USDA Office of the Chief Economist

Report to Congress:

A General Assessment of the Role of Agriculture and Forestry in U.S. Carbon Markets

Written in support of the Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program

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PURPOSE OF GENERAL ASSESSMENT REPORT

The *General Assessment of the Role of Agriculture and Forestry in U.S. Carbon Markets* (General Assessment Report) assesses the current state of voluntary carbon markets in the United States, as required by the Consolidated Appropriations Act of 2023 (Act), signed into law on December 29, 2022. The Act authorizes development of a Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program (Program), and, pending a determination from the Secretary of Agriculture, directs the Department to carry out actions in three main areas:

1. Establish the Program, which:
   a. Evaluates and publishes a list of recognized protocols for voluntary agriculture or forestry carbon credit markets;
   b. Determines qualifications for private-sector entities to register under the new USDA Program;
   c. Provides a process for registration of private-sector entities (covered entities) under the Program to provide technical assistance to producers interested in carbon markets, or to verify protocol processes (verify carbon credits);
   d. Provides information for producers on participating in voluntary environmental credit markets, including with support from covered entities.
2. Establish an Advisory Council to advise the Secretary on the Program.
3. Conduct a general and quadrennial assessment of the state of the voluntary environmental credit market, including on the supply and demand of credits, state of technology, barriers to participation, and potential roles for USDA.

This Assessment is in response to the third direction above and provides an overview of agriculture and forestry carbon markets. The Act broadly refers to “environmental credits,” however, this assessment largely covers carbon credits as greenhouse gas markets are the focus of the report’s scope as defined in the legislation.

WHAT DID THE ASSESSMENT FIND?

Carbon markets offer a potential tool to achieve greenhouse gas (GHG) reductions from the forest and agriculture sectors. Farmers, ranchers, and forest landowners can generate carbon credits by adopting practices to reduce emissions or sequester carbon on their land, and carbon markets may incentivize them to adopt new practices by generating additional income from carbon credit sales. Carbon credits may also help companies achieve GHG reduction goals. However, barriers exist that have hindered the participation of agriculture in these markets. There are opportunities for the U.S. Department of Agriculture (USDA) to help address these barriers and expand market participation, including through implementing a potential Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program.

Agriculture and Forestry Credits in Carbon Markets

Carbon credits are generated according to protocols that specify requirements for participant eligibility, what sources of emissions must be included, and procedures for the measurement, monitoring, reporting and verification (MMRV) of carbon credits. As of mid-2023, there were more than 40 active protocols applicable to agriculture, forestry, and land use projects in the United States. Of the 55 protocols reviewed in this assessment (which include inactive protocols and protocols under development), 18 have been successfully used to generate carbon credits from domestic projects.

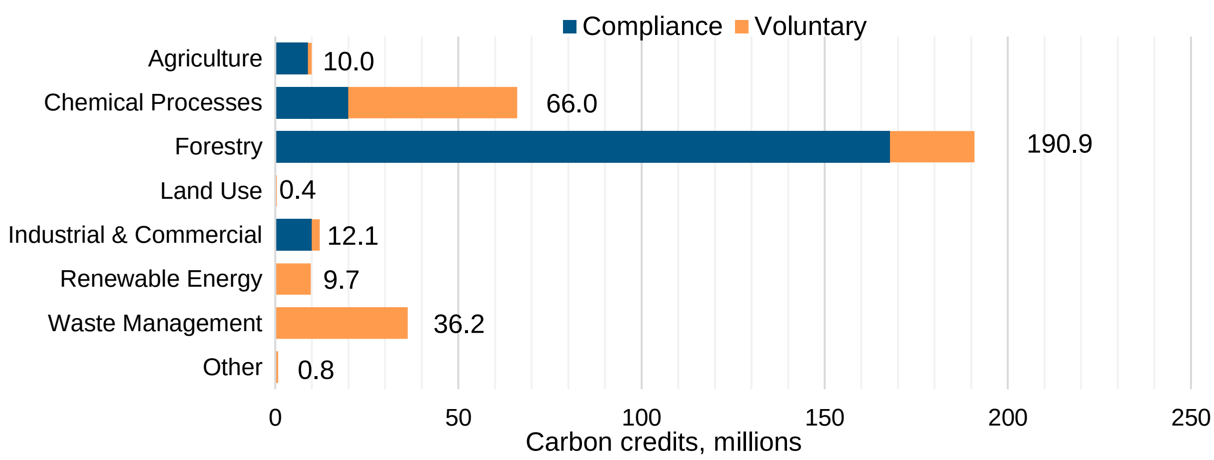
Carbon credits are sold on compliance and voluntary markets. Compliance carbon markets support regulatory programs that require GHG emissions reductions (e.g., compliance carbon markets are traditionally used in cap-and-trade systems). Voluntary carbon markets encompass the voluntary buying and selling of carbon credits outside of a regulatory framework to achieve a voluntary emissions reduction goal.

Previous studies have shown that some carbon credit projects do not represent the claimed reduction or removal of GHGs (Haya, et al., 2023; Badgley, et al., 2022; Stapp, 2022). While many research studies focused on international renewable energy and Reducing Emissions from Deforestation and Forest Degradation (REDD+) projects, the identified inadequacies in carbon credit projects have led to broader concerns over the quality of credits and the accuracy of emission reduction claims made by entities purchasing credits (Lakhani, 2023; White, 2023; Twidale & McFarlane, 2023).

Supply and Demand of Agricultural and Forestry Credits in the United States

The future of voluntary carbon markets will be influenced, in part, by the supply of credits which has varied significantly over time. In the last decade, there has been a large supply of carbon credits generated from forestry projects in the United States. Carbon credits generated from agricultural projects have been significantly fewer; most agricultural credits are generated by livestock projects.

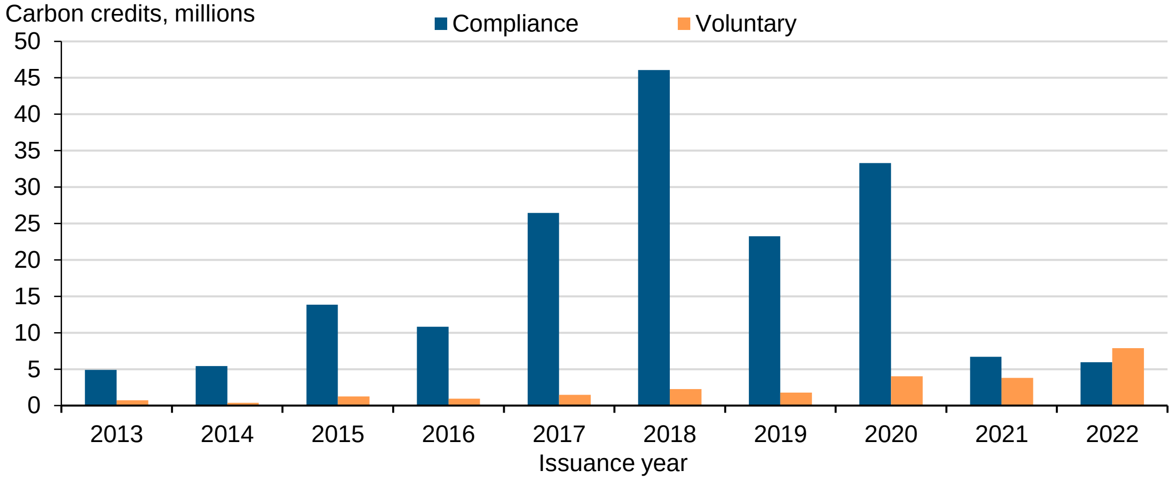
Carbon credits issued by scope for projects in the United States, 2013–2022



Note: Only includes voluntary credits issues by ACR, CAR, VCS, or Gold Standard. Compliance credits represent offsets in the California cap-and-trade program. Other includes credits under transportation and the household and community scope. Source: So, Haya, & Elias, 2023.

Between 2013 and 2022, the United States produced more than 176.7 million metric tons of carbon dioxide equivalent ($MMtCO_2e$) compliance carbon credits and 24.5 $MMtCO_2e$ voluntary carbon credits from agriculture, forestry, and land use projects.

Agriculture, forestry, and land use carbon credits by issuance year: Compliance and voluntary markets in the United States, 2013–2022



Source: So, Haya, & Elias, 2023.

Over the past 4 years, the volume of carbon credits issued in the compliance market has dramatically decreased. Meanwhile, the volume of voluntary carbon offsets increased from 2.3 $MMtCO_2e$ in 2018 to 7.9 $MMtCO_2e$ in 2022. The recent increase in voluntary carbon credits is expected to continue. Demand for voluntary carbon credits is high because companies have set ambitious GHG reduction and carbon neutrality goals, and many are purchasing credits in pursuit of these goals.

Accounting Systems for Agricultural and Forestry Carbon Credit Projects

An accurate quantification of GHG emissions and carbon sequestration in a project is critical to the functioning of carbon markets and to achievement of the GHG reduction goals driving participation in the market. However, the dynamic nature of agriculture and forestry makes quantification more challenging than in other sectors of the economy.

Protocols attempt to address challenges – such as additionality, leakage, permanence, and uncertainty – through protocol design and rules to mitigate risk. These include standardized baselines, permanence contracts, and alternative accounting for soil carbon storage projects, such as ton-year accounting. Some elements of protocol design, e.g., buffer pools, discounting, and conservative accounting of benefits generated, are intended to reduce the likelihood that projects receive more credits than are actually generated. This can limit participation as these provisions result in fewer credits being issued and lower incentives for project development.

Protocols also establish clear requirements for participant eligibility, which may include specifying eligible geographies or timeframes. Often, an independent third-party verifies whether a project met the requirements of a protocol.

GHG Quantification Systems

The significant variability in agriculture and forestry systems makes it challenging to quantify the GHG impacts of projects in these systems. Direct measurement of GHG impacts is often cost-prohibitive and impractical; no protocol or GHG program requires direct measurement, instead they prescribe a variety of modeling and site-specific measurements that can estimate impacts within certain bounds of uncertainty. Process-based models require many data inputs, which can be a barrier for producers.

While there are emerging remote sensing technologies, on-site sensors, machine learning developments, and improvements to conventional sampling that may make localized assessment more accurate and accessible, there remain technical barriers to integrating these solutions across carbon market opportunities.

Barriers to Entry

The continued generation of carbon credits from agriculture and forestry projects will be influenced by farmers, ranchers, and landowners' willingness and ability to participate in carbon markets and credit purchaser confidence in credit integrity. High rates of awareness of carbon markets have not translated into high rates of participation among landowners and operators. A recent survey by Trust in Foods indicated awareness of carbon markets among 93 percent of livestock and cropland managers, but only a 3-percent participation rate. For forest landowners, a 2018 survey indicated that participation rate and familiarity is low among family forest owners with 93.5 percent unfamiliar with carbon markets and less than 1 percent of surveyed landowners participating in markets (Sass, 2022).

Low participation stems from several barriers including limited return on investment as a result of high transaction costs including quantification, verification, and reporting costs, where credit prices are insufficient to cover these costs; conservative accounting of benefits generated; limited access to early adopters; stringent permanence requirements; small scale of agriculture projects; confusion over the options; and lack of demand.

Role of USDA in Reducing Market Barriers

Through several of its existing or new programs and resources, USDA can play a role in helping to reduce several of the identified barriers to entry that agricultural and forestry producers face in accessing voluntary environmental credit markets. These include technical assistance through USDA's Natural Resources Conservation Service (NRCS); forest landowner support; the USDA Climate Hubs; and USDA's Office of Environmental Markets; and by offering innovative grants and partnerships.

They also include reducing uncertainties and building confidence in quantification through investments in a soil carbon monitoring network; advancing GHG research; improving models and tools to estimate GHG sources and sinks; and advancing data products for use in MMRV. Through a potential Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program, USDA could further contribute to reducing market confusion faced by producers by serving as a trusted authority for a range of relevant carbon market information.

Other Market Opportunities for Ecosystem Services

In addition to carbon markets, farmers and forest owners have opportunities to participate in other environmental credit markets that can provide payments for generating or maintain ecosystem services on their lands. These include government and regulatory policies that provide opportunities for payments for ecosystem services such as mitigation and conservation banks, habitat exchanges, water rights trading, water quality trading, and markets for alternative fuels.

1 INTRODUCTION

Carbon markets create an opportunity to incentivize adoption of agricultural and forestry practices that reduce greenhouse gas (GHG) emissions or sequester carbon. In a carbon market, carbon credits – which represent a standard amount of GHG reduction or sequestration – are bought and sold. Farmers, ranchers, and private forest landowners can benefit from carbon markets by generating carbon credits for sale and earning additional income from their working lands.

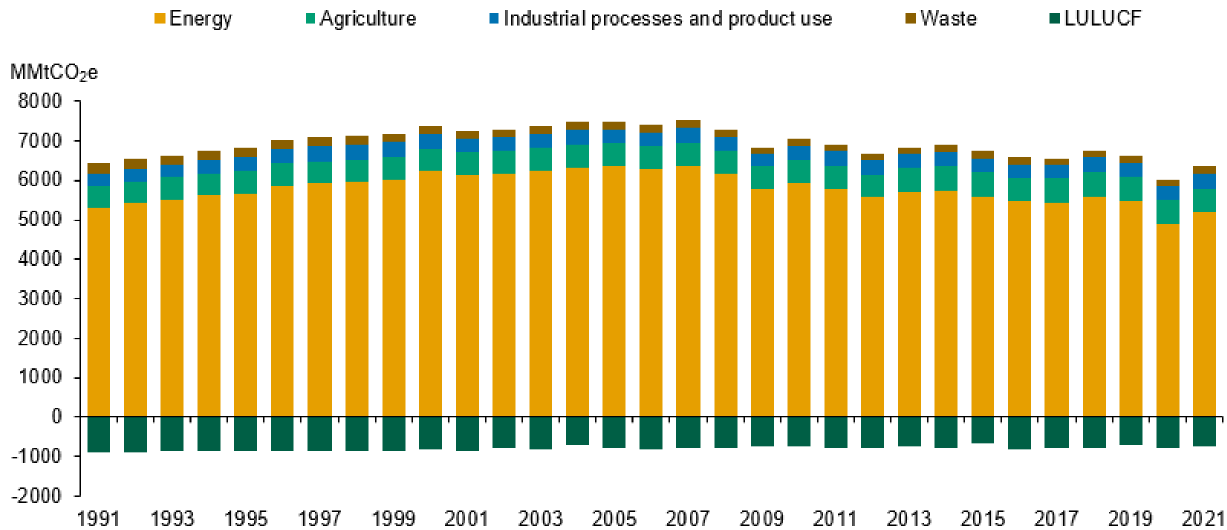
The recent proliferation and expansion of carbon markets has created some uncertainty among producers and landowners. There are several programs that enroll producers and landowners to generate carbon credits, but they often differ in their requirements and potential return on investment. With many options available, it can be difficult for individuals to assess whether participation is feasible and which program is best suited to their farm, ranch, or forest. Clarity on the current state of carbon markets, along with additional technical assistance, will help farmers, ranchers, and landowners better navigate their options and may increase market participation.

This report assesses the current state of carbon markets and provides foundational information to determine the establishment of a Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program at the U.S. Department of Agriculture (USDA). It begins with an overview of current carbon credit markets and activities related to forestry and agricultural carbon credit generation. It then provides information on the supply and demand for carbon credits; descriptions of protocols and registries and other systems used to generate carbon credits; a summary of quantification and accounting methods; an assessment of barriers to entry into carbon markets; and options to address these barriers. Finally, the report discusses opportunities for other voluntary markets outside of voluntary environmental credit markets to foster the trading, buying, or selling of credits that are derived from activities that provide other ecosystem service benefits, including activities that improve water quality, water quantity, wildlife habitat enhancement, and other ecosystem services.

To contextualize the potential impact of carbon markets, it is helpful to understand the scope of U.S. agriculture and forestry and the sector's impact on greenhouse gas emissions. The United States has over 900 million acres of land in farms according to USDA's *2017 Census of Agriculture* (USDA, 2019). In addition, there are more than 470 million acres of privately owned forest and woodlands (Oswalt, Smith, Miles, & Pugh, 2019). The changing climate creates uncertainty and threatens the resilience of agriculture and forestry operations. Communities across the country support and depend on agriculture, forests, and grasslands for food, fiber, and ongoing stewardship of natural and cultural resources.

Over the past decade, the U.S. agricultural industry's annual average GHG emissions accounted for approximately 9 percent of total gross U.S. GHG emissions (Figure 1-1). Agricultural and forestry GHG emissions include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Agriculture and forestry also provide removals of CO_2 through sequestration in soils and above-ground biomass. To compare their impact on climate change, GHGs are converted into a metric ton CO_2-equivalent ($MtCO_2e$) using a 100-year global warming potential (GWP), which is also the standard environmental credit markets typically use to quantify GHG reduction and sequestration resulting from carbon credit projects.

Figure 1-1. Estimated U.S. greenhouse gas emissions by industry sector, 1991–2021

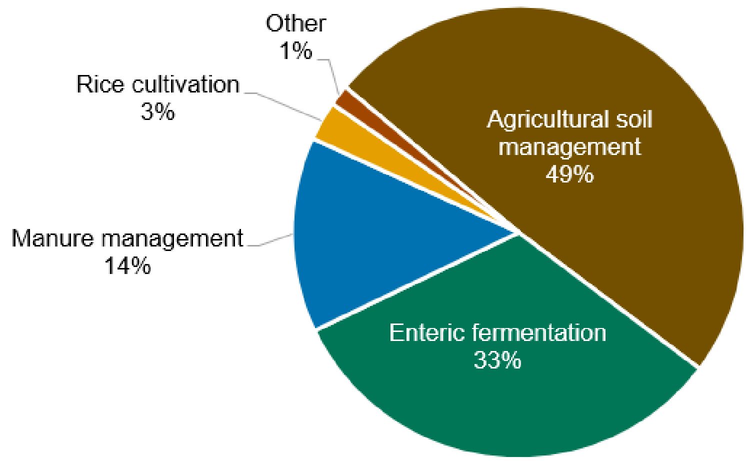


Source: U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021.*

In 2021, U.S. Environmental Protection Agency (U.S. EPA) attributed 49 percent of agriculture's GHG emissions to agricultural soil management, 33 percent to enteric fermentation, 14 percent to manure management, 3 percent to rice cultivation, and the remaining 1 percent to other agricultural practices (Figure 1-2). While the agricultural sector is almost one-tenth of U.S. GHG total gross emissions, the agricultural and forestry sectors also serve as an important carbon sink through Land-Use, Land-Use Change, and Forestry (LULUCF) activities.

Figure 1-2. Estimated U.S. agriculture greenhouse gas emissions by activity, 2021

Total U.S. agriculture emissions by activity in 2021 =
598.1 million metric tons of carbon-dioxide equivalent



Note: Other includes urea fertilizer, liming, and field burning of agricultural residues.
Source: U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*.

In response to climate change, there is growing interest in voluntary carbon markets as a mechanism to incentivize practices that reduce GHG emissions or sequester carbon. With the passage of the Consolidated Appropriations Act of 2023 (Act), signed into law on December 29, 2022, Congress authorized the establishment of a Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program (Program) within USDA. The Program would establish a process for evaluating recognized protocols; create a registry of third-parties that provide technical assistance to producers interested in carbon markets, or that verify protocol processes; and provide information for producers on participating in voluntary environmental credit markets. The aim of the Program is to facilitate the participation of farmers, ranchers, and forest landowners in voluntary carbon markets; improve the provision of technical assistance to farmers, ranchers, and forest landowners; help ensure that participating farmers, ranchers, and forest landowners receive fair distribution of revenues from the sale of credits; and increase access for farmers, ranchers, and forest landowners to resources related to existing carbon markets.

Voluntary carbon markets offer a promising tool to achieve GHG reductions from the forest and agriculture sectors. Within the statute, the term ''agriculture or forestry credit'' is defined as a credit representing an amount of GHG emissions from an agricultural or forestry activity that are voluntarily prevented, reduced, or mitigated (including through the sequestration of carbon) as a result of an agricultural or forestry activity. For this report, we use the term 'carbon credit' to represent a measurable avoidance, reduction, or sequestration of CO_2 or other GHG emissions that is generated through a voluntary action and used to meet a voluntary emission reduction goal, or an offset permitted within a compliance obligation scheme.

Carbon credits provide a potential lower-cost option for companies to achieve GHG emissions reduction goals or obligations by allowing flexibility and access to emissions reductions outside of an entity's operations or facilities. While direct corporate actions within a company footprint is critical for economywide GHG reductions, carbon credits serve as a supplemental tool that may cover emissions sources outside of a company's direct control or where there are technical or financial constraints to full decarbonization. Carbon credits may also address activities with more cost-effective interventions that may reduce the costs of meeting GHG commitments, allowing for more efficient investment of capital. Carbon credits are also a potential income source for agricultural producers and forest landowners that can supply carbon credits through actions such as changes in land management practices (e.g., reduced tillage, increased fertilizer efficiency, afforestation/tree planting), animal management (e.g., dietary modifications), and manure management (e.g., biogas capture).

Over the past two decades, a number of carbon credit systems have been established, and infrastructure to support these systems has evolved. The developers of these markets sought to capture the potential benefits of voluntary carbon market systems while addressing shortcomings and limitations of these systems due to their voluntary nature. Specifically, rules and procedures have been developed to help to ensure that carbon credits provide real and additional benefits, can be accurately quantified, and minimize the shifting of emissions elsewhere.

2 AGRICULTURE AND FORESTRY CREDITS IN CARBON MARKETS

2.1 OVERVIEW AND KEY TERMS

The focus of this report is on carbon markets and the role of agriculture and forestry in generating carbon credits. A carbon credit is a measurable avoidance, reduction, or sequestration of CO_2 or other GHG emissions. Credits are generated through activities that are defined by protocols (also called standards or methodologies), which describe processes for generating an agriculture or forestry carbon credit, including requirements for participant eligibility, what sources of emissions must be included, and procedures for the measurement, monitoring, reporting and verification (MMRV) of carbon credits.

Carbon markets can provide a financial incentive for farmers, ranchers, and forest landowners to voluntarily reduce GHG emissions, or increase carbon sequestration, by voluntarily implementing eligible practices. A carbon market refers to an economic framework that supports the buying and selling of “carbon credits”— environmental commodities that signify GHG emission reductions, avoidance, or sequestration (i.e., carbon uptake and storage). Carbon credits are also often referred to as carbon offsets or offset credits where one credit is equivalent to one metric ton of carbon dioxide equivalent (1 $MtCO_2e$). Carbon credits may be used in the compliance or voluntary market to offset other sources of GHG emissions. Carbon markets generally take one of two forms:

- **Compliance carbon markets** support a regulatory program that requires GHG emission reductions from particular emission sources. A traditional example of such a mandatory program is a GHG emission cap-and-trade system, which creates a cap on GHG emissions for covered entities while providing flexibility in how these entities comply. In some cases, covered entities may be able to use carbon offsets as a compliance option.
- **Voluntary carbon markets** encompass the voluntary buying and selling of carbon credits outside of a regulatory framework to achieve a voluntary emissions reduction goal. There are several voluntary carbon market platforms, but there is not a single authoritative marketplace. Carbon credit transactions typically occur with the assistance of a carbon credit broker who facilitates the transaction rather than directly between those who generate credits (e.g., farmers, ranchers, landowners) and buyers.

Both regulatory and voluntary carbon markets generally involve multiple entities, groups, and organizations. Below we introduce some of the key terms used in carbon market discussions and subsequent sections of this report.

