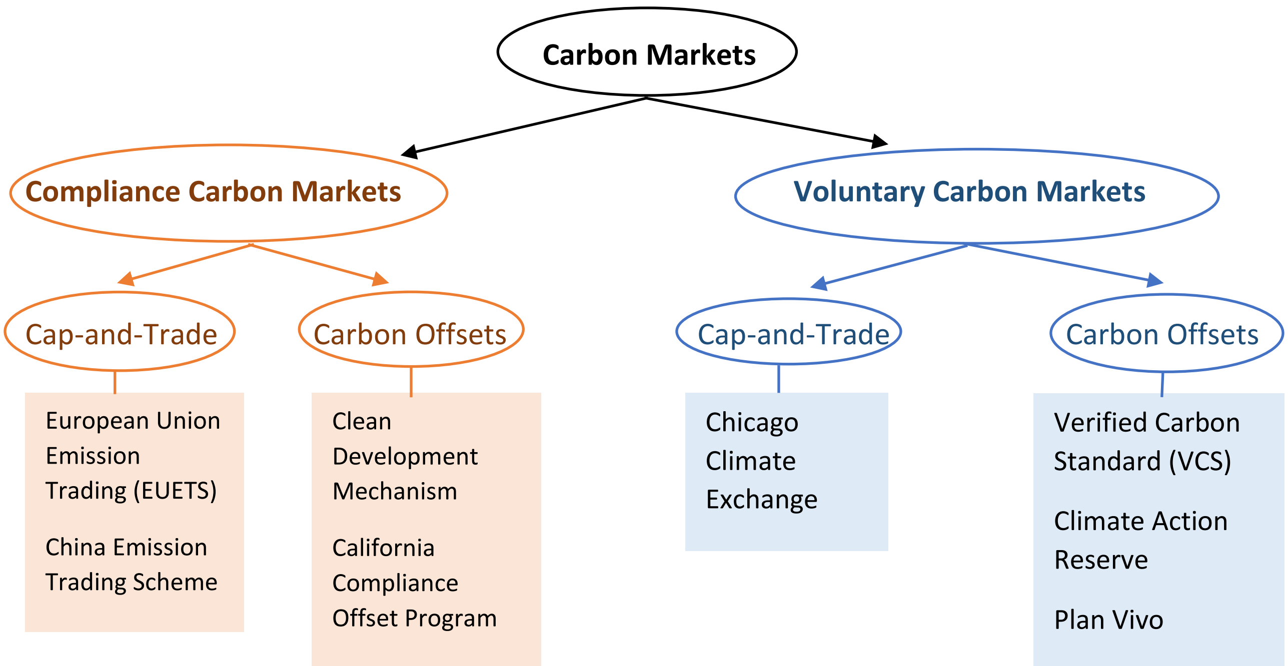
Carbon markets are differentiated by their overall purpose (compliance versus voluntary emission reduction) and the process through which the carbon credits are being generated (cap-and-trade versus carbon offsetting) (figure 2).

Compliance markets originate from government regulation or legislation to reduce GHG emissions within a particular jurisdiction. All specified emitters within this jurisdiction (companies with emissions above a certain threshold or entities within a specific sector, such as power plants) are legally bound to reduce their emissions as per the government notification;

[1] NDCs relate to emission reduction targets developed by each country according to their specific priorities, varying from economy-wide emission reduction targets to sub-national plans and strategies (Pauw et al. 2018). These NDCs will be reviewed every five years to ramp up emission targets progressively over time (Clemencon 2016; Rajamani 2016).

there are heavy fines if these entities fail to comply. Compliance carbon markets have been set up across various jurisdictions worldwide, including the European Union Emission Trading Scheme, the Alberta Emission Offset Program, and the China Emission Trading Scheme. These markets have effectively reduced GHG emissions, although there is also criticism of some programs being too lax in setting emission reduction targets.

Figure 2: Types of Carbon Markets



Source: Adapted from Jindal et al. 2008.

Voluntary markets facilitate the voluntary exchange of carbon credits. Primarily run by nongovernment organizations (NGOs), voluntary carbon markets assist companies and individuals in demonstrating their commitment to mitigate climate change by investing in emission reduction activities that the government does not mandate; the government does not fine companies if they do not meet their commitments. An essential benefit of voluntary carbon markets is that they provide additional funding sources for projects that may not otherwise be viable, such as community-based renewable energy projects or sustainable agriculture interventions. Until its closure in 2010, the Chicago Climate Exchange (CCX) was the biggest voluntary carbon market in the world.

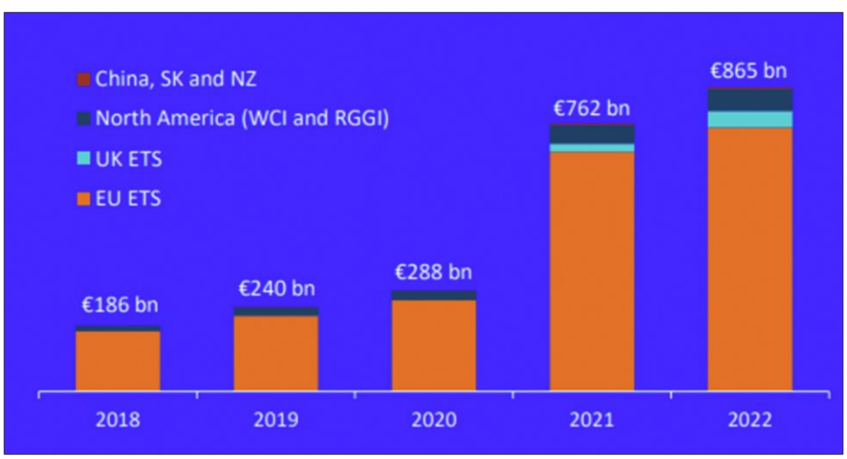
Cap-and-trade mechanism is a market-based mechanism that aims to limit GHG emissions within a given jurisdiction, such as a country or region. Under a cap-and-trade system, the government sets a limit, or cap, on the total amount of GHGs that regulated entities, such as power plants, factories, or airlines, can emit. The cap typically declines over time, which creates a pathway for reducing emissions. Once the cap is in place, the government issues permits or allowances representing the right to emit a certain amount of GHGs (usually in the form tCO_2-eq). These permits are allocated to regulated entities, either for free or through auction, and can be bought and sold among these entities on the market. Regulated entities that emit more than their allotted permits must purchase additional allowances from those that have reduced their emissions below their allocation. This requirement creates a financial incentive for companies to reduce their emissions, as they can profit by selling their excess allowances. The interplay between the supply and demand of permits or allowances sets prices, which typically increase as the cap tightens and emissions become more expensive. The price of emissions encourages businesses to invest in low-carbon technologies, reduce their energy consumption, and develop new business models that rely less on fossil fuels. Although cap-and-trade programs can be administered by non-government or private organizations (as in the case of Chicago Climate Exchange, a voluntary program), governments typically run to address market failures related to GHG emissions, which are seen as public goods.

The carbon offset mechanism helps mitigate the carbon footprint of an entity or activity by reducing GHG emissions elsewhere. The basic idea is that emissions reductions are made in one place to compensate for emissions produced at another location, aiming to achieve net-zero emissions. For example, a company may purchase carbon credits or offsets (as tCO_2-eq) from a renewable energy project that reduces carbon emissions by generating wind or solar power instead of fossil fuels. The company can then use these emission reductions to offset their GHG emissions, such as from running their factories or transporting their goods.

3.2 Growth in Compliance Carbon Markets

The European Union Emission Trading Scheme (EU ETS), set up in 2005, is one of the largest compliance-based carbon markets in the world. It currently covers 31 countries, including all 27 member states of the European Union and Iceland, Liechtenstein, Norway, and Switzerland. Since its establishment, several other carbon markets have been set up across different jurisdictions, ranging from national to sub-national and city-based programs. Prominent among these is the China Emissions Trading Scheme, which operates across several provinces and sectors in China and is the world's largest carbon market in terms of emissions covered (4 billion Mt CO_2-eq per year). The California Cap-and-Trade Program and Regional Greenhouse Gas Initiative (RGGI) are two big cap-and-trade systems within North America.

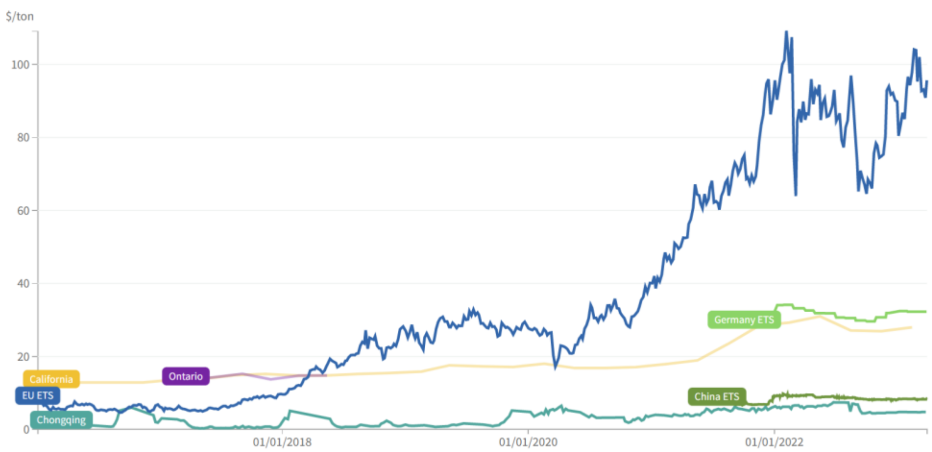
Figure 3: Global Compliance Carbon Markets - Total Value by Segment



Source: Refinitiv 2023 (https://www.refinitiv.com)

In terms of carbon revenue, EU ETS continues to be the leading carbon market in the world, both in terms of average carbon price and the total value of all transactions (figure 3). In 2022, EU carbon credits averaged over $80 per tCO_2e, up 50% from the previous year (figure 4). When accounting for the major markets operating in the world, the global carbon transactions were worth $950 billion, representing a 14% increase from 2021. As countries enact more ambitious climate targets as part of their NDCs under the Paris Climate Agreement, the prices should continue rising.

Figure 4: Price increases in Carbon Markets (2015 to 2023)



Source: ICAP 2023 (https://icapcarbonaction.com/en/ets-prices)

3.3 Growth in Voluntary Carbon Markets

Carbon offsets traded through voluntary carbon markets reached almost $2 billion in 2021, with a cumulative value of over $8 billion (figure 5). In 2021, the average price of voluntary offsets was $4 per tCO_2-eq, representing an increase of nearly 60% since the previous year (Ecosystem Marketplace 2022). Despite this impressive growth, it is worth noting that the total annual trade in voluntary carbon markets is still less than 1% of the value of carbon trading in compliance markets. Moreover, the average price of carbon offsets sold on voluntary markets is much lower than that in compliance markets.

Chicago Climate Exchange, set up in 2003, was the world's biggest voluntary carbon market until its closure in 2010. Since then, many other carbon markets have come up in different parts of the world. Most of these VCMs use a carbon offset mechanism such as the Verified Carbon Standard (VCS), and the American Carbon Registry (ACR)[2].

[2] CCX was an exception. It was one of the few voluntary carbon markets based on a cap-and-trade system.

Figure 5: Growth of Voluntary Carbon Markets

Source: Ecosystem Marketplace 2022

Although voluntary carbon markets are comparatively small compared to compliance-based carbon markets, they are increasingly important due to their flexibility in creating carbon offsets. Ecosystem Marketplace (2022) estimates that in 2020-21 alone, voluntary markets traded in carbon offsets from more than 170 project types. Agriculture offsets commanded the highest average price at $8.81 per tCO_2-eq, while forestry offsets generated the most revenue at $1.33 billion (table 4).

Table 4: Voluntary Carbon Market Size by Category (2020-21)

	2020			2021		
	VOLUME (MtCO2e)	PRICE (USD)	VALUE (USD)	VOLUME (MtCO2e)	PRICE (USD)	VALUE (USD)
FORESTRY AND LAND USE	57.8M	$5.40	$315.4M	227.7M	$5.80	$1,327.5M
RENEWABLE ENERGY	93.8M	$1.08	$101.5M	211.4M	$2.26	$479.1M
CHEMICAL PROCESSES / INDUSTRIAL MANUFACTURING	1.8M	$2.15	$3.9M	17.3M	$3.12	$53.9M
WASTE DISPOSAL	8.5M	$2.69	$22.8M	11.4M	$3.62	$41.2M
ENERGY EFFICIENCY / FUEL SWTICHING	30.9M	$0.98	$30.4M	10.9M	$1.99	$21.9M
HOUSEHOLD / COMMUNITY DEVICES	8.3M	$4.34	$36.2M	8.0M	$5.36	$43.3M
TRANSPORTATION	1.1M	$0.64	$0.7M	5.4M	$1.16	$6.3M
AGRICULTURE	0.5M	$10.38	$4.7M	1.0M	$8.81	$8.7M

Source: Ecosystem Marketplace 2022

4. Agriculture-Based Carbon Offsets

Agriculture-based carbon offsets (or credits) are created through a **reduction** in GHG emissions or **removal** of atmospheric carbon dioxide through carbon sequestration – used to compensate for emissions that occur elsewhere. Once certified by the government or an independent certification body (such as Verra or Plan Vivo), these offsets are sold to other companies or individuals who can use the underlying emission reduction towards their own GHG emissions.

4.1 Lifecycle of Agricultural Carbon Offsets

Production of land-based carbon offsets involves the following key activities in their life cycle (La Hoz Theuer et al. 2023; Broekhoff et al. 2019):

(i) **Methodology development** refers to the specific protocol or rules that determine how and what quantity of carbon offsets will be generated by an emission reduction activity. Both compliance and voluntary markets have a vast array of methodologies already developed for a wide range of project types (see section 4.3). However, new methodologies are being developed every year, sometimes even while projects are being implemented. In some cases, buyers of carbon offsets may also sponsor the development of a new methodology that doesn't exist yet. A critical component of developing a methodology is the creation of a robust **baseline** used to measure emission reductions or the number of carbon offsets to be generated by the project (figure 7).

(ii) **Project development, validation, and registration**: The next step is to develop the project, verify it with a certified agency, and register with a carbon offset program such as a carbon registry. Purchasing options include direct investment in a project or contracting a project developer to deliver carbon offsets.

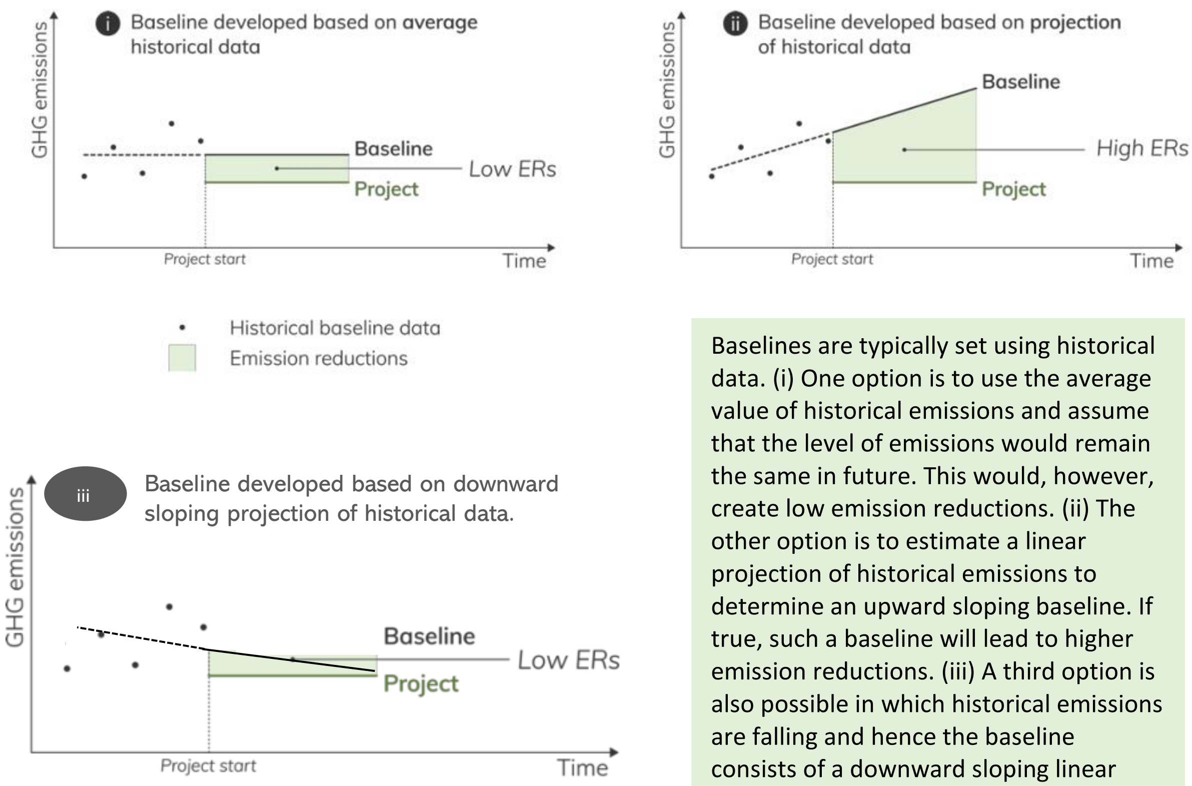
(iii) **Project implementation, verification, and offset credit issuance:** involves implementing activities that result in emission reductions or removals and getting them verified by an independent agency. Once verified, the project can issue carbon offsets, with buyers sometimes purchasing all the offsets from a developer in one transaction.

