Research Paper

Why aren't more landowners enrolling in land-based carbon credit exchanges?

By Landon R. Schofield, Micayla E. Pearson, Samuel Newell, Nathan Clackum and Benjamin L. Turner

On the Ground

- Increasing concern from both private citizens and intergovernmental organizations about the effects of climate change has led to regulatory and voluntary mechanisms aimed at reducing greenhouse gas emissions, including an emerging carbon credit market.
- Despite the opportunities for landowners to diversify revenue streams within current operations, there are risks (i.e., production and financial, market, legal-transactional, and social) that could reduce landowner enrollment rates.
- We used a systems thinking approach to map the feedback relationships among landowner decision-making considerations, soil system processes, and carbon credit market incentives.
- Our findings illustrate the complex set of constraints of participation in carbon credit programs and how they interact by revealing a limits to growth archetype.
- Landowners and crop and livestock producers are uniquely positioned to shape and develop the carbon credit market by filling the gap between equitable transaction participation for both carbon credit buyers and sellers looking to capture value from mitigating greenhouse gas emissions.

Keywords: Carbon credits, Carbon markets, Carbon sequestration, Climate change, Limits to growth, Mental models, Systems thinking.

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Introduction

In recent decades, there has been increasing public concern about the potential effects of long-term climate change due to rising greenhouse gas levels in the atmosphere.[1,2] Intergovernmental organizations have incentivized reductions in greenhouse gas emissions through both regulatory and voluntary actions.[3-5] This increase of concern and attention has amplified pressure on many industries and governments to develop carbon-neutral systems.[6-8] An organization or corporation pledging to be carbon neutral is setting the goal to remove from the atmosphere the same amount of carbon it emits into the atmosphere annually.[9] This can be accomplished by reducing emissions resulting from their activities, supporting renewable projects, or purchasing carbon offsets or credits.[5,10,11] Of these approaches to become net zero, the practice of seeking carbon offsets is driving a new and emerging market of land-based carbon credits using carbon-capture efforts in cultivated farming and forest and rangeland ecosystems.[3,12-14] These offsets are designed to balance emissions that cannot be otherwise eliminated.[i,6,15] When carbon credits or offsets purchased equals or surpasses total emissions, the corporation is said to be net zero.

Land-based carbon credits, or offsets, represent carbon dioxide (CO_2) being removed from the atmosphere and stored within terrestrial ecosystems. Plants capture CO_2 from the atmosphere and combine it with water through photosynthesis to assemble it into complex carbon containing molecules (i.e., carbohydrates). Many of these complex carbon molecules are transported to the plant's root system and excreted or assimilated into the soil as organic matter.[12,15] This process results in soil carbon storage that generates a tradeable carbon credit to be exchanged for monetary value. Over time, a diverse mix of participants have arisen to develop market programs and account for transacted credits (Table 1).

[i] To facilitate trade in the carbon market, carbon credits, typically defined as one metric ton (1000 kg) of CO_2 or CO_2 equivalent removed from the atmosphere, are verified and exchanged between market participants.[16] The verification, certification, and accounting for carbon credits requires quantification of carbon accumulated and retained in the soil over time.[4,5,10,14]

Table 1
Historical timeline of agricultural carbon credit market developments illustrated by the noteworthy organizations and offerings over time. Adapted from Parkhurst et al.[4]