- **Carbon market programs** enroll participants (e.g., farmers, ranchers, or landowners) and offer financial opportunities for implementing specified practices that are associated with GHG mitigation in agriculture and forestry.
- **Carbon registries** develop and update the standards for the management of their program, create the protocols for the generation of credits, and track the status of projects and ownership of carbon credits.
- **Measurement, Monitoring, Reporting, and Verification (MMRV)** refers to activities undertaken to quantify GHG emissions and sinks (through direct measurement and/or modeling), monitor emissions over time, verify estimates, and synthesize and report on findings.
- **Protocols** are the criteria and standards under which carbon credits are generated. They include requirements for participant eligibility and what sources of emissions must

be included. They also include procedures for the measurement, monitoring, reporting, and verification of GHG reductions or carbon sequestration.

- **Project Developers** are entities who formally represent offset projects by engaging proponents (such as landowners or operators), defining and documenting interventions, interfacing with third-party verifiers and registries, and often marketing credits on behalf of the project.
- **Purchasers/Buyers** of carbon credits include regulated entities that use the credits to comply with mandatory emission-reduction requirements or entities such as corporations and individuals that are pursuing voluntary GHG emissions reduction goals.
- **Technical assistance providers** support farmers, ranchers, or private forest landowners in implementing sustainable land use management and livestock practices that prevent, reduce, or mitigate GHG emissions, and may be eligible for carbon credits. They use specialized expertise and tools to assist a farmer, rancher, or private forest landowner in the development of projects that allow for engaging in voluntary environmental credit markets. They often work with carbon project developers and may be affiliated with carbon programs that offer participating producers support for implementation of eligible practices.
- **Third-party verifiers** are entities unaffiliated with project activities, carbon registries, and carbon programs, who independently verify that projects correctly followed the requirements in carbon offset protocols.
- **Vintage** is the calendar year in which the emission reduction or removal associated with a carbon credit took place. A registry or carbon-crediting program may issue carbon credits after the vintage year because the verification process is conducted after the emission reductions or removals occurred (ICVCM, 2023).

2.2 CARBON REGISTRIES

One of the key components in both regulatory and voluntary carbon markets are carbon registries. A carbon registry generally performs three functions: (1) development and approval of protocols (standards) that set criteria for the generation of carbon credits; (2) oversight of the project review and verification against these standards (usually with the help of third-party verifiers); and (3) operation of registry systems that issues, transfers, and retires credits.

There are 4 primary carbon registries, or exchanges, actively operating in the United States: ACR (formerly known as American Carbon Registry), Climate Action Reserve (CAR), Verra's Verified Carbon Standard (VCS), and Gold Standard. These registries have issued more than 412 million credits ($MtCO_2e$) to projects based in the United States for both voluntary and compliance markets from many protocols over the past two decades.

ACR was founded in 1995 and was the first private voluntary GHG registry in the world. Today, ACR has 12 approved protocols designed for agriculture, forestry, or land use activities in the United States. Six of those protocols are active, and six are inactive. Active protocols are approved for current use, while inactive protocols were previously approved but are no longer eligible for new projects for various reasons, including lack of use. The combined active and inactive protocols involve practices such as avoided grassland conversion, improved forest management, reducing CH_4 releases from manure storage or wetlands, afforestation of degraded lands, and decreasing N_2O emissions via precision fertilizer applications (So, Haya, & Elias, 2023). A list of the protocols can be found in Appendix Table A-2.

Climate Action Reserve (CAR) began as the California Climate Action Registry (CCAR) in 2001. In 2007, CCAR was rebranded as CAR and refocused on developing credits throughout North America and Central America. It is in the process of expanding globally. Today, CAR has

22 protocols with projects spanning the region. Of the 22 approved protocols, 8 are applicable to agricultural and forestry practices in the United States—Forests, Grassland, Livestock, Nitrogen Management, Rice Cultivation, Soil Enrichment, Urban Forest Management, and Urban Tree Planting (CAR, n.d.). CAR is also developing a protocol for the production and use of biochar. Since 2013, CAR has issued slightly over 76.6 $MMtCO_2e$ of agriculture and forest-related credits with approximately 90 percent of the credits generated from forest projects (So, Haya, & Elias, 2023).

Verra lists information on certified projects developed through its Verified Carbon Standard (VCS) Program. VCS currently has over 2,000 certified projects worldwide and has more than 1 billion carbon credits issued. The VCS Program was launched in 2006 and has more than 40 approved protocols related to agriculture, forestry, or land use. While some of the active VCS protocols are tailored for international projects, there are 15 active VCS protocols identified in Appendix Table A-2 that are applicable to projects based in the United States. VCS has issued more than 1.6 million carbon credits from these protocols since 2013 (So, Haya, & Elias, 2023).

Gold Standard has generated more than 257 $MMtCO_2e$ worth of GHG credits from 2,902 projects around the world (So, Haya, & Elias, 2023). While Gold Standard has issued carbon credits to projects in almost 100 different countries, projects in three countries (Turkey, India, and China) accounted for 54 percent of issued carbon credits. Gold Standard has issued less than 14,000 $MtCO_2e$ to projects based in the United States.

2.3 Voluntary and Compliance Carbon Markets

Compliance and voluntary carbon markets, and their use of registry protocols, are summarized in the sections below.

2.3.1 Compliance Carbon Markets

The four compliance markets that operate in the United States are California's Cap-and-Trade program, the Regional Greenhouse Gas Initiative (RGGI) in the northeast, the International Civil Aviation Organization's Carbon Offset Reduction Scheme for International Aviation (CORSIA), and the Washington Cap-and-Invest Program. Each of these markets is discussed briefly below.

2.3.1.1 California's Cap-and-Trade Program

California's Cap-and-Trade Program was established under Assembly Bill 32, the California Global Warming Solutions Act of 2006. AB 32 requires a statewide reduction in GHG emissions through a suite of programs, including a Cap-and-Trade Program which sets an annual declining limit on major sources of GHG emissions throughout California. California Air Resources Board (CARB) allows regulated entities to meet their compliance obligation by purchasing allowances from the State and eligible offset credits. Offset credits are generated by projects using one of six approved offset protocols, four of which are for forestry and agricultural projects: U.S. forests, urban forests, livestock digesters and rice cultivation (CARB, n.d.-b).

From program launch in 2013 through August 2023, California's Cap-and-Trade Program has generated 9 $MMtCO_2e$ of offsets from livestock digesters and 205 $MMtCO_2e$ of offsets from forest projects. Combined, livestock and forestry offset credits accounted for approximately 85 percent of total offset credit issuances. Between 2023 and 2030, California's market will allow the use of an additional 107 $MMtCO_2e$ of offsets (CARB, 2019). All offset projects generating compliance offset credits under CARB must be listed with one of three approved Offset Project Registries: ACR, CAR, or VCS. These carbon registries facilitate the listing, reporting, and verification of compliance offset projects, and issue registry offset credits, which are then approved by CARB for regulated companies to use (CARB, 2019).

In addition, a portion of proceeds from allowances sold in California's Cap-and-Trade Program are allocated to the Greenhouse Gas Reduction Fund (GGRF) used for California Climate Investments (California Climate Investments, 2023). There are several agriculture and forestry-related programs funded through the California Climate Investments that result in millions of metric tons of additional GHG reductions. Some of these programs include the Healthy Soil Program, Alternative Manure Management Program, and Healthy Soils Program.

2.3.1.2 Carbon Offsetting and Reduction Scheme for International Aviation

At its 39th triennial Assembly in 2016, the International Civil Aviation Organization (ICAO) adopted Assembly Resolutions A39-2 and A39-3, which set the goal for the aviation sector to achieve 2 percent annual fuel efficiency improvement through 2050 and capped GHG emissions from international aviation at 2020 levels. Strategies to achieve these goals include market-based measures. The primary market-based measure is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (ICAO, 2019).

ICAO CORSIA has approved eight registries to supply credits to the program. In the United States, they include ACR, CAR, and VCS Program (ICAO Environment, n.d.). The program has approved the use of several agriculture and forestry protocols from the above registries. Demand for credits is expected to increase as the program enters its first phase in 2024 (UNDP, 2022).

2.3.1.3 Regional Greenhouse Gas Initiative

The Regional Greenhouse Gas Initiative (RGGI) is a market-based cap-and-trade program for the power sector in the Northeast United States. The program started in 2009 and in 2021, included 12 participating States (RGGI, n.d.-a). RGGI allows for five types of offset projects with two types, avoided agricultural methane and forestry or afforestation, applicable to the agriculture or forestry sector (RGGI, n.d.-b). Since its start in 2009, RGGI has only generated about 50,000 MtCO_2e of credits, none from agricultural or forestry standards, and there are no current efforts to expand the program to include additional agriculture or forestry carbon offset protocols (RGGI, n.d.-c).

2.3.1.4 Washington's Cap-and-Invest Program

In 2021, the Washington Legislature passed the Climate Commitment Act, which established the State's Cap-and-Invest Program. Washington's Cap-and-Invest Program sets a limit on overall carbon emissions and requires certain businesses to obtain allowances equal to their covered GHG emissions. The program also allows participating entities to use a limited number of offset credits to meet their GHG emission compliance obligations. Each offset credit needs to demonstrate direct environmental benefits to the State, meaning forestry and manure digester projects generating credits are likely to be located within Washington State or nearby tribal lands.

The Cap-and-Invest Program Rule adopted four offset protocols from California's cap-and-trade system (livestock, forestry, urban forestry, and ozone-depleting substances). Washington's program also mirrored California's project registration and verification requirements by approving two existing project registries (CAR and ACR) to support the program. These approved Offset Project Registries review and approve offset project submittals to ensure all requirements are met before the Washington State Department of Ecology conducts its review and issues offset credits eligible for its program.

2.3.2 Voluntary Carbon Markets

Over the past 28 years, more than 12 agricultural and forestry carbon offset programs and 4 offset registries or exchanges have been created by for-profit businesses and non-profit organizations. New program development has accelerated over time, with more than 9 new programs created in the past 5 years (Table 2-1). This is likely due to the significant economic opportunities presented by carbon markets, described more in Chapter 3. To compete for market share, these programs may differentiate themselves by creating proprietary data tracking and trading platforms, marketing specific aspects of their program (e.g., ease-of-use or integrity of the credits issued), partnering with agriculture corporations, or targeting a specific group of participants (e.g., family forest owners).

As the carbon market space is rapidly evolving, different program models have emerged. Some programs in the voluntary carbon market space have developed their own protocols and other activities that are analogous to registries. For example, these programs may issue, track, and sell carbon credits (at times, programs use different terminology and issue “certificates” or “tokens,” rather than “credits”). Other programs adopt existing protocols developed by the registries (e.g., ACR, CAR, VCS). While a program may develop its own protocols and define methodologies at initiation, it may also generate carbon credits through more traditional registries and protocols.

Many programs operate as project developers, where they work directly with farmers, ranchers, or landowners to initiate and track projects. Oftentimes, the program will provide technical assistance and other support to ensure that the project is implemented within the parameters of the protocol. They may also help assess the potential of prospective projects and provide upfront financing. To drive demand, these programs may actively market their credits to businesses, individuals, or other entities looking to offset their carbon emissions.

Table 2-1. Examples of Voluntary Carbon Market Programs and Registries

Launch Year	Name
1996	ACR (formerly known as American Carbon Registry)
2003	Chicago Climate Exchange (discontinued in 2010)
2003	Verra’s Verified Carbon Standard (VCS) Program
2003	Gold Standard
2007	Climate Action Reserve
2016	CIBO
2016	Truterra
2017	Puro.earth
2018	Nori
2018	Pachama
2019	Carbon by Indigo Ag
2020	Forest Carbon Works
2021	Agoro Carbon
2021	Family Forest Carbon Program
2021	Locus Ag’s CarbonNOW
2022	Bayer Carbon Program
2022	ESMC
2022	Nutrien

2.3.3 Insetting Programs

Carbon insetting refers to reducing emissions within a company's own supply chain. Insetting has recently become attractive to corporations interested in reducing the GHG emissions associated with the goods and services they purchase, also referred to as Scope 3 emissions. These emissions are often the largest sources of a company's GHG emissions. By developing stronger relationships with the entities in their supply chain, both corporations and their suppliers have a mutual interest in the products and production practices of farmers, ranchers, and private forest owners.

Activities that establish an offset credit for sale in a carbon market cannot be used to claim an inset within the supply chain as that would be considered double-counting. When an offset credit is sold, the reductions are transferred from the supplier to the credit buyer. Conversely, efforts to generate and account for emissions reductions as an inset help ensure that emissions claims do not "leave" the supply chain in the form of credits sold to other industries.

To the extent that brands have GHG emissions targets or seek to make carbon neutral claims, they need to take care to avoid double counting of reductions already accounted for elsewhere in the form of credits. When pursuing environmental claims, corporations in forestry and agricultural supply chains often include language regarding insetting in contracts with their suppliers. As many agricultural supply chains utilize intermediate infrastructure that aggregate commodities, insetting initiatives also involve defining and documenting traceability back to participating producers or to a regional supply shed surrounding processing facilities and other offtake points.

One insetting platform in agriculture is the Ecosystem Service Market Consortium's (ESMC) Eco-Harvest Program. ESMC uses the Gold Standard Value Chain Initiative (Gold Standard, 2021) guidance to create a framework for farmers to quantify the outcomes associated with practice interventions and market those benefits to entities in their supply chain. ESMC's members include industry leading commercial brands, input providers, and grain infrastructure partners who are seeking to meet climate goals through engagement with farmers. Other examples of insetting initiatives in the agricultural and food sectors include Field to Market, Athian's livestock focused platform, the Soil and Water Outcomes Fund, and CIBO's program engine that helps implement corporate environmental claims initiatives on croplands.

2.4 Role of Project Developers and Third-Party Verifiers

Project developers and third-party verification bodies play important roles in the carbon market. These roles are described in more detail below.

2.4.1 Project Developers

Project developers are the entities that originate carbon credit projects. They work with the proponents of the project to implement interventions, collect the data, conduct the calculations, complete the paperwork, and coordinate the third-party verification. There are more than 150 project developers identified in compliance and voluntary agriculture, forestry, or land use carbon credit projects over the last decade. However, approximately 20 project developers were associated with more than half of the projects that received credits. These 20 project developers include private companies and nonprofits. While several project developers are associated with a higher number of credited projects that involved agriculture, forestry, and land use scopes, there are also several project developers that focus primarily on one type of project type (e.g., improved forestry management or manure digesters).

2.4.2 Third-Party Verification Bodies

Before credit issuance, many carbon crediting programs require verification from an independent third-party verifier. The independent third-party verification process helps to ensure ample documentation exists to ensure the obligations of the protocol have been met. Carbon programs requiring third-party verification may have specific rules regarding the qualifications of verification bodies. For example, in California's Cap-and-Trade Program, CARB accredits verification bodies that meet certain requirements, including relevant experience and policies in place to prevent conflicts of interest. California also requires members of the verification body take CARB-approved trainings and exams. In the voluntary carbon market, registries like ACR and CAR require verification bodies to be accredited by ANSI National Accreditation Board to demonstrate competency and conformance to ISO 14065[1] (ACR, 2023; CAR, 2023a).

In 2023, CARB listed 16 accredited offset verification bodies eligible to perform third-party verification services (CARB, 2023b). Of the 16 verification bodies accredited by CARB, 8 of those entities also held accreditation for voluntary projects with ACR, CAR, or VCS (ACR, 2023; CAR, 2023a; Verra, n.d.). All of the verification bodies based in the United States that were accredited to verify voluntary carbon credit projects (8 total) with ACR, CAR, or VCS also were accreditated by CARB.

2.5 Carbon Credit Quality Initiatives

Previous studies have shown that some projects received carbon credits that did not represent a reduction or removal of GHGs (Haya, et al., 2023; Badgley, et al., 2022; Stapp, 2022). These studies tend to focus on project-type-specific over-crediting and the likelihood of additionality (i.e., whether the activity would have occurred without revenue from sales of carbon credits). While the types of project activities examined vary, several research findings focused on international renewable energy and Reducing Emissions from Deforestation and Forest Degradation (REDD+) projects (Haya, et al., 2023; Rathi, White, & Pogkas, 2022; Guizar-Coutino, Jones, Balmford, Carmenta, & Coomes, 2022). Studies that identified inadequacies in carbon credit projects have led to broader concerns over the quality of credits and the accuracy of emission reduction claims made by entities purchasing credits (Lakhani, 2023; White, 2023; Twidale & McFarlane, 2023).

Due in part to concerns over quality and inconsistencies across different carbon markets, various organizations have developed standards for carbon-crediting programs, protocol methodologies, and guidance on climate action claims associated with carbon credits. The standards apply to projects in various sectors, including agriculture and forestry. Some examples of organizations setting market-wide guidance for carbon programs are:

- **The Integrity Council for the Voluntary Carbon Market (ICVCM)**. ICVCM has three primary goals: (1) Establish, host, and curate a set of Core Carbon Principles (CCPs), which will set new threshold standards for high-quality carbon credits and define which carbon-crediting programs and methodology types are CCP-eligible. (2) Provide governance and oversight over standard setting organizations on adherence to CCPs as well as on market infrastructure and participant eligibility. (3) Help to coordinate and manage interlinkages between individual bodies; define a roadmap for the responsible growth of the Voluntary Carbon Market (ICVCM, 2022).

[1] ISO 14065 is a document published by the International Organization of Standards (ISO) that specifies principles and requirements for bodies performing validation and verification of environmental information statements (ISO, 2020). ISO 14065 has general principles and requirements for the competence, consistent operation, and impartiality of bodies performing validation/verification activities.

- **Voluntary Carbon Markets Initiative (VCMI)**. VCMI's mission is to enable high-integrity voluntary carbon markets that deliver real and additional benefits to the atmosphere, help protect nature, and accelerate the transition to ambitious, economywide climate policies and regulation. VCMI has developed a Claims Code of Practice rulebook on how companies can make use of voluntary carbon credits as part of credible, science-aligned net-zero decarbonization pathways (VCMI, n.d.).

- **Carbon Credit Quality Initiative (CCQI)**. This effort was founded by the Environmental Defense Fund (EDF), World Wildlife Fund (WWF), and Öko-Institut and provides a transparent score on the quality of carbon protocols. This information enables users to understand what types of carbon credits are more likely to deliver actual emission reductions as well as social and environmental benefits (CCQI, n.d.).

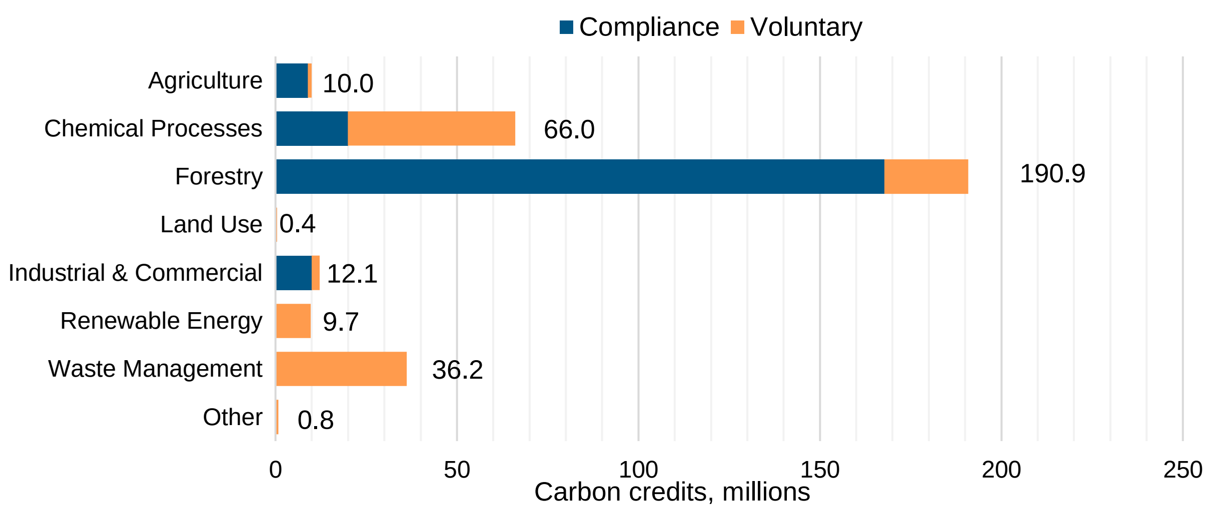
Similar types of standard initiatives are also being developed for insetting and indirect emission reductions (Scope 3) reporting from agriculture and forestry. Examples of programs include the Science Based Targets initiative (SBTi) Forest, Land and Agriculture (FLAG) Guidance, GHG Protocol Land Sector and Removals Guidance, and the Value Change Initiative (VCI). However, a 2022 report by the United Nations Food and Agriculture Organization and the European Bank found that standard-setting organizations have diverged in recommended approaches and definitions related to insetting and carbon neutrality claims (Santos, Monzini Taccone di Sitizano, Pedersen, & Borgomeo, 2022).

3 Supply and Demand of Agricultural and Forestry Credits in the United States

3.1 Supply of Agricultural and Forestry Carbon Credits

In the last decade, registries issued more than 326 million carbon credits to projects in the United States for a variety of activities in both the compliance market (California Cap-and-Trade Program) and voluntary market (Figure 3-1).[2] Projects under the forestry scope accounted for more than half of all credit issuance volume (58 percent). Carbon credits from agricultural and land use projects have been significantly fewer, accounting for 3 percent credit volume between 2013–22.

Figure 3-1. Carbon credits issued by scope for projects in the United States, 2013–2022

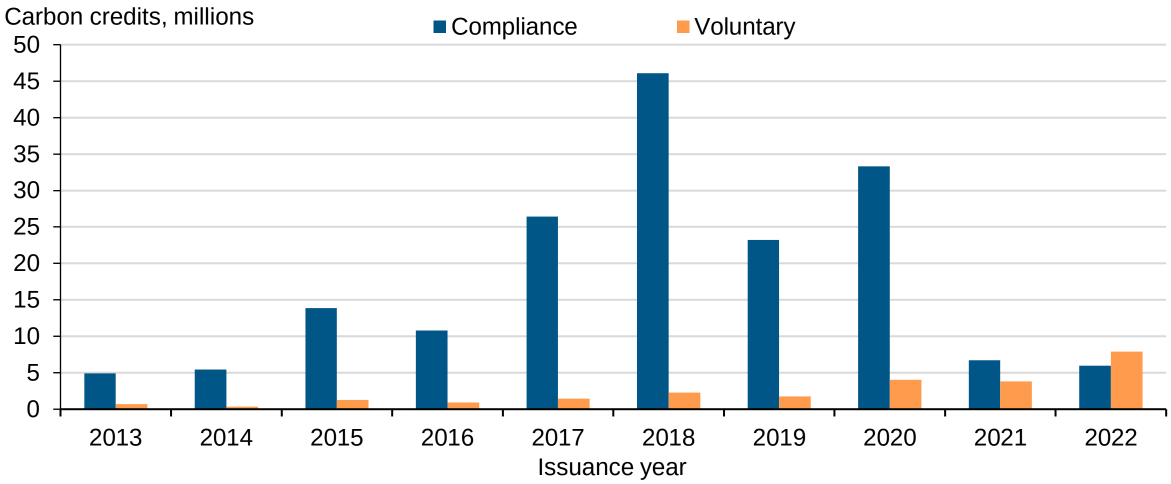


Note: Only includes voluntary credits issues by ACR, CAR, VCS, or Gold Standard. Compliance credits represent offsets in the California cap-and-trade program. Other includes credits under transportation and the household and community scope.
Source: So, Haya, & Elias, 2023.