Usually, each offset represents an emission reduction of one ton of CO_2 or an equivalent amount of other GHGs. In general, agriculture-based carbon offset activities are differentiated based on whether they primarily focus on above-ground or below-ground activities and whether they aim for avoided emissions or carbon dioxide removal (CDR) from the atmosphere (table 6).

Table 6: Differentiation of Agricultural Carbon Offsets

	Avoided Emissions/Reduction	Carbon Removal
Above Ground	• Cover Cropping • Reduced/efficient use of fertilizers	• Agroforestry • Afforestation/Reforestation
Below Ground	• Conservation tillage • Efficient irrigation techniques	• Cover cropping • Nutrient management

Figure 7: Baseline Assessment for Generating Carbon Offsets



Baselines are typically set using historical data. (i) One option is to use the average value of historical emissions and assume that the level of emissions would remain the same in future. This would, however, create low emission reductions. (ii) The other option is to estimate a linear projection of historical emissions to determine an upward sloping baseline. If true, such a baseline will lead to higher emission reductions. (iii) A third option is also possible in which historical emissions are falling and hence the baseline consists of a downward sloping linear projection. Such a scenario will produce very low emission reductions.
Source: Chagas et al. 2020

Above-ground

Avoided emissions: These agricultural practices focus on limiting GHG emissions from above-ground sources, such as by installing methane digesters to manage livestock waste (CRS 2021). Another example is improved livestock management, which involves implementing strategies to reduce methane emissions from enteric fermentation and manure management. Emissions can be minimized by optimizing feed, implementing anaerobic digesters, or modifying grazing patterns, thereby avoiding the release of GHGs into the atmosphere.

Carbon removal: Some agricultural practices aim to actively remove carbon dioxide (CO_2) from the atmosphere by promoting carbon sequestration in above-ground biomass. Agroforestry is an excellent example of this. By integrating trees with crops or livestock, agroforestry systems enhance carbon capture through tree growth and vegetation cover. These systems provide multiple benefits, such as increased biodiversity, improved soil health, and reduced erosion while sequestering atmospheric carbon.

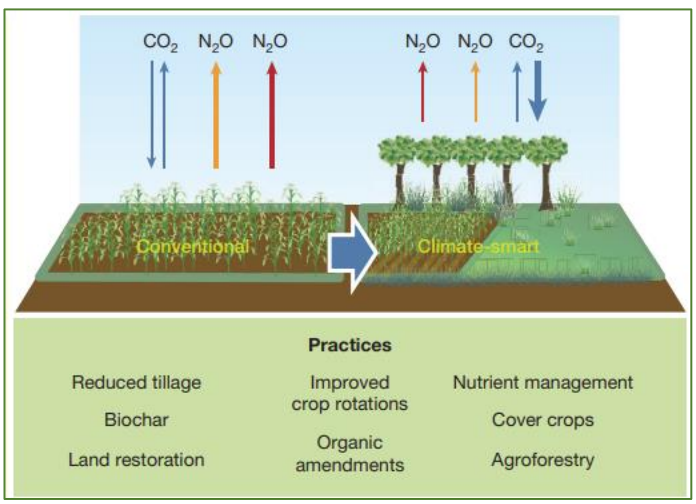
Below-ground

Avoided emissions: These activities concentrate on reducing GHG emissions by targeting below-ground sources, primarily soil management practices. For instance, adopting conservation tillage or no-till practices minimizes soil disturbance during planting, reducing the release of CO_2 into the atmosphere from the decomposition of organic matter. Additionally, implementing efficient irrigation techniques can prevent waterlogging and increase oxygen availability in soils, reducing methane emissions from anaerobic conditions.

Carbon removal: Agricultural activities focusing on below-ground carbon removal typically enhance soil carbon sequestration. One example is the adoption of cover cropping. Farmers can provide continuous root growth and organic matter inputs to the soil by planting cover crops during fallow periods, promoting carbon sequestration (Poeplau Don 2015). Cover crops improve soil structure, water infiltration, and nutrient cycling, contributing to soil health and resilience.

It is important to note that some agricultural practices may involve a combination of above-ground and below-ground carbon offset activities. For instance, a holistic approach to climate-smart agriculture might integrate agroforestry, no-till farming, and cover cropping, collectively addressing avoided emissions and carbon removal from the atmosphere (figure 8).

Figure 8: Climate-smart Agriculture for GHG Mitigation

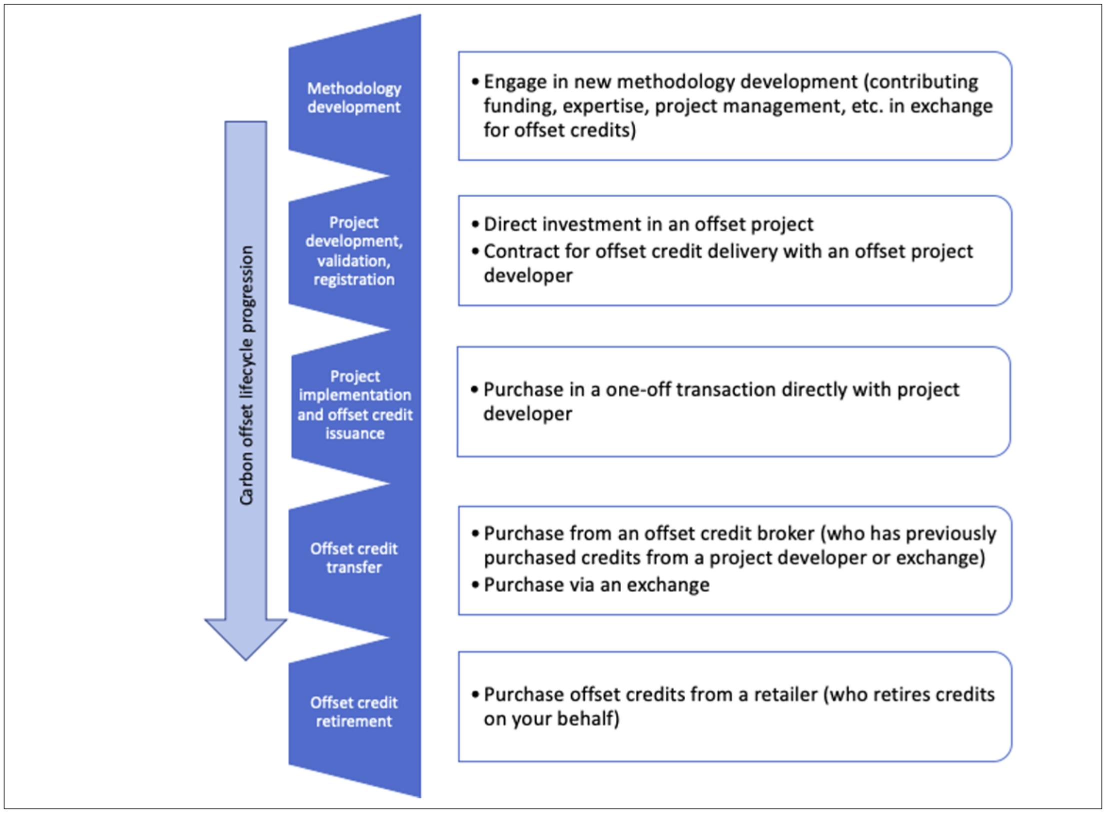


Source: Paustian et al. 2016

(iv) **Offset credit transfer**: After being issued, carbon offsets are recorded in an official registry of the program. Project developers can sell these offsets to multiple buyers through brokers (intermediaries between buyers and sellers) or a carbon exchange linked with the registry (figure 9).

(v) **Offset credit retirement:** Purchasers can retire carbon offsets by using them against their GHG emissions. Buyers who only need small quantities of carbon offsets can purchase them from retailers with access to several projects producing carbon offsets. Once an offset is retired, it can neither be traded nor reused (Broekhoff et al. 2019).

Figure 9: Lifecycle of Carbon Offsets with Purchase Options

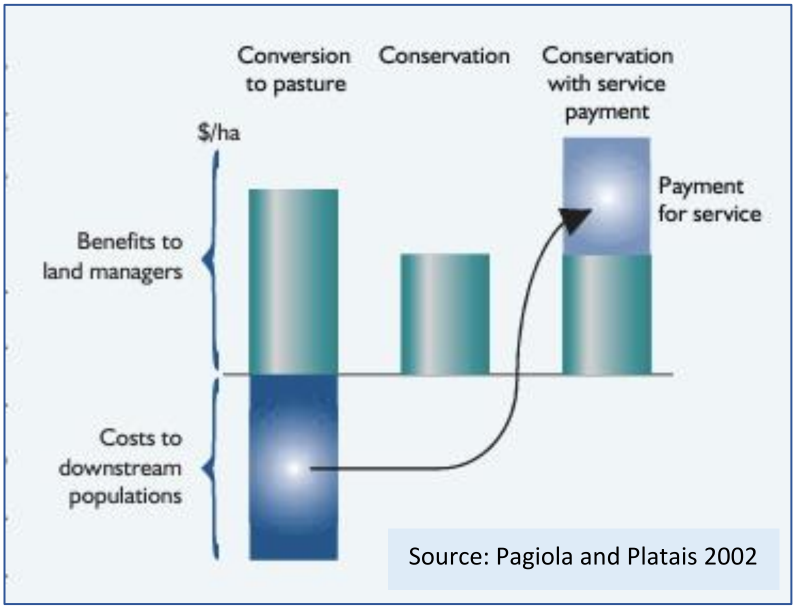


Source: Broekhoff et al. 2019

4.2 Agricultural Carbon Offsets and Ecosystem Payments

Agriculture-based carbon offsets and payments for ecosystem services (PES) share a close relationship as they both involve recognizing and valuing the environmental benefits of land-based activities. Carbon offsets primarily focus on mitigating climate change by reducing or removing GHG emissions from the atmosphere through projects like improved land management. One approach to accomplish this is through PES, which involves users of environmental services paying individuals or communities who produce these environmental services (Jindal et al. 2007). For example, farmers may benefit less from conserving uphill slopes covered by trees than from clearing them and converting them into pastures. However such deforestation releases carbon into the atmosphere and causes ecological damage for the downstream communities (such as excess surface runoff). Payment by downstream communities or companies that need carbon offsets to balance their GHG emissions makes tree conservation more profitable for upstream farmers. According to the logic of PES, this payment should be more than the opportunity cost of upstream farmers and less than the total economic value for downstream communities, such as the cost of using improved technology to directly reduce emissions rather than buying carbon offsets (figure 10). Indeed, a large segment of agriculture and forestry carbon offset projects are based on the PES approach.

Figure 10: Payments for Ecosystem Services



Source: Pagiola and Platais 2002

4.3 Standards for Agriculture-Based Carbon Offsets

Carbon standards provide a framework for ensuring the credibility and transparency of agriculture-based carbon offset projects. They establish clear guidelines for project design, monitoring, reporting, and verification, ensuring the generated offsets are accurate and reliable (Broekhoff et al. 2019). This safeguards against overestimation or double counting of offsets and ensures that the projects contribute to real emissions reductions and climate change mitigation. Standards thus help build trust among stakeholders, including buyers, investors, and regulators, by ensuring that the claimed emissions reductions or carbon sequestration are legitimate and verifiable (CRS 2021). Given the wide range of activities that produce carbon offsets, standards facilitate consistency and comparability across projects, allowing for meaningful project comparisons.

Standards also increase market confidence in agriculture-based carbon offsets, attracting investors and buyers (Lokuge and Anders 2022). A well-established and respected standard assures buyers that the offsets meet rigorous criteria and deliver the expected environmental benefits. This confidence encourages market participation and promotes the flow of finance into agriculture-based offset projects, enabling their scalability and long-term viability (Kreibich and Hermwille 2021). Table 7 summarizes some of the main standards across both the compliance-based markets and the voluntary carbon markets.

Table 7: Standards for Agriculture-based Carbon Offset Projects

Compliance Based Markets	
Standard	***Jurisdiction***
1. Clean Development Mechanism methodologies & standards (CDM)	International
2. Australian Carbon Farming Initiative (CFI)	National
3. Alberta Emission Offset System (AEOS)	Sub-national
4. California Climate Registry (CCR)	Sub-national
Voluntary Carbon Markets	
Standard	***Jurisdiction***
1. Verra Verified Carbon Standard (VCS)	International
2. The Gold Standard (GS)	International
3. American Carbon Registry (ACR)	National
4. Climate Action Reserve (CAR)	Sub-national

4.4.1 Standards for Compliance-Based Markets

The four main carbon standards in the compliance markets are the Clean Development Mechanism, the Australian Carbon Initiative, the Alberta Emission Offset System, and the California Climate Registry:

1. **The Clean Development Mechanism (CDM)** operates globally, a project-based carbon offsetting scheme under the United Nations Framework Convention on Climate Change (UNFCCC). More than 7,800 CDM projects have been developed based on methodologies specific to each sector and project activity. Within the agricultural sector, there are particular methodologies and standards for generating carbon offsets[3]:

    - **AR-AMS3**: is for AFOLU projects, including agricultural activities. It covers a range of project types, such as soil carbon sequestration, agroforestry, and methane capture from livestock or manure management. It provides guidelines on monitoring, reporting, and verifying emissions reductions or removals associated with these activities.

    - **AMS-III.AO**: focuses on "Methane recovery through controlled anaerobic digestion". It provides guidelines for capturing methane emissions from animal waste management systems, anaerobic digestion of agricultural residues, or municipal solid waste treatment.

    - **AMS-III.AU**: provides guidelines for reducing methane emissions from rice paddy fields through alternate wetting and drying (AWD) techniques, intermittent flooding, or other management practices. It covers aspects such as water control, soil moisture measurement, and monitoring of methane emissions.

    - **AMS-III.BE** pertains to " Avoidance of methane and nitrous oxide emissions from sugarcane pre-harvest open burning through mulching," including composting and anaerobic digestion.

[3] CDM is currently in transition, with the Paris Agreement establishing a new mechanism called the Sustainable Development Mechanism (SDM), which will likely build on the experiences and methodologies developed under the CDM while incorporating new provisions and guidance for carbon offset projects (https://cdm.unfccc.int).