Launch year	Program	Type of market or program
1995	American Carbon Registry (ACR)	Voluntary offset market
2003	Chicago Climate Exchange (discontinued in 2010)	Voluntary offset market
2006	Verra's Verified Carbon Standard (VCS) Program	Voluntary offset market
2007	Climate Action Reserve (CAR)	Voluntary offset market
2009	Regional Greenhouse Gas Initiative (RGGI)	Compliance offset market
2010	California Air Resources Board's (CARB) Cap & Trade Program	Compliance offset market
2016	CIBO	Voluntary program, both offset and inset
2016	Truterra	Voluntary program, both offset and inset
2018	Corteva	Voluntary program, offset
2018	Nori	Voluntary program, offset
2019	Carbon by Indigo Ag	Voluntary program, offset
2019	Indigo Ag: Market + Source	Voluntary program, inset
2020	Soil & Water Outcomes Fund (SWOF)	Voluntary program, inset
2021	Agoro Carbon	Voluntary program, offset
2021	Cargill RegenConnect	Voluntary program, inset
2021	Locus Ag's CarbonNOW	Voluntary program, offset
2022	ADM re:generations	Voluntary program, inset
2022	Bayer Carbon Program	Voluntary program, offset
2022	Ecosystem Services Markets Consortiums (ESMC) Eco-harvest	Voluntary program, inset
2022	Nutrient	Voluntary program, offset
2022	PepsiCo-PCM	Voluntary program, inset
2024	ICAO for CORSIA	Compliance offset market

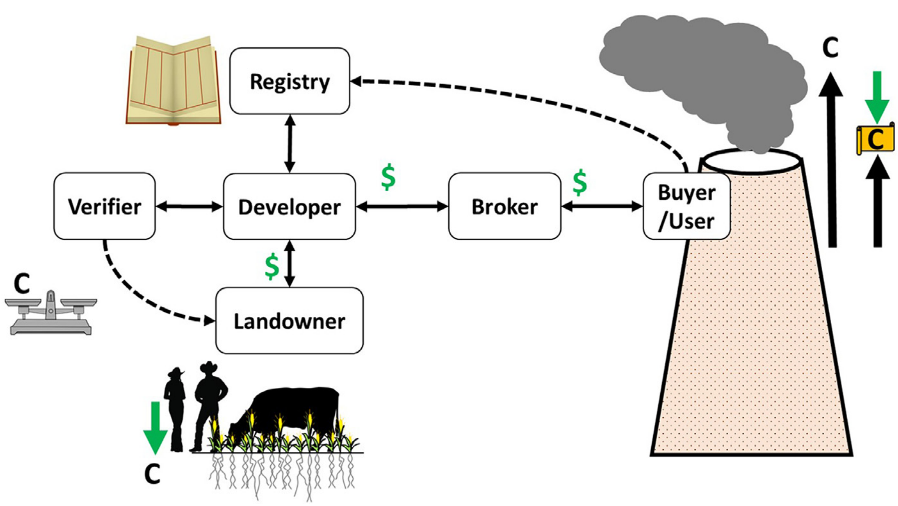

Figure 1. Carbon credit market schematic illustrating the stakeholders and transactions along the value chain: Landowners enroll to supply credits through a developer; a verifier ensures the amount of carbon (C) stored was a result of the program and verifies the amount of the transactional credits; buyers or users then purchase credits through brokers; and the verified C is then deducted from the user's emissions levels. The registry serves as the ledger balance to ensure that credits are not "double counted" by any end users. Adapted from Sawyer et al.[6]

Participation in a carbon market consists of several players (Fig. 1). Landowners provide potential carbon credit "supply" by providing land area and managing the mechanisms for soil carbon accumulation. Developers establish a process for measuring carbon accumulation according to a standard. The process and measurements are submitted to a registry that seeks third-party verifiers of adherence to the standards and certifies and tracks the issued carbon credits. Brokers connect those offering credits to those on the "demand" side of the market (e.g., carbon-emitting corporations). Duplication of credits is prevented by the registry being notified an offset has been purchased and applied.[10,16,17] The verified equivalent of carbon captured by the "supplier" represented in a contract is then "credited" to the buyer's carbon emission.

The new and emerging carbon credit market provides unique opportunities for participating landowners as well as research and development of new technologies. These technologies will likely enhance net benefits for landowners to take an active part in mitigating rising greenhouse gas emissions through carbon-capture efforts. Despite these opportunities, adoption and enrollment by landowners remains slow.[18-21] We used a systems thinking approach to unpack the

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underlying structures and barriers to landowner enrollment and associated financial returns achievable by participating in carbon credit markets.