Driven largely by forestry projects, the supply of credits has varied significantly over time. Over the past decade, compliance and voluntary projects using agriculture, forestry, or land use protocols generated approximately 201 MMtCO_2e (So, Haya, & Elias, 2023) (Figure 3-2). The compliance market peaked in 2018 with the creation of more than 46 MMtCO_2e. While compliance credit volume was higher than voluntary volume for credits issued between 2013 and 2021, registries issued more voluntary carbon credits in 2022 (7.9 MMtCO_2e) than carbon credits in the compliance market.

[2] Unless otherwise noted, carbon credit volume data cited throughout this report were obtained from the Voluntary Registry Offsets Database (version 8) developed by the Berkeley Carbon Trading Project (So, Haya, & Elias, 2023). This database held all carbon offset projects, credit issuances, and credit retirements listed globally by four major voluntary offset project registries—ACR, CAR, Gold Standard, and VCS. The database also contains offset credit issuance data from California's Cap-and-Trade Program. The database is released under Creative Commons Attribution (CC BY 4.0) license.

Figure 3-2. Agriculture, forestry, and land use carbon credits by issuance year: Compliance and voluntary markets in the United States, 2013–2022



Source: So, Haya, & Elias, 2023.

Over the past 4 years, the volume of carbon credits for the compliance market has dramatically decreased. This may be because regulated companies have banked about 321 MMtCO_2e of allowances (as opposed to offset credits), which represent about 90 percent of 2022 emissions. Companies with sufficient banked allowances will not need to purchase new carbon credits to meet their current compliance requirements (Kurbanov, 2023).

Meanwhile, the volume of voluntary carbon offsets issued increased from 2.2 MMtCO_2e in 2018 to 7.9 MMtCO_2e in 2022. This increase in supply is expected to continue as an increasing number of companies have raised demand by setting ambitious GHG reduction goals. See section 3.5 for a discussion of the demand of carbon offsets.

3.2 Types of Agricultural and Forestry Credits in the United States

In 2023, there were 55 protocols reviewed during this general assessment related to the generation of agriculture and forestry carbon credits in the United States (Table 3-1). That total includes 41 active protocols, 5 protocols under development, and 9 protocols listed as inactive.[3] A list of each reviewed voluntary and compliance protocol, and their associated carbon programs, is in Appendix Table A-2. The majority of these protocols (53) were associated with ACR, CAR, Gold Standard, VCS, or CARB. Of the 55 protocols identified, only 18 protocols have been used to issue credits. These existing protocols can be categorized into three project scopes: agriculture production, forestry, and land use.

There are more forestry-related protocols than other types, accounting for 16 of 41 active protocols. Forestry protocols cover a variety of practices including improved forest management, afforestation, reforestation, avoided conversion, and urban forestry. While improved forest management continues to be the most popular protocol in terms of credit generation, there are no issued credits under any of the urban forestry protocols.

[3]When a protocol is considered "active" projects can generate carbon credits under the published protocol. In some cases, protocols may become "inactive" as registries replace or archive methodologies over time. Data from inactive protocols is included in the summary tables and throughout this report to reflect market activity to date.

Table 3-1. Number and status of agriculture, forestry, and land use protocols

Scope	Project Type	Protocol Status			Protocols with issued credits	Total protocols
		Active	**In Development**	**Inactive**		
Agriculture	Animal Waste Management	2			1	2
	Enteric Methane	3				3
	Grassland Management	2	1	2		5
	Livestock Manure Digester	2			2	2
	Optimized Nutrient Management	2		2	2	4
	Rice Management	3		1	1	4
	Soil Carbon	4	1	2	2	7
	Agriculture Total	**18**	**2**	**7**	**8**	**27**
Forestry & Land Use	Biochar	2	1	1		4
	Forestry	16	2		7	18
	Grasslands Protection	2			2	2
	Wetlands	3		1	1	4
	Forestry & Land Use Total	**23**	**3**	**2**	**10**	**28**
Agriculture, Forestry, and Land Use Total		**41**	**5**	**9**	**18**	**55**

Under the agriculture scope, 11 of the 27 protocols focus on cropland-related activities like optimized nitrogen management and soil carbon sequestration. Grasslands protocols are split between the land use and agriculture project types, as two of these protocols focus on avoiding emissions associated with the conversion of grasslands to croplands; the remaining address improved grassland management. Wetland restoration protocols fall under the land use project type.

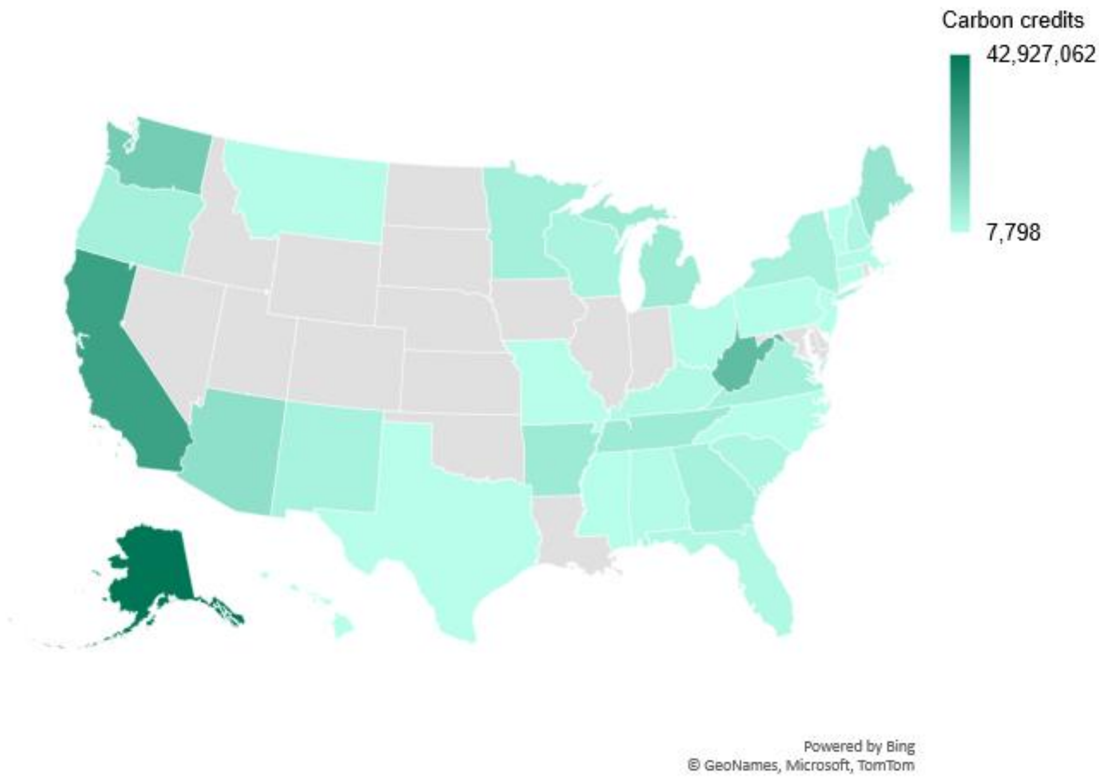
3.2.1 Forestry Project Scope

Trees have the ability to both emit and sequester CO_2 from the atmosphere. Through the process of photosynthesis, trees absorb CO_2 and store it as carbon in their trunk, leaves, branches, and roots. Carbon is also stored in the forest soils, as well as through dead wood and litter on the forest floor. The long-term storage of carbon can continue after the harvest of trees through durable wood products that are harvested from forests, though some portion of that carbon is lost during harvesting and the production process.

In addition to transfer of carbon from the atmosphere to wood products through harvesting, forests can transfer carbon or emit CO_2, CH_4, and N_2O through tree mortality and related decay/combustion events like fire, disease, or pest infestations. The quantity and rate of CO_2e that is emitted varies depending on the circumstances of the event. Forests are the largest reservoirs storing CO_2 in the United States, according to the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. GHG Inventory). Forest lands increased carbon stocks by 670.5 $MMtCO_2e$ in 2021 relative to 2022 (USEPA, 2021).

More than 190 million credits have been issued to projects located across the United States in the past decade (Figure 3-3). In total, forestry projects represent approximately 95 percent of all agricultural and forestry credits. The majority of forestry credits were predominantly used for offset credits in California's Cap-and-Trade Program with only about 12 percent issued for the voluntary market (So, Haya, & Elias, 2023).

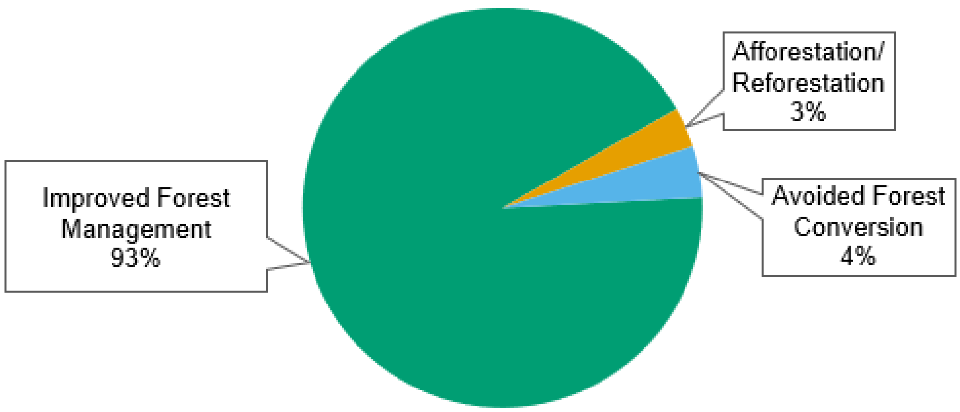
Figure 3-3. Forestry carbon credits issued to projects in the United States, 2013–2022



Note: 1 carbon credit = 1 $MtCO_2e$.
Source: So, Haya, Elias, 2023.

Forestry projects generate credits through three main practices: avoiding the conversion of a forest to another land use with lower amounts of carbon storage, afforestation/reforestation, or improved forest management practices. Approximately 93 percent of forestry carbon credits projects issued over the last decade fall under improved forest management (Figure 34). These types of projects focus on increasing carbon in existing forests by changing management practices. Many improved forest management projects generate their highest volume of credits in their first year. This is because the protocols use the baseline assumption that either the trees in the project would be harvested in the first year of the project and then the forest would regrow and be harvested again according to industry standard forestry practices or that the carbon stored in the forest is above the regional average. Due in part to these counterfactual baseline assumptions in improved forestry management protocols, researchers have raised concerns about potential over-crediting of projects the United States (Haya, et al., 2023; Badgley, et al., 2022).

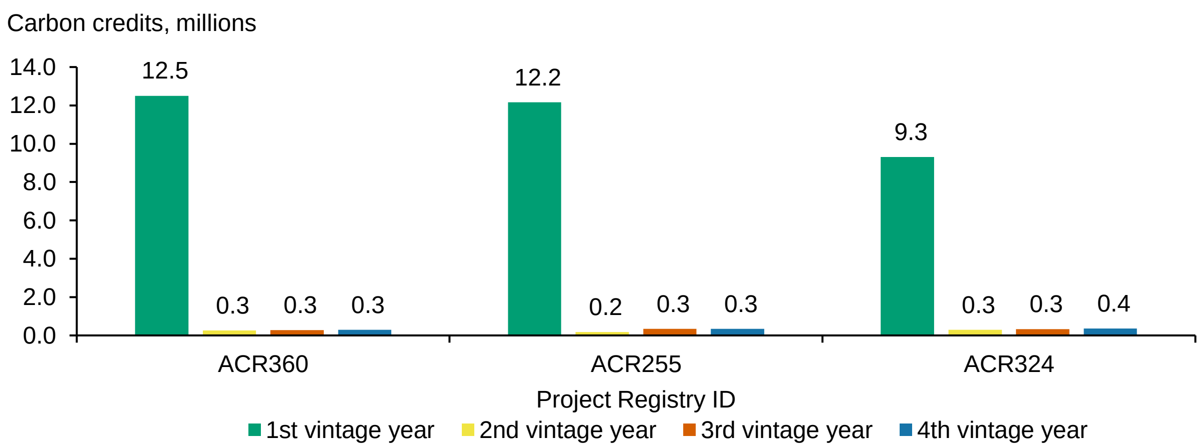
Figure 3-4. Percent of carbon credits issued by forestry project type in the United States, 2013–2022



Source: So, Haya, Elias, 2023.

Between 2013 and 2022, three projects generated more than 37.6 million credits, representing 20 percent of all forestry credits generated in the United States (So, Haya, & Elias, 2023). One project alone, a 500,000-acre improved forestry management project in Alaska (ACR360), generated more than 12.5 $MMtCO_2e$ in its first vintage year issuance, but less than 300,000 $MtCO_2e$ credits the following vintage years (Figure 3-5).

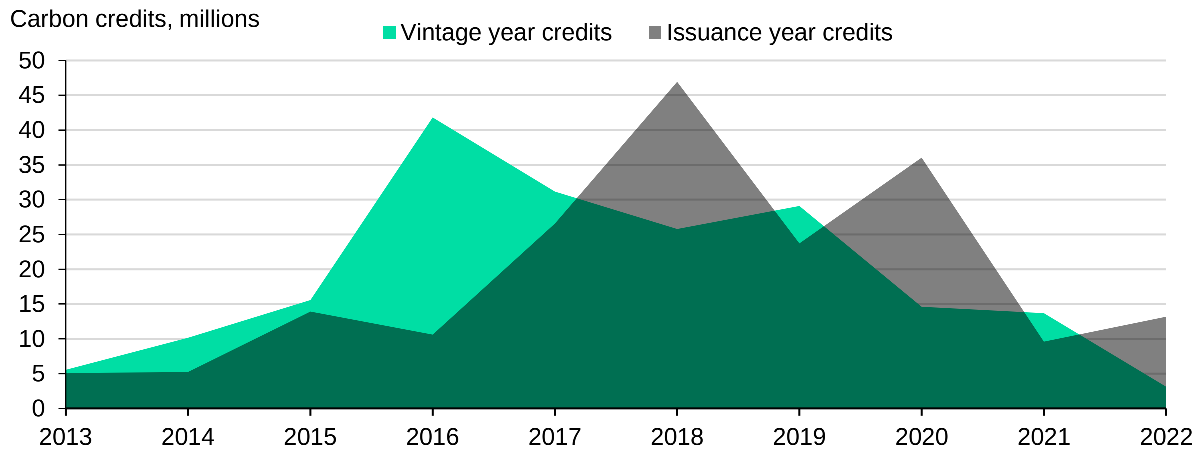
Figure 3-4. Top improved forest management projects by vintage year credit issuance



Note: 1st vintage year varies by project: ACR360 = 2017, ACR225 = 2016, ACR294 = 2016.
Source: So, Haya, & Elias, 2023.

A large volume of credits generated in the initial vintage year from large projects is one of the reasons year-to-year changes in carbon credit issuance from forestry projects have increased and decreased over the last 7 years (Figure 3-6). The lag in issuance year credits compared to vintage year credits also highlights the delay between when sequestration activities occur and the issuance of credits from a registry.[4]

Figure 3-6. Forestry projects in the United States: Carbon credits by vintage year and issuance year, 2013–2022



Source: So, Haya, & Elias, 2023.

3.2.1.1 Forestry Projects in Development

There are 43 forestry projects that are currently in development with initiation dates since 2020, 28 percent of which are destined for the compliance market. Over the past 4 years, an average of 22 forest projects were created per year. The current number of projects in development appears consistent with previous years.

3.2.2 Agriculture Project Scope

Agricultural carbon projects address emissions associated with livestock, nitrogen management, methane byproducts from rice production, as well as the sequestration of soil organic carbon in agricultural soils. The largest portion of agricultural credits stems from livestock digester projects, though soil focused cropland protocols are relatively new and started producing credits in 2020.

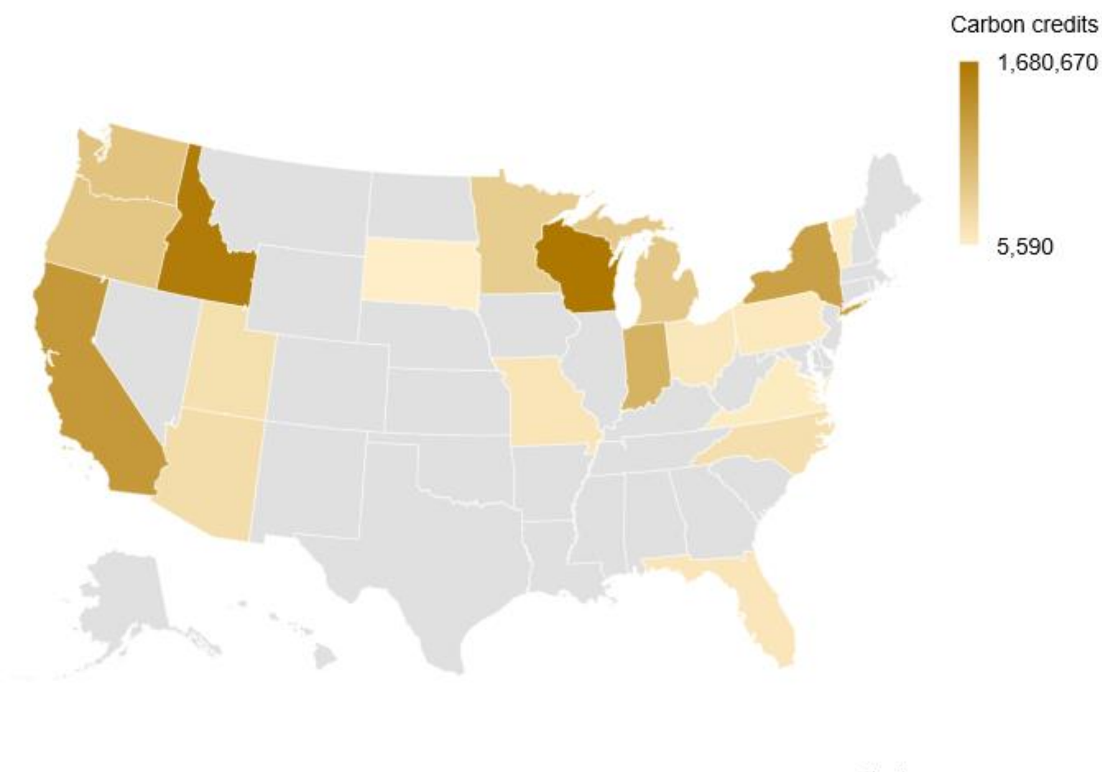
3.2.2.1 Livestock Manure Methane Digester Projects

Between 2013 and 2022, projects implementing livestock protocols that address the capture and destruction of methane from manure management systems have generated approximately 9.8 $MMtCO_2e$ worth of carbon credits. Livestock methane digester projects are created by installing digesters, or reactors, which process manure in a controlled, sealed environment. As the manure breaks down, the reactor captures biogas, which is primarily composed of methane. The methane in the captured biogas can then be combusted at the operation (e.g., flared or burned in a generator to create electricity) or further processed and used as transportation fuel (e.g., renewable natural gas). Unlike carbon sequestration projects, the biogas captured by the manure digester and combusted by a destruction device can be directly measured. Therefore, avoided methane emissions that are generated and captured by livestock digesters are not subject to the same reversal risks or project emission quantification concerns that non-point source sequestration projects face (see Chapter 4).

[4] Carbon offsets are issued based on the year in which the reductions were generated. These are called vintages. During the initial verification of a project, many protocols allow for the generation of offset credits for a limited timeframe prior to the official filing of paperwork with the offset registry. This historic crediting timeframe is typically limited to no more than 24 months.

The compliance market (e.g., California's Cap-and-Trade Program) accounts for more than 90 percent of carbon credits issued from livestock manure digester projects over the last decade. In general, these projects generate between 1,500 $MtCO_2e$ and 70,000 $MtCO_2e$ per year. While livestock digester projects generate a reliable volume of credits per year, fluctuations may occur depending on the volume of manure generated by the livestock operations and fed to project digesters. Livestock manure digester protocols from both CARB and CAR are only applicable to operations with cattle (including dairy cows) or swine. While manure digester projects across the United States have participated in carbon markets, Wisconsin, Idaho, California, and New York accounted for almost 60 percent of carbon credits issued over the last decade under this scope (Figure 3-7).

Figure 3-7. Manure digester carbon credits issued from projects in the United States, 2013–2022



Note: 1 carbon credit = 1 MtCO2e.
Source: So, Haya, Elias, 2023.

In 2017, CARB updated the state's Low Carbon Fuel Standard (LCFS) to include new fuel pathways for the generation of LCFS credits from the capture of methane generated by dairy manure. While not an offset program, the LCFS program uses the same offset protocol as the Cap-and-Trade program to generate LCFS credits (CARB, 2018).[5] See section 7.1.8.2 for more detail.

3.2.2.2 Enteric Fermentation

Cattle generate methane in two ways. This first, as described above, is through manure management. The second, called enteric fermentation, occurs when the microbes in a cattle's

[5] While similar to an offset program, low carbon fuels programs are narrower in scope—they only apply to the creation of alternative transportation fuels.

digestive system ferment food and generate methane. According to the U.S. GHG Inventory, enteric fermentation is the largest anthropogenic source of methane emissions in the United States.

There are currently two offset protocols that credit for reductions in enteric fermentation emissions. The first was developed and adopted by the Gold Standard in March 2019. The second was developed and adopted by Verra's VCS Program in November 2019. Both protocols generate credits based on the use of feed additives. In the United States, three projects have been initiated under the VCS Program protocol (So, Haya, & Elias, 2023).

In January 2021, CARB published a study conducted by Ermias Kebreab and Xiaoyu Feng of the University of California, Davis that identified 90 different potential feed additives available in the scientific literature. These additives were grouped into three categories:

1. Those that are safe and effective for use to reduce methane production and are recommended once all regulatory approvals are in place.
2. Compounds where research shows that the product may be effective, but more research is required before it is recommended for use.
3. Feed additives where research to date has:
    - Provided insufficient evidence to conclude that the product may be effective;
    - Shown that product is not effective; or
    - Shown that the product should not be used for other reasons.

3.2.2.3 Optimized Nitrogen Management

Cropland nitrogen management protocols credit reductions of direct and indirect N_2O emissions from nitrogen (N) fertilizer applications as well as practices that increase N availability in soil. According to the latest U.S. GHG Inventory, N_2O emissions from agricultural soil management—including croplands and grasslands—totaled 294 $MMtCO_2e$ in 2021 (USEPA, 2021). This accounts for just over 75 percent of economywide N_2O emissions, roughly 49 percent of all agricultural sector emissions, and about 5 percent of net U.S. emissions.

Three voluntary carbon offset registries (CAR, VCS, and ACR) have developed and adopted a total of four protocols related to nitrogen management. The protocols are listed in Table 3-2 and include the current version number, date the latest version was issued, and current status.

Table 3-2. Nitrogen Management Offset Protocols

Program	Protocol	Latest Version	Date Issued	Protocol Status
CAR	Nitrogen Management Project Protocol (NMPP)	2.0	October 2018	Active
VCS	Quantifying N_2O Emissions Reductions in Agricultural Crops through Nitrogen Fertilizer Rate Reduction (VM0022)	1.1	September 2013	Active
ACR	Methodology for Quantifying N_2O Emissions Reductions from Reduced Use of Nitrogen Fertilizer on Agricultural Crops	1.0	July 2012	Inactive
ACR	Methodology for N_2O Emissions Reductions from Changes in Fertilizer Management (ACR DNDC)	2.0	January 2014	Inactive

Between the four nitrogen management protocols, only six projects have been created since 2013. Three of the projects generated a total of 75 $MtCO_2e$, one of the projects was terminated prior to generating credits, and two projects are still in development. Since 2019, there have not been any new credits issued under these nitrogen management protocols. Based on the history of these protocols, additional projects solely focused on nitrogen management are unlikely.