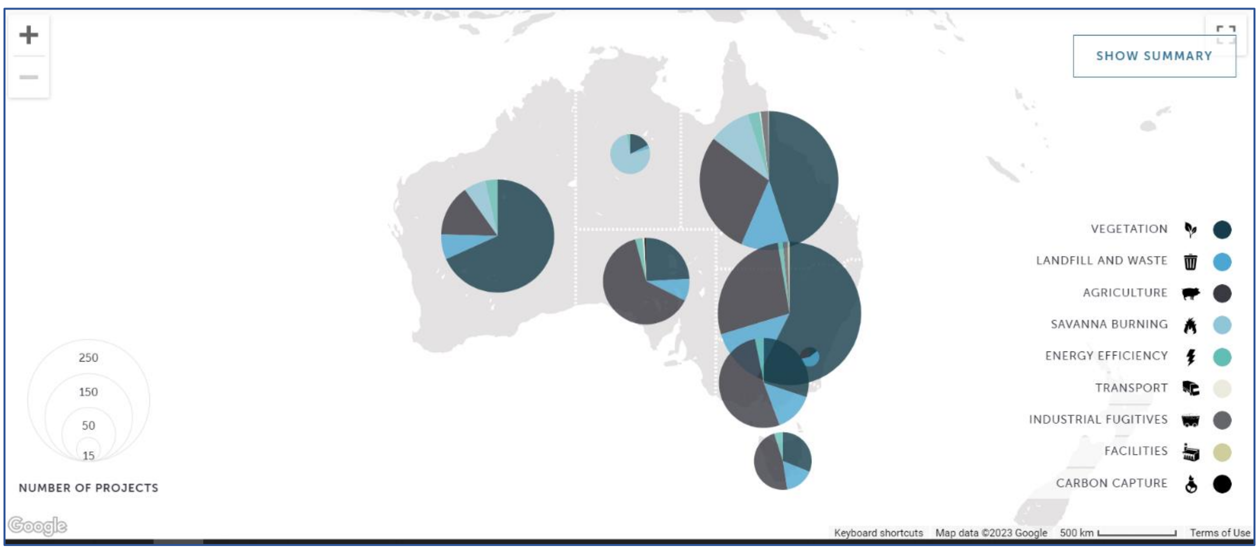
2. **The Australian Carbon Farming Initiative (CFI)** is a national carbon offset scheme that provides opportunities for landholders and farmers in Australia to generate carbon credits known as Australian Carbon Credit Units (ACCUs). Of the 1,532 projects registered under the national emission reduction fund, 484 are related to agricultural activities that have generated 1,984,502 ACCUs based on the following methodologies (figure 11):

    - **Methodology for Savanna Burning**: addresses emissions reduction from savanna fires in northern Australia. Land managers can generate carbon offsets by implementing strategic fire management practices that reduce greenhouse gas emissions from savanna fires. It considers fire frequency, intensity, and timing to calculate emissions reductions.

    - **Methodology for Grazing Land Management**: focuses on improving carbon sequestration in grazing lands, primarily through changes in grazing management practices. It provides guidelines for pasture management, rotational grazing, and soil improvement practices in grasslands and grazing systems.

    - **Methodology for Rice Cultivation**: allows rice farmers to generate carbon credits by implementing practices that reduce methane emissions, such as alternate wetting and drying, intermittent flooding, or water management strategies. The methodology specifies monitoring and reporting requirements to measure emissions reductions accurately.

Figure 11: Agriculture-based Carbon Projects are Located Across Most Australian Provinces



Source: [Interactive Map | Emissions Reduction Fund | Clean Energy Regulator]

3. **The Alberta Emission Offset System (AEOS)** is a sub-national carbon offset program established by the Government of Alberta, Canada. It allows agricultural projects to generate carbon offsets through different protocols[4]:

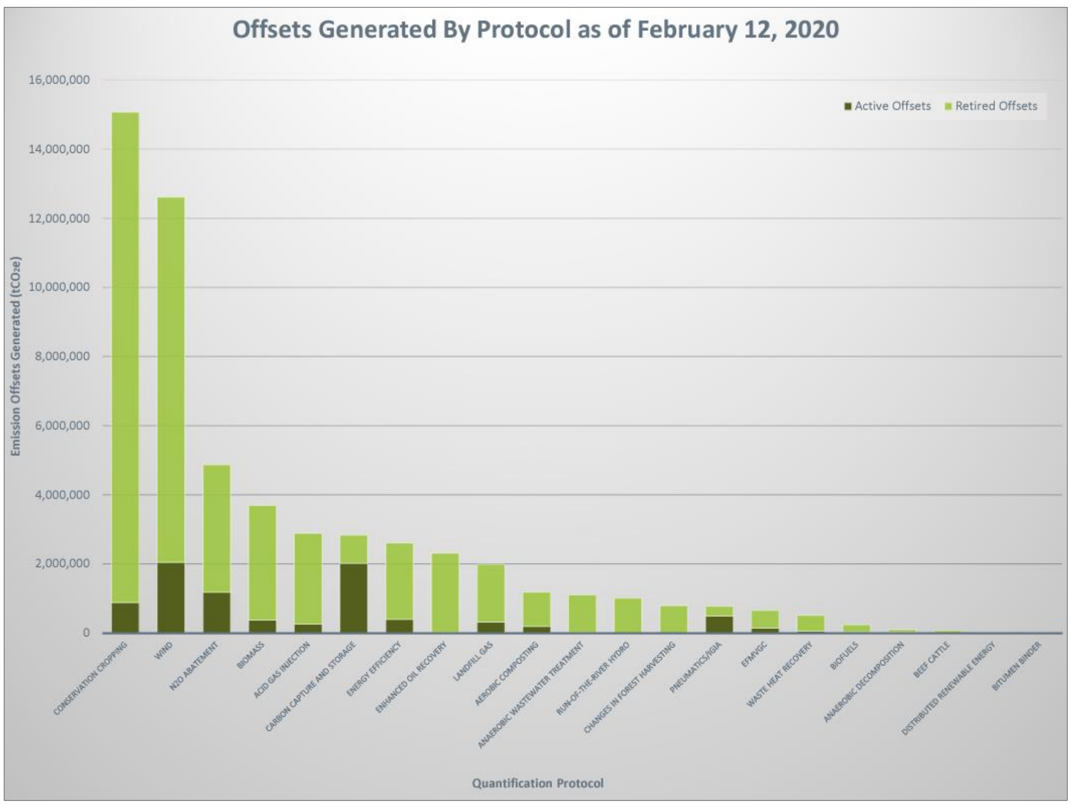
[4] Opportunities to sell carbon offsets from agriculture in both the CFI and the AEOS are restricted to domestic farmers in Australia and Canada respectively. Moreover, carbon offsets under these schemes are produced

- **Conservation Cropping Protocol**: encourages farmers to implement direct seeding, reduced tillage, crop rotation, and cover cropping to improve soil health, increase carbon sequestration, and reduce emissions from soil management. Within the AEOS, conservation cropping is the single most significant source of carbon offsets (figure 12).

- **Methane Emission Reduction Protocol**: provides guidelines for implementing methane mitigation measures, such as anaerobic digestion systems, composting, or improved manure management practices. By reducing methane emissions from livestock operations, farmers can generate carbon offsets.

- **Nitrous Oxide Emission Reduction Protocol**: encourages the adoption of best management practices such as optimized fertilizer application, timing, and placement, as well as the use of nitrogen inhibitors. These practices help minimize N_2O emissions and generate carbon offsets.

Figure 12: Agriculture-Based Carbon Offsets are Prominent in Alberta



Source: https://www.alberta.ca/alberta-emission-offset-system

through agricultural interventions over large tracts of lands, which may not be feasible for smallholders in developing countries who own small, fragmented plots of lands. For these smallholders, voluntary carbon standards are more appropriate (section 4.4.2).
(Lokuge and Anders 2022; https://www.alberta.ca/alberta-emission-offset-system.aspx)

4. **The California Climate Registry (CCR)** is a voluntary GHG reporting program in California, United States, that was established in 2007. Agricultural projects registered with the CCR can sell offsets on the California cap-and-trade program, a domestic compliance-based emission reduction program in California[5]:

   - **Livestock Projects**: aim to reduce methane emissions from livestock operations, primarily focusing on dairy and beef cattle. These projects employ anaerobic digestion, biogas capture, and methane capture covers to capture and reduce methane emissions from manure management systems.

   - **Rice Cultivation Projects**: aim to reduce methane emissions from rice paddies by implementing alternative practices to traditional continuous flooding. Alternate wetting and drying (AWD) or intermittent flooding can reduce methane emissions while maintaining crop productivity.

4.4.2 Standards for Voluntary Carbon Markets (VCM)

Within the Voluntary Carbon Markets, the leading carbon standards are the Verified Carbon Standard (VCS), the Gold Standard (GS), the American Carbon Registry (ACR), and the Climate Action Reserve (CAR):

1. **The Verified Carbon Standard (VCS)** provided by Verra, is one of the most widely recognized and respected voluntary GHG standards for carbon offset projects[6]. More than 1,792 projects are registered with the VCS across 82 countries (table 8). While the VCS does not have specific standards dedicated solely to agriculture-based projects, several VCS methodologies and protocols apply to agriculture-related activities :

   - **Agriculture, Forestry, and Other Land Use Projects**: cover a range of land-based activities, including carbon sequestration in agricultural landscapes, soil carbon sequestration, agroforestry, and reforestation projects.

   - **Livestock Projects**: methodology addresses emissions reductions from livestock-related activities, including enteric fermentation (methane emissions from digestive systems of ruminant animals) and manure management.

   - **Nitric Acid Production Projects**: focuses on reducing emissions from nitric acid production facilities. While not directly related to agriculture, it can be relevant to projects that use nitrogen-based fertilizers in agriculture.

   - **Methodology for Wetland Restoration and Conservation**: guides projects that restore or conserve wetlands, including agricultural ones. It outlines the requirements for baseline establishment, monitoring, and quantification of carbon stock changes resulting from wetland restoration or conservation efforts.

[5] https://theclimateregistry.org/about/#our-story
[6] For more information, see the Verra website at https://verra.org

2. **The Gold Standard (GS)** is a voluntary carbon offset standard that aims to promote high-quality carbon offset projects with substantial environmental and social benefits, such as biodiversity conservation, local stakeholder engagement, gender equality, and sustainable livelihoods. It is a premium standard highly regarded for the co-benefits that carbon offsets projects generate for the local communities[7]. After the VCS, it is the second most prominent standard in VCM, accounting for 1,313 projects registered across 80 countries. While the Gold Standard does not have specific standards dedicated solely to agriculture-based projects, several of its methodologies and criteria apply to agriculture-related activities:

   - **Land Use and Soil Carbon Projects**: focus on projects that enhance carbon sequestration in agricultural landscapes through sustainable land management practices. These methodologies guide soil carbon sequestration, agroforestry, and sustainable agriculture practices.

   - **Biogas Projects**: address projects that capture and utilize agricultural and organic waste methane emissions. These projects can involve installing and operating anaerobic digestion systems, which convert organic waste into biogas for energy generation.

   - **Water Efficiency Projects**: promote enhanced water efficiency in various sectors through water-efficient irrigation systems or practices, including agriculture.

3. **The American Carbon Registry (ACR)** develops and manages offset protocols for various sectors, including agriculture[8]. There are currently 156 projects registered in the US that follow ACR standards. Examples of agriculture-based carbon offset standards include:

   - **ACR Grassland Protocol**: focuses on projects implementing sustainable grazing management practices or conservation activities to enhance grassland carbon storage.

   - **ACR Wetland Restoration and Conservation Protocol**: guides projects that restore or protect wetlands, including agricultural wetlands, to enhance carbon storage and achieve emissions reductions.

   - **ACR Nitric Acid Production Protocol**: focuses on reducing emissions from nitric acid production facilities. Although not directly related to agriculture, this protocol can apply to nitrogen-based fertilizer projects. Adopting advanced production technologies can reduce emissions from nitrogen fertilizer production, indirectly benefiting agricultural emissions.

4. **The Climate Action Reserve (CAR)** is a carbon offset program in the United States that develops and manages offset protocols for various sectors, including agriculture. There are currently 26 projects registered with CAR, many of them related to agriculture-based carbon offset standards:

[7] https://www.goldstandard.org
[8] https://americancarbonregistry.org

- **Rice Cultivation Projects Protocol**: addresses methane emissions from rice cultivation. It guides projects implementing methane reduction practices, such as intermittent flooding, alternate wetting and drying techniques, or other water management strategies[9].
- **Livestock Projects Protocol**: provides guidelines for projects implementing methane capture or reduction practices, such as anaerobic digestion systems, manure management improvements, or biogas utilization.

Table 8: Four Main Carbon Standards in the Voluntary Carbon Markets

Standard	Market Volume (M = million)	Name of credits (Representing 1 tCO2e)	Geographical Scope	Sectoral Scope
Verified Carbon Standard (VCS)	746 M credits, 70.44% share	Verified Carbon Units (VCUs)	1,792 registered projects in 82 countries. VCS is dominant in developing countries.	Covers all project classes.
Gold Standard (GS)	184 M credits, 17.37% share	Verified Emission Reductions (VERs)	1,313 registered projects in 80 countries. Credits are purchased especially by buyers in the European Union.	Covers most project classes, but excludes project-level REDD+. After 2025, will only cover credits backed by **corresponding adjustments**.
American Carbon Registry (ACR)	63 M credits, 5.95% share	Emission Reduction Tons (ERTs)	156 projects in the United States.	Covers industrial processes; land use, land use change and forestry; carbon capture; waste.
Climate Action Reserve (CAR)	66 M credits, 6.23% share	Climate Reserve Tonnes (CRTs)	26 projects in the US. **CAR serves as the Offset Project Registry for California's Cap-and-Trade Program**. CAR is also running a pilot Emissions Trading System in Mexico from 2020-2023.	Covers agriculture and forestry; energy; waste; and non-CO2 GHG abatement.

Source: Streck et al. 2021; www.vcmprimer.org

[9] https://www.climateactionreserve.org

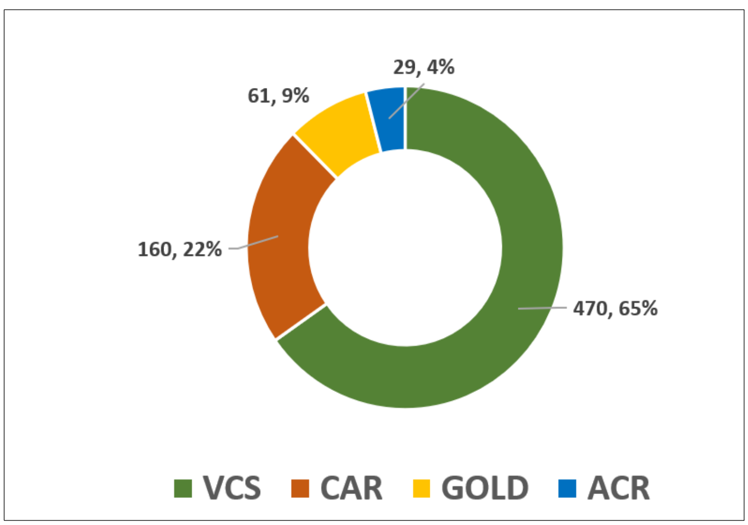
5. Review of Agriculture-Based Voluntary Carbon Offset Projects

This section explores the existing carbon offset projects that are agriculture-based. Our focus is on the voluntary carbon market and, within it, the four leading standards: the American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard (GS), and Verified Carbon Standard (VCS)**.** These four registries generate almost all of the world's voluntary market offsets and include projects eligible for use under the California / Quebec linked cap-and-trade programs and UN Clean Development Mechanism projects that transitioned into one of the voluntary registries. The section is based primarily on the database maintained by the Berkeley Carbon Trading Project[10].

5.1 Voluntary Carbon Standard (VCS) Leads the Way

Within the Voluntary Carbon Market (VCM), there currently exist 720 agriculture-based projects that either produced carbon offsets in the recent past or continue to do so. This number does not include carbon offset projects from the forestry sector (such as REDD+ or afforestation and reforestation activities). However, some agricultural projects may consist of forestry activities. In terms of the distribution of the projects concerning voluntary standards, it is the Verra-run VCS that leads the way with 65% (470 out of 720 projects) of all agricultural carbon offset projects (figure 13), followed by CAR (22% or 160 projects), GS (9% or 61 projects), and ACR (4% or 29 projects). These numbers indicate that VCS is a quality standard accepted globally and includes versatile methodologies for various projects.

Figure 13: Agricultural Voluntary Carbon Offset Projects By Standard/Registry



Since their inception in the early 2000s and until the end of 2022, agricultural carbon projects produced emission reductions of nearly 22 $MtCO_2$-eq (table 9). Despite impressive growth, these offsets only represent a tiny segment of the entire carbon market.