Methodology: the systems thinking approach to problem solving

Systems thinking is an investigative methodology for describing and analyzing the complex factors and feedback interactions contributing to observed problems over time, including those in rangeland systems.[22,23] Rhoades et al.[22] and Wayland et al.[23] described the systems thinking process using the analogy of uncovering an iceberg, in which the bulk of the mass resides below the water surface level out of view. At the surface level of the iceberg are the important events of interest and easily observed trends and patterns over time. To facilitate a systems analysis, investigators proceed by answering questions such as "what's happened?" and "what's been happening in the long-term?"[22,23] To answer these questions, both qualitative and quantitative data (e.g., contemporary or industry periodicals, anecdotes from managers, scientific peer-reviewed literature, scientific databases) are collected to catalog and describe the events and historical time-path trajectory of variables of interest intertwined in the problem.[23] The results of examining events and trends often include a mix of descriptive as well as quantitative information represented graphically over time, which are used in the next steps of the analysis.

Beneath the surface level are the underlying social, ecological, economic, policy and regulatory structures as well as mental models (i.e., the relationships and assumptions about a system held in a person's mind) and system-level feedback relationships or loops (i.e., closed chains of causality whereby the effect of a causal impact comes back to influence the original cause of that effect) governing and directing the observed behaviors and outcomes over time. In this stage, data provided by the previous stages describing events and trends and patterns over time are used to identify and visually map the causal connections, relationships, and feedbacks between variables of interest via construction of a causal loop diagram (CLD; a conceptual model representing closed loops of cause–effect linkages intended to capture how a system's variables interrelate and how external variables impact them). To focus the systems thinking investigation, a *focusing question* is developed to uncover and better understand these deeper levels of causality. The focusing question asks: Why has the problem persisted despite our best efforts? Efforts to answer the focusing question leads to uncovering and mapping the deeper levels of causality that give rise to and perpetuate the problem at hand. In addition, stakeholder mental models that influence decision-making are elucidated, either via interviews or through a managers' review of the resulting CLD. Once CLD structures and mental models are identified, managers or policymakers are equipped to pinpoint places of leverage where interventions will have more effective impact.

In fall 2022 as part of a graduate-level natural resource management class, our team[ii] employed the systems thinking approach to address our focusing question: Why aren't more landowners enrolling in land-based carbon credit exchanges? We reviewed contemporary and scientific literature to describe what has happened and explored publicly available databases to graph key trends and behaviors over time. We created a CLD of the underlying causal feedback structures of the problem. Using personal contacts in the ranching industry, we solicited input from three managers who had some enrollment experience in or exposure to various carbon credit programs via unstructured interviews.[iii] Managers also provided informal feedback for improving the CLD. We describe the results of each stage of the process and unpack potential leverage points that may lead to improved financial, soil, and land health benefits for landowners. Readers less interested in the systems thinking process and its outputs (e.g., historical background and context, quantitative trends over time, and the descriptive structure they provide along with management experience) may skip to the next section ("Modeling the system") and reference preceding sections as needed.

What has happened?

Gases that trap heat in the atmosphere and contribute to air pollution and adverse human health outcomes are called greenhouse gases and come primarily as a result of human activities (e.g., transportation, electricity generation, and industrial manufacturing processes).[24] Gases categorized as greenhouse gases include CO_2, methane (CH_4), and nitrous oxide (N_2O). Recent reviews of current greenhouse gas emissions of the United States found CO_2 accounted for 79% of all greenhouse gases emitted[25] with the bulk of emissions coming from exponential growth in burning of fossil fuels beginning in the 1800s.[26] Greenhouse gas emissions have increased over time, with five countries accounting for 41.6% of all greenhouse gas emissions worldwide.[24] Coupled with projected global population increases, this trend of increased emissions is expected to continue for the foreseeable future[27] and contribute to rising global temperatures as well as food supply disruptions and extreme events (e.g., wildfire damages).[4]

With increasing demands to mitigate climate change risks, public pressure has amplified on many industries to develop carbon-neutral practices or carbon-neutral systems by incorporating a combination of approaches, including direct emission reductions via reductions in emitted greenhouse gases[5] and/or by participating in emission or carbon offsets.[28]

[ii] All coauthors of this manuscript.