3.2.2.4 Improved Rice Management

According to the U.S. EPA, CH_4 emissions from rice cultivation totaled 15.1 $MMtCO_2e$ in 2019, making rice the fourth largest source of GHG emissions from agriculture, after agricultural soil management, enteric fermentation, and manure management (USEPA, 2021). However, given its limited acreage in the United States, rice cultivation has comparatively less project development capacity than projects affecting the top three crops – corn, soy, and wheat – which consist of about 69 percent of harvested cropland in the United States (USDA, 2019). The potential methane reduction practices for rice are dry seeding, early drainage, baling and alternate wetting and drying (AWD). AWD has the largest potential and is implemented by periodically draining fields to prevent the anerobic conditions that encourage formation of methane producing bacteria, and reflooded to prevent plant stress.

Four protocols related to rice methane management have been developed and adopted for use in compliance and voluntary carbon markets. A protocol developed by CARB covers two rice growing regions in the United States: the Sacramento Valley of California and parts of four Mid-South States (the Mississippi River Delta of Arkansas, Missouri, and Mississippi as well as the Gulf Coast of Louisiana). One protocol developed by CAR only allows projects from the Sacramento Valley of California. The ACR rice management protocol includes a methodology applicable rice-growing regions around the world as well as regional-specific protocol requirements for rice growers in California and the mid-South growing region. Finally, a protocol by the Gold Standard is applicable to projects globally.

To date, only two voluntary projects have generated carbon credits for emissions reductions in rice management systems in the United States. These projects generated 590 $MtCO_2e$ of credits between 2012 and 2015 under ACR's rice management protocol, which is now inactive. The small number of carbon credits generated from rice management projects is due in part to relatively small volume of GHG reductions per acre and transaction costs required under existing protocols.

3.2.2.5 Soil Carbon Sequestration

The most commonly used practices to sequester carbon in agricultural soils involve reductions in tillage, through practices like no-till and strip-till management. Conventional tillage tills 20 cm deep before the first crop rotation and 10 cm deep for following rotations. In comparison, no-till mulches the crop residue while leaving the soil undisturbed. This form of residue incorporation leaves the majority of crop residues on the field, which can be incorporated in the next tillage. A 2020 study found that no-till or strip-till is practiced on only 30 percent of U.S. cropland (Pannell, 2020).

Use of cover crops are another common practice used to sequester additional carbon in agricultural soils. Cover crops are plants that are generally planted after cash crops have been harvested and that are used to slow erosion, improve soil health, enhance water availability, smother weeds, and help control pests and diseases (Clark, 2015). The adoption of cover crops is much lower compared to no-till or conservation tillage in the United States (Wallander, Smith, Bowman, & Claassen, 2021). Because of their low adoption rate, cover crops have high emissions reduction potential. One study has estimated that if an additional 217 million acres of the five largest crops in the United States adopted cover crops, approximately 103 $MMtCO_2e$ could be sequestered every year (Fargione, 2018).

Three carbon credit protocols have been created that credit practices that sequester soil carbon. They are the most recently developed agriculture protocols. The first is CAR's Soil Enrichment Protocol, which was first adopted in September 2020 and has generated 111,677 $MtCO_2e$ from two projects. A second protocol, Methodology for Improved Agricultural Land Management, was published by VCS in October 2020. While no credits have been generated by this protocol in the United States, there are currently two projects under development. The third soil carbon protocol is the Croplands Methodology developed by Nori in 2020. Nori has credited 20 carbon removal projects under its Croplands Protocol on more than 43,000 acres, which have generated more than 125,000 $MtCO_2e$ of credits (Nori, n.d.).

3.2.2.6 Agricultural Projects in Development

There are a total of six livestock manure and three feed additive projects in development. There is some concern about the future development of digesters because of a law passed in 2016 that requires CARB, in consultation with the California Department of Food and Agriculture (CDFA), to consider the adoption of regulations to reduce methane from dairy and livestock manure management operations. These regulations can be implemented no earlier than 2024 (California State Legislature, 2016). If adopted, these regulations could require California dairies to implement manure digesters or other manure management practices. In addition, the volume of carbon credits from feed additive projects may be limited until more feed additives are approved by the Food and Drug Administration (FDA).

Under the VCS soil carbon protocol, there are two projects currently under development in the United States. In addition, two soil carbon projects have issued credits. There is expected to be a high demand for these credits because soil carbon sequestration is viewed by credit buyers to have attractive co-benefits and substantial carbon removal potential, in spite of the permanence and quantification challenges many projects under this scope face.

The optimized nitrogen management and improved rice management protocols are not expected to generate a significant volume of credits. This is in part because volume of credits per acre for either protocol type has not been cost effective for project developers. Voluntary credits were last generated under an improved rice management protocol in 2017.

The CAR and ACR nutrient management protocols generated only 75 $MtCO_2e$ from three projects. Three additional projects are under development for optimized nutrient management, and they will provide valuable information regarding the potential for these protocols to generate credits.

3.2.3 Land Use Project Scope

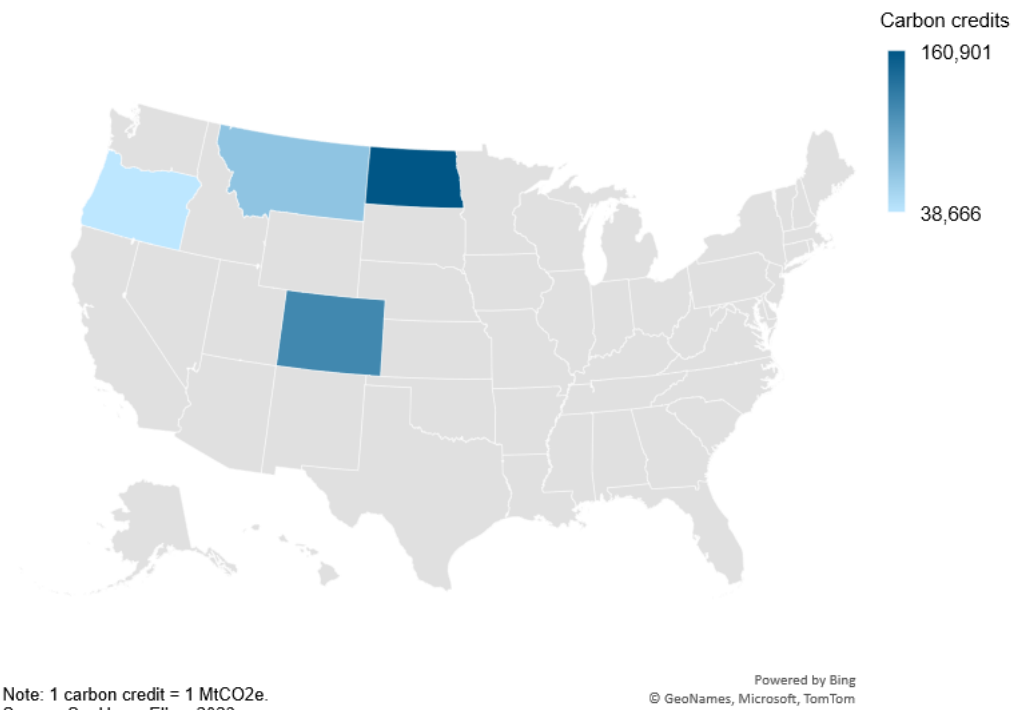
Land use projects can involve either protecting carbon sinks from land conversion or generating new ecological services relative to previous land use. Carbon protocols have focused on grassland preservation and, to a lesser extent, promotion of wetlands.

3.2.3.1 Grassland Projects

Grassland projects credit the benefits of preserving a grassland relative to the local threat of its conversion to row crop production. When grasslands are tilled for crop cultivation, a portion of the carbon stored in the soil is released as CO_2 into the atmosphere. CAR estimates that between 3,600 to 153,900 $MtCO_2e$ are released through this annual conversion of approximately 185,000 grassland acres (Diaz, et al., 2015). There are currently two grassland protocols including ACR's Avoided Conversion of Grasslands and Shrublands to Crop Production Protocol and CAR's U.S. Grassland Protocol.

Between 2013 and 2023, 12 grasslands projects have generated nearly 400,000 $MtCO_2e$ of credits. A project by Ducks Unlimited using ACR's Avoided Conversion of Grasslands and Shrublands to Crop Production protocol in the prairie pothole region of North Dakota generated 160,901 $MtCO_2e$ during this period. This represents the largest volume of credits generated by a grasslands project (Figure 3-8). No other project has used ACR's protocol.

Figure 3-8. Avoided grassland carbon credits issued from projects in the United States, 2013–2022



Note: 1 carbon credit = 1 MtCO2e.
Source: So, Haya, Elias, 2023.

CAR also has a grassland protocol and 11 projects have generated 236,693 $MtCO_2e$. These projects are located in Oregon, Montana, and Colorado. The annual volume of credits from these projects ranges from about 100 to 12,000 $MtCO_2e$. Because the CAR protocol is based on emissions factors, the volume of credits per project are reasonably constant on an annual basis.

3.2.3.2 Wetland Projects

Wetlands provide many ecosystem services, including storm surge reduction, fish and wildlife habitat, water quality improvement, as well as the potential for carbon sequestration (Batker, 2010; Jenkins, 2010). Carbon that is sequestered in vegetated coastal and marine ecosystems, such as mangrove forests, seagrass beds, and salt marshes, has been called 'blue carbon.' These ecosystems efficiently trap suspended matter and the associated organic carbon during tidal inundation (Mack, 2022).

Four protocols have been created for the crediting of carbon sequestration from wetlands. Three of the protocols were developed by ACR and one by VCS. Over the past decade, one project was developed in California under the ACR Restoration of California Deltaic and Coastal Wetlands. In 2020, ACR issued approximately 52,000 credits to this project. While VCS has not issued credits for a wetland restoration project based in the United States as of mid-2023, it has issued more than 4.7 million carbon credits to international voluntary projects (So, Haya, & Elias, 2023).

3.2.3.3 Land Use Projects in Development

There are 16 grassland projects under development. The CAR protocol is being used for 14 projects, which are located in Montana, Texas, Georgia, Colorado, and Massachusetts. Most grassland projects are located in the U.S. northwest because this region has higher carbon containing soils and a significant risk of conversion to row agriculture.

In addition, three wetland restoration projects are currently under development with ACR and VCS, in addition to three ACR projects that have been canceled. The first wetland protocols were developed in 2012; to date, only one project has generated credits. These projects often require significant capital as well as coordination with the U.S. Army Corps of Engineers for projects impacting wetlands that fall under the jurisdiction of the Clean Water Act. While wetlands provide significant environmental benefits, cost and complexity create barriers to implementation.

3.2.4 Inactive Protocols

ACR and VCS developed several protocols that have since been made inactive. The most common reason that a protocol is made inactive is because the protocol no longer conforms with the registry's MMRV requirements. To maintain active status, these protocols would need to be updated to the latest standards of each of the registries. When a protocol has resulted in no or few projects and when there is limited external interest in updates, it is unlikely the registry will update the protocol for future project development.

ACR has made the following eight protocols inactive (Appendix Table A-2 indicates which inactive protocols have generated credits):

1. Biochar Projects
2. Changes in Fertilizer Management
3. Compost Addition to Grazed Grasslands
4. Reduced Use of Nitrogen Fertilizer on Agricultural Crops
5. Restoration of Degraded Wetlands in the Mississippi Delta
6. Rice Management Systems
7. Grazing Land and Livestock Management
8. Methane Recovery in Animal Manure Management Systems (ACR, n.d.)

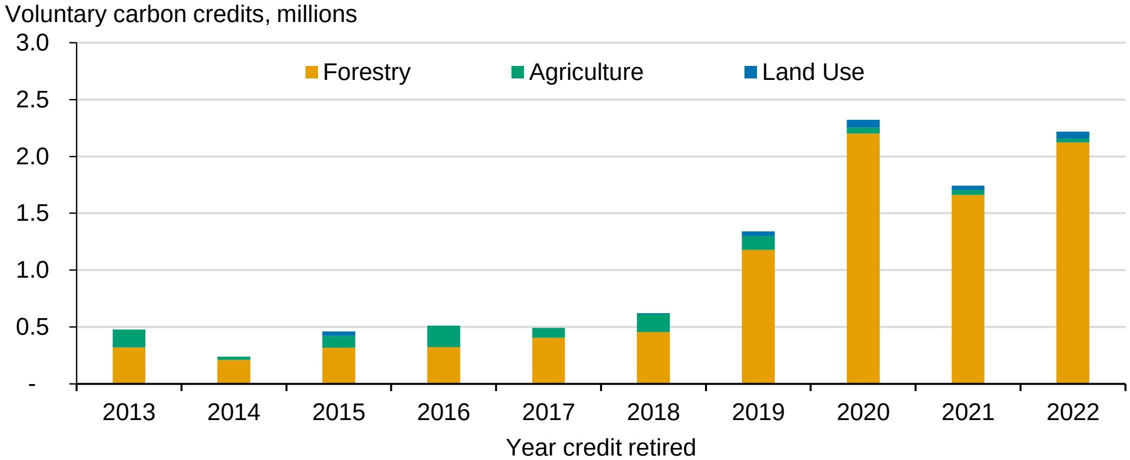
The VCS Program has two inactive protocols applicable to agricultural and forestry practices:

1. Adoption of Sustainable Agricultural Land Management
2. Soil Carbon Quantification Methodology (Verra, n.d.)

3.3 CARBON CREDITS SOLD

Registries do not typically publish carbon credit transaction information, such as purchaser information and sale price. However, they do publish the date when carbon credits are retired, which serves as a good proxy for the sale date (Figure 3-9). A voluntary carbon credit is retired from a registry when the associated emission reduction or removal is claimed towards voluntary goals. While it is possible for buyers to purchase carbon credits and hold them for future retirement, referred to as "banking," this is not a common practice by non-regulated corporations that purchase most voluntary credits (Trouwloon, Streck, Chagas, & Martinus, 2023).

Figure 3-9. Voluntary carbon credits retired from agriculture, forestry, and land use projects based in the United States, 2013–2022



Note: Land Use category includes avoided grassland conversion and wetland restoration projects.
Source: So, Haya, & Elias, 2023.

The price of a carbon credit can vary by project type, perceptions of credit quality, protocol type, vintage, and co-benefits of the activity (World Bank, 2023). Therefore, the variance in the price of carbon credits may reflect attributes specific to the project generating the credits as well as the buyer's preference. In 2022, the weighted average price of offset credits from livestock and forestry projects ranged from $16.57 to $19.91 per Mt$CO_2$e in the California Cap-and-Trade Program (CARB, 2023d). The weighted average price for forestry projects was slightly higher than livestock, and both project types had a slight price premium if they qualified as having direct environmental benefits to the State. While price information on the voluntary market is limited, a World Bank publication on carbon pricing found the average monthly global price for nature-based carbon credits (agriculture, forestry, and land use) in 2022 ranged from $5 to $16 (World Bank, 2023). The lower end typically represents prices for reducing emissions from deforestation and forest degradation in developing countries (REDD+) projects, while there is no dominant project type for the higher prices.

3.4 Future Agricultural and Forestry Carbon Credit Supply

The potential supply of agricultural and forestry carbon credits is expected to increase, largely driven by traditional forestry projects (i.e., urban forest projects are not expected to drive supply trends). In addition, avoided conversion of grassland projects and cropland soil carbon projects are also expected to increase and generate more credit supply based on the number of newly listed projects (So, Haya, & Elias, 2023). One market force impacting all credits is the growing interest in removal rather than avoidance and reduction projects. Currently, 82 percent of all projects in carbon markets avoid or reduce GHG emissions. Removal projects, which remove CO_2 from the atmosphere, represent only 5 percent of all projects (the remaining 13 percent are a mix of avoidance/reduction and removal) (Morgan Stanley, 2023). But recent increases in pricing for high quality removal projects relative to avoidance may induce additional supply in coming years. The only agriculture and forestry protocols considered as removal are reforestation and soil carbon sequestration protocols. Improved forest management and avoided grassland conversion protocols, while technically removing CO_2 over time, are typically considered carbon retention protocols by the marketplace. Therefore, it is expected that reforestation and soil carbon protocols will be preferentially purchased compared to other agriculture and forestry projects (WRI, n.d.).

3.4.1 Protocols Under Development

Each of the major registries (ACR, CAR and VCS) have a unique and detailed process for the development of new carbon credit protocols. All of them include a public review process. ACR and VCS also include a scientific peer review, while CAR employs a workgroup approach that includes scientists and experts in the industry and development of projects.

ACR has one protocol under development for the Avoided Conversion of U.S. Forests. This protocol credits projects that forego conversion of non-federal U.S. forestlands to alternative land uses, including agriculture, mining, or development.

Verra currently has three protocols relevant to U.S. agricultural producers and forest landowners under development in its VCS Program. They are:

1. **Methodology for Carbon Sequestration Through Cultivating Hemp:** The proposed methodology is global and applies to project activities that sequester carbon through hemp cultivation and biomass storage in long-lived hemp products (hempcrete and batt insulation). Eligible project activities must ensure hemp is cultivated on degraded or marginal agricultural fields.
2. **Methodology for Reducing Emissions Intensity of Grassland-based Cattle Production:** The proposed methodology incentivizes improved practices in grassland-based beef cattle production. Eligible land areas are those undergoing agricultural land expansion and grassland degradation. The methodology proposes to credit reductions in the GHG emissions intensity of cattle production. A performance benchmark method is proposed for additionality assessment and for the crediting baseline. Eligible project activities must include at least one practice that increases grassland and cattle productivity and may also include other activities that increase cattle productivity.
3. **Methodology for Afforestation, Reforestation, and Revegetation Projects:** This methodology applies to afforestation, reforestation, and revegetation project activities, resulting in removals of GHG from the atmosphere. This methodology is globally applicable, as opposed to CAR's U.S. Forest Protocol which is restricted to domestic forests. The methodology is applicable to all afforestation, reforestation, and revegetation activities that do not take place on organic soils or wetlands and result in an intentional manipulation of the water table, or that do not take place in tidal wetlands.

CAR is developing a U.S. and Canada Biochar Protocol that will provide guidance on how to quantify, monitor, report, and verify climate benefits from the production and use of biochar, which is capable of locking up carbon and keeping it from re-entering the atmosphere for centuries (CAR, 2023b). Biochar production provides an opportunity for the productive use of a variety of feedstocks that are otherwise considered waste biomass, including non-merchantable residues from timber harvests and forest thinning intended to reduce fuel levels to decrease wildfire risk. Partial funding for this biochar protocol development was provided through the USDA Forest Service Wood Innovations Program and the California Department of Forestry and Fire Protection.

3.5 Future Demand for Carbon Credits

According to market analysts, the global carbon credit market demand is estimated to be 181.1 MMtCO_2e in 2023 and is expected to grow to 1.2 billion metric tons (GtCO_2e) by 2030 and 5.4 GtCO_2e by 2050 (BloombergNEF, 2023a). In the next several years the demand for carbon credits is expected to increase drastically because of the growing number of corporate net-zero commitments. A recent survey found that 90 percent of more than 500 global companies in 13 different business sectors see GHG emissions reductions as an urgent priority of their organization (Conservation International & We Mean Business Coalition, 2023). According to a report by McKinsey and Company, these goals and priorities could increase the demand for carbon credits by a factor of more than 15 by 2030 and up to a factor of 100 by 2050 (Blaufelder, 2021).

Companies are not the only entities developing GHG emissions targets and associated programs. Several countries have recently established carbon crediting mechanisms, including Indonesia, Vietnam, South Africa, India, and Canada. These international efforts are expected to further drive demand of credits worldwide. Many of these programs are prioritizing reductions from nature-based solutions. In response to these demands, Ecosystem Marketplace found in 2022 that 54 percent of new project listing were for agricultural and forestry credits (World Bank, 2023).

These corporate and country goals and programs are estimated to expand the carbon market to between 1.5 and 2.0 $GtCO_2e$ by 2030 and 7 to 13 $GtCO_2e$ by 2050 (Blaufelder, 2021). The credits in this market are expected to be sold at an average of price of $38 per $MtCO_2e$ by 2039 according to a 2023 Bloomberg New Energy Finance forecast. The forecast also included a scenario where carbon markets are limited to carbon removals and prohibit the use of avoidance (such as avoided deforestation) and clean energy projects. Prices under this scenario are expected to be above $250 per $MtCO_2e$ (BloombergNEF, 2023b).

4 ACCOUNTING SYSTEMS FOR AGRICULTURAL AND FORESTRY CARBON CREDIT PROJECTS

4.1 OVERVIEW

An accurate accounting of GHG emissions and carbon sequestration benefits due to a project is critical to the functioning of carbon markets and to achievement of the GHG reduction goals driving participation in the market. Over the past nearly 30 years, carbon credit protocols have evolved to align with a series of basic concepts for defining carbon credits and determining producer eligibility for carbon projects.

4.2 QUANTIFYING CARBON CREDITS

Accounting for the carbon effects associated with a mitigation activity generally involves comparing the emissions and sequestration associated with a project activity in place to a baseline scenario that represents what emissions and sequestration would be without the activity. The difference in the GHG reduction, GHG removals, or carbon sequestration between the baseline and project scenario need to be positive for that activity to generate carbon credits. The general formula for calculating such credits is:

> Carbon credits = (Incremental Project Sequestration – Incremental Baseline Sequestration) + (Baseline Emissions – Project Emissions)

For practices that involve only changes in emissions, with no sequestration component, that formula simplifies to:

> Carbon credits = Baseline Emissions – Project Emissions

The most common way of determining an emission baseline in GHG offset markets is to estimate emissions under a “business-as-usual” scenario that would have likely occurred without implementing the activities in the protocol. The baseline scenario allows a project to estimate net emissions reductions corresponding to protocol-specific activities within a specific time period. Depending on the type of project, annual baseline estimates may stay the same or be regularly adjusted using site-specific annual data. Adjusted baselines, also called dynamic baselines, are often used in agriculture projects and quantified across multiple years to capture the impacts of variables like precipitation and temperature that fluctuate during each crediting period. Verra recently adopted a protocol that credits improved forest management practices using a dynamic baseline (Verra, 2022c). Adjusted baselines are also used to model dynamic management practices like crops that rotate each year (e.g., corn and soybean rotation) (CAR, 2022; Verra, 2023).

For project emissions and sequestration, quantification methods usually involve a combination of emission factors, process-based modeling, and direct measurement of emissions or sequestration. While direct emissions measurements are feasible for point-source activities like methane combustion from manure digesters, many agriculture and forestry protocols rely more on dynamic modeling and random sampling due to the variability of emissions and sequestration from agricultural and forestry sources. Quantification systems are discussed in more detail in Chapter 5. Current protocols often require both ongoing monitoring activities and detailed historic production data to accurately estimate GHG benefits. For example, CARB’s Rice Cultivation Projects Compliance Offset Protocol requires a baseline period consisting of data from “at least five years immediately prior to the commencement of a project that comprises at least two cropping cycles” (CARB, 2015). Producers without accurate historic records for their practices or site-specific data may not have the data necessary to meet requirements for credit quantification under agricultural or forestry protocols.

4.2.1 Complications

The heterogeneity and dynamic nature of agriculture and forestry make quantification challenging. Many complications associated with accounting and quantification of carbon benefits from agriculture and forestry projects can be grouped into four categories: additionality, leakage, permanence, and uncertainty.