[10] https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project

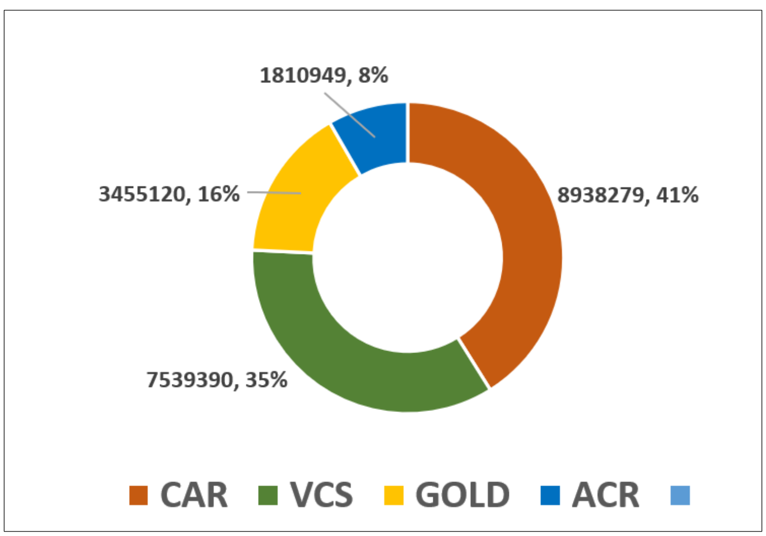
Table 8: Distribution of Agricultural Voluntary Carbon Offset Projects

Registry/ Standard	Number of Projects	Carbon Offsets Issued	Average Size (Offsets Issued/Project)
CAR	29	8,938,279	308,217
VCS	160	7,539,390	47,121
GOLD	61	3,455,120	56,641
ACR	470	1,810,949	3,853
Total	**720**	**21,743,738**	**30,200**

Source: Berkeley Carbon Trading Project. The database is cumulative until 2022.
ACR = American Carbon Registry CAR = Climate Action Reserve GS = Gold Standard
VCS = Verified Carbon Standard. Each carbon offset = 1 t CO_2-eq

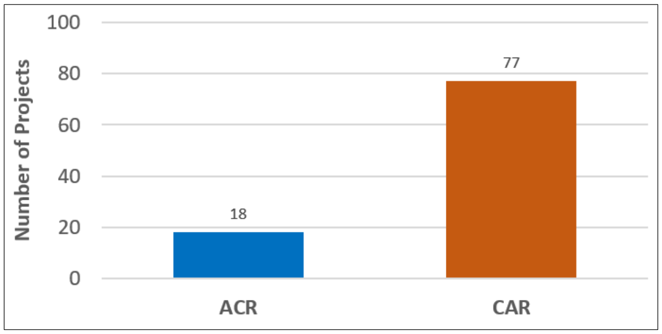
Compared to the overall voluntary carbon market, the distribution of agricultural carbon offset projects is quite different (figure 14). In the voluntary carbon market, VCS leads (68.5% or 520 MtCO2-eq), while for agricultural projects, CAR is ahead with 41% of the total carbon offsets issued (8.9 $MtCO_2$-eq). This is followed by VCS (35%), GS (16%), and ACR (8%). CAR, on the other hand, generates an emission reduction of 308,217 tCO_2-eq per project, which is more than five times the average size of GS projects (56,641 tCO_2-eq per project), and VCS (47,121 tCO_2-eq), and almost ten times the average size of ACR projects (3,853 tCO_2-eq). This is because nearly all projects registered with CAR focus on manure methane digesters located in the US, which are typically large (table 9). In contrast, GS-registered projects include sustainable agriculture and improved irrigation projects located in developing countries, where the average size of emission reductions per project is comparatively much lower.

Figure 14: Agricultural Carbon Offsets Issued by Standard/Registry



Many VCM projects are complaint with California Air Resources Board (ARB) which registers and approves offset projects for the California cap-and-trade emission reduction program. Out of 720 agriculture-based carbon offset projects, about 13% (95) are complaint with ARB standards. Most of these are CAR (77 projects), followed by ACR-registered projects (18) (figure 15).

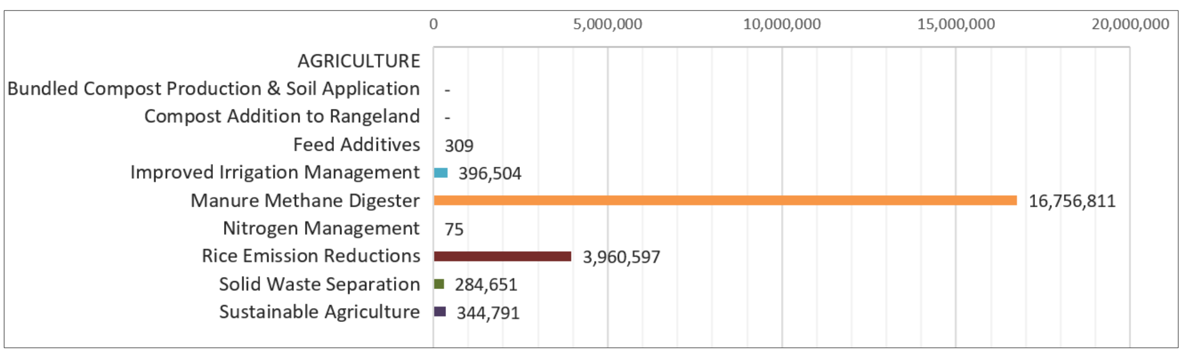
Figure 15: Air Resources Board Compliant Projects



5.2 Two Main Sub-sectors: Methane Digesters and Rice Emissions

In agricultural projects, manure methane digesters and rice emission reductions are most prominent in terms of the number of projects and carbon offsets issued (figure 16). Out of 720 projects, 331 projects related to methane digesters have issued 16.8 MtCO_2-eq of emissions reductions, followed by 277 projects that have generated almost 4 MtCO_2-eq of emissions reductions from improved rice cultivation methods. This is followed by improved irrigation management (14 projects with an emission reduction of 396,504 tCO_2-eq) and sustainable agriculture (69 projects; 344,791 tCO_2-eq of emission reductions). These data indicate that the technology related to methane digesters and improved rice management is relatively easier to adopt than other technologies in the agricultural sector.

Figure 16: Methane Digesters Generate the Most Carbon Offsets

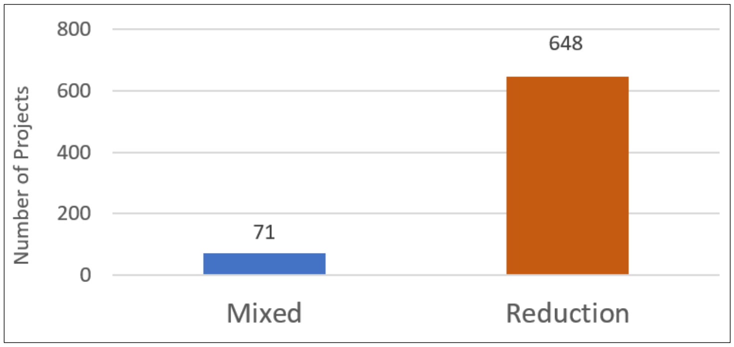


Source: Berkeley Carbon Trading Project
Each carbon offset = 1 t CO_2-eq

5.3 Reductions versus Removals

More than 90% of projects (648) are carbon reduction projects, while less than 10% (71 projects) achieve some carbon removal (figure 17). While some projects only remove carbon, most removal projects are "mixed" - combining carbon sequestration with emission reduction activities. These are almost all sustainable agriculture projects which include conservation measures that both reduce and remove atmospheric carbon.

Figure 17: Agricultural Projects Focus on Emissions Reductions



5.4 Unequal Distribution by Location

Agricultural carbon projects have a skewed distribution when it comes to geographical location. Out of the 720 projects, China leads the way with almost 50% share (333 projects), followed by the US (207 projects) and India (59 projects), respectively (figure 18). This is unsurprising, considering all three are large countries with well-evolved agricultural sectors. Furthermore, many voluntary carbon registries, such as ACR and CAR, are located in the US, which makes it a prime player in the agricultural carbon offset market.

Figure 18: Global Distribution of Agricultural Carbon Projects

Source: Berkeley Carbon Trading Project

As a result, Asia (East Asia, South Asia, and South East Asia) as the highest concentration of agriculture-based voluntary carbon offset projects, followed by North America. In terms of the number of carbon offsets generated, North America leads the way with 11.1 $MtCO_2$-eq of emission reductions, followed by Asia (figure 19). Africa is far behind, with all its emissions reductions (345,825 tCO_2-eq) from the Kenya Agricultural Carbon Project (Nyberg et al. 2020.

Figure 19: Regional Distribution of Agricultural Carbon Projects

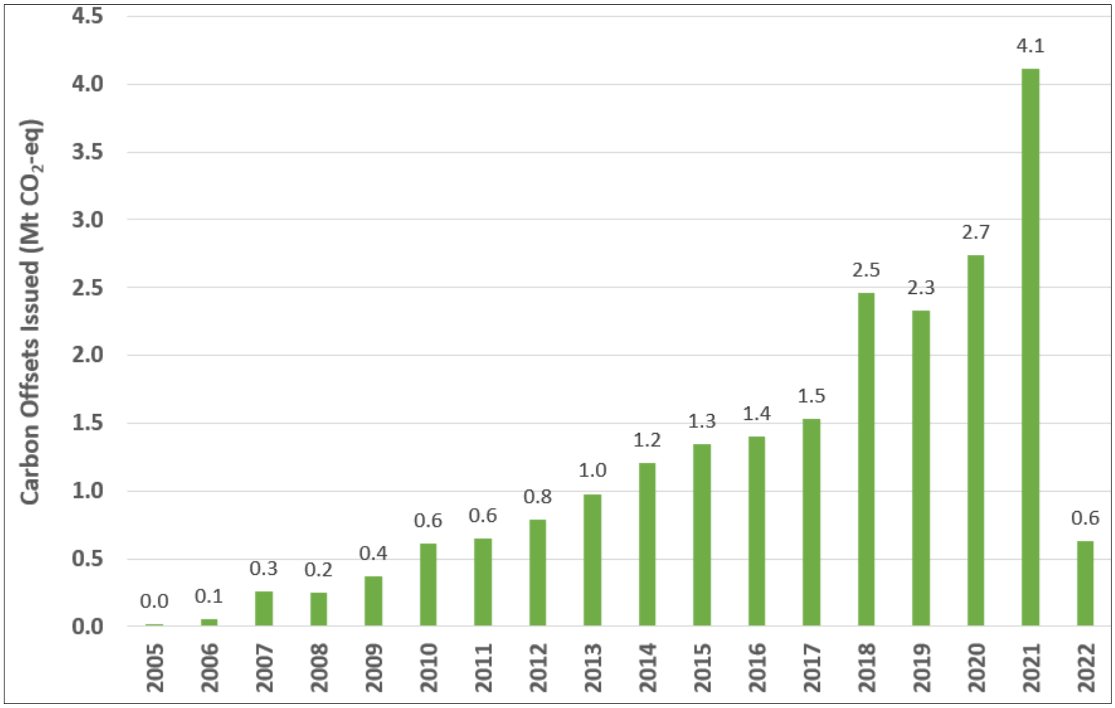
Source: Berkeley Carbon Trading Project

Although Canada and Australia have the highest concentration of agricultural carbon offset projects for the compliance market, they do not play a significant role in voluntary markets. This is probably because landowners in both these countries have access to compliance markets where the prices of carbon offsets are usually much higher than those on the VCMs.

5.5 Growth of the Agricultural Carbon Projects

Since 2005, when agricultural carbon offsets were first traded in VCMs outside of the Chicago Climate Exchange, there has been a steady increase in offsets every year (figure 20). The annual number of carbon offsets issued from agricultural activities first crossed a million in 2013. Since then, the number of offsets has increased every year except in 2019. In 2019, agricultural projects generated emissions reductions of 2,331,384 tCO_2-eq, followed by 2,739,023 tCO_2-eq in 2020. The following year (2021) was the first time the agricultural projects crossed the threshold of 4 $MtCO_2$-eq, achieving emissions reductions of 4,111,899 tCO_2-eq. Given this impressive growth in voluntary carbon offsets from agriculture conservation projects, the market will likely expand further in the coming years and add newer sub-sectoral categories.

Figure 20: Growth of Agriculture-based Carbon Offset Projects



Source: Berkeley Carbon Trading Project

5.6 Further Experimentation in Agriculture-Based Emissions Reduction

The agricultural sector is both a source and sink of GHG emissions in the form of carbon dioxide, methane, and nitrous oxide. Croplands emit CO_2 through mainly deforestation and oxidation of soil organic matter. The primary sources of CH_4 are enteric fermentation from ruminant animals and rice cultivation. N_2O emissions are from manure application, nitrogen deposition, and fertilizer use in agricultural activities. Agriculture also has a significant mitigation potential of 4.1 $GtCO_2$-eq per year up to $100 per tCO_2-eq, about one-third of the technical potential (IPCC 2022).

Table 9: Annual Mitigation potential of the Agriculture Sector ($GtCO_2$-eq per year) by carbon price (2020-50)

Mitigation Option	<$20 per tCO_2-eq/year	<$50 per tCO_2-eq/year	<$100 per tCO_2-eq/year	Technical
Agriculture – Carbon sequestration: (soil carbon in croplands and grasslands, agroforestry, and biochar)	0.5 (0.4–0.6)	1.2 (0.9–1.6)	3.4 (1.4–5.5)	9.5 (1.1–25.3)
Agriculture – Reduce CH_4 and N_2O emissions: (manure & nutrient management, rice cultivation, improved enteric fermentation)	0.4 (0.1–0.8)	0.4 (0.1–0.8)	0.6 (0.3–1.3)	1.7 (0.5–3.2)
Total Agriculture	**0.9 (0.5–1.4)**	**1.6 (1–2.4)**	**4.1 (1.7–6.7)**	**11.2 (1.6–28.5)**

Source: Jia et al. 2019; Roe at al. 2021; IPCC 2022

Although there has been impressive growth in the number and scope of agriculture-based carbon offset projects over the last two decades, they only cover a tiny percentage of the technical potential of the agricultural sector to mitigate GHG emissions. Hence, scientists are developing newer technologies that help reduce carbon emissions via climate-smart agriculture. Many of these technologies are still experimental and have not resulted in real, verifiable carbon offsets for compliance-based or voluntary carbon markets. Nonetheless, these innovations or technologies provide appropriate options for project managers and field-based practitioners looking for ideas to create agriculture-based carbon offsets that are economically feasible, especially for smallholders in developing countries.

5.6.1 Experiments on Soil Carbon Management

Improved management of soils can produce both avoided emissions and carbon dioxide removal (CDR) from the atmosphere. The global soil carbon (C) pool, estimated to be around 2500 Gt C (Giga tons of Carbon) [11], with 1500 Gt C in the form of soil organic carbon (SOC), is approximately 3.2 times larger than the atmospheric pool and four times larger than the biotic pool (Lal 2010). Zomer et al. (2017) estimate that croplands worldwide could sequester between 0.90 and 1.85 Gt C per year, equivalent to 26-53% of the target of the 4p1000 initiative to sequester approximately 3.5 Gt C annually in soils. Based on a meta-analysis of 90 case studies, Maucieri et al. (2021) show that no-tillage significantly decreases CH_4 emissions from paddy fields, from 12.39 to 9.55 mg m^{-2} h^{-1}, but a non-significant tendency to increase CH_4 emissions in maize-cultivated fields. Overall, they prove that no-tillage can effectively reduce soil CH_4 emissions in rice production or other production systems that use flooded soils, but not in the case of dryland crops (table 10). Zhao et al. (2015) conducted a meta-analysis of 83 studies from China to reveal significant increases in soil organic carbon (SOC) concentration and stocks at the 0-30 cm depth range when transitioning from plow tillage with residue removal to no-till with residue retention (NT). Payen et al. (2021) indicate how soil carbon sequestration (SCS) practices can produce a SOC sequestration rate of 7.53 Mg CO_2-eq. ha^{-1} yr^{-1} in vineyards up to a soil depth of 30 cm.

Simwaka et al. (2020) assess the impacts of conservation agriculture (CA) and traditional tillage on soil organic carbon (SOC) and selected hydraulic properties in two distinct agro-ecological zones of Malawi. Results showed that CA significantly improved total SOC, carbon stocks, and the stable fraction of particulate organic carbon (POMP) compared to traditional tillage. Similarly, O'Dell et al. (2015) show how winter cover crops can sequester carbon and reduce emissions during the non-growing season. The micrometeorological methods employed in this study detected significant differences between treatments within a few months, providing insights into smallholder soil management practices. Haque et al. (2015) find that maintaining current SOC levels requires incorporating more than 30% of the cover crop's aboveground biomass (3.4-3.6 Mg ha^{-1}, dry weight) as green manure in mono-rice cultivation systems with chemical fertilization. Similarly, Naresh et al. (2016) examine the impact of different tillage, crop residue, and irrigation combinations on SOC in a wheat monoculture under subtropical climatic conditions. Their results reveal significant improvements in water-stable aggregates due to tillage, crop residue, and better irrigation practices.