[iii] Questions varied depending on the individual's experiences because some had been involved in carbon credit exchanges, and others had not. All were aware of carbon credit opportunities and had been solicited by vendors about potential enrollment. Respondents were from either Texas or South Dakota, aged 38 to 70, and directly involved in managing commercial cow-calf operations.

What has been happening over time?

The concept of carbon offsetting began in 1989 with an agriforest in Guatemala. Since then, efforts at carbon offsetting have evolved over three development periods: the 1997 Kyoto Protocol, the 2005 European Union (EU) Emissions Trading Scheme (ETS), and the 2015 Paris Agreement.[28] The Kyoto Protocol established a 5.2% greenhouse gas emission reduction objective (from 1990 emissions levels) agreed to by 41 countries and the EU.[29] The flexible and broad international mechanisms agreed to in the Kyoto Protocol provided the starting point of climate policy negotiations since 1997.[28,29]

The 2005 EU-ETS is credited as being the first large-scale greenhouse gas emissions trading scheme in the world and remains a significant component of European climate policy.[30] The EU-ETS sets a cap on maximum emissions levels for various sectors and established a market for emission permits needed to generate a carbon price. In the market, companies emitting less than their cap are permitted to sell the excess carbon permits to companies emitting above their respective cap.

The 2015 Paris Agreement was adopted by 196 parties and is a legally binding international treaty to limit global warming to well below 2°C compared with preindustrial levels.[31] This was the first attempt to link international climate mitigation efforts with a long-term temperature reduction goal. Additionally, the Paris Agreement was considered a landmark agreement because, for the first time, agreements were legally binding participating nations.[32]

The enactment of these policies over time has bolstered efforts to form market exchanges to buy and sell carbon credits. Although changes to industrial production or process efficiencies have reduced short-term emissions rates, these will not fully eliminate all emissions. Purchasing carbon credits allows corporations to offset or balance emissions above the legally or voluntarily imposed cap. The majority of market structures are voluntary; however, some mandatory cap-and-trade programs exist (e.g., California or the EU-ETS; Table 1). Voluntary participation by corporations stem from industry social responsibility incentives; their own environmental, social, and governance policies and reporting requirements; or to improve their competitive position in the marketplace.[6]

With these market structures in place and strong demand for carbon credits, the number of publicly documented carbon-capture projects globally have grown to more than 1.9 billion tonnes (2.09 billion tons) as of 2022.[33] Of these documented projects to date, only 7.6% are land-based projects related to agriculture, forestry, or grassland or rangeland management (representing more than 221 million credits or 16.7% of total carbon value, approximately 0.32 billion tonnes [0.35 billion tons]), with the bulk of these in the improved forest management category (87% of carbon credits issued in the categories listed previously).[iv] The evolution of documented voluntary agriculture, forestry, and range and grassland carbon credits in the United States shows market growth followed by decline over time (Fig. 2). Although the number of credits transacted in this category grew rapidly in the first decade of market expansion (2006–2016, up to >80% of all new US carbon credits issues), since then the number of new credits has diminished and now represents <25% of the total US market (Fig. 2B).[33]