4.2.1.1 Additionality

To qualify for carbon credits, the emissions reductions or carbon sequestration achieved through an agriculture or forestry project need to be "additional" to what would have happened in the absence of the project (the baseline). Defining a baseline against which to determine additionality is challenging, however, because it requires projecting a counterfactual scenario that encompasses all drivers that would likely have influenced behavior and emissions/sequestration in the absence of that project. Protocols require specific evaluations of additionality in order for a project to be considered additional. These requirements include an evaluation of legal requirements, financial, practice barriers, and common practice. Not all of these additionality requirements are part of every protocol.

- **Legal additionality:** To meet legal additionality, projects must demonstrate that the practices they implement are above and beyond any GHG reductions or sequestration that would have resulted anyway from compliance with any federal, state, or local law, statute, rule, regulation, or ordinance.
- **Financial additionality:** Some protocols require projects to demonstrate that without the revenue received from the selling of carbon credits, they would not have implemented the practice.
- **Practice barriers:** Projects must describe the barriers that have discouraged the adoption of the practice that generates the emissions reductions or sequestration and how the project allows producers to overcome them. Practice barriers could include cultural or social barriers related to the risk of implementing the practice. It could also include technical barriers, such as access to the necessary equipment required for the practice.
- **Common practices:** To exclude practices with a high likelihood of being adopted even in the absence of the project, some protocols set a cap on adoption rates beyond which practices are considered so "common" that they cannot generate credits. For example, in the CAR SEP protocol, once the adoption of a practice such as no-till or rotational grazing exceeds an "uptake rate of more than 50 percent of either total cropland area, or total pasture operations," they are considered ineligible for crediting under the protocol (CAR, 2022).

4.2.1.2 Leakage

Leakage occurs when project activities that reduce emissions or increase sequestration directly or indirectly result in activities outside of the scope of the project to increase emissions or decrease sequestration. Leakage and secondary effects create challenges for the accurate quantification of benefits associated with agricultural and forestry projects. An example of leakage or secondary effects occurs when the yield of a given crop drops on project fields as a result of project activities. This drop in production is then compensated for by a proportionate increase in production (and associated GHG emissions) elsewhere, outside of the project boundaries, in response to market forces. In such scenarios, GHG emissions are partially shifted, not eliminated – they "leak" outside of the project boundary.

4.2.1.3 Permanence/Reversals
Practices that retain or increase biomass or soil carbon are subject to the threat of reversal. If the forest associated with a sequestration project burns down, or a no-till field is tilled, then a significant portion of the carbon that has been sequestered in the biomass or in the soil may be released as carbon dioxide, “reversing” the carbon storage credited to the project. This reversal can be due to events that are unavoidable (such as a fire) or avoidable (such as through tilling).

4.2.1.4 Quantification Uncertainty
All quantification of GHG emissions and carbon sequestration includes a level of uncertainty. The Intergovernmental Panel on Climate Change (IPCC) has recognized this and has included methods for determining the uncertainty of emissions quantification or sequestration as part of developing national GHG inventories (IPCC, 2019). Accurately quantifying baseline and project emissions or sequestration for projects in ecological systems, such as agriculture and forestry, is even more challenging because agriculture and forestry systems have highly variable conditions, such as weather, forest species, and soil types, that impact both the baseline and project scenarios and associated factors such as yields (Malhi, Kaur, & Kaushik, 2018).

4.3 Protocol Design
Protocols describe a set of rules under which carbon credits are generated. They list the practices and geographies covered, determine the boundary of the project, detail the equations to quantify reductions and sequestration, and provide requirements for third-party verification. These rules are designed to create protocols that are accurate, comprehensive, and practicable.

- **Accurate:** Carbon credits should be based on quantification methods that yield accurate results. The accuracy includes the use of the most recent science on the quantification of the benefits including deductions for uncertainty. All current protocols require an assessment of uncertainties for the practices included in the protocol. They require reasonable assumptions of the uncertainty ranges of all the parameters.
- **Comprehensive:** The baseline and project scenarios should comprehensively quantify the emissions impacts associated with the project’s activities. The protocol establishes project boundaries addressing spatial, temporal, and operational boundaries of the project. The project boundaries should be set to cover all the GHG emissions impacted by the practices implemented by the project. Establishing appropriate temporal boundaries for the quantification of GHG benefits is important because many practices, such as no-till and cover crops, result in GHG benefits over longer periods of time (Bolinder, et al., 2020).
- **Practicable**: If the requirements to meet the other principles require significant time and resources, or result in small amounts of reductions or sequestration, the protocols may not be economically viable.

In addition, many protocols apply conservative adjustments in order to avoid overstating the GHG benefits. This concept is called conservatism and is widely used within carbon credit protocols and programs. Conservative assumptions are used in protocols to systematically underestimate the total GHG reductions and removals associated with a project activity. While this helps to ensure that credits used to offset emissions elsewhere do not overestimate the amount of allowable emissions at the source, these provisions result in fewer credits being issued and lower incentives to participate in carbon projects.

4.3.1 Protocol Design Mechanisms to Address Accounting Issues
Some of the challenges to ensuring alignment with these principles have been described above, and protocols have developed an array of strategies to mitigate the risk and uncertainty arising

from those quantification challenges. Attempts to align protocols with the above principles may involve tradeoffs, such as in cases where simplified and standardized baselines are used to reduce transaction costs and improve practicability but may have the effect of increasing the uncertainty of GHG estimates. To address risks associated with carbon credit reversal, various policy mechanisms like discounting, buffer pools, permanence contracts, and ton-year accounting are used. Six strategies to address quantification challenges are described below.

4.3.1.1 Standardized Baselines

The majority of existing protocols with issued credits in Appendix A-2 use a mixture of project-specific data and a standardized baseline approach. A standardized approach means all projects apply the same assumptions, emission factors, and calculation methods in determining their baseline (CAR, 2021). Establishing a standardized baseline involves collecting relevant data, understanding alternative technologies and practices, and considering broader economic, technological, regulatory, and policy trends all relevant to the specific sector. By investing in the upfront effort of developing a standardized baseline, registries avoid project-by-project baseline analysis, establish consistency across projects, and reduce transaction costs. While a standardized baseline approach may result in cost-saving at the project-development level, overly lenient or conservative protocol-specific standards result in over or under-crediting of individual projects when compared to baseline assumptions derived from a project-by-project approach (Haya, et al., 2020).

4.3.1.2 Discounting

Discounts have been proposed to reduce the likelihood that a project receives credits for more emissions or sequestration benefits than could occur based on uncertainty in the quantification of the emission reductions (Kollmuss & Lazarus, 2011). Under a discount, a carbon credit representing 1 metric ton of GHG reduction or removal is multiplied by a discount factor (between 0 and 1), such that the net number of credits issued to the project is reduced. Discounts can be applied before credits are issued or at the time the credits are used to offset emissions (Kollmuss & Lazarus, 2011). They can take a number of forms and can be integrated into protocols in different ways, depending on whether they are proposed to address uncertainty, leakage, or additionality:

- **Discount factor**. In some cases, protocols invoke discount factors when parameters that impact emissions from specific project-level activities have a high level of uncertainty. For example, the CAR Forest Project protocol uses a 6-percent discount for the initial baseline to “account for legal and financial constraints that may prevent harvesting to minimum baseline levels” (CAR, 2023c).
- **Conservative default value**. Protocols may also allow a project developer to choose between monitoring a given parameter and using a conservative default value that effectively discounts the quantified emissions.
- **Discount factor linked to yield threshold**. One way protocols address leakage in cropland projects is by comparing the average crop yield of the project during the baseline period to the average crop yield during the project period. If the yield declines by more than a threshold level, typically 5 percent, the possibility for leakage triggers application of a discount rate, and the number of credits generated by the project are discounted by the percent yield reduction.

4.3.1.3 Buffer Pools

The sequestration of carbon from project activities generating agricultural and forestry carbon credits may be disrupted due to avoidable or unavoidable events that re-release stored carbon into the atmosphere. The risk of reversal or permanence is a major determinant of carbon credit quality. Carbon credits generated from LULUCF projects face natural risks such as fire, disease, pest outbreaks, and other natural disasters. In the past several years, some issued carbon credits were reversed because of wildfires.

A buffer pool is a programmatic insurance pool, where the program requires sequestration-based projects to contribute a percentage of credits to a common pool each time credits are issued. These buffer pool contributions are set based on protocol-specific risk profiles, focusing on unavoidable risks to permanence and events that may cause sequestered carbon to be released back into the atmosphere. Each offset registry has a slightly different approach to buffer pool contributions, as well as differing rules for the scenarios where the registry draws on the buffer pool as the result of a reversal. These registries may segregate buffer pools by protocol/project type, but they currently have one buffer for all protocols with an unavoidable reversal risk. The size of the buffer pool should also reflect the fact that while natural disasters like fire result in carbon transfers between carbon stocks, such as from living to dead biomass, not all carbon is released back into the atmosphere.

Currently all carbon programs limit the use of credits in a buffer pool to unavoidable reversals. In the case of avoidable reversals, where an activity is intentionally reversed, project owners may be required to procure and retire carbon credits available on the market to compensate for the reversal. Some agricultural carbon programs and developers are considering setting aside additional credits to insure against intentional reversals (Parkhurst, Moore, Wright, & Perez, 2023).

4.3.1.4 Permanence Contracts

Permanence contracts are another mechanism to ensure permanence as they create legally binding terms for storing carbon permanently. The different registries have developed contracts for various offset project types and employ a range of options. Protocol requirements differ in terms of which entities must be a party to the contracts in question, and how many parties with an interest in the land or offset project must be a party to such contracts.

Permanence related to carbon sequestration on agriculture and forestry lands can create significant contracting challenges for project developers. Protocols have differing timeframes for which carbon must remain in biomass. Some methodologies, like the CAR Grassland Protocol, currently require a 100-year conservation easement period following the issuance of credits to demonstrate permanence. ACR's Improved Forest Management in Non-Federal U.S. Forestlands requires projects to "commit to a minimum project term of 40 years" (ACR, 2022). VCS requires all projects to assess potential carbon loss over 100 years (VCS, 2023) and Nori requires 10 years (Nori, 2020). Landowners may be unwilling or legally unable to sign long-term contracts (ex. 10-100 years) regarding ongoing management activities and carbon storage.

4.3.1.5 Alternative Types of Accounting for Sequestration and Carbon Storage Projects: Ton-Ton and Ton-Year

The Global Warming Potentials used by the IPCC in national inventories are based on a 100-year lifetime of CO_2 in the atmosphere. Carbon credit protocols that credit carbon sequestration adopt versions of this concept. Two policy approaches have evolved for ensuring permanence for carbon credits. The first of these is Ton-Ton-Accounting (TTA). TTA means that for each ton of sequestered carbon dioxide accounted for by a project, one metric ton is issued in the form of a carbon credit. This approach has been used since the first forest protocol was created in 2005. Protocols utilizing TTA rely on the suite of policy options detailed in the sections above to ensure the permanence of credits, including buffer pools and permanence contracts. Each offset program typically employs one or more permanence-related policy options, as well as a suite of MMRV requirements to meet the TTA standard.

The second quantification approach, referred to as Ton-Year-Accounting (TYA), allows for a shorter permanence period, in exchange for a reduced volume of credits issued based on the temporal value of carbon. TYA is proffered as an alternative approach to sequestration-based land-use projects that are difficult to contractually commit to 100-years of permanence. While the general concept of TYA is not new for country-level GHG inventory quantification of sources and sinks, the generation of a carbon credit from temporary sequestration activities raises concerns about carbon credit equivalency compared to projects associated with more permanent climate mitigation efforts. Since TYA is crediting short-term climate benefits, there are different methods to assess valuation. Two factors influencing TYA are the estimated value of temporary carbon storage during the time horizon and assumptions about the immediate or partial release of stored carbon following the end of the permanence period (Levasseur, et al., 2012; Marshall & Kelly, 2010). While several protocols currently allow for TYA as an option, such as CAR's Soil Enrichment Protocol (CAR, 2022), no projects have utilized the approach. In April 2022, Verra published a proposed approach to TYA (Verra, 2022a). During the same timeframe NCX proposed a Methodology for Improved Forest Management through Targeted, Short-Term Harvest Deferral. However, in June, Verra decided to defer adoption of TYA while reserving the right to revisit its use in the future (Verra, 2022b).

A related method proposed for addressing permanence through establishment of short-term credits is "carbon leasing." Under a carbon leasing arrangement, ownership of the credit does not transfer from seller to buyer; instead, the "buyer" leases the carbon benefits on a periodic basis as they accrue. At the end of the leasing period, the renter can either renew the lease at a price that reflects any changes in rates of accrual in the new period or replace the credit with a lease on another activity to ensure continuity in their claimed emissions benefits (Marland, Fruit, & Sedjo, 2001). Because such arrangements have no assumption of permanence beyond the leasing period, and the renter's portfolio of leases must be renewed and rebalanced periodically, the price paid for a lease would be lower than the price paid for purchased credits. At this point, there are no known programs or projects that use a carbon leasing arrangement.

4.3.1.6 Producer Eligibility Criteria

Protocols also specify eligibility criteria that a project must meet to participate in a carbon market. Eligibility criteria based on geography or location have not been controversial. However, eligibility criteria may also be designed to address issues related to additionality. For instance, some producers will have previously adopted practices prior to initiation of the project. These "early adopters" often are not allowed to generate credits for practices that were implemented in the past, because emissions benefits from such practices are not interpreted as "additional" reductions. Some registries allow for a few years of historical credits to be included in a project as part of a look-back period. For example, Verra allows projects to credit practices up to 3 years in the past (Verra, 2023a). Some protocols allow projects to participate only if the activities are not considered "common practice" for the industry. For example, the CAR Soil Enrichment Protocol uses a common practice additionality assessment to determine what practices are allowed in a county (CAR, 2022).

4.4 Third-Party verification's Role in Project Accounting

The primary goal of verification is for an independent third-party to determine if a project met the requirements of a protocol and the carbon credits that would be issued are accurate within a reasonable level of assurance. Verification is performed after the carbon reduction/sequestration activities occur, which could be after one or more reporting periods (e.g., 1 calendar year) depending on the protocol requirements.

Since verification is ex-post (after the activities were implemented), verifiers rely on information collected by the project owner that relates to quantification, like data collection (e.g., yield monitors from tractors), equipment calibration records, and energy consumption. However, verifiers will also use information from sources like satellite imagery, property ownership records, national weather stations, State- or Federal-level permits, and interviews with relevant compliance entities. Protocols may also require a verifier to conduct a site visit to review monitoring equipment and aspects affecting project eligibility and quantification.

There are voluntary carbon registries that also require a validation process (e.g., ACR and VCS) by an independent auditor. The validation process evaluates the project design and conformance with the protocol before the project is officially listed on a voluntary registry. When validation is required, a project would receive an independent validation review before registration and verification by a verifier before carbon credit issuance.

All of the protocols listed in Appendix Table A-2 require some level of third-party verification. Using an independent verifier adds transparency to the carbon credit processes and decreases the inherent conflict of interest project owners have when quantifying credit generation. However, whether a project is self-verified or verified by an independent third-party, the verification processes are only as good as the accounting systems and standards required in the protocol.

5 GHG QUANTIFICATION SYSTEMS

5.1 STATE OF GREENHOUSE GAS QUANTIFICATION SYSTEMS

There are challenges to quantifying the GHG benefits of agricultural and forestry projects, due to the variability of management systems, species, soils, and climatic variables within agriculture and forestry systems. Outside of research applications, it is cost-prohibitive and impractical to directly measure and monitor GHG fluxes and/or carbon storage from agricultural and forestry activities. No protocol or GHG program requires this kind of direct flux measurement, instead they prescribe a variety of modeling and site-specific sampling measurements (such as soil samples on croplands or gas flow meters on digester projects) that can estimate impacts within certain bounds of uncertainty. This chapter will focus on describing the state of quantification systems currently utilized in carbon projects, and potential roles for USDA and their impacts on GHG assessment for producers participating in carbon markets.

A threshold criterion for registering a carbon project is implementing an eligible practice or activity that is known to reduce or avoid emissions or sequester and store carbon. There are many ways to confidently document the implementation of these practices, from basic record collection (e.g., photographs, seed receipts, data systems) to more sophisticated remote sensing techniques. The challenge for offset projects is to confidently quantify the GHG impact of implemented practices or activities while accounting for the web of interconnected climatic, management, and site-specific factors that also influence net emissions.

There are a variety of approaches available to quantify the impact of activities that seek to prevent, reduce, or mitigate GHGs. Adoption of specific quantification approaches in forestry and agricultural carbon markets depends on each method's accuracy, ability to characterize and minimize uncertainty, affordability relative to incentive payments, accessibility to producers and project developers, and their ability to compare results to defensible baselines. Many technologies that are not yet cost-effective can be valuable in research contexts to help train and improve more scalable models.

In agricultural and forestry carbon projects, direct measurement through soil sampling or gas flux instrumentation is expensive and labor intensive and does not serve as the quantification method for most projects. Even manure digester carbon projects, which measure gas flows to pollution control devices with conventional methane flow meters and gas analyzers, require the use of models and emissions factors from peer-reviewed studies to help substantiate baseline emissions and net emissions reductions.

In lieu of direct measurement, carbon credit projects focused on cropland emissions typically use process-based models, whereas forestry projects more often utilize sampling methods and on-site biomass measurements to estimate carbon stocks. Process-based models can carry significant uncertainty for field-level estimates, and require many data inputs to use, which can be a barrier for producers evaluating carbon programs. While there are emerging remote-sensing technologies, on-site sensors, machine learning developments, and improvements to conventional sampling (e.g., soil sampling technologies) that promise to make localized assessment more accurate and accessible, there remain technical barriers to integrating these solutions across carbon market opportunities.

5.2 MONITORING AND MEASUREMENT TECHNOLOGIES

Monitoring and measurement technologies and methods vary across cropland, livestock, and forest project types. Technologies and methods can include process-based models, simple look-up values, direct measurements, and stratified sampling techniques. Below we discuss the various methods and how they are utilized to quantify or verify emissions within carbon credit projects.

5.2.1 Croplands: Process-Based Models

Process-based models are the most common tool used by carbon markets to quantify GHG reductions for croplands projects. Biogeochemical models simulate the complex interactions between biological, geological, and chemical processes that occur in a system and predict the cycling of nutrients and GHGs under various land management scenarios. While these models provide broad coverage of agricultural systems across the United States, they require detailed site-level inputs on management, soils, and weather. These models can be difficult to operate, and results may carry high levels of uncertainty (Ogle S. B., 2010; Ogle, et al., 2019). Many project developers and protocols leverage on-site measurements to help parameterize models for a given project location, which may reduce uncertainties, but increases costs.

Many process-based models are also used to characterize a dynamic baseline, to compare project interventions against a business-as-usual scenario affected by the same weather conditions experienced by the project. Without elaborate experimental design methods, it is difficult to simulate a similar baseline scenario utilizing only soil samples or other in situ measurements. Examples of the process-based models currently used in the carbon market are in Table 5-1.

Table 5-1. Process-based models used to quantify GHG benefits in agricultural systems

Model	Developer	Systems Covered	Registry Approvals
DayCent	Colorado State University with support from USDA	Croplands, Specialty Crops, Grazing	VCS, CAR, Gold Standard
DNDC	University of New Hampshire	Croplands	VCS, CAR, Gold Standard
SALUS	Michigan State University	Croplands	VCS
Ecosys	University of Alberta	Croplands	Pending CAR certification within Habiterre MRV

Process-based models require detailed management data, including a farm's management history, such as planting, tilling, and fertilization activities. These data are combined with site-specific weather and soil data to estimate GHG emissions and sinks. Because of the range of data required to run these systems, running process-based models typically requires well organized, comprehensive farm management records (Trust in Food, 2021). Remote-sensing data have begun to improve uncertainty and reduce the reliance on extensive management records from producers to provision these models. However, the current sensors or resolution of remote-sensing systems cannot be used for practices like nitrogen management and livestock practices. Remotely sensed data can be used to detect historic planting patterns and tillage intensity, constrain models based on observed conditions, characterize sub-field variability, and evaluate biomass signals that help assess the quality of practice implementation (Wu, 2023).

Research data are critical for the calibration and validation of GHG models as well as for data training and ground-truthing of remote-sensing data. Process models generally require long-term data where soils, weather conditions and management systems are adequately documented. These data can be used to calibrate the model to real-world conditions and validate results. However, the relatively small amount of research data available for calibration/validation and ground-truthing leads to significant uncertainties in modeling and remote-sensing approaches. In some instances, project developers have attempted to reduce model uncertainties with private data collection efforts—though inconsistent data collection methods and transparency challenges make these data less useful for improving models at regional and national scales. USDA has recently announced new investments in improving measurement and monitoring of soil carbon and GHGs from agricultural sources (Greenhouse Gas Monitoring and Measurement Interagency Working Group, 2023). These investments include a soil carbon monitoring network as well as increased investments in GHG research to improve our understanding of soil organic carbon, N_2O, and CH_4 emissions under varied management practices. Over time these investments are expected to inform process models and remote-sensing products, improving accuracy and reducing uncertainty, and potentially reducing the sampling density required of projects. Reducing uncertainty through public investment in robust and extensive monitoring can build trust in the GHG claims projects make, while reducing the need for credit discounting to compensate for uncertainties.

5.2.2 Croplands: Soil Sampling

Protocols addressing soil carbon often require soil sampling in addition to modeling approaches for quantification. For example, soil sampling is used in CAR's Soil Enrichment Protocol to establish values to be used as the basis for baseline and project modeling, as well as for ongoing updates to sampled soil organic carbon levels required at least every 5 years. The complexity of agricultural soils complicates sampling design and analysis. Soil sampling also fails to capture changes in other GHGs that may represent more substantial GHG impacts than those stemming from changes in soil carbon stocks.

Measuring carbon accrual in soil poses challenges given the variability within fields, the cost of sampling, and the slow pace of change of carbon stocks in soil. Complex dynamics between soil strata further complicate sampling. For example, some conservation tillage practices have been shown to cause a redistribution of carbon between soil strata rather than net gains of new organic carbon (Angers & Eriksen-Hamel, 2008; Luo, Wang, & Sun, 2010), whereas some perennial and cover crops have produced SOC gains at deeper depths than most projects sample (Ledo, et al., 2020). Additionally, differences in soil moisture, texture, and slope across a field create challenges in capturing representative samples that can be extrapolated across a field. Grid sampling can help control for some of these variability challenges but introduces significant extra costs. For these reasons, sampling has increasingly been used to help parameterize and calibrate models, rather than serving as a stand-alone quantification approach.

Because soil carbon accrual can also be a gradual process that may not be detectable for more than 5 years after starting an intervention, some soil carbon protocols allow for a truing-up process where modeling may be used as a basis for early crediting, until a credible trendline can be established. However, it is unclear what the implications may be of systematic discrepancies between models and samples, which themselves may also carry wide bands of uncertainty, including from factors like soil handling, bulk density measurements, and lab analysis that are out of the control of a producer.

5.2.3 Livestock: Quantification Methods

Livestock manure digester projects use equipment to measure the volume of biogas, methane concentration, and applicable destruction device activity (e.g., natural gas engine or flare). The data recorded from biogas flow meters and methane sensors is used to calculate the methane generated by the digester and destroyed during project activity. These direct measurements are then coupled with baseline methane estimates to quantify GHG reductions achieved by the project. Manure digester protocols require methane measurement devices to be regularly calibrated and maintained to ensure accurate operation. While these systems demonstrate relatively high confidence evidence of biogas destruction in equipment, empirical models and emission factors are still required to calculate baseline emissions that are not directly measured (e.g., emissions from land applied digestate).