[11] 1 t C = 3.67 t CO_2 (1 ton of carbon = 3.67 tons of carbon dioxide)

Table 10: Experimentation in Soil Carbon Management

	Author/s	Details/Measures	Location	Outcome/Main Results
1.	Zomer et al. 2017	Literature review, satellite imagery	Global	Croplands worldwide could sequester significant amounts of carbon every year.
2.	Maucieri et al. 2021	Meta-analysis of 90 case studies	Global	No-tillage can reduce soil CH_4 emissions in rice production but not in dryland crops.
3.	Zhao et al. 2015	Meta-analysis of 83 studies	China	Increases in soil carbon at the 0-30 cm depth range when transitioning from plow tillage with residue removal to no-till with residue retention can be further enhanced by combining with manure application.
4.	Payen et al. 2021	Meta-analysis	Global	Improved soil management in vineyards resulted in an average increase in carbon sequestration rate up to a soil depth of 30 cm. The highest sequestration rate was observed in vineyards with organic amendments and no-tillage.
5.	Simwaka et al. 2020	Trials on farmers' fields	Malawi	Transitioning from traditional tillage with continuous sole maize to conservation agriculture improves soil organic matter and hydraulic properties. Recommends farmers to minimize tillage, retain crop residues as mulch, and practice crop rotation.
6.	O'Dell et al. 2015	Experiment at CIMMYT research station	Zimbabwe	Winter cover crops can sequester carbon and reduce emissions during the non-growing season. Micrometeorological methods can provide insights into smallholder soil management practices within a short period.
7.	Haque et al. 2015	Experiment plots on a university research farm	South Korea	Maintaining current SOC levels requires incorporating more than 30% of the cover crop's aboveground biomass as green manure in mono-rice cultivation systems with chemical fertilization.
8.	Naresh et al. 2016	Trials on a university research farm	India	Conservation tillage practices can increase SOC stocks in sandy loam soils under subtropical climatic conditions.
9.	Wegner et al. 2018	Experiment on an agricultural research station	USA	For both corn and soybean, the residue-returned intervention reduced CO_2 and N_2O fluxes compared to the residue not returned intervention.
10.	Tadesse et al. 2021	Household survey with 245 farmers, along with soil samples from fields	Ethiopia	Climate-smart agriculture practiced over ten years increased wheat yields and stored more carbon in the soil.
11.	Hou et al. 2022	Field trials on experimental plots	China	Even though the green manure amendment is a beneficial practice for enhancing carbon sequestration, it cannot replace the critical role of nitrogen fertilizer in rice production.
12.	Sapkota et al. 2017	Trials on a university research farm	India	Combining zero-till and partial residue retention can increase biomass production, allowing for enhanced SOC while utilizing residues for other purposes in rice-wheat rotations.

Wegner et al. (2018) show that the residue-returned treatment significantly reduces cumulative CO_2 and N_2O fluxes for corn and soybean compared to residue-not-returned. Tadesse et al. (2021) conducted a survey with 245 households to indicate that over ten years of climate-smart agriculture (installing soil and water conservation structures in conjunction with biological measures, hedgerow planting, crop residue management, grazing management, crop rotation, and agroforestry systems based on perennial crops) led to higher what yields, enhanced soil fertility, and more carbon sequestration. Hou et al. (2022) suggest that green manure amendment enhances carbon sequestration without causing a substantial increase in paddy CH_4 emissions. However, green manure amendment cannot replace the critical role of nitrogen fertilizer in rice production. Similarly, Sapkota et al. (2017) conducted measurements of SOC concentrations after seven years of rice (*Oryza sativa L.*)–wheat (*Triticum aestivum L.*) rotations in the eastern Indo-Gangetic Plains (IGP) of India. The study focused on various combinations of tillage and crop establishment methods. Their findings suggest that combining zero-till and partial residue retention can increase biomass production, allowing for enhanced SOC while utilizing residues for other purposes.

It is important to note that even though many of these studies find a beneficial relationship between improved soil management and sequestration of atmospheric carbon, carbon storage time scales can range from decades to centuries. Hence, many scientists question the feasibility of accurately measuring changes in soil carbon on shorter time scales as required by carbon offset projects (Bradford et al. 2019). Moreover, maintaining the permanence of carbon stocks created via such carbon offset projects requires continuing the same land use patterns for a long time, severely restricting future land use options.

5.6.2 Experiments on Wheat-Maize Systems

Both wheat and maize are important food crops globally. To investigate strategies to reduce GHG emissions from maize, Zhao et al. (2017) evaluate two economic and two environmental Nitrogen (N) fertilizer rate reduction strategies (table 11). They highlight the inherent tension between achieving agronomic and financial goals while reducing GHG emissions, a factor often overlooked in policy discussions. Yang et al. (2014) find that appropriately diversified crop rotation systems can reduce carbon footprints compared to conventional intensive crop production systems. Similarly, Cui et al. (2019) assessed the carbon emissions of five maize-based systems in China. Their findings suggest that maize-soybean intercropping and maize-potato relay cropping result in lower carbon emissions than mono-cropped maize.
Similarly, Kumar et al. (2018) show that diversifying cereal-based cropping systems and integrating them with precision resource management can improve yields, reduce irrigation water use and energy consumption, and lower global warming potential (GWP). Chaudhary et al. (2017) highlight the influence of organic manure selection on the stability of SOC, emphasizing the importance of considering the long-term carbon sequestration potential when choosing organic manure options. Millar et al. (2018) assess the trade-offs between Nitrogen (N) fertilizer inputs, spring wheat yields, and N_2O emissions. Their results suggest that reducing N fertilizer rates to the optimum economic levels can mitigate N_2O emissions equivalent to 0.5 to 0.8 Mg CO_2-eq ha^{-1} yr^{-1} or 84-138 Gg CO_2-eq yr^{-1} at a regional scale without compromising yields.

Table 11: Experiments on Wheat-Maize Systems

	Author/s	Details/Measures	Location	Outcome/Main Results
1.	Zhao et al. 2017	Trials on farmers' fields	USA	Highlights the inherent tension between achieving agronomic and economic goals while reducing GHG emissions.
2.	Yang et al. 2014	Experiment on plots set up at a science research station	China	Diversified crop rotation systems can contribute to reduced carbon footprints compared to conventional intensive crop production systems.
3.	Cui et al. 2019	Trials on plots set up at an agricultural experiment station	China	Maize-soybean intercropping and maize-potato relay cropping result in lower carbon emissions as compared to mono-cropped maize.
4.	Kumar et al. 2018	Experimental plots on an agricultural research station	India	Diversifying cereal-based cropping systems and integrating them with precision resource management can improve yields and reduce emissions.
5.	Chaudhary et al. 2017	Research trials on an agricultural university campus	India	Highlights the influence of organic manure selection on the stability of SOC in rice-wheat systems.
6.	Millar et al. 2018	Trial plots on the CIMMYT experiment station	Mexico	Implementing reduced Nitrogen fertilizer rates can result in substantial reductions in agricultural GHG emissions, increased income for farmers, and sustained high productivity of spring wheat.

5.6.3 Emissions Reductions from Rice Cultivation

Rice is a staple food for more than half of the world's population, with Asia as the foremost producer globally. Bharali et al. (2021) study the significance of *Azolla caroliniana*-compost (AC) as a component of integrated nutrient management in comparison to other organic inputs (green manure (GM), rice husk dust (RHD), and cow dung (CD)) in two rice ecosystems (irrigated and rainfed) in India (table 12). They find AC and RHD promising options for sustainable rice cultivation in subtropical regions, offering low methane emissions and high productivity. Xu et al. (2022) investigate the efficacy of the ratoon rice (RR) system as an alternative to the double-season rice (DR) system in China. Their results show that RR had a 27.37% lower annual carbon footprint compared to DR. Gathorne-Hardy et al. (2016) analyze the System of Rice Intensification (SRI) in comparison to conventional flooded-rice production systems (control) in India. Their findings show that SRI resulted in higher yields while reducing GHG emissions, groundwater usage, and fossil energy consumption. However, these benefits primarily accrued to landowners at the expense of landless laborers (especially women laborers) as demand for wage labor went down.

Arianti et al. (2022) find that the Inpari 20 rice variety exhibits significantly higher productivity and lower CH_4 emissions than the Inpari 30 and Ciherang rice varieties. Janz et al. (2019) demonstrate how rice-maize cropping systems have low yield-scaled GWPs and irrigation water demand compared to aerobic rice and double-rice cropping systems, respectively.

Table 12: Emissions Reductions from Rice Cultivation

	Author/s	Details/Measures	Location	Outcome/Main Results
1.	Bharali et al. 2021	Experiments on a university campus	India	*Azolla caroliniana*-compost and rice husk dust can reduce CH_4 emissions and increase productivity for rice cultivation in subtropical regions.
2.	Xu et al. 2022	Trials on an experiment farm station	China	Ratoon rice system can reduce carbon emissions and yield higher productivity than double-season rice.
3.	Gathorne-Hardy et al. 2016	Household survey with farmers combined with modeling	India	The system of rice intensification improved productivity while reducing GHG emissions but at the cost of negative impacts for wage laborers.
4.	Arianti et al. 2022	Trials on irrigated rice fields	Indonesia	Inpari 20 rice varieties yielded higher productivity and lower CH_4 emissions when compared to Ciherang and Inpari 30 rice varieties.
5.	Janz et al. 2019	Experiments at the International Rice Research Institute campus	Philippines	Rice-maize cropping systems have low global warming potential and irrigation water demand, as compared to aerobic rice and double rice systems.
6.	Toma et al. 2021	Experiment on a university farm	Japan	Mid-season drainage one week earlier maintains rice yield, reducing GHG emissions in rice paddy fields with green manure.
7.	Arunrat et al. 2022	Farm data from selected farmers combined with soil samples	Thailand	Organic rice produces lower GHG emissions than conventional rice. Even though organic rice yields are lower, the economic returns are higher due to lower production costs and higher prices.
8.	Gangopadhyay et al. 2022	Trials on a field research station	India	The system of rice intensification exhibited a lower carbon footprint, higher carbon sequestration, and higher carbon efficiency ratio compared to conventional rice and zero-tillage.
9.	Yao et al. 2017	Experiments on a research farm	China	Ground cover rice production systems, particularly when utilizing biodegradable films, offer a promising solution for farmers to maintain or increase yields while reducing GHG emissions.

Toma et al. (2021) indicate that implementing mid-season drainage before conventional practice can effectively maintain brown rice yield, promote soil C sequestration, and mitigate global warming in rice paddy fields utilizing green manure. Similarly, Arunrate et al. (2022) find that organic rice has a lower carbon footprint, nitrogen footprint, and water usage than conventional rice farming. Even though the rice yields in organic rice are approximately half that of conventional rice, the economic return is higher due to lower production costs and higher prices for organic rice. Gangopadhyay et al. (2022) found that the system of rice intensification exhibited a lower carbon footprint, higher carbon sequestration, and higher carbon efficiency ratio than other cultivation practices. Similarly, Yao et al. (2017) find that compared to conventional paddy, ground-cover rice production systems demonstrate higher rice yields and nitrogen use efficiencies, reduced irrigation requirements, and lower emissions of CH_4 and N_2O (54% reduction). Substituting polyethylene film with biodegradable film yielded similar benefits. Overall, ground-cover rice production systems, particularly with biodegradable films, can increase yields while reducing the carbon footprint.

5.6.4 Carbon Mitigation from Agroforestry

Agroforestry encompasses many technologies, such as biochar, a nutrient-rich material derived from biomass. Allohverdi et al. (2021) highlight biochar's manifold benefits, including increased nutrient density, improved water-holding capacity, reduced fertilizer requirements, enhanced soil microbiota, and higher crop yields (table 13). Similarly, Sundberg et al. (2020) found that biochar-producing cookstoves resulted in reduced smoke, fuel wood savings, and biochar production in Kenya. On-farm trials with varying rates of biochar inputs, with and without mineral fertilizers, demonstrated sustained increases in maize yields following a one-time application.

Dubiez et al. (2018) investigate the influence of successive phases of *Acacia auriculiformis* stands, grown in rotation with crops, on the chemical properties of sandy and nutrient-poor tropical soils in the Democratic Republic of Congo. They find that despite an increase in soil C and N, the sustainability of the acacia rotational agroforestry system after 22 years is questionable due to the continuous decline in soil quality, increase in soil acidification, and the associated risk of decreased tree and crop productivity. They recommend debarking tree stems before carbonization, returning small branches and charcoal residues to the soil, and applying natural rock phosphate to replenish nutrients. Karssen (2022) demonstrates the potential for obtaining carbon offsets from coffee plants in agroforestry systems in the lowlands of Bolivia. However, plantations must be at least 2.2 years old to ensure sufficient carbon storage.

Pakhom et al. (2021) assess the carbon sequestration and climate risk adaptation potential of different cropland and agroforestry systems. They highlight trade-offs between carbon sequestration potential and economic returns of various agroforestry systems. Among the cropland systems, the composite cropland agroforestry system exhibited the highest total cropland carbon sequestration (328.11 t/ha), while the scattered cropland agroforestry system had the lowest (81.61 t/ha). Regarding the agroforestry practices, the eucalyptus-mahagoni-maize practice showed the highest carbon sequestration (402.09 t/ha), while the mango-vegetable agroforestry practice had the lowest (9.75 t/ha). From an economic perspective, the composite cropland system and eucalyptus-mahagoni-maize agroforestry practice were the most favorable options.

Table 13: Carbon mitigation from Agroforestry

	Author/s	Details/Measures	Location	Outcome/Main Results
1.	Allohverdi et al. 2021	Review of published papers	Global	Biochar offers numerous environmental and economic advantages, making it a potential player in agriculture-based carbon offset systems.
2.	Sundberg et al. 2020	Pilot testing of improved cookstoves combined with household survey	Kenya	Cookstoves resulted in reduced smoke, fuel wood savings, and biochar production. On-farm trials demonstrated sustained increases in maize yields following a one-time application of biochar inputs.
3.	Dubiez et al. 2018	Comparative study of woodlots that had been allocated to farmers	Democratic Republic of Congo	Although acacia woodlots increase carbon and nitrogen content in the soil, the sustainability of these rotational agroforestry systems is questionable due to a decline in soil quality, an increase in soil acidification, and the associated risk of decreased tree and crop productivity.
4.	Karssen 2022	Field measurements on coffee plantations	Bolivia	Highlights potential for obtaining carbon offsets from coffee plants in agroforestry systems.
5.	Pakhom et al. 2021	Field measurements of existing cropland agroforestry systems	Bangladesh	Highlights trade-offs between carbon sequestration potential and economic returns of various agroforestry systems.