The problem thus far can be depicted in a basic feedback loop structure (Fig. 3). The increase in atmospheric carbon level has led to increased effort to develop carbon markets (indicated by the "s" link, meaning as carbon level increase or decrease, market development efforts change in the same direction). As carbon markets develop and provide opportunities for suppliers to enter the marketplace, greater effort is placed on farm, forest, and grassland and rangeland carbon capture strategies (e.g., altered, deferred, or removal of grazing).[34,35] The intent of these strategies is that over time (year to decadal timescales) atmospheric carbon levels will decrease due to the increased carbon-capture efforts to bind and store more carbon in soils (represented by the delay marks on the link between carbon-capture efforts and atmospheric carbon). Given the current state of affairs (what's happened?) and the stagnate nature of landowner enrollment rates despite increasing carbon credit market opportunities (what's been happening over time?), we can infer market incentives and policies forming this feedback process are not working as intended.

Why aren't more landowners enrolling in land-based carbon credit exchanges?

With key events and trends and patterns over time described, we turn to the underlying causal relationships hindering landowner enrollment in carbon credit exchanges. We synthesized or reviewed the most recent and relevant published work in this area as well as captured the thoughts and perceptions of three managers who volunteered their experiences around carbon markets.

Certainly, the emergent carbon market has been marketed as a win–win for large-scale industrial carbon emitters and landowners in agriculture, forestry, and rangeland contexts because it serves as a tool for mitigating carbon emissions for credit buyers and an additional revenue source for credit suppliers. We identified several underlying, systemic structural

[iv] According to Berkely Carbon Trading Project, which tracks carbon capture projects from the major registries (American Carbon Registry, Climate Action Reserve, Gold Standard, Verified Carbon Standard, and California Air Resources Board). In 2022, 16.7% of the lifetime 1.9 billion tonnes (2.09 billion tons) of contracted carbon credits (or 0.32 billion tonnes [0.35 billion tons]) were related to agriculture, forestry, or grassland- or rangeland-related projects (excluding reduce emissions from deforestation and forest degradatiaon in developing countries [REDD+] projects that focus on forests in developing nations): compost addition to rangeland (0.000%), feed additives (0.000%), improved irrigation management (0.021%), manure methane digester (1.190%), nitrogen management (0.00%), sustainable agriculture (0.023%), afforestation or reforestation (3.095%), avoided forest conversion (0.540%), avoided grassland conversion (0.039%), improved forest management (10.897%), sustainable grassland management (0.651%), and wetland restoration (0.252%).[33]