Livestock projects other than anaerobic digesters (e.g., those involving other methods of manure management, animal diets, and feed additives) tend to utilize default emissions factors to estimate emissions reductions. Monitoring devices (e.g., respiration chambers and micrometeorology) are utilized in peer reviewed studies to establish system-specific emissions factors but are not practical for carbon credit projects.

Earth observation tools may eventually help improve emissions factors and indicate where leaks or operational issues lead to CH_4 releases (USEPA, 2021). These tools remain too coarse to translate dispersed signals of low concentration emissions in agricultural systems into site-based emissions estimates, though CH_4 sensors from NASA and private providers are improving spatial resolution and may eventually assist livestock monitoring or other more concentrated sources.

5.2.4 Forestry: Quantification Methods

As the forest carbon cycle is often complex across space and time, associated quantification methods often involve combining data (site-specific forest inventories and/or remotely sensed information) and models (tree allometry and/or non-live tree carbon pool models such as soils) to estimate the carbon attributes of any forest parcel. Often, the most accurate forest carbon assessments are conducted by experienced field crew using site specific models, which often excludes owners lacking such resources from carbon markets. In lieu of such inventories, there is emerging focus on using data from the Nation's forest inventory (the USDA Forest Service Forest Inventory and Analysis program) combined with remotely-sensed information and a suite of curated models to accurately estimate carbon attributes of any given parcel (Burrill, 2021; Murray, 2023). Despite the complexity of forest carbon pools and carbon cycling, the focus of forest carbon projects, particularly avoided deforestation projects, tends to be on assessing aboveground live tree biomass. Aboveground biomass is generally evaluated with site visits, a defined sampling scheme, and associated biometric measurements such as tree diameter and species. Most protocols provide projects with standard conversion factors of biomass to CO_2 to translate sampled fields into $MtCO_2e$ estimates.

Site-specific forest inventories that solely focus on aboveground live tree biomass do not provide the full GHG impact of forestry projects, as there are other pools of carbon that need to be assessed to help characterize baseline[6] and project emissions. Root systems, for example, are challenging to sample in forests, but because the biomass in tree roots bear a strong relationship to aboveground live tree biomass (i.e., root to shoot ratios), allometric equations can be applied to translate sample-based estimates into a more complete inventory. Projects must also assess the decay status of dead trees, duff and litter pools, and even quantity, type, and final deposition of harvested wood products. Given the trajectory of computing resources, artificial intelligence, and an emerging cadre of remote-sensing technologies such as radar and Light Detection and Ranging (LiDAR) from terrestrial, airborne, and space-based platforms, it is expected that the uncertainty regarding forest carbon inventories will be reduced in the future. Until then, there is some flexibility around what inventory and modeling approaches project

[6] Note that for the CAR Improved Forest Management projects a default baseline approach may be utilized in lieu of baseline simulation within an approved model.

developers use to draw relationships between standard tree inventories and carbon attributes, including simulation tools such as the USDA Forest Service Forest Vegetation Simulator (FVS), California Conifer Timber Output Simulator (CACTOS), Cooperative Redwood Yield and Timber Output Simulator (CRYPTOS), and the Forest Resource Inventory Growth and Harvest Tracking System (FREIGHTS). CAR also developed a free, pre-approved tool for offset project developers called the Climate Action Reserve Inventory Tool, which was developed with a USDA Natural Resources Conservation Service Conservation Innovation Grant. The tool helps ensure projects collect the right sampling data to power simulations, and it integrates project data with the FVS to help projects characterize baselines and carbon stock projections.

CAR similarly has produced a tool for quantifying GHG impacts of harvested wood products, where developers can leverage emissions factors for milling processes and different products made of hard and softwood lumber.

5.2.5 Empirical Models and Emissions Factors

Simpler quantification tools such as emissions factors and empirical (linear) models can be useful for some activities. Peer-reviewed studies of GHG interventions, particularly in the livestock sector, provide a foundation for emissions factors that have been used to project emissions reductions. Given the high cost and technical complexity of measuring CH_4 flux at a livestock facility, an emissions factor approach can simplify project development.

Emissions factors derived from models have also been developed for other GHGs such as N_2O and carbon. For example, the CAR U.S. Grassland Protocol has developed the GrassTool to assist with the quantification of projects using the U.S. Grassland Protocol. The tool uses emissions factors to estimate carbon stocks based on various soil types, length of time the land has been grassland, and the location of the project. The emissions factors were derived from geographically distributed implementations of the DayCent model, allowing for grassland operators to input their location and review whether land was eligible for crediting and a projection of carbon credits. CAR similarly has produced a tool for quantifying GHG impacts of harvested wood products, where developers can leverage default emissions factors for milling processes and different types of harvested lumber.

Some simpler empirical models and emissions factors have also been leveraged in Scope 3[7] and insetting initiatives that may not result in tradable carbon credits but do provide directional guidance to producers and facilitate environmental claims within a supply chain. The Cool Farm Tool (Hillier, et al., 2011) and Fieldprint Platform (Johnson, Shapiro, Moody, & Snyder, 2018) are common empirical tools used by brands in croplands supply chains to facilitate environmental claims.

[7] Scope 3 emissions are the indirect emissions that occur in a company's value chain. These are different than the direct (Scope 1) emissions that are emitted by the company's own facilities under their direct control, and the GHG emissions associated with the purchase of electricity for use in their operations (Scope 2 emissions). Examples of Scope 3 emissions include purchased goods and services, business travel, transportation and distribution of products, and use of sold products.

6 BARRIERS TO ENTRY

6.1 BARRIERS TO LANDOWNER PARTICIPATION IN CARBON MARKETS

For most producers and forest landowners, high rates of awareness of carbon markets have not translated into high rates of participation among landowners and operators. A recent survey by Trust in Foods indicated awareness of carbon markets among 93 percent of livestock and cropland managers, but only a 3-percent participation rate (Trust in Food, 2022). This gap in participation stems from several factors. Producers cite the concerns about the return on investment, upfront costs, data collection burdens, compensation for pre-existing practices, permanence requirements, issues of scale, and confusion about carbon markets and programs as key factors in their evaluation into whether to participate in a carbon project (McKinsey & Company, 2022; Trust in Food, 2022). Below we discuss some of these barriers in more detail.

6.1.1 Return on Investment

There is a strong perception among producers that the costs of implementing and maintaining new practices may exceed the benefit, and that carbon projects will require a significant investment in time and resources. A survey of more than 800 corn and soy producers in Indiana found that producers who have not implemented any form of reduced tillage would require revenue of at least $39.40 per acre to adopt no-till practices (Gramig & Widmar, 2018). Even in instances where the carbon price is close to $40, many projects may not be profitable for the producer or landowner because of high transaction costs. Transaction costs can include costs to measure/quantify environmental benefits, costs of annual verification and reporting, registry fees, compliance costs as well as time and opportunity costs associated with the project. Cropland projects can face higher ongoing transaction costs for measurement, monitoring and verification, whereas forest and grassland projects may face higher upfront transaction costs for negotiation where easements may be required to complete the project. While most of these costs are carried by the project developer, they significantly reduce the potential returns on investment for agriculture and forestry credits and directly impact the price that a producer receives for credits. Below, we discuss transaction costs related to verification and quantification in more detail.

6.1.1.1 Costs of Quantification

While it is possible to directly measure above ground biomass, N_2O, CH_4, or soil carbon, it can be expensive, time consuming, and impractical given the heterogeneity in conditions across a farm or ranch. As a result, models are often used to calculate the GHG fluxes on working lands. Even this lower-cost approach results in significant costs, however. GHG estimation models must be accurate to an acceptable degree, which takes significant data, time, and investment. Furthermore, models must be calibrated, validated, and parameterized to accurately represent the various conservation practices, species and crops, and geographies relevant to the project. Running the models with the level of rigor needed to register a project requires significant expertise and time in addition to detailed historical production, weather, and soil data for the project area (see 6.1.3 Record Keeping and Data Collection, below). Likewise, forest carbon programs typically rely on field-based forest inventories to calculate carbon pools, which can be cost-prohibitive for smaller-scale landowners. Finally, even protocols that allow process-based models require periodic on-site sampling to confirm the accuracy of the model both at project initiation and periodically throughout its use. This upfront expense may precede any carbon payment by more than a year.

6.1.1.2 Verification Costs

Verification costs are one of the largest ongoing annual costs for carbon credit projects in the agriculture and forestry sectors. Verification costs are associated with activities that allow verification bodies to reach a reasonable level of assurance in the integrity of carbon credits. These activities include reviewing project data and conducting risk-based sampling. In addition, some protocols that use process-based models require verifiers to rerun the models with project information to confirm the accuracy of the model results. This requirement results in substantial costs and requires verifiers to develop the expertise to run multiple process-based models. While livestock and large-scale forestry projects tend to generate sufficient credits per project to overcome high verification costs, for projects that generate 1 $MtCO_2e$ per acre or less (e.g., most cropland projects), verification can account for as much as 50 percent of the development cost of a project (Proville, et al., 2020).

6.1.2 Upfront Costs to Implement Projects

Because most carbon programs issue credits only after activities have been independently verified, it can often be 18 months to 2 years before producers are paid for their efforts. This puts a burden on farmers, ranchers, and forest owners to implement practices at their own expense and for which they may not receive payments sufficient to cover costs for many months or even years. Without upfront payments or financing, many landowners may not be willing or able to take on additional financial risk or loans needed to implement projects (Biggs, Hafner, Mashiri, Huntsinger, & Lambin, 2021)..

6.1.3 Record Keeping and Data Collection

Record keeping and data collection requirements can present a barrier to participation in carbon markets where protocols require data collection to document ongoing activities as well as detailed historical production and management data to accurately estimate and document GHG benefits. According to a survey by Trust in Food, nearly two-thirds of croplands producers do not use a farm management software system to track practices, relying on a patchwork of spreadsheets or paper records (Trust in Food, 2022). While systems can be developed and implemented for future monitoring, it is more difficult to collect the necessary historical data for GHG quantification. For example, CARB's Rice Cultivation Projects Compliance Offset Protocol requires estimating a baseline period using data from "at least 5 years immediately prior to the commencement of a project that comprises at least two cropping cycles" (CARB, 2015). Producers without accurate historical records for their practices or electronic site-specific data may not have the data necessary to meet requirements under certain protocols. In addition, producers often work with multiple partners who manage practices like planting, irrigation, and fertilizer application; some of those partners work directly for the farmer, while some are contracted out. Managing production data for offset projects requires technical expertise, training, and individuals to collect, analyze, and report the data. While some of this work can be done by the project developer, core information, such as when practices happen (planting, harvesting, fertilizer application) need to be recorded by the producer.

6.1.4 Early Adopters

Additionality requirements of most protocols disallow crediting activities that were implemented in years prior to the eligible start date in carbon offset protocols. While this ensures that carbon credits represent new GHG reductions, it may also exclude early adopters of practices. A majority of farmers surveyed by Trust in Food indicated that they felt pre-existing practices are not fairly compensated by carbon markets (Trust in Food, 2022).

6.1.5 Permanence Requirements

Most protocols require carbon sequestration projects to store the carbon in acceptable carbon pools (e.g., biomass, harvested wood products, soil) for 40 to 100 years. This is a significant challenge for many crop producers because approximately 39 percent of farmland in the United States is rented (USDA ERS, n.d.) and many have 1-year informal agreements with the landowners. In addition, producers are reluctant to enter into multi-year contracts that are necessary to meet the permanence requirements of protocols. This may restrict their flexibility to respond to weather impacts, new markets, and technologies in the future. Likewise, forest landowners are less inclined to participate in carbon programs as contract length increases (Miller, 2012). To compensate for these opportunity costs, producers may require additional incentives. In one Indiana study, farmers indicated that they would require an additional $10.57 per acre to enter into contracts that require long-term permanence (Gramig & Widmar, 2018). Another challenge with 100-year permanence requirements is that they span multiple lifespans and create a contracting challenge because of the common law concept of the "rule against perpetuities," which prevents people from using legal instruments, such as a deed or a will, to control the ownership of property indefinitely (Waggoner, 1986).

6.1.6 Scale

The majority of cropland agricultural offset projects generate between 0.25 and 2 tons per acre (Smith & Parkhurst, 2018). This is a significantly smaller volume than other project types, such as forest projects, which can generate between 1 and 6 tons per acre. This per acre volume is reflected in the size of offset projects. While there is significant variability, the approximate size of forest carbon projects are approximately 62,000 acres, compared to 160 acres for projects created under nitrogen management protocols. Small producers and landowners will face even greater challenges since the generation of credits requires large amounts of land. With smaller projects, quantification, accounting, reporting, verification, and other transaction costs are a comparatively higher portion of project costs. As a result, few agricultural and forestry carbon credit projects are able to justify or cover the transaction costs with landowners of smaller tracts of land. According to a Family Forest Foundation report, forest carbon projects "have only been accessible to forest owners who own several thousand acres or more" (Family Forest Carbon Program, n.d.).

In addition, socially disadvantaged, limited resource, beginning, and veteran farmers may face unique or higher barriers to participation in carbon markets. These farmers tend to have less acreage, earn less income, and rely more on off-farm income relative to the general farming population (Callahan & Hellerstein, 2022; Key & Lyons, 2019; ERS, 2019). They also may have more difficulty accessing financial resources needed for upfront investments to change management practices or to absorb high transaction costs associated with generating credits on working lands.

6.1.7 Market Confusion

The proliferation of agricultural carbon credit programs with varying requirements has created confusion among producers. A 2022 McKinsey survey found that 39 percent of farmers are not participating in a carbon program because they did not understand the programs (McKinsey & Company, 2022). Similarly, a recent report by American Farmland Trust suggests that the recent creation of many carbon programs, and subsequent merging or discontinuation of some, has contributed to producer uncertainty and hesitancy to participate. Different data, practice, compensation, and time period requirements for carbon programs also make it difficult for producers to understand what they need to do to access programs and what benefit they would receive from participation (Parkhurst, Moore, Wright, & Perez, 2023). The various options and lack of consistency between programs make it challenging for producers to compare requirements and determine the potential return on investment of each of the programs in order to decide which program may be the best fit for their operation.

6.2 REDUCING BARRIERS TO LANDOWNER CARBON MARKET PARTICIPATION

There are several strategies that can help overcome producer and forest landowner barriers to market entry. Below we explore some of the strategies being used or proposed to reduce transaction costs, minimize record-keeping burdens, address early-adopter and permanence requirement concerns, and address barriers related to project scale.

6.2.1 Reducing Transaction Costs

High transaction costs in agriculture and forestry carbon projects can drive down profitability and make these projects unappealing to producers and project developers. Quantification and verification costs are two areas where registries and project developers have worked to find solutions to reduce these costs. By driving down these costs, a greater number of agriculture and forestry projects become profitable and can lead to increased participation in the market. Ways in which quantification and verification costs may be reduced are discussed below.

6.2.1.1 Reducing Quantification Costs

As an alternative to having project developers run complex biogeochemical models, several registries have pre-run the models to develop regional, crop, and practice-based emission factors. This eliminates the need for the project developer to run the model for each project, which dramatically reduces the time and cost to develop a project. As an example, CAR, in the development of their Grassland Project Protocol, ran the DayCent biogeochemical model to develop approximately 1,000 different emission factors based on the geography, soil type, and the number of years the land has been managed as grassland. An approach that uses pre-run regional emission factors not only speeds the calculation of emission reductions but allows developers to screen potential lands more quickly to determine their ability to economically generate offsets. This approach may not work for all crops or geographies, however. For example, as part of a USDA Conservation Innovation Grant (CIG), EDF, ACR and Dagan (now ReGrow) investigated the development of emission factors for rice cultivation projects, but because there were too many independent variables, the project was unable to generate emissions factors with acceptable levels of uncertainty (USDA, n.d.-b).

For those crops or geographies where pre-run factors do not work, some registries have pre-approved biogeochemical models to quantify the reductions and carbon sequestration. This approach reduces the requirements for project developers to calibrate, validate, and parameterize the biogeochemical models. These approved models reduce the significant costs for parameterizing and calibrating a biogeochemical model to develop agricultural carbon projects.

6.2.1.2 Reducing Verification Costs

Many of the agricultural and forestry protocols require all fields or operations to be visited at least once over the crediting period of the project, which is one of the drivers for the high costs of verification for agriculture and forestry projects. A few protocols, like the CAR's *Grassland Project Protocol*, allow a contribution to the buffer pool to substitute for a field visit. This is because the primary activity of the project, the preservation of grasslands, can be verified through remote-sensing technology, such as satellite images. As more technology is deployed that can remotely sense practices, the need for site visits could be reduced. The ACR is in the process of developing a framework for assessing remote sensing in forest projects (Taylor, n.d.). While remote sensing is an option for grassland and some forest projects, it is currently difficult to remotely sense practices like fertilizer management or livestock practices. As more satellites are launched, sensor accuracy is improved, and analytical tools are expanded, remote sensing may be expanded to include quantification of additional practices, such as those that increase carbon sequestration in soil. The support and deployment of these remote-sensing technologies may reduce the need, and thereby the cost, of site visits.

Another option to reduce the number and frequency of site visits is to allow for random sampling of fields or operations. Although several protocols allow for sampling, the minimum number of sites or the type of sampling varies between protocols. For example, CAR's Soil Enrichment Protocol allows verifiers to use a combination of risk-based and random sampling for site visits (CAR, 2022). The ACR Validation and Verification Standard allows verifiers to "randomly select a subset of the project for field verification." Furthermore, ACR does not "require the [verifiers] to visit every site or to conduct a minimum number of measurements, provided the GHG assertion for the overall project can be verified at a reasonable level of assurance and the Verification Statement worded accordingly" (ACR, 2018).

6.2.2 Upfront Financing and Forward Crediting

Some project developers are able to sign contracts with buyers for the future delivery of carbon credits. This allows the project developer to provide upfront financing to the producer for the implementation of practices that reduce GHG emissions. Receiving financing upfront helps projects cover costs associated with implementing new practices as opposed to waiting to receive revenue when carbon credits are sold. However, these payments generally use a conservative estimate of the number of credits that are expected to be generated which will be reflected in the upfront payment.

In addition, there are some programs, such as CAR's Climate Forward program, which allow for the forward crediting of projects in order to facilitate early investment in innovative and creative emission reduction projects (CAR, n.d.-b). These programs allow for the investment in practices such as decreasing wildfire intensity or reforestation. However, these programs have not generated significant volumes of credits. Over the past 4 years, the Climate Forward program has generated less than 1 million credits from all of its protocols (CAR, n.d.-c).

6.2.3 Reducing Record Keeping and Data Collection Burdens

For data needs related to historical practices, registries might conduct a sensitivity analysis to determine which variables have the largest impact on carbon credit generation. Using this information, the registries could create additional guidance about where it is acceptable to use default values or those derived from remote-sensing tools. Slimming down the number of variables a producer is required to provide can reduce the record keeping burdens and reduce the time required to collect, model, and audit data. Modeling firms and private project developers can also leverage remote-sensing tools to help prepopulate a first draft of data before asking a producer to review and corroborate. Putting more of the data gathering process upstream of a producer can lead to more efficient analysis and allow producers to make more evidence-based decisions regarding potential value capture for different land management scenarios.

6.2.4 Addressing Early Adopter Concerns

Additionality criteria are critical to ensuring that carbon credits represent real carbon reductions. However, additionality requirements can have the effect of reducing opportunities for early adopters to enter the carbon market. Early adopters can still participate in carbon markets by adopting additional eligible practices or adopting eligible practices on additional fields or areas of their operation. Some protocols may allow for a look-back period to determine eligibility, where farmers who adopted an eligible mitigation activity within the specified timeframe are still eligible for credit generation in future years if they agree to maintain the activity (Verra, 2023a; Nori, 2020)). In other cases, protocols may award credits for ongoing mitigation activities that are not currently the industry standard. For example, a new livestock facility originally built with a manure digester (i.e., no prior manure management infrastructure) may be eligible for offset credits under CARB's livestock protocol if the facility demonstrates manure digesters are not common practice in the industry and geographic region where the project is located (CARB, n.d.-b).

6.2.5 Addressing Permanence

To address challenges related to permanence and risk of reversal in agriculture, forestry, and land use projects, some protocols allow for a shorter permanence period. A shorter permanence requirement may reduce the contractual requirements and financial liability project owners face. However, a shorter permanence period may result in a reduced volume of credits based on the temporal value of carbon. TYA is a potential approach to eliminate the contractual challenges of 100-year permanence requirements, though, as discussed in chapter 4, this approach raises concerns about carbon credit equivalency compared to projects associated with more permanent climate mitigation efforts.

6.2.6 Addressing Scale Through Project Aggregation

One strategy to address issues of scale and reduce the cost of agriculture offset projects is the aggregation of smaller producers or landowners into a single project.[8] Allowing for aggregation of projects reduces transaction costs and protocols that allow for multiple landowners on non-contiguous sites to reduce barriers for smaller scale operations to participate in carbon projects in a more cost-competitive manner. Since historically underrepresented, beginning, socially disadvantaged, limited resource and veteran farmers tend to be smaller operations, aggregation may help encourage participation of these farmers in carbon markets. Of the active existing protocols listed in Appendix Table A-2 with issued credits, each protocol allows for aggregation of landowners/fields in some form. Examples of voluntary projects that aggregated multiple landowners and site locations include:

- **ACR Grassland Protocol:** Ducks Unlimited, Inc., ACR222 included 74 landowners across 15 different counties.
- **CAR Soil Enrichment Protocol:** Indigo Carbon PBC, CAR1459 included 427 growers and 5,083 fields across 19 States encompassing over 420,000 acres.
- **ACR Forest Carbon Project Standard:** GreenTrees, ACR114 included over 500 landowners and 115,000 acres across 3 different States in the Mississippi Alluvial Valley.
- **Verra's Family Forest Carbon Program:** Family Forest Impact Foundation, VCS3996 includes 2 cohorts with over 7,000 acres each, spanning 46 counties.

The ACR Validation and Verification Standard has an entire chapter dedicated to aggregated projects, something few other programs address in such a broad way (ACR, 2018).

There are multiple ways to design aggregation and each approach has a different impact on transaction costs. For example, the current regulations from CARB allow multiple landowners to be verified all at once however, the project developer must develop a monitoring and reporting plan for every landowner in the project and list them separately in a public registry. While this approach reduces some of the costs of verification, it does not decrease the significant costs of quantifying the GHG reductions from each farm.

[8] Aggregation is more of an option for the voluntary carbon market. While California's offset program technically allows for aggregation, the rules are difficult enough that they are not expected to significantly reduce project costs.

6.2.7 Carbon Market Resources and Standards

There are dozens of agricultural and forest carbon programs soliciting producers for their participation, which has led to confusion on the part of many producers and forest landowners. To help sort through all these options, many organizations, including the American Farmland Trust (ISAP, 2023), Farm Foundation (Farm Foundation, 2022), Farm Journal (Farm Journal, 2020; Farm Journal Editors, 2021), Iowa State University (Iowa State University Extension and Outreach, March 2023), and the United Soybean Board (United Soybean Board, n.d.), have created guides to help producers understand the options available to them and determine the program with the best fit for their operation. Numerous efforts also exist to educate family forest landowners on forest carbon market program opportunities, including the *Securing Northeast Forest Carbon Program*, which is a cooperative effort of the State Foresters of seven northeast U.S. States, Penn State University's *Forest Owner Carbon and Climate Education* program, and Michigan State University's *Forest Carbon and Climate Program* (Securing Northeast Forest Carbon Program, n.d.; FOCCE, n.d.; Michigan State University, n.d.). While these guides have been helpful, agriculture and forest carbon programs are rapidly evolving with new market entrants, mergers between organizations, and market exits. This dynamic landscape makes it challenging for any organization to maintain updated guidance.