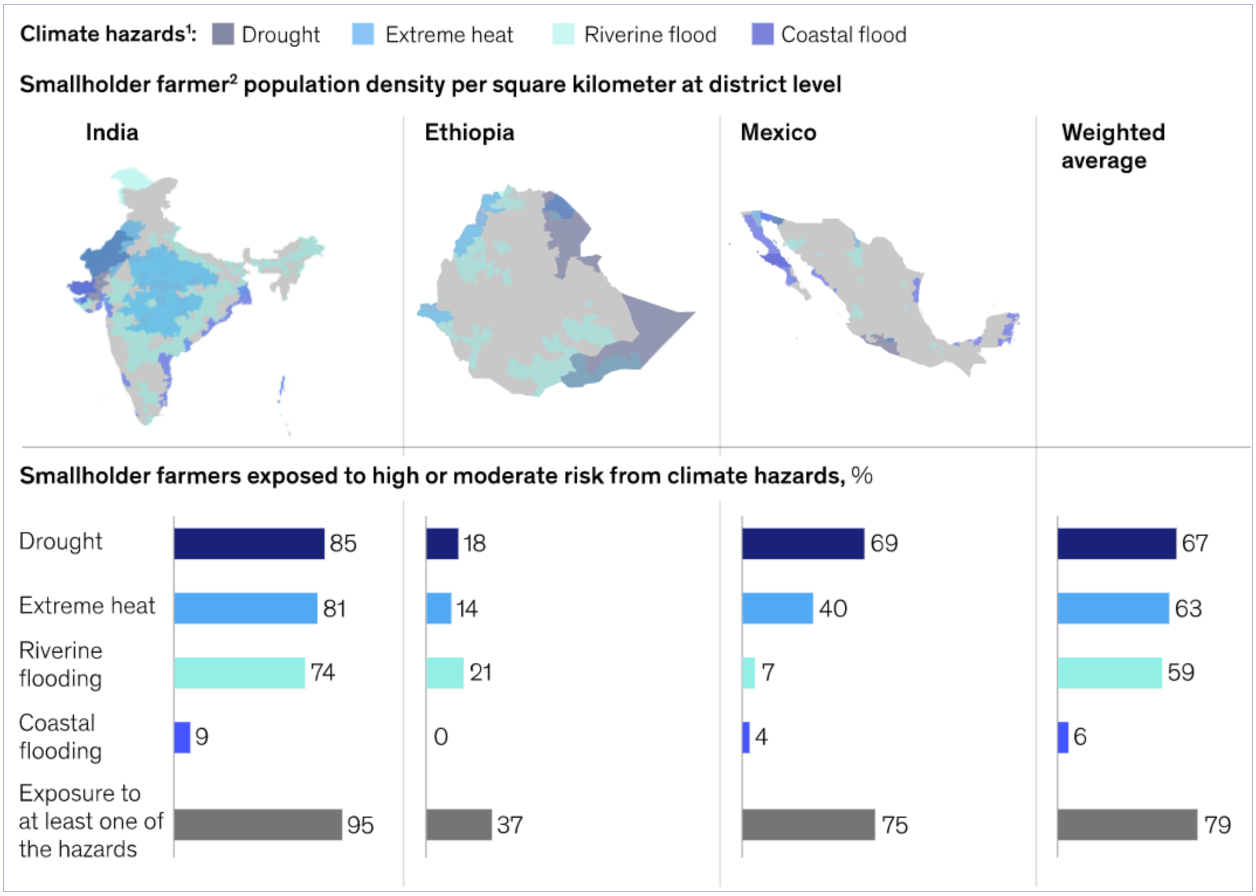
6. Smallholder and Gender Impacts

Local impacts of climate change mitigation projects on smallholders in developing countries are an essential concern for policymakers. Smallholder farms generate almost 32% of agricultural GHG emissions (Vermeulen and Wollenberg 2017). They are also vulnerable to climate change risks, making them important stakeholders for all land-based carbon mitigation activities across low to middle-income countries (IPCC 2022). For example, India, Ethiopia, and Mexico contain more than 40% of the smallholder farmers worldwide. Agricultural operations carried out by these smallholders are a significant source of GHG emissions, with livestock management and cultivation of food crops as the main emission-generating activities across all three countries (Frost et al. 2023). By 2050, nearly 80% of the smallholder population in these countries will face at least one climate hazard, with most facing many more (figure 21). Hence, it is necessary to integrate smallholders with national emission reduction strategies, especially all agriculture-based carbon mitigation activities.

6.1 Impacts of Carbon Offset Projects on Smallholders

Land-based carbon mitigation projects can yield several local benefits: increase in smallholder incomes, secure land tenure, adoption of better agricultural technology, improvement in resource productivity, more investments in social well-being, and creation of more effective governance structures (Kerr et al. 2006; Herr et al. 2019). However, few studies go beyond anecdotal summaries to measure the impact of carbon offset projects on local smallholders.

Figure 21: Percentage of Smallholders Suceptible to Climate Hazards by 2050 India, Ethiopia, and Mexico



Source: Frost et al. 2023 (McKinsey & Company)
[1]Denotes an area's exposure to climate hazard by 2050.

6.1.1 Positive Impacts on Smallholders

Among the projects with positive impacts in the local area is the **Kenya Agricultural Carbon Project (KACP)**, Africa's first agriculture-based carbon offset project (Nyberg et al. 2020). Located in western Kenya, KACP covers almost 45,000 hectares (ha) of agricultural land that is undulating and characterized by low productivity. The average farm size is 0.6 ha, with maize and beans as the main crops. Many farmers supplement their meager incomes by cultivating vegetables, groundnut, cassava, and sorghum. As part of the project, local farmers have adopted agroforestry, conservation tillage, crop rotations, and land terracing. The World Bank BioCarbon Fund has bought carbon offsets produced by these activities at $4 per tCO_2. Lee (2017) states these activities have increased smallholder incomes and agricultural productivity.

Herr et al. (2019) assess the impact of **carbon offset projects along coastal areas in India, Indonesia, Kenya, and Madagascar**. As part of these projects, mangrove trees were planted over several thousand hectares of land, yielding more than 1 $MtCO_2$-eq over 20 years. Field evidence shows that these carbon offset projects have created new income streams for local subsistence farmers and helped them to get better market access for their agricultural produce. However, not all project impacts are positive (see section 6.1.1). Similarly, in a review of **ten agriculture and forestry-based carbon offset projects across Africa and South America**, Tamba et al. (2021) state even though carbon payments were low, the primary motivation for local farmers to participate in carbon mitigation activities was non-monetary benefits, such as improved farm productivity, access to extension services, and the diversification of income sources through establishment of tree nurseries.

In a comprehensive review of the Nhambita Community Carbon Project in Mozambique, Jindal et al. (2012) state that local farmers used carbon payments to buy high-quality seeds, install better roofs on their mudhouses, and buy books and clothes for their children. The project generated carbon offsets through agroforestry on smallholder farms and forest conservation areas within the neighboring Gorongosa National Park. These activities helped sequester more than 200,000 tCO_2. Carbon payments from forestry activities were used for the local school's upkeep and for opening a new primary health clinic. The authors find that even though carbon payments increased local incomes, they were not enough to move local smallholders out of poverty.

6.1.2 Negative Impacts on Smallholders

Carbon offset projects do not always benefit local communities. Projects can exclude poor people from participating or tempt them into long-term contracts over which they have little control (Kerr et al. 2006). In many forest-based projects, smallholders may plant monocultures of exotic species that would harm the local ecology (Jindal et al. 2008). There are also concerns that GHG mitigation activities such as no-till farming can reduce wage labor opportunities for local people while increasing the drudgery of family members, particularly women, in doing more weeding and other non-paid operations (Bayrak and Marafa 2016). Moreover, carbon and land rights are not always synchronized. So, while local households may own land, they may not own rights to carbon revenue.

For example, in the coastal areas across India and Indonesia, the carbon project developer Livelihood Carbon Funds owns carbon rights and the resultant revenue (Herr et al. 2019). In this case, local smallholders have little to gain when carbon prices rise. In the case of the **Haryana Forest Carbon Project** (India), the government forest department owns rights to carbon revenue from tree planting on local farmlands. Even though farmers get a proportion of the revenue as carbon payments, it is insufficient to cover their opportunity costs. As a result, many local farmers have exited the project with little or no benefits (Agarwal 2020). Similarly, in Ethiopia's Bale Mountain Ecoregion REDD project, carbon payments have not fully compensated farmers for the restrictions placed against using local forests for grazing animals and collecting non-timber forest products. As a result, these groups are marginalized even more, and there are concerns that they could fall further into poverty (Duker et al. 2019).

6.2 Barriers to Participation of Smallholders

Even though many agriculture and forestry-based carbon offset projects aim to encourage smallholders to become offset producers, several barriers hinder their participation (table 14). Foremost among them is insecure land tenure (Tamba et al. 2021). Payments in carbon offset projects depend on verifiable and measurable emission reduction activities on plots with clear ownership. Projects may deliberately or inadvertently exclude farmers lacking legal land tenure rights to avoid conflicts. Moreover, without secure land rights, farmers may not adopt emission reduction activities with longer life spans or require significant investments (Wreford et al. 2017). Certification bodies such as Plan Vivo help participating farmers get land tenure for at least twenty years when enrolling in carbon offset projects to address this constraint. Others recognize customary land rights or even help landless farmers obtain land titles from the local governments (Tamba et al. 2021).

Another barrier is low offset prices, especially in the case of VCMs. When there are high transaction costs, payments to farmers are even lower. In addition, projects only estimate the average cost of mitigation measures without considering the heterogeneity of local expenses (Wreford et al. 2017; Jindal et al. 2013). So, not all local farmers find mitigation measures profitable. Another issue is inconsistency in the timing of carbon payments (Strong and Barbato 2023). Projects may not readily sell their carbon offsets or find it challenging to receive premium prices. This creates uncertainty amongst farmers and acts as a barrier against their participation. Projects try to address these constraints by usually committing to a payment schedule for the first few years of a project, after which they expect mitigation measures, such as agroforestry, to start yielding additional benefits to the participants (Henderson et al. 2022).

To reduce the risk of discontinuing carbon mitigation activities, project developers may adopt rigid contracts that remain in force for long periods. As a result, local farmers may discontinue their participation or stay away altogether. Possibly, project developers should design more flexible contracts by modifying key aspects such as contract duration, payment schedules, and recommended mitigation measures (Tamba et al. 2021).

Another barrier to the participation of smallholders is that they usually cannot bear the risk of adopting carbon mitigation measures when their paramount need is to ensure food security for their families. On the other hand, big landowners can test new agricultural practices on some of their farms while practicing conventional agriculture on different plots. As a possible alternative, some projects encourage smallholders to participate in non-farm-based activities, such as establishing tree nurseries or taking up apiculture (Jindal et al. 2012), while others encourage farmers to pool their plots to share the risk.

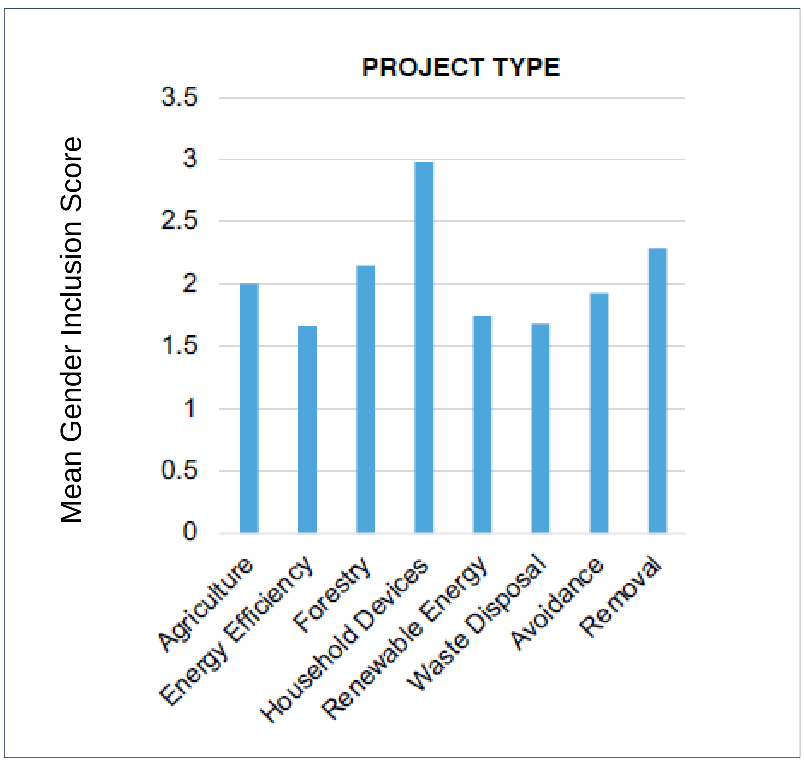
6.3 Gender and Carbon Offset Projects

Climate change impacts often differ between women and men. Considering that gender equity and climate change action are closely aligned, most buyers and sellers of carbon offsets agree with the need to integrate gender concerns into the functioning of the voluntary carbon markets (Arora-Jonsson and Gurung 2023). Women constitute 38% of the worldwide agriculture labor force, with their share increasing to 50% in regions such as sub-Saharan Africa (FAO 2023), so women have an essential stake in carbon offsetting activities involving agricultural interventions.

According to Phillips and Jenkins (2023), within VCMs, sustainable agriculture and projects involving improved cookstoves have a high potential to benefit women. However, until now, only a few carbon offset projects integrate gender concerns.

After studying a broad spectrum of carbon offset projects, Nicholson (2022) found that overall, only 21% of the projects had a documented positive impact on women (score of 3 or 4)[12], with 79% of the projects only able to provide women with a basic participation role at the most (Score of 2 or lower). Among land-based carbon offset projects, forestry projects scored a mean score of 2.2, while agriculture had an average score of 2 (figure 22). This indicates that most agriculture and forestry-based carbon offset projects provide women a basic participation role. This is evident in the case of **the Noel Kempff Mercado Climate Action Project** in Bolivia (established in 1996), which creates carbon offsets through the conservation of local forests and uses the resultant revenue to promote sustainable agriculture and forest management activities. Even though the project is hailed as one of the first large-scale attempts at using agriculture and forest conservation to mitigate climate change, the impacts on women have been uneven. While men were offered technical positions such as sawmill work with higher pay, women were either hired for low-paying jobs or continued their traditional roles of harvesting maize, collecting fuelwood, or growing vegetables in their home gardens (Boyd 2002). Women were not included in decision-making or higher-level committees. As a result, men dominated public meetings, with issues important to women pushed down the list of priorities.

Figure 22: Extent of Gender Integration into VCM



Source: Nicholson 2022

[12] Projects were given a gender inclusion score from 0 to 4 (0 = least inclusive and 4 = most gender inclusive).

In contrast, the project on **Agroforestry and Clean Cookstoves in Honduras** has achieved a win-win for women and carbon mitigation. It introduced improved cookstoves and agroforestry coffee systems to transition to less GHG-intensive farming practices. An evaluation of the cookstoves shows that 80% of the surveyed women have decreased their firewood consumption by 50%. The savings in fuel wood consumption translate into time savings for women as they do not have to spend long hours searching for fuel wood. In addition, agroforestry-coffee systems including the choice of tree species were selected according to the interests of participating women. Many of these agroforestry systems are managed by women farmers. The project's success in improving the social and material conditions of women is in part attributed to the engagement of men in women-led projects that created conditions for them to extend support to women, the strong relationship of the implementing NGO with farmers on the ground, and an exceptionally well designed and executed project, which considered the needs of local farmers (Hottle 2015).

Similarly, in the case of **the Oaxaca Carbon Forestry Project** in Mexico, carbon offsets are created through forest restoration, agroforestry, and the natural regeneration of local forests. Out of the $10 per carbon offset the project earns, $8 is transferred to the community. Field research (Gay-Antaki, 2016) indicates that local women primarily carried out reforestation even though they were not involved in any decision-making processes. In effect, women's labor subsidized most labor-intensive activities in the project. At the same time, the carbon project did not take any steps to address the unequal division of labor that women faced (table 14).

The Kenya Agricultural Carbon Project is another example of a carbon offset project that has failed to address the strategic needs of women. The project generates carbon offsets for the VCM by adopting improved crop varieties, agroforestry, and reduced tillage on agricultural lands. Research by Lee et al. (2015) reveals that while men and women had little role in project design, women faced more significant participation barriers than men, primarily due to their limited influence in household decision-making processes. Women experienced a substantial increase in their farm labor time due to the extensive effort required to implement new agricultural practices. Although the carbon payment received was minimal, both men and women still chose to participate in the project because they perceived the co-benefits, such as access to funds and enterprise development, as meaningful.

These findings suggest that carbon offset projects do not necessarily achieve gender equality beyond women's participation and rarely address women's strategic interests. One key reason for the limited focus on gender is that few carbon registries require an explicit strategy for gender integration except the Gold Standard (table 15). There is also a lack of resources (case studies, methodologies, tools) for gender integration into project design and implementation. Another challenge is that most carbon projects need extensive monitoring and reporting that are prohibitively expensive and leave little financial room to incorporate other components, such as gender parity. In addition, there exists limited gender expertise within project staff who are predominantly male. Indeed, for agricultural carbon projects to attain improved equity outcomes, project developers should prioritize multiple facets of equity, such as equitable access, decision-making, and results that benefit both men and women.