Not only is there a proliferation of carbon programs, but each program may set different standards generating credits. In an effort to create standardization between the bevy of carbon market programs, several organizations have been created to develop guidelines and rules for the carbon market. These are discussed in Section 2.3 and include the Integrity Council for the Voluntary Carbon Market, Voluntary Carbon Markets Initiative, and Carbon Credit Quality Initiative. Even though these organizations are less than 5 years old, several of the carbon offset registries, such as Verra, have acknowledged the importance of the guidance and are preparing to incorporate it in their protocols and program documentation (Verra, 2023b).

6.3 Role of USDA in Reducing Market Barriers

Through several of its existing or new programs and resources, USDA can play a role in helping to reduce several of the identified barriers to entry that agricultural and forestry producers face in accessing voluntary environmental credit markets. USDA's role includes providing technical assistance, outreach, and education, and improving market infrastructure through investments in MMRV.

6.3.1 Technical Assistance, Outreach and Education

USDA currently plays an important role in providing technical assistance, outreach, and education to producers. The sections below describe NRCS's technical assistance activities as well as the role of the USDA Climate Hubs and USDA's Office of Environmental Markets in outreach and education activities around the voluntary carbon markets.

6.3.1.1 NRCS Conservation Technical Assistance

NRCS's Conservation Technical Assistance program provides producers customized and site-specific advice, information, and resources to support their conservation goals and help them make informed decisions for their operations. Through this assistance, NRCS provides producers with access to expertise on implementing conservation practices, including those that result in GHG emission reductions and removals, in ways that are tailored to a producer's needs, geography, and operation. NRCS currently offers information and resources on environmental market opportunities that complement its work and mission by bringing non-Federal investments to working lands conservation. This role could be further enhanced through additional resources focused particularly on carbon markets and ways for producers to access and navigate those opportunities. This may also include targeted support and resources tailored to the unique challenges faced by beginning, socially disadvantaged, limited resource, and veteran farmers, ranchers, and private forest landowners.

6.3.1.2 Forest Landowner Support Programming

Through its new Forest Landowner Support programming, supported by the Inflation Reduction Act, the USDA Forest Service is providing financial assistance for projects that support underserved and small-acreage forest landowner participation in emerging private markets for climate mitigation and forest resilience (U.S. Forest Service, n.d.).

6.3.1.3 USDA Climate Hubs

The Climate Hubs link USDA research and program agencies in their regional delivery of timely and authoritative tools and information to agricultural producers and professionals. The mission of the Climate Hubs is to develop and deliver science-based, region-specific information, and technologies, with USDA agencies and partners, to agricultural and natural resource managers that enable climate-informed decision-making, and to provide access to assistance to implement those decisions. Resources like the Climate Hubs may be able to play a role in developing useful, regionally appropriate information and partnerships to support producers in decision-making around carbon market opportunities.

6.3.1.4 USDA Office of Environmental Markets

The Food, Conservation, and Energy Act of 2008 (often referred to as the 2008 Farm Bill) directed USDA to facilitate the participation of American farmers, ranchers, and forest landowners in environmental markets, and led to the establishment of the Office of Environmental Markets (OEM). OEM operates within the Office of Energy and Environmental Policy (OEEP) to support the development of these emerging markets, working closely with several USDA agencies, including NRCS, Forest Service, and Economic Research Service. OEM’s role has been to provide helpful outreach and analysis tools related to environmental markets, including carbon markets, to producers and landowners.

6.3.2 Conservation Programs

Through its conservation programs, USDA may also continue to play a role in providing alternative incentive options for producers who apply practices that contribute to GHG reductions but may not be able to meet requirements to participate in carbon market programs. Through conservation programs like the Environmental Quality Incentives Program and Conservation Stewardship Program, NRCS provides financial assistance to producers and landowners to implement conservation practices, including ones that reduce or remove GHG emissions. USDA does not prohibit producers participating in these conservation programs from pursuing additional environmental market opportunities, though their eligibility for such opportunities would be based on the requirements of the specific carbon market program.

6.3.3 Innovative Grants and Partnerships

USDA can also continue to facilitate participation in carbon markets through grants, agreements, and partnerships that stimulate development and adoption of innovative conservation approaches and technologies through programs such as the Regional Conservation Partnerships Program, Conservation Innovation Grant Program, and Partnerships for Climate-Smart Commodities.

6.3.3.1 Conservation Innovation Grant Program

Through its CIG program, NRCS supports the development of new tools, approaches, practices, and technologies to further working lands conversation, including projects focused on piloting conservation finance approaches and developing methods that may be applicable to carbon markets. USDA has supported several CIG projects that have explored the development and adoption of carbon market protocols and appropriate practices. Examples of past projects include:

- A 2011 project with Ducks Unlimited and partners that developed a methodology to quantify carbon stored in the soil by avoiding grassland conversions, which led to the first-of-its-kind sale of carbon credits from working ranch grasslands (USDA, n.d.-c).
- A 2011 project with Environmental Defense Fund and partners to demonstrate greenhouse gas emissions reductions in California and Mid-South rice production, resulting in the first carbon credits generated from rice farmers (USDA, n.d.-b).
- A 2011 project with the Delta Institute and other partners, that aimed to evaluate different methods of quantification and scale implementation of nutrient management practices using N_2O emission reduction credits, eventually leading to the first fertilizer N_2O emission reduction project transacted through ACR (USDA, n.d.-a).
- A 2011 project with Confederated Tribes of the Colville Indian Reservation to adapt and implement forest carbon sequestering practices and develop protocols that could overcome the legal and technical barriers faced by tribes in entering carbon credit trading markets (USDA, n.d.-f).
- A 2015 project with The Nature Conservancy and partners that aimed to enroll 50,000 acres of rangeland in North and South Dakota into a carbon offset program by layering perpetual conservation easements and direct carbon payments, building upon a methodology developed through a 2011 CIG project and adopted by ACR.

6.3.3.2 Partnerships for Climate-Smart Commodities

Through the Partnerships for Climate-Smart Commodities opportunity, USDA is supporting 141 projects that will "pilot innovative and cost-effective methods for quantification, monitoring, reporting and verification of greenhouse gas benefits," among other goals. Advancements resulting from these projects can contribute to bringing down costs for MMRV and reducing financial barriers to participation, which could be applicable both to the program's primary purpose of supporting the marketing of climate-smart commodities, as well as other opportunities within the voluntary carbon market space.

6.3.4 Supporting Infrastructure

USDA can also play a role in providing access to necessary infrastructure that can support participation in carbon market opportunities. Through its Rural Development office, USDA offers loans and grants to support the costs of construction, improvement, and acquisition of facilities and equipment needed to provide enabling infrastructure and technology, such as broadband service, in eligible rural areas (USDA, n.d.-e). Expanded broadband service can increase access to information around carbon market programs and entities, as well as support more advanced data collection needs required for participation.

6.3.5 Investments in MMRV

USDA makes ongoing investments and contributions to improvements in our ability to quantify sources and sinks of GHGs from agriculture and forestry activities. This includes advancing the science to quantify GHG impacts of agricultural and forestry management activities, developing and advancing models and tools for quantifying GHG sources and sinks from agriculture and forestry, and improving data products that can be used to provision tools and establish regional baselines. In 2022, through the passage of the Inflation Reduction Act, USDA received $300M to improve quantification of GHGs from agricultural sources. Over the next 8 years, USDA plans to increase investment in science and research, establish a soil carbon monitoring network, and improve remote sensing and data products that can be used in the estimation of GHGs. In turn, these investments will lead to reduced uncertainty and improved accuracy of GHG sources and sinks estimates for agriculture and forestry. Below we discuss the investments USDA is making to improve quantification of agriculture and forestry activities in more detail.

6.3.5.1 Soil Carbon Monitoring Network

As part of a broader Federal strategy announced in 2023, the USDA will establish a soil carbon monitoring and research network that will (1) collect field-based data for carbon sequestration over space and time; and (2) develop a network of on-site experiments on carbon sequestration from management practices to strengthen predictive models and support GHG assessment at multiple scales (Greenhouse Gas Monitoring and Measurement Interagency Working Group, 2023). The soil carbon monitoring and research network will provide statistically valid national coverage. The network of on-site experiments will focus on practices and gaps needed to reduce uncertainties related to the impact on agricultural management practices on soil carbon. In addition, the soil carbon monitoring network will establish a soil carbon baseline that may be useful for establishing regional soil carbon baselines.

6.3.5.2 Advance USDA GHG Research Networks

USDA plans to increase investment in research networks to collect and synthesize field-scale data on trace greenhouse gas (N_2O and CH_4) emissions from agricultural sources. These networks will evaluate cropping systems, grazing systems, and livestock production systems. Data and analysis will be used to strengthen predictive models and support GHG assessment at multiple scales. This includes N_2O dynamics in crop and pasture systems and CH_4 dynamics focused on livestock systems and rice production.

6.3.5.3 Advance Models and Tools Used to Estimate GHG Sources and Sinks

USDA has supported the development and advancement of several models and tools that are used to quantify GHG emissions and sinks from agriculture and forestry, including DayCent, COMET-Farm, COMET-Planner, Forest Vegetation Simulator, and the Ruminant Farm Systems Model (RuFaS), among others. These models and tools undergo continuous improvement and are aligned with the state of the science as defined by the *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory* report, also referred to as the Methods Report (USDA, 2014). The Methods Report is authored by a team of subject-matter experts that determine the most appropriate GHG quantification methods for each agriculture and forestry source given the state of the science. A revised Methods Report is due to be released in late 2023 and will precipitate updates to USDA's models and tools to ensure alignment.

It is expected that USDA's investments in the soil carbon monitoring network as well as the GHG Research Network will produce additional data that can be used to better parameterize and calibrate models and tools and improve the accuracy of estimates. USDA will work to ensure that advances in our monitoring and research networks are reflected in our models, tools, and methods, many of which are used to help quantify carbon credits.

6.3.5.4 Advance Data Products for MMRV

USDA currently provides data that are central in the estimation of GHG emissions and sinks for the agricultural and forestry sector. Data currently used for GHG estimation include products such as the National Resources Inventory, Cropland Data Layer, Crop Progress and Condition Reports, Forest Inventory and Analysis (FIA) plot network data streams, Monitoring Trends in Burn Severity, Land Change Monitoring System, and more. USDA is also working to improve data collection, data access, and advance remote-sensing products that can be used to improve the temporal and spatial coverage of conservation activity data, determine baselines across scales, ground truth GHG estimates, and constrain model estimates. For example, USDA is exploring remote-sensing data products for identifying cover crop and tillage practices. Similarly, the USDA Forest Service is developing refined statistical procedures for joining FIA plot data with remotely sensed information for more dynamic estimation of project level carbon stocks and associated change.

6.3.6 Potential Role of Greenhouse Gas Technical Assistance Provider and Third-Party Verification Program

Through a potential Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Program, USDA could further contribute to reducing market confusion faced by producers by serving as a trusted authority for a range of relevant carbon market information. The Program would provide educational resources and greater transparency related to agriculture and forestry carbon credit market opportunities in the United States. By providing information relating to the basic market structure, various roles and qualifications of different parties, and increased access to technical assistance, the Program can reduce barriers and help facilitate market participation. Given the current concerns and inconsistencies with carbon market programs, the Program can help provide context and increased certainty around qualified market actors and expected market outcomes.

Under the current legislation, the Program would not create a USDA carbon registry. Instead, the Program would enhance USDA's efforts to provide farmers, ranchers, and foresters with the necessary resources when deciding if and how to participate in a carbon market. Since the Program would not compete with voluntary carbon credit markets, USDA's role in education and market information would not impede or constrict existing markets.

7 BEYOND GREENHOUSE GASES: OTHER MARKET OPPORTUNITIES FOR ECOSYSTEM SERVICES

7.1 INTRODUCTION

In addition to carbon markets, farmers and forest owners have opportunities to participate in other environmental credit markets that can provide payments for generating or maintaining ecosystem services on their lands. The United Nations' Millennium Ecosystem Assessment defines ecosystem services as the "benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2003), which can include goods such as food and timber or services such as clean air and water, flood control, and wildlife habitat—and can also encompass cultural, recreational, and aesthetic benefits.

Regulatory policies, government programs, and voluntary commitments have provided the structures and financial resources to support local, State, regional, and national environmental credit markets. In particular, the Food, Conservation and Energy Act of 2008 (or the 2008 Farm Bill) directed USDA to support participation of American farmers, ranchers, and forest landowners in environmental credit markets by developing science-based technical guidelines to measure environmental service benefits from conservation and land management activities (USDA, n.d.-d; 110th Congress, 2008). As part of this, USDA has developed, in partnership with outside groups, tools and resources for land managers to quantify the environmental benefits of conservation practices and participate in environmental markets. These tools include the Nutrient Tracking Tool, which helps farmers estimate nutrient and sediment losses from crop and pastureland depending on management practices and other farm conditions and is used in some water quality trading programs in the United States. Similarly, USDA, in partnership with Colorado State University, developed the COMET-Farm and COMET-Planner tools to help farmers account for GHG emissions they generate and how changes to farm practices might affect their emissions. USDA has also worked with EPA and others to provide detailed environmental markets data for EnviroAtlas, an EPA-managed, publicly available interactive mapping tool and data resource.

Other Federal environmental policies, including the Clean Water Act and Endangered Species Act, have spurred the development of compensatory mitigation and market-based compliance mechanisms. While farmer engagement in compensatory mitigation is relatively limited, this idea has been extended to protect and preserve other ecosystem services and natural resources in ways that would allow for significant participation by farmers.

Regional and State policy as well as voluntary or private initiatives have also enabled the establishment and growth of environmental credit markets for the protection and enhancement of ecosystem services. For example, Virginia established the Chesapeake Bay Nutrient Credit Exchange Program in 2005 to help it comply with Federal limits on nutrient loading and improve water quality in the Chesapeake Bay and the waterways that feed into it (USEPA, 2009; News Link Environmental, 2005). While this program is primarily intended to reduce point source pollution in the Chesapeake Bay watershed[9], agricultural producers can generate credits to sell to point source polluters by adopting State-approved best management practices that reduce

[9] Point source pollution is defined by the U.S. Environmental Protection Agency under Section 502 of the Clean Water Act as any means any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture. (USEPA, n.d.-a)

nutrient runoff or erosion from agricultural fields (Code of Virginia, n.d.). In other instances, farmers may purchase credits. For example, USDA NRCS established the Wetland Mitigation Banking Program (WMBP) to support the development of wetland mitigation credits for agricultural producers to offset unavoidable impacts to wetlands, allowing them to remain eligible to participate in USDA programs.

While markets and mechanisms for buying, selling, and trading environmental credits vary in form, they are all underpinned by the notion that (1) there is value to ecosystem services, (2) there are buyers willing to pay for such services, and (3) other parties have economic incentives or other objectives (i.e., Federal, State, municipal compliance or regulatory policies) to protect or offset impacts to natural resources or ecosystem services. The following sections describe different environmental markets and market mechanisms that currently exist in the United States.

7.1.1 Payments for Ecosystem Services

Governments, private, or non-profit organizations can pay directly for ecosystem services to the parties that generate them (e.g., farmers or private landowners). For example, in Florida, a payment for ecosystem services (PES) program was established by the South Florida Water Management District (SFWMD) to pay private landowners to provide water storage, water quality, and habitat improvement benefits to the Northern Everglades. Payments for watershed services (PWS) is a type of PES where a government agency or water provider collects payments from downstream service beneficiaries, such as water consumers, and pays upstream forest landowners for provision of watershed services. One example of a PWS program is New York City which was able to avoid building a costly filtration plant by investing $1.5B in watershed conservation efforts. As part of these investments, farmers and private landowners were paid to change management practices that help reduce downstream pollution (USDA Farm Service Agency, 2023; USDA Farm Service Agency, n.d.).

7.1.2 Mitigation and Conservation Banks

A mitigation bank is a wetland, stream, or other aquatic resource area that has been restored, established, enhanced, or (in certain circumstances) preserved for the purpose of providing compensation for unavoidable impacts to aquatic resources permitted under Section 404 of the Clean Water Act or a similar state or local wetland regulation. Government, private companies, and non-profits operate such banks across the United States. Opportunities for farmers to engage in mitigation banks are limited since they are exempt from Section 404 compliance requirements, except if they want to establish a mitigation bank on their agricultural land, which may come with high costs and require significant operational changes. In-lieu fee (ILF) programs are similar to mitigation banks in that payments are made to organizations or private companies that offset impacts to wetlands and other aquatic resources in a nearby location. However, operators of ILFs can engage in enhancement or preservation activities throughout a watershed instead of at one specific site or on one parcel of land. Unlike mitigation banks, ILF programs are allowed to be constructed or completed after environmental impacts of the offsetting project have already occurred.

In contrast, the objective of conservation banks is to preserve, protect, or restore land that is inhabited by species deemed threatened or endangered by the U.S. Fish and Wildlife Service under the Endangered Species Act (U.S. Fish & Wildlife Service, n.d.-a). Parcels or plots of private, Tribal, State, and Local government land are permanently set aside as a conservation bank and those that operate it sell credits to others to offset impacts to endangered or threated species within the conservation bank service area (which is determined by U.S. Fish and Wildlife Service and is based on the location of endangered or threated species impacted). Farmers could establish conservation banks on their land if endangered or threated species are present, in turn generating additional income or revenue (U.S. Fish & Wildlife Service, n.d.-b). Private companies operate U.S. Fish and Wildlife Service-approved mitigation and conservation banks in California, Washington, Oregon, Nevada, and South Dakota (Wildlands, n.d.; RIBITS, n.d.). Some States also have their own State laws governing the protection of endangered species and allows for both mitigation conservation bank opportunities to offset impacts (California Department of Fish and Wildlife, n.d.). Mitigation and conservation bank purchase opportunities can be found on the Army Corp of Engineers Regulatory In-Lieu Fee and Bank Information Tracking System (RIBITS) website.

7.1.3 Habitat Exchanges

Habitat exchanges are similar to conservation banks and allow private landowners to receive payments to protect endangered or threatened species as an offset to impacts to species elsewhere. For example, the Central Valley Habitat Exchange in California that protects flyways for migratory birds by receiving payments from others who may have impacted such species elsewhere (Environmental Incentives, n.d.). The payments they received are used to pay farmers, ranchers, and other private landowners to protect and develop habitat for at-risk wildlife. However, habitat exchanges differ from conservation banks in that they are not necessarily protected permanently (although they can be) and are areas outside of the U.S. Fish and Wildlife Service-approved conservation banks.

7.1.4 Water Rights Trading and Instream Buybacks in the Western United States

Water scarcity, especially in the arid parts of the Western United States, has driven the development of market-based mechanisms that allow water users to buy, sell, and lease the rights to use water for agricultural production and other beneficial uses. In some cases, these rights are leased or sold to governments or non-governmental organizations that want to restore or enhance waterways or habitats. These “instream buybacks” may provide a means for farmers to protect ecosystem services.

7.1.5 Water Quality Trading Programs

In addition to protecting wetlands, the Clean Water Act regulates discharges of pollutants into waters of the United States and sets quality standards for surface waters (USEPA, 1972). The Clean Water Act made it unlawful to discharge pollutants into waters of the United States without a permit issued by the U.S. EPA National Pollutant Discharge Elimination System (NPDES). Most agricultural production is not covered by these regulations (because it is a non-point source), so farmers do not have to obtain permits under NPDES. However, farmers can implement conservation best management practices to reduce the amount of pollution runoff or leaching from farm fields and in so doing generate payments or credits that can be purchased by polluters seeking to offset their discharges of non-bioaccumulative pollutants, such as nitrogen, phosphorus, sediment, or temperature, under EPA’s Water Quality Trading Policy (USEPA, 2022). States that have established water quality trading programs under EPA’s Water Quality Trading Policy include: Arkansas, Colorado, Connecticut, Florida, Louisiana, Maryland, Minnesota, Missouri, Montana, North Carolina, Ohio, Oregon, Pennsylvania, Utah, Virginia, West Virginia, and Wisconsin (Willamette Partnership, World Resources Institute, and the National Network on Water Quality Trading, 2015; US GAO, 2017). Washington, Kentucky, Tennessee, Georgia, and Vermont are assessing the potential for establishing trading programs (The Environmental Trading Network). Other States such as Alabama, Arizona, California, Illinois, Massachusetts, Nevada, New Mexico, New York, South Carolina, South Dakota, Utah, and Wyoming have established watershed scale pilots or permit specific trading projects. There are also multi-state water trading programs in the Lake Erie Basin (covering Ohio, Indiana, and Michigan); Idaho, Washington, and Oregon; and in the Ohio River Basin. The payment or credit farmers can earn for adopting practices that reduce nutrient runoff will vary depending on the requirements and characteristics of each of these programs.

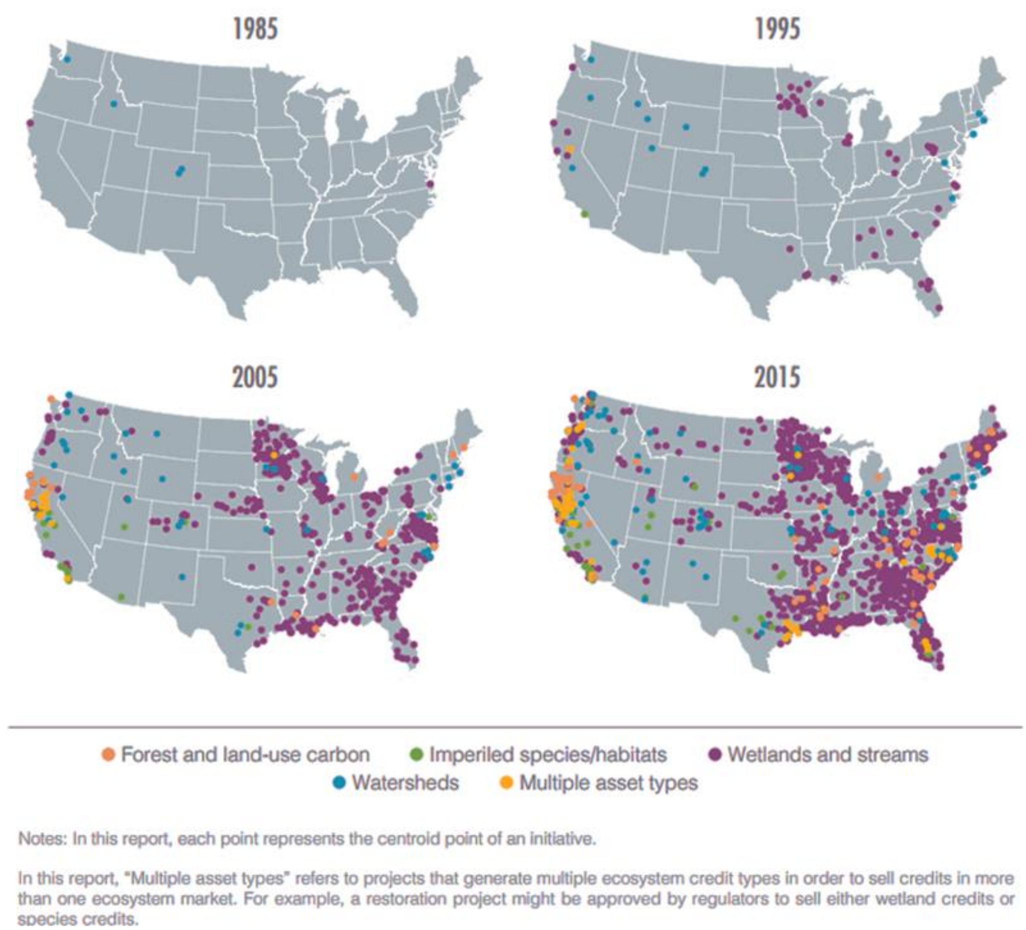
7.1.6 Other Types of Market-Based Mechanisms

A variety of other mechanisms and platforms exist for buying, selling, and trading ecosystem services including bilateral agreements, collective action funds, voluntary payment programs, and green labeling. Additional details about these other types of mechanisms can be found in the Atlas of Ecosystem Markets in the United States (Bennett, 2016).