Table 14: Documented Impacts of Carbon Offset Projects

	Positive Impacts	Negative Impacts	Barriers to Participation
Smallholders	• Higher incomes from carbon payments. • Diversification of livelihoods. • Creation of new income streams. • Increase in farm productivity. • Availability of cash to buy high-quality seeds. • Non-monetary benefits, such as access to agricultural extension services.	• Farmers receive inadequate compensation. • Restrictions against local resource use. • Long-duration contracts.	• Insecure land tenure. • Inadequate and inconsistent carbon payments. • Rigid contracts. • Land fragmentation and tiny plots in many areas.
Gendered Outcomes	• Women's practical needs (medical facilities) addressed. • Some employment opportunities for women. • Improved access to funds. • Non-monetary benefits.	• Strategic needs (women's empowerment) not addressed. • Women are subsidizing labor-intensive activities. • Low-paying opportunities (cooks). • Limited role in decision-making for women. • Increase in farm labor.	• Absence of mandatory labeling of projects. • The prohibitive cost of monitoring and verification. • Limited gender expertise. • Access to land. • Intra-household dynamics. • Extension services may marginalize women.

6.3.1 Gender Aspects of Climate-Smart Agriculture

Climate-smart agriculture (CSA) is another approach for transforming and reorienting agricultural systems to support food security and reduce GHG emissions from conventional agriculture (Lipper et al. 2014). However, these interventions also have gendered implications that must be understood well (Roy et al. 2022; Diiro et al. 2018; Wekesah et al. 2019).

On the positive side, CSA and CA can significantly impact intra and inter-household gender relations. The adoption of CA has transformed intra-household gender relations, decision-making, crop management practices, and increased agency among some women in Honduras (Hottle 2015). In Kenya, CA led to men showing greater acceptance and respect for women's leadership and ability to make decisions that improve the farm (Lee et al. 2015). In Zimbabwe, women report active involvement in deciding which crops to grow, where and when to plant, when to weed, apply fertilizer, and harvest despite such roles being traditionally a male responsibility (Hove and Gweme 2018).

While CA can raise incomes and food security, the relative impacts on men and women are context-specific. In Zambia, for example, among women CA farmers, early land preparation facilitated timely planting and earlier crop maturity, resulting in food availability during food scarcity (Nyanga et al. 2012). However, increased productivity and incomes due to CA can also lead to disempowerment and dispossession of women. Men can take over the production of traditional women's crops to expand their incomes (Beuchelt and Badstue 2013). For instance, in Zambia, women's risk of losing their traditional control of farming and trading in pulses to men increased as the latter recorded enhanced yields and incomes from CA (Nyanga 2012). There are also cases of herbicides being used in CA that may kill vegetable plants collected by women, impacting household food security (Farnworth et al., 2016).

Similarly, switching to zero tillage under CA has been shown to require more effort in weeding, a task typically undertaken by women, as opposed to land preparation, traditionally done by males (Baudron et al. 2017). Research from the Philippines finds that women shoulder multiple responsibilities in the productive and reproductive spheres. Any extra demands on their time placed by weeding under zero tillage can be a gender-based constraint against adopting CA. Research on changes in rice cultivation practices on women's labor use in India has found that while technologies promise to reduce women's drudgery, they can also have potentially negative consequences for wage labor opportunities for women. In contrast, research from India and Nepal shows that switching to zero tillage can contribute to substantial time savings for women and may not result in any reallocation of labor responsibilities between men and women (Brown et al. 2021).

These findings suggest that the gendered impacts of CA practices such as zero tillage differ according to the local context. Project developers should refrain from promoting CSA and CA interventions such as zero tillage as a one-size-fits-all solution across regions.

6.3.2 Barriers to Women's Participation in CSA and Carbon Offset Projects

As table 14 indicates, the impacts of carbon offset projects on women are not always consistent and depend hugely on the local context. However, despite positive results, several barriers constrain women's participation in these projects. Like smallholders, women's lack of access to land tenure is a significant constraint against their involvement in agriculture-based carbon offset projects. In the absence of land titles, when households lease land for a limited time, they are primarily interested in maximizing crop output instead of maintaining soil quality over the long term, which can generate carbon offsets (Parks et al. 2014). Similarly, male-headed households have a higher chance of adopting new agricultural interventions than female-headed households due to their better access to land and other farming inputs (Kristjanson et al. 2017).

Decisions about agricultural livelihoods are not always made jointly, with socio-cultural norms and responsibilities structuring an individual's ability to participate in intra-household negotiations (Sumner et al. 2017). Herbicide use is a crucial factor contributing to achieving success under CSA systems that can potentially generate carbon offsets. In Malawi, however, the high cost of herbicide and the fact that men make decisions on its purchase resulted in women relying on manual weeding, thereby undoing the benefits of CSA (Farnworth et al. 2016). The power of men to adopt or dis-adopt CSA was also demonstrated in Kenya, where men who did not favor CSA overruled their wives who did (Farnworth et al., 2016)

Agricultural demonstration events and training are sometimes hosted by or delivered through lead farmers. However, lead farmer selection criteria often exclude most women and poorer men in the community. When CSA is introduced through the example of wealthier male farmers, poorer farmers – whether women or men – may feel that the technology is irrelevant to them. Moreover, field training focusing on technical knowledge is perceived as a men's domain. While men and women are listed as members of farmers' associations, men primarily attend these sessions (Sumner et al. 2017). In the Philippines, for example, a rule to invite only one person per household to information sessions on CSA left most women out (Parks et al. 2014).

6.4 Safeguards to Address Gender and Smallholder Concerns

As discussed in previous sections, carbon offset projects can positively and negatively impact women, smallholders, and other vulnerable groups. Moreover, significant barriers constrain these groups' access to emission reduction activities and other climate-smart interventions. To address these concerns, carbon mitigation projects have developed safeguards (table 15) categorized as: "do no harm," "do good," and "do better" in terms of contributing towards sustainable development benefits. These safeguards are intended to protect the rights, well-being, and interests of smallholders and other vulnerable groups.

6.4.1 The Climate, Community & Biodiversity Standards (CCB Standards)

The Climate, Community & Biodiversity Standards (CCB Standards) were developed by the climate registry Verra to safeguard the interests of smallholders and women in carbon offset projects[13]. The standards require projects to demonstrate equitable benefit sharing among community members, ensure net-positive social and environmental benefits, involve local communities in project design and implementation, identify and mitigate any negative impacts, and ensure that women have equal access to all project benefits, including opportunities for participation in decision-making processes. By incorporating these safeguards, the CCBS standards aim to ensure that carbon offset projects contribute to climate change mitigation while promoting the well-being, rights, and sustainable development of local communities, including smallholders and women.

6.4.2 The Gold Standard

The Gold Standard ensures that carbon offset projects exhibit environmental integrity and contribute to sustainable development by explicitly integrating gender into project design, implementation, and monitoring. It offers gender certification to projects at two levels: (i) Gender-Sensitive Certification which is mandatory for all projects seeking the certification. The purpose is to follow 'do no harm' approach and address safeguards to prevent or mitigate adverse impacts on women or other vulnerable groups. (ii) Gender Responsive Guidelines that are optional and apply only to those projects that fulfill all gender-sensitive requirements and seek further gender certification at the performance level. These projects must conduct deeper gender analysis, select gender-targeted project goals and actions, and design project-specific gender indicators and parameters. An example of a Gold-certified project is the **Uganda Domestic Biogas Program,** which has generated emission reductions of 141 638 tCO2-eq by promoting alternate energy sources in the form of biodigesters. With women responsible for fuelwood collection in most households, the project has helped them save time that they can now use for other income-generating activities, leisure, and education (Gold Standard 2023).

[13] For more details, see: https://verra.org/programs/ccbs/

Table 15: Smallholder and Gender Safeguards in Voluntary Carbon Markets

Carbon Offset Standards/ Registries	Coverage of Gender and Smallholder Concerns
Gold Standard	**Strong Coverage:** Two levels of certification; All projects must be 'Gender-Sensitive': – Gold Standard Safeguarding Principles include a principle on Gender Equality & Women's Rights. – Gold Standard Stakeholder Consultation & Engagement Procedure. Projects can seek further gender certification to be 'Gender-Responsive'. All Gold Standard projects must monitor and report against the SDG impacts.
VERRA's Verified Carbon Standard (VCS)	**Minimal Coverage:** Safeguards include 'Do No Net Harm' in terms of environmental and socio-economic impacts: - Engagement with local stakeholders includes assessment of different groups that the project will impact
VERRA's Climate, Community & Biodiversity (CCB) Standard	**Good Coverage:** Social safeguards go further than the VCS: – Stakeholder consultations must be gender-sensitive, with particular attention to vulnerable and/or marginalized people. – Capacity building of local workers covering a wide range of people in the community. Also, a possibility to 'Do Good' under the 'Exceptional Community Benefits (Gold Level),' which projects can comply with as an add-on. There are substantial requirements around marginalized and/or vulnerable groups, specifically women.
Climate Action Reserve (CAR)	**Minimal Coverage:** Little guidance on gender or social safeguards, but a general environmental and social 'Do No Harm' approach.
American Carbon Registry (ACR)	**Minimal Coverage:** Community impacts should be net positive, and projects must 'Do No Harm' in terms of violating local, national, or international laws or regulations.
Plan Vivo	**Good Coverage:** Plan Vivo Standard principles include: – Community members, including women and members of marginalized groups, must be given an equal opportunity to fill employment positions in the project. – Projects demonstrate community ownership - Smallholders or community groups must not be excluded from participation in the project. – Demonstrate positive livelihood and socioeconomic impacts, and avoid negative impacts on participants and non-participants, especially vulnerable groups.

Source: Adapted from Phillips and Jenkins 2023

6.4.3 WOCAN W+ Standard

The W+ Standard, created by WOCAN, is the first women-specific standard that measures women's empowerment in carbon offset projects and creates a new channel to direct financial resources to women[14]. It measures six domains that are critical for women's empowerment: (i) time savings, (ii) income & assets, (iii) health, (iv) leadership, (v) education and knowledge, and (vi) food security. WOCAN has developed methodologies to track progress on specific indicators for each domain using qualitative and quantitative data. One W+ standard credit equals a 10% change per woman concerning the domain(s) selected. Once carbon offsets are sold, 20% of this money must be shared with women's groups for climate adaptation or development.

The **Kasigau Corridor Project** is a WOCAN W+ project that protects over 500,000 acres of highly threatened forest and wildlife migration corridor between two national parks in Kenya. The project has brought the benefits of carbon financing to more than 115,000 people in surrounding communities. Gender activities within the project include marketing and sales support to 49 craft groups, enabling women to increase their income and diversify their revenue streams. The project also provides improved family planning and sexual and reproductive health education to women within the community. The project has helped improve access to water for local households, resulting in time savings for women.

7. Quality and Sustainability Concerns Regarding Carbon Offsets

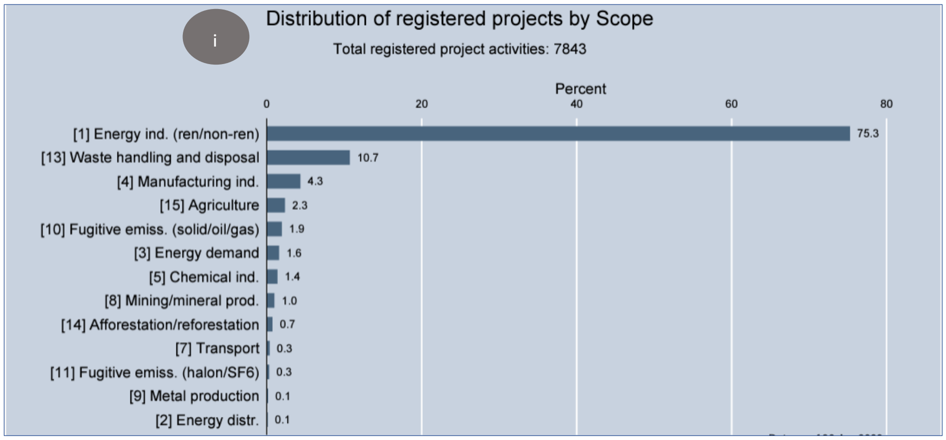
Even though the trade in agricultural carbon offsets has been growing, it is still a tiny segment of the compliance-based carbon markets and VCMs. For example, of the 7,843 CDM projects approved to date, only 2.3% generate carbon offsets from the agricultural sector. The proportion of agriculture-based carbon offsets is even lower at 1% of the overall trade in VCMs (figure 23). An important reason for this comparatively slow uptake is that agriculture-based carbon offsets are considered high-risk, with concerns regarding the quality and sustainability of these offsets (Broekhoff et al. 2019; Castagné et al. 2020). If these concerns persist, there are doubts about the integrity of carbon offsets in achieving real emissions reductions. Genuine emissions reductions should adequately address the risks of additionality, leakage, and permanence, apart from dealing with the threat of high transaction costs.

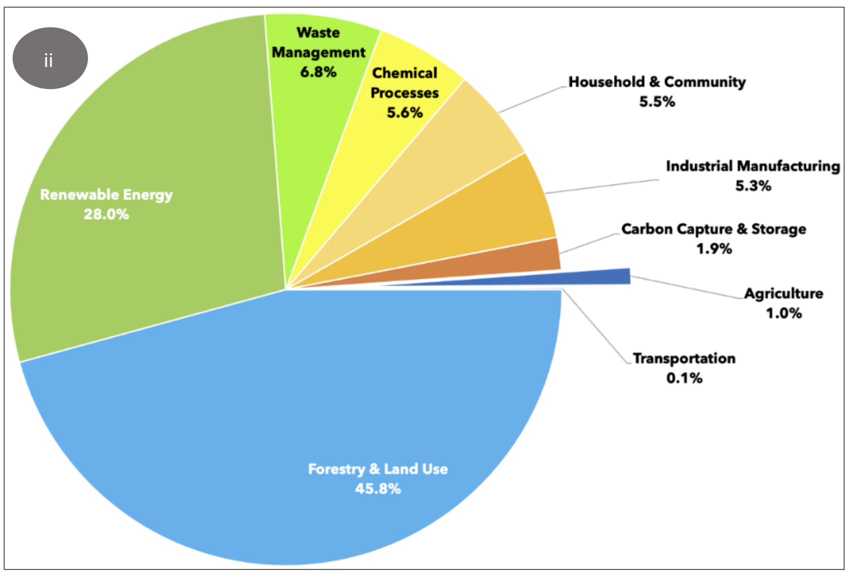
7.1 Additionality

Additionality requires carbon offsets to represent real emission reductions that would not have occurred without offset activities (Chagas et al. 2020). In agriculture, it can be challenging to establish additionality because many agricultural practices already sequester carbon naturally. Additionality is thus crucial in determining the quality of such carbon offsets. Without proper accounting and verification, it becomes difficult to determine if the offset project is genuinely achieving additional emissions reductions. If the declines are not additional, relying solely on purchasing offsets can lead to increased carbon emissions into the atmosphere.