7.1.7 Ecosystem Service Markets in the United States

Between 1985 and 2015, there was a substantial growth in the number of market-based mechanisms and programs that exist to buy, sell, and trade environmental credits (Figure 7-1). The majority of these were established for compliance purposes under the Clean Water Act, including Section 404, and the Endangered Species Act. But a sizable fraction of these were established and supported by State legislative actions. Some are also voluntary in nature.

Figure 5-1. As these markets have grown over time, watershed-based markets predominate in the West, while wetland and stream markets are more common in the Eastern United States.



Data source: Figure obtained from The Forest Trends Ecosystem Service Marketplace Initiative Atlas of Ecosystem Service Markets in the United States which is available online at: https://www.forest-trends.org/wp-content/uploads/2017/03/doc_5440.pdf This report was supported through a USDA cooperative agreement and a data sharing agreement with Forest Trends, USDA, and EPA.

While these data indicate growth overall in the establishment and use of various environmental credit markets, they do not represent the entire scope of opportunities specifically available to agricultural producers to earn payments or buy credits. Additional data collections would be needed to systematically evaluate the scope of all of the opportunities that agricultural producers could engage in. Further, these data are current as of 2015 and do not reflect more recent establishment or activity of ecosystem service market-based mechanisms and programs. USDA is currently working to provide updates to the data.

7.1.8 Federal and State-level Fuel Markets

Alternative fuels markets started in the early 2000's and have continued to expand over time. Over time, they have evolved in the feedstocks allowed for fuels and program complexity. For example, when many of the State programs started in the early 2010's, there was no verification requirement. Existing programs are being revised to include an independent verification requirement and new programs are including the requirement from the outset.

Neither Federal nor State biofuel programs, as currently structured, provide incentives for many climate-smart farming practices. One exception to this is that anaerobic digesters can receive biofuel credits when they use biogas for renewable natural gas (RNG) production. Anaerobic digesters are the only climate-smart farming practice for which a standardized protocol has been used in California's regulated LCFS program.

CARB adopted the Cap-and-Trade Program's livestock offset protocol for use in the LCFS. Since digesters receive credit for avoided methane emissions in both programs, this implies that an expansion in digester credits issued in the LCFS has contributed to a reduction in digester offset credits issued in the Cap-and-Trade Program.

A second reason for discussing the State-level biofuel programs is that, unlike the U.S. EPA Renewable Fuel Standard (RFS), they provide incentives for biofuel producers to reduce their carbon intensity. As currently structured, however, this opportunity to reduce their carbon intensity does not extend to feedstock production. This implies that a biofuel producer that sourced crops grown with conservation tillage, cover crops, and enhanced efficiency fertilizers would receive the same feedstock carbon intensity score as a producer that sourced crops that used conventional practices. Still, since the programs are based on carbon intensity calculations, providing credits for climate-smart practices could be accomplished through an administrative change to the program rules.

Through 2022, California and Oregon had the only State-level biofuel programs. However, Washington launched a new program in 2023. Analogs are also being scoped in other States across the United States, including Michigan and Minnesota. So, it is possible that these programs proliferate throughout the United States in future years.

7.1.8.1 Renewable Fuels Standard (RFS)

The U.S. EPA's RFS program is the oldest biofuel incentive program. It was created under the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act of 2007 (EISA). The RFS program requires a certain volume of renewable fuels to replace or reduce the quantity of petroleum-based transportation fuel, heating oil, or jet fuel. Obligated parties under the RFS program are refiners or importers of gasoline or diesel fuel. Refiners or importers comply with the program by blending renewable fuels into their transportation fuel or by obtaining credits called Renewable Identification Numbers (RINs) from other parties that blended the renewable fuels. There are four categories of renewable fuels required by the RFS program, and the GHG reduction requirement varies based on the category. EPA currently uses various models to determine this reduction for renewable fuels.

Since the GHG emission reduction requirements in the RFS are based on thresholds set in EISA, there are limited incentives for reducing carbon intensity beyond that needed to meet the threshold. However, since renewable fuel can receive both RINs and LCFS credits simultaneously, the programs working together tend to incentivize the lowest Carbon Intensity (CI) renewable fuels.

7.1.8.2 California's Low Carbon Fuel Standard (LCFS)

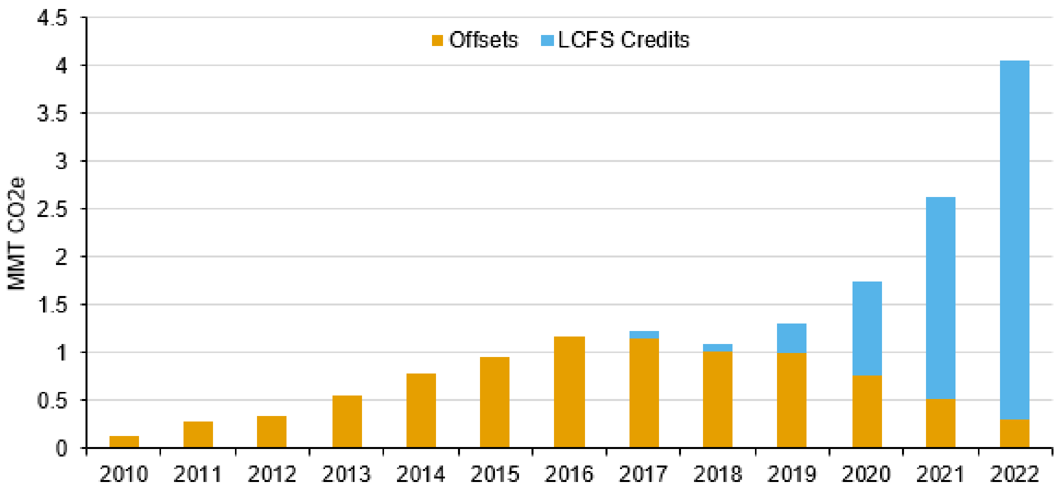
One of the climate change strategies developed by California in 2008 is the LCFS. The LCFS is designed to decrease the Carbon Intensity (CI) of California's transportation fuels and create a market for an increasing range of low-carbon and renewable fuel alternatives, which reduces petroleum dependency and achieves air quality benefits. CARB adopted regulations for the LCFS in 2009 and the program began operating in 2011. The goal of the program initially was to reduce the CI of transportation fuel used in California by at least 10 percent by 2020 from a 2010 baseline. In 2018, the Board extended the program to 2030 with a goal to reduce the CI of transportation fuel by 20 percent (CARB, n.d.-c). CARB is currently revising the program again and may make additional changes to feedstocks and reduction targets (CARB, 2023).

Between 2011 and 2022, more than 25.1 billion gallons of petroleum fuel were displaced by alternative fuels supported by the LCFS program (CARB, 2023a). These low-carbon transportation fuels generated credits representing a reduction of 123.98 $MMtCO_2e$. LCFS credits are generated using a customized version of the Argonne National Laboratories Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model that includes indirect land use change values based on the Global Trade Analysis Project (GTAP) model to calculate a lifecycle analysis (LCA) of different biofuels (CARB, n.d.-a). The GREET model is used to calculate the number of LCFS credits each fuel receives, called pathways.

Agricultural bioenergy crops are a significant feedstock for fuels used in California under the LCFS program. Under the program, fuel volume of biodiesel and renewable diesel has increased from 3 percent in 2012 to 55 percent in 2022 (CARB, 2023a). One of the benefits of the LCFS program, which is echoed in other State clean fuel programs, is that they can generate both LCFS credits and RINs.

Biogas from dairy and swine manure digesters is also an eligible low-carbon feedstock in the LCFS program. In 2022, 38 percent of total biomethane volume (151.95 million diesel gallon equivalent) was from dairy or swine operations with 64 percent of that volume generated from operations outside California. Manure digesters cannot receive LCFS and offset credits for the same activity in the same period. Due in part to this crediting restriction and higher LCFS credit prices relative to offsets, LCFS credits associated with manure digesters have increased while offset credit volume decreased between 2017 and 2022 (O'Hara, Xiarchos, & Weber, 2023; CARB, 2023a) (Figure 7-2).

Figure 7-2. Offsets and LCFS credits in CARB programs from dairy and swine manure digesters



Note. Offset credits year is vintage year of credits.
Source: CARB Offset Credit Issuance Table and Low Carbon Fuel Standard Reporting Tool (accessed 8/17/2023).

7.1.8.3 Oregon Clean Fuels Program

In 2009, the Oregon Legislature passed HB 2186, which authorized the Oregon Department of Environmental Quality (ODEQ) to adopt a Clean Fuel Standard (CFS), which was based on California's LCFS program. The program began implementation in 2016. It requires a reduction in CI of at least 10 percent below 2015 levels by 2025. Executive Order 20-04 (Office of the Governor - State of Oregon, 2020) directed the expansion of the CFS to achieve reductions in the average CI by at least 20 percent by 2030, and at least 25 percent by 2035. The Oregon program was modeled after California's program and has adopted many of the same strategies and policies. While the Oregon program also uses the GREET model to calculate the CI of fuels, it uses different modeling assumptions (Yeh, Witcover, Lade, & Sperling, 2016). For example, Oregon has a much smaller CI value for indirect land use change, which results in less credits being generated by fuel producers (ODEQ, 2023).

7.1.8.4 Washington Clean Fuel Standard

The State of Washington started developing a Clean Fuels Standard (CFS) in July 2021. The Standard requires fuel suppliers to reduce the CI of transportation fuels by 4.3 $MMtCO_2e$ annually by 2038, equivalent to a reduction in the CI by 20 percent below 2017 levels. The state implemented the program on January 1, 2023. The credits are issued after each quarterly reporting cycle (Department of Ecology, State of Washington, n.d.-a). The Washington CFS uses a Washington version of the GREET model, which accounts for production and delivery of clean fuels to the State, to calculate the carbon-intensity values for use in the CFS. The program also accepts fuel carbon-intensity values that have been approved by the California or Oregon programs (Department of Ecology, State of Washington, n.d.-b).

APPENDIX TABLES

Table A-1. Summary Statistics of Carbon Credits for Projects Based in the United States from Selected Registries, 2013–2022

Project Type	Voluntary credits issued	Compliance credits issued	Total credits issued	Share of credits issued in Voluntary Market	Projects with issued credits
	-------- 1,000 carbon credits --------			*-- Percent --*	
Agriculture	**1,031.9**	**8,929.4**	**9,961.2**	**10.4**	**169**
Manure Methane Digester	868.6	8,929.4	9,798.0	8.9	157
Compost Addition to Rangeland	--	--	--	--	0
Feed Additives	--	--	--	--	0
Nitrogen Management	0.1	--	0.1	100.0	3
Rice Emission Reductions	0.6	--	0.6	100.0	2
Solid Waste Separation	143.6	--	143.6	100.0	5
Sustainable Agriculture	19.0	--	19.0	100.0	2
Forestry & Land Use	**23,507.3**	**167,802.8**	**191,310.1**	**12.3**	**230**
Improved Forest Management	16,852.4	159,945.8	176,798.2	9.5	204
Afforestation/Reforesta tion	6,215.5	--	6,215.5	100.0	2
Avoided Forest Conversion	--	7,857.1	7,857.1	--	12
Avoided Grassland Conversion	387.0	--	387.0	100.0	11
Sustainable Grassland Management	--	--	--	--	0
Wetland Restoration	52.4	--	52.4	100.0	1
Total Agriculture, Forestry & Land Use	**24,539.1**	**176,732.2**	**201,271.3**	**12.2**	**399**

-- = No data reported.
Source: (So, Haya, & Elias, 2023)

Table A-2. Selected agricultural, forestry, and land use carbon credit protocols

Scope	Category	Protocol	Registry	Year protocol first adopted by registry	Credits issued to projects in the United States	Protocol status with registry
Agriculture	Soil Carbon Sequestration	Adoption of Sustainable Agricultural Land Management	Verra's Voluntary Carbon Standard Program	2010	No	Inactive
Agriculture	Animal Waste Management	Methane avoidance through separation of solids from wastewater or manure treatment systems (AMS-III.Y.)	Verra's Voluntary Carbon Standard Program	2008	Yes	Active
Agriculture	Animal Waste Management	Methodology for animal waste management and biogas application	Gold Standard	2022	No	Active
Agriculture	Enteric Methane	Methane emissions reduction from enteric fermentation in beef cattle through application of feed supplements	Gold Standard	2023	No	Active
Agriculture	Enteric Methane	Reducing Methane Emissions from Enteric Fermentation in Dairy Cows through Application of Feed Supplements	Gold Standard	2018	No	Active
Agriculture	Enteric Methane	Methodology for the Reduction of Enteric Methane Emissions from Ruminants through the Use of 100% Natural Feed Supplement	Verra's Voluntary Carbon Standard Program	2019	No	Active

Scope	Category	Protocol	Registry	Year protocol first adopted by registry	Credits issued to projects in the United States	Protocol status with registry
Agriculture	Grassland	Methodology for Reducing Emissions Intensity of Grassland-based Cattle Production	Verra's Voluntary Carbon Standard Program	n/a	No	In Development
Agriculture	Grassland	Methodology for Sustainable Grassland Management (SGM)	Verra's Voluntary Carbon Standard Program	2014	No	Active
Agriculture	Grassland	Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing	Verra's Voluntary Carbon Standard Program	2015	No	Active
Agriculture	Grassland	Compost Additions to Grazed Grasslands	ACR	2014	No	Inactive
Agriculture	Grassland	Grazing Land and Livestock Management	ACR	2014	No	Inactive
Agriculture	Livestock Manure Digester	Livestock Projects	California Air Resources Board	2011	Yes	Active
Agriculture	Livestock Manure Digester	U.S. Livestock	Climate Action Reserve	2007	Yes	Active
Agriculture	Optimized Nitrogen Management	U.S. Nitrogen Management	Climate Action Reserve	2012	Yes	Active

Scope	Category	Protocol	Registry	Year protocol first adopted by registry	Credits issued to projects in the United States	Protocol status with registry
Agriculture	Optimized Nitrogen Management	Quantifying N_2O Emissions Reductions in Agricultural Crops through Nitrogen Fertilizer Rate Reduction	Verra's Voluntary Carbon Standard Program	2013	No	Active
Agriculture	Optimized Nitrogen Management	Reduced Use of Nitrogen Fertilizer on Agricultural Crops	ACR	2012	Yes	Inactive
Agriculture	Optimized Nitrogen Management	Changes in Fertilizer Management	ACR	2010	No	Inactive
Agriculture	Rice Management	Rice Cultivation Projects	California Air Resources Board	2015	No	Active
Agriculture	Rice Management	U.S. Rice Cultivation	Climate Action Reserve	2011	No	Active
Agriculture	Rice Management	Methane Emission Reduction by adjusted Water management practice in rice cultivation	Gold Standard	2023	No	Active
Agriculture	Rice Management	Rice Management Systems	ACR	2013	Yes	Inactive
Agriculture	Soil Carbon Sequestration	U.S. Soil Enrichment	Climate Action Reserve	2020	Yes	Active
Agriculture	Soil Carbon Sequestration	Croplands Methodology	Nori	2020	Yes	Active
Agriculture	Soil Carbon Sequestration	Soil Organic Carbon Framework Methodology	Gold Standard	2020	No	Active

Scope	Category	Protocol	Registry	Year protocol first adopted by registry	Credits issued to projects in the United States	Protocol status with registry
Agriculture	Soil Carbon Sequestration	Methodology for Improved Agricultural Land Management	Verra's Voluntary Carbon Standard Program	2020	No	Active
Agriculture	Soil Carbon Sequestration	Methodology for Carbon Sequestration Through Cultivating Hemp	Verra's Voluntary Carbon Standard Program	n/a	No	In Development
Agriculture	Soil Carbon Sequestration	Soil Carbon Quantification Methodology	Verra's Voluntary Carbon Standard Program	2012	No	Inactive
Forestry & Land Use	Biochar	Biochar Methodology	Puro.Earth	2019	No	Active
Forestry & Land Use	Biochar	Methodology for Biochar Utilization in Soil and Non-Soil Applications	Verra's Voluntary Carbon Standard Program	2022	No	Active
Forestry & Land Use	Biochar	U.S. and Canada Biochar	Climate Action Reserve	n/a	No	In Development
Forestry & Land Use	Biochar	Biochar Projects	ACR	2013	No	Inactive
Forestry & Land Use	Forestry	Afforestation and Reforestation of Degraded Lands	ACR	2011	Yes	Active

Scope	Category	Protocol	Registry	Year protocol first adopted by registry	Credits issued to projects in the United States	Protocol status with registry
Forestry & Land Use	Forestry	Improved Forest Management (IFM) on Non-Federal U.S. Forestlands	ACR	2011	Yes	Active
Forestry & Land Use	Forestry	U.S. Forest Projects	California Air Resources Board	2014	Yes	Active
Forestry & Land Use	Forestry	U.S. Forest	Climate Action Reserve	2005	Yes	Active
Forestry & Land Use	Forestry	Afforestation/ reforestation GHG Emissions Reduction & Sequestration Methodology	Gold Standard	2017	Yes	Active
Forestry & Land Use	Forestry	Methodology for Improved Forest Management through Extension of Rotation Age	Verra's Voluntary Carbon Standard Program	2010	Yes	Active
Forestry & Land Use	Forestry	Improved Forest Management in Temperate and Boreal Forests	Verra's Voluntary Carbon Standard Program	2011	Yes	Active
Forestry & Land Use	Forestry	Improved Forest Management (IFM) on Small Non-Industrial Private Forestlands	ACR	2021	No	Active
Forestry & Land Use	Forestry	Afforestation and reforestation project activities implemented on lands other than wetlands (AR-AMS0007)	Verra's Voluntary Carbon Standard Program	2010	No	Active

Scope	Category	Protocol	Registry	Year protocol first adopted by registry	Credits issued to projects in the United States	Protocol status with registry
Forestry & Land Use	Forestry	Improved Forest Management Methodology Using Dynamic Matched Baselines from National Forest Inventories	Verra's Voluntary Carbon Standard Program	2022	No	Active
Forestry & Land Use	Forestry	Methodology for Avoided Forest Degradation through Fire Management	Verra's Voluntary Carbon Standard Program	2015	No	Active
Forestry & Land Use	Forestry	Methodology for Conversion of Low-Productive Forest to High-Productive Forest	Verra's Voluntary Carbon Standard Program	2010	No	Active
Forestry & Land Use	Forestry	Methodology for Improved Forest Management through Reduced Impact Logging	Verra's Voluntary Carbon Standard Program	2016	No	Active
Forestry & Land Use	Forestry	Avoided Conversion of U.S. Forests	ACR	n/a	No	In Development
Forestry & Land Use	Forestry	New Methodology for Afforestation, Reforestation and Revegetation (ARR) project activities	Verra's Voluntary Carbon Standard Program	n/a	No	In Development
Forestry & Land Use	Grassland	Avoided Conversion of Grasslands and Shrublands to Crop Production	ACR	2013	Yes	Active

Scope	Category	Protocol	Registry	Year protocol first adopted by registry	Credits issued to projects in the United States	Protocol status with registry
Forestry & Land Use	Grassland	U.S. Grassland	Climate Action Reserve	2015	Yes	Active
Forestry & Land Use	Forestry	Urban Forest Projects	California Air Resources Board	2011	No	Active
Forestry & Land Use	Forestry	U.S. Urban Forest Management	Climate Action Reserve	2014	No	Active
Forestry & Land Use	Forestry	U.S. Urban Tree Planting	Climate Action Reserve	2014	No	Active
Forestry & Land Use	Wetland	Restoration of California Deltaic and Coastal Wetlands	ACR	2017	Yes	Active
Forestry & Land Use	Wetland	Restoration of Pocosin Wetlands	ACR	2017	No	Active
Forestry & Land Use	Wetland	Methodology for Tidal Wetland and Seagrass Restoration	Verra's Voluntary Carbon Standard Program	2021	No	Active
Forestry & Land Use	Wetland	Restoration of Degraded Wetlands of the Mississippi Delta	ACR	2012	No	Inactive

* In the United States, as of July 23, 2023 from ACR (https://americancarbonregistry.org/), California Air Resources Board (https://ww2.arb.ca.gov/homepage), Climate Action Reserve (http://www.climateactionreserve.org/), Verra's Voluntary Carbon Standard Program (https://registry.verra.org/app/search/VCS/All%20Projects), Gold Standard (https://registry.goldstandard.org/projects) websites. Verra and Gold Standard predominantly credit projects outside of the United States; zero credit issuance does not indicate the methodologies are not in use internationally.

Table A-3. List of acronyms and their definitions

Acronym	Definition
3NOP	3-nitrooxypropanol (feed additive)
ARR	Afforestation, Reforestation, & Revegetation
AWD	Alternate Wetting and Drying
CACTOS	California Coniger Timber Output Simulator
CAR	Climate Action Reserve
CARB	California Air Resources Board
CCAR	California Climate Action Registry
CCP	Core Carbon Principles
CDFA	California Department of Food and Agriculture
CDM	Clean Development Mechanism
CFS	Clean Fuel Standard
CH_4	Methane
CI	Carbon Intensity
CIG	Conservation Innovation Grants
CO_2	Carbon Dioxide
CORSIA	Carbon Offset Reduction Scheme for International Aviation
CRYPTOS	Cooperative Redwood Yield and Timber Output Simulator
EDF	Environmental Defense Fund
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
FREIGHTS	Forest Resource Inventory Growth, and Harvest Tracking System
FVS	Forest Vegetation Simulator
GHG	Greenhouse Gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GWP	Global Warming Potential
ICAO	International Civil Aviation Organization
ICVCM	Integrity Council for the Voluntary Carbon Market
IFM	Improved Forest Management
ILF	In-Lieu Fee
IPCC	Intergovernmental Panel on Climate Change
ITMO	Internationally Transferred Mitigation Options
LCA	Lifecycle Assessment
LCFS	Low Carbon Fuel Standard
LiDAR	Light Detection and Ranging
LULUCF	Land Use, Land Use Change, and Forestry
MMRV	Measurement, Monitoring, Reporting, and Verification
$MtCO_2e$	Metric Tons of Carbon Dioxide Equivalent
N	Nitrogen
N_2O	Nitrous oxide
NMPP	Nitrogen Management Project Protocol
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ODEQ	Oregon Department of Environmental Quality
PES	Payment for Ecosystem Services
PWS	Payments for Watershed Services

Acronym	Definition
RCPP	Regional Conservation Partnerships Program
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RFS	Renewable Fuels Standard
RGGI	Regional Greenhouse Gas Initiative
RIBITS	Regulatory In Lieu Fee and Bank Information Tracking System
RINs	Renewable Identification Numbers
RNG	Renewable Natural Gas
SBTi	Science-Based Targets initiative
SEP	Soil Enrichment Protocol
SFWMD	South Florida Water Management District
SGM	Sustainable Grassland Management
TTA	Ton-Ton-Accounting
TYA	Ton-Year-Accounting
UN	United Nations
USDA	United States Department of Agriculture
USDA FS	United States Department of Agriculture's Forest Service
VCI	Value Change Initiative
VCMI	Voluntary Carbon Markets Initiative
VCS	Verified Carbon Standard (Program within Verra)
WMBP	Wetland Mitigation Banking Program
WWF	World Wildlife Fund

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