[14] https://www.wocan.org/the-w-standard/

Figure 23: Agriculture-based Carbon Offsets are a Tiny Segment of the Carbon Market





Agriculture-based carbon offsets constitute only:

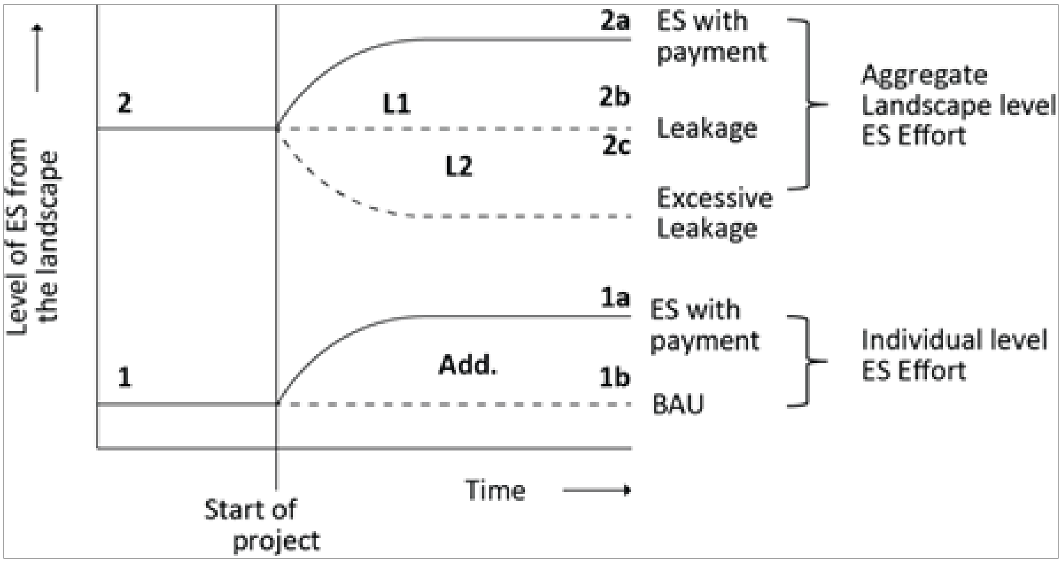
(i) 2.3% of the 7843 CDM projects

(ii) 1% of the offsets sold in voluntary markets

(i) Source: https://cdm.unfccc.int/
(ii) Source: Berkeley Carbon Trading Project (https://gspp.berkeley.edu/)

A carbon offset project should lead to more Emission reduction or carbon Sequestration (ES) than business as usual (BAU). In figure 24, line segment 1 represents the level of ES from an individual carbon offset project (or even an individual farmer within a project). The level of ES under the project (line 1a) should be more than the business as usual (BAU) scenario, i.e., the level of ES if there were no project (line 1b). The difference between segment 1a and segment 1b represents the net additionality of emission reduction (or carbon sequestration) created under the project. Carbon offset projects establish additionality either by following a "project-specific" approach or a "standardized" approach. The specific approach includes a demonstration that the project activity would not have happened without the carbon investment or that it is different from what is commonly followed in the area where the project is located. The standardized approach is based on some pre-determined eligibility criteria developed by various carbon registries. This helps reduce administrative costs in collecting extensive data but is restricted to only certain project types (Broekhoff et al. 2019).

Figure 24: Additionality and Leakage in Agriculture-based Carbon Offset Projects



Source: Jindal and Vardhan 2018
ES = Emission reduction or carbon Sequestration. BAU = Business As Usual

7.2 Leakage

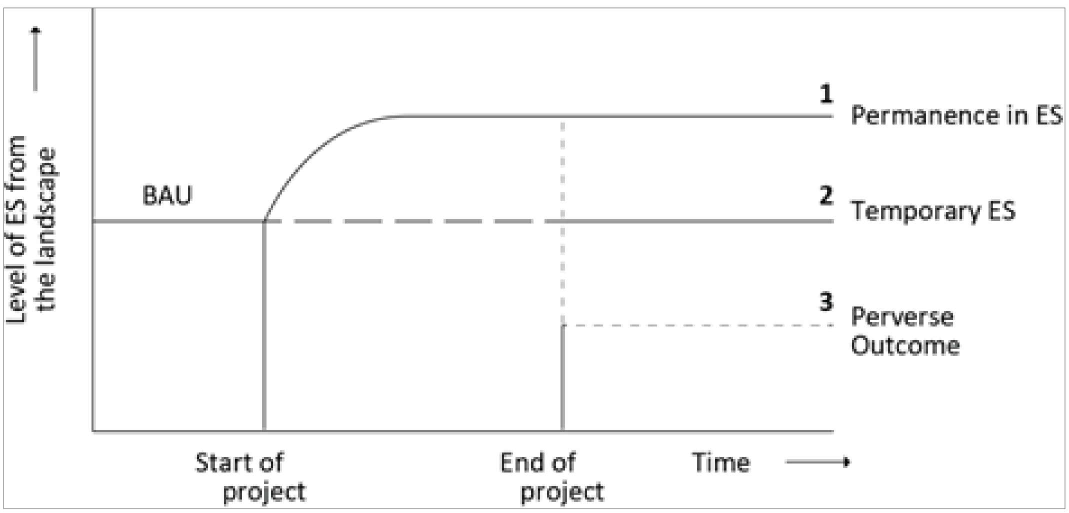
Leakage results from emission reductions achieved in one area or aspect of agricultural activity that are canceled out by increased emissions elsewhere. For example, a project that focuses on reducing emissions from deforestation might lead to the displacement of deforestation activities to nearby areas, nullifying the intended emission reductions. Often, leakage is associated with the level of Emission reduction or carbon Sequestration (ES) from the entire agricultural landscape covered under the project (line 2 in figure 24). The level of ES after the start of the project should ideally increase to line 2a, which aggregates the additional ES generated by individual farmers who have adopted conservation activities on their farms. However, if the level of ES from the entire landscape aggregates to line 2b, it indicates that even though some conservation activities are generating emission reductions, these reductions are being canceled due to resource exploitation activities within the same landscape. The area L1, which is the difference between segments 2a and 2b, represents the leakage that is taking place at the project or landscape level - even though farmers increase ES on their farms, the overall project does not provide any additional ES. If the extra ES created by some farmers is less than the emissions due to resource exploitation by other farmers (line 2c), the carbon project will result in a lower level of ES than BAU. The area L2, which is the difference between lines 2b (or the BAU at the landscape level) and 2c, represents excessive leakage – the carbon project is now subsidizing resource exploitation at the landscape level.

Carbon offset projects tend to enroll large numbers of landholders to address the threat of leakage so that the entire local community has a stake in ensuring the carbon project is successful. For example, in the Kenya Agricultural Carbon Project, conservation activities are extended to several thousand farmers, covering over 45,000 hectares of land.

7.3 Permanence

Permanence refers to concerns regarding the sustainability of carbon offsets produced from agricultural activities. For example, carbon sequestered in soils or vegetation could be released back into the atmosphere due to land-use changes or altered management practices, rendering the offset ineffective (Chagas et al. 2020). In other words, permanence refers to the continued availability of Emission reduction or carbon Sequestration (ES) even after the end of the project. In figure 25, the level of ES increases from the BAU level after the start of the carbon offset project. As the project ends, the level of ES may fall back to the BAU level (i.e., line segment 2), which implies that the ES created by the project was temporary. Suppose the level of ES after the end of the project is higher than BAU (line 1). In that case, it indicates that the project has created permanence or long-term sustainability of emission reduction activities. A project may also have a perverse outcome; as the project ends, the level of ES may be lower (line segment 3) than at the beginning of the project (BAU). This indicates that over the long term, the project resulted in a net loss of Emission reduction or carbon Sequestration.

Figure 25: Permanence in Agriculture-based Carbon Offset Projects



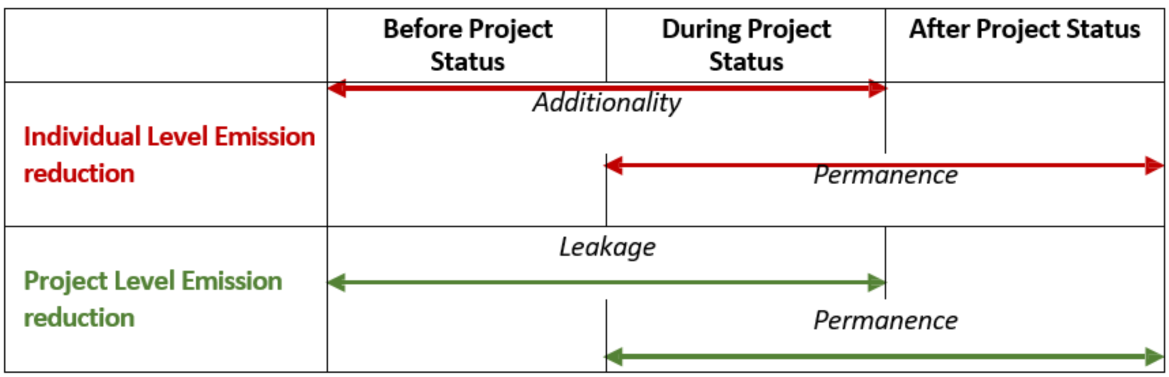
Source: Jindal and Vardhan 2018
ES = Emission reduction or carbon Sequestration. BAU = Business As Usual

To address the threat of the impermanence of carbon stocks, the Clean Development Mechanism categorized offsets as either temporary (high-risk offsets that had to be replaced by another set of carbon offsets before the end of the project) or long-term (low-risk offsets issued for an extended period) (Foucherot and Bellassen, 2011; van Kooten and de Vries, 2013). VCM projects, on the other hand, have tended to establish a "buffer reserve" that acts as insurance against any threats to permanence. Under this approach, a certain proportion of carbon offsets from individual landowners are accumulated in a shared reserve pool to compensate for any emission reversals. For example, in the case of the Nhambita Community Carbon Project, individual farmers received payments for only 85% of the carbon offsets they produced. The project developer retained carbon revenue from the balance 15% of the offsets as a buffer against any emission reversals (Jindal et al. 2012).

7.4 Monitoring and Verification

Accurately measuring and monitoring emission reductions in agriculture can be complex. The lack of standardized measurement protocols and data collection techniques can lead to uncertainties and inaccuracies in assessing the actual carbon benefits of agriculture-based offset projects. There are concerns that some projects may be overestimating their emissions reductions or may be failing to monitor their emissions accurately. To ensure additionality, a sufficient level of permanence, and no leakage from agricultural activities, the challenge for a carbon offset project is to monitor individual farmers and the level of emission reduction in the entire area covered by the project. This monitoring needs to be done at all stages of implementation: before the start of the project, during implementation, and after the completion of project activities (table 16). In some cases, such kind of monitoring can be done through remote sensing (carbon sequestration from the forest), while in others, field-based monitoring is essential (carbon sequestration in soils).

Table 16: Monitoring and Verification in Carbon Offset Projects



Source: Jindal and Vardhan 2018

7.5 Transaction Costs

Transaction costs include all costs borne by an offset project other than producing the carbon offsets (Jindal and Kerr 2007). These costs include monetary and non-monetary costs and can be divided into two broad categories: (1) *ex-ante* or initial costs of setting up a project and (2) *ex-post* or costs of implementing and monitoring a project. In general, buyers and sellers of offsets incur substantial transaction costs when entering into agreements to trade these offsets through the carbon market (table 17). These costs can include significant upfront investment in setting up offset projects, monitoring and verifying emission reductions, training and supporting project staff and participating farmers and paying for relevant certification and/or registration with carbon registries.

Phan et al. (2017) estimate that the average transaction costs for land-based carbon offset projects can be as high as \$3.3/tCO_2. With higher rates of inflation recently, these costs have escalated even higher. In the case of VCMs, where carbon prices are low, transaction costs can thus eat into the margins for offset producers, reducing the attractiveness of the projects.

Table 17: Sources of Transaction Costs in Agricultural Carbon Projects

Cost	Buyer	Seller
Search and negotiation	• Find sites and contact potential participants • Establish baseline for region • Estimate project offsets • Design individual farm plans • Draft contracts • Provide training	• Attend information sessions • Undertake training • Design farm plan
Approval	• Validate the project proposal • Submit to relevant authority	• Obtain documentation required for participation
Project management	• Establish and run local office • Establish permanent sampling plots • Maintain database and administer payments to landholders • Arrange sale of carbon offsets	• Purchase equipment for measuring trees and sampling soil • Attend project meetings
Monitoring	• Monitor activities against contracts • Maintain carbon inventory • Verify and certify carbon offsets	• Measure carbon stocks • Deliver annual report to project office
Enforcement and insurance	• Maintain buffer of C • Purchase liability insurance • Settle disputes	• Protect plot from poachers and fire • Purchase insurance • Cover legal cost of disputes

Source: Cacho et al. 2013

7.5.1 Strategies to Reduce Transaction Costs

Transaction costs usually have a high fixed component, meaning relative costs decline as the volume of traded carbon offsets increases. Costs are also higher in absolute terms when dealing with multiple parties than a single party. Consequently, high-volume projects that contract with a few large landowners face much lower transaction costs than those that enroll many farmers who own only small pieces of land. Carbon offset projects that aim to alleviate poverty by contracting smallholders find it difficult to break even (Jindal and Kerr 2007). To address these challenges, carbon projects follow standardized protocols such as the Verified Carbon Standard (VCS) that are simple to follow when designing and implementing mitigation activities, resulting in widespread use worldwide. Building local capacity can also reduce the costs of hiring external experts and empower stakeholders to participate more effectively in carbon offset projects. Many multilateral agencies, such as the World Bank, are involved in building capacities amongst project developers that operate in developing countries.

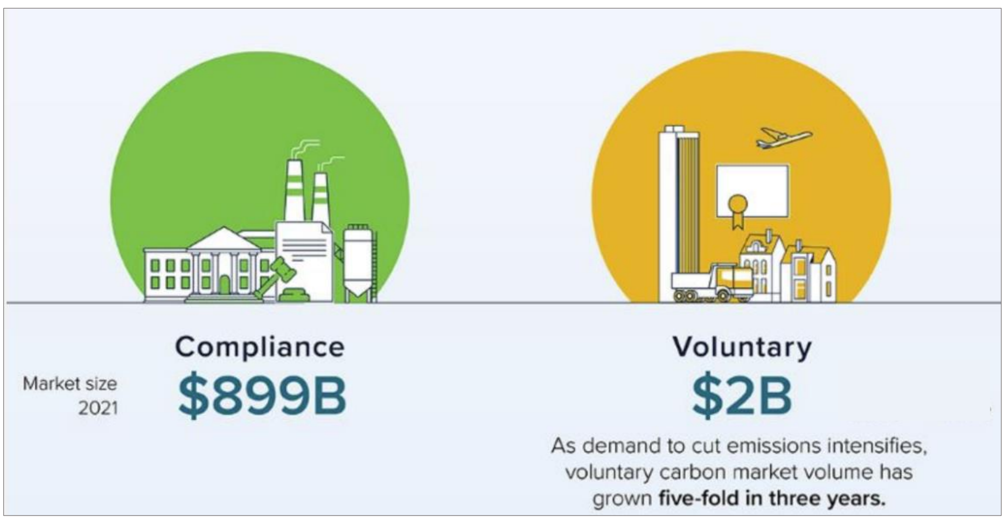
In addition, efficient carbon markets with clear price signals and accessible platforms can lower transaction costs and attract more participants. As such, information clearing houses such as the Ecosystem Marketplace are an invaluable source of information for VCM participants worldwide. Project developers often need financial support to meet the upfront costs of investing in mitigation activities. Financial mechanisms such as the World Bank's Forest Carbon Partnership and the BioCrabon Fund provide this financial support until projects can start selling carbon offsets in the VCMs.

In recent years, innovations in remote sensing technologies and Internet of Things sensors have also helped streamline data collection in monitoring and verification processes. Another promising innovation is blockchain technology which provides a decentralized and transparent ledger where all transactions related to carbon offsets can be recorded. This eliminates the need for intermediaries and reduces transaction costs associated with verification and auditing (Vilkov and Tian 2023). Blockchain-based tokens can enable fractional ownership, divisibility, and easier transferability of carbon offsets, eliminating the need for complex paperwork and manual processing. However, the technology is still in its early stages of development, and more field testing needs to be done before large-scale commercialization.

8. Conclusion

From its humble beginning in the early 2000s, the global carbon markets are now huge. Overall, the markets are closing in on a trillion dollars' worth of transactions per year, which, in financial terms alone, already makes them as important as many of the commodity markets worldwide (Refinitiv 2023). Compared to the compliance markets, VCMs are still small. With an annual trade of $2 billion, the total value of VCMs is less than 1% of the value of carbon trading on compliance markets (figure 26). Even the price of carbon offsets on VCMs ($1-10 per tCO_2-eq) is much lower than the average carbon price on compliance markets ($100 per tCO_2-eq in the case of EU ETS).

Figure 26: Size of Compliance Versus Voluntary Carbon Market



Source: Refinitiv.com; Ecosystem Marketplace

Nonetheless, VCMs remain vital as they allow experimentation and trials in newer ways of generating carbon offsets. Once these experimental trials are successful, they can be scaled up in the compliance markets. Often, VCMs are the only way entities can participate in carbon mitigation activities in jurisdictions without government regulation on climate change. VCMs are also hugely important for agriculture and forestry activities that are excluded from many compliance markets, such as EU ETS. Even though VCMs are small, they still offer the best opportunity for smallholders in developing countries to participate in carbon mitigation measures. Many NGOs and field researchers are therefore concerned that carbon markets should not harm the global poor, who already are facing the vagaries of climate change. Overall, however, the effectiveness of these markets in tackling climate change will depend on how well they can address concerns regarding the integrity of carbon offsets. If the offsets are real, verifiable, and sustainable, they will lead to a reduction in global greenhouse gas emissions.

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