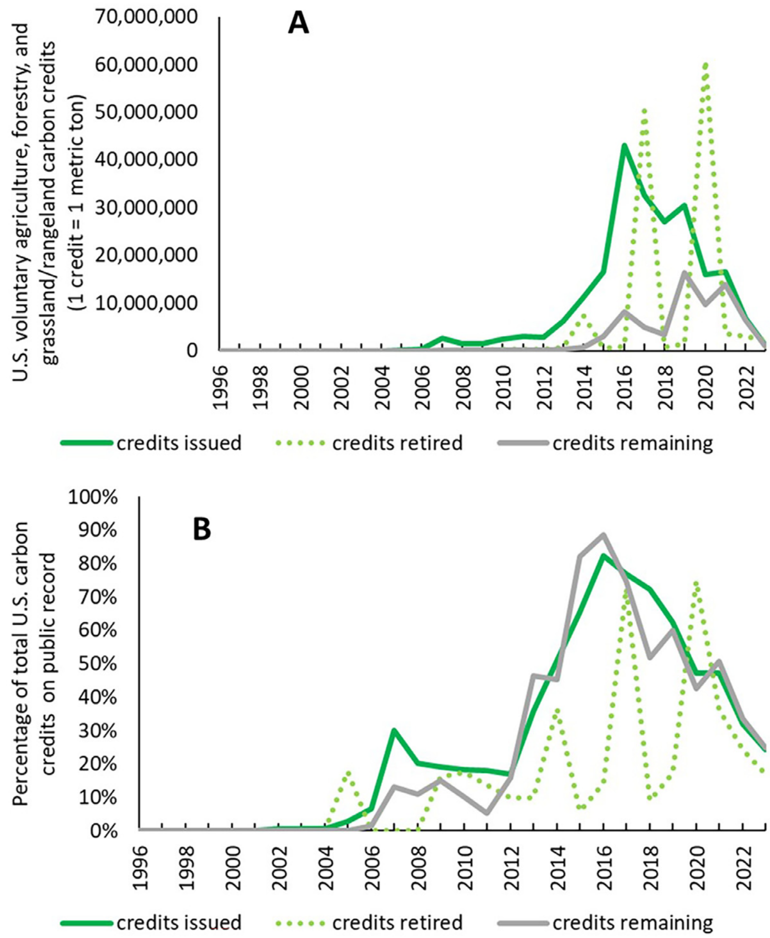

Figure 2. Agricultural-based carbon credit transactions in the United States (A) and as a percentage of total voluntary US carbon credits (B). Data from So et al.[33]

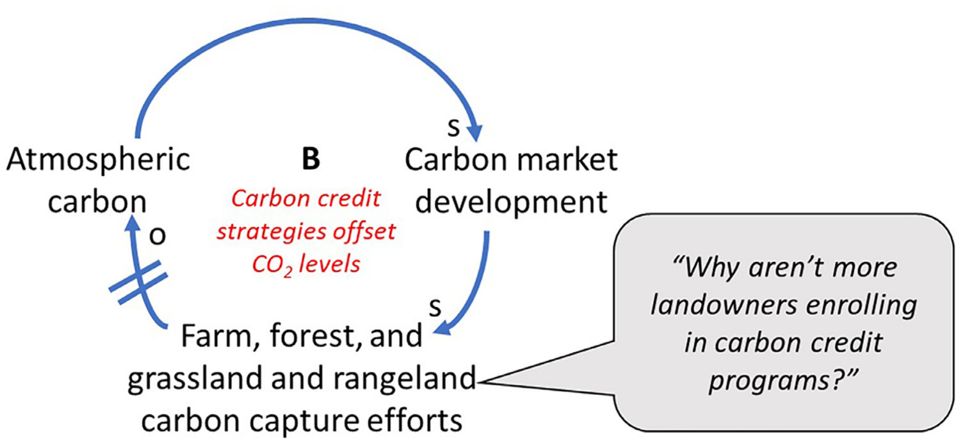

Figure 3. Basic feedback loop structure capturing the rationale of carbon credit markets and our focusing question: Why aren't more landowners enrolling in land-based carbon credit exchanges? As atmospheric carbon increases (decreases), development effort in the carbon market moves to likewise increase (decreased; denoted by a S-link). As the carbon market increases (decreases), farm, forest, grassland, and rangeland carbon capture efforts likewise increase (decrease; S-link). As carbon capture efforts increase (decrease), atmospheric carbon moves in the opposite direction and decreases (increases; denoted by the O-link) after some time delay (denoted by the ≠ link). When working effectively, increased emissions spur carbon capture efforts that in the long term feeds back to reduce emissions. When such feedback returns to offset the initial change in behavior, the feedback is termed a *balancing loop* (denoted with the capital B in center of loop).

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issues complicating and unintentionally conspiring against increasing rates of landowner participation, which we categorized and described as follows: production risks and rewards (the benefit-to-cost ratio problem), carbon prices (the supply-curve problem), accuracy and precision of soil carbon measurement protocols and confidence in verification processes (the confidence problem), and transaction risk (the risk-aversion problem).

Production risks and rewards (the benefit-to-cost ratio problem)—Entering into a carbon contract requires the landowner to evaluate if the addition of a new enterprise (the direct costs as well as the subsequent operational changes required in preexisting enterprises) outweighs the adjusted financial returns from current land enterprises plus the expected revenue generated from the new soil carbon enterprise.[6,36,37] The benefit-to-cost ratio (BCR) is:

$$BCR = \frac{ops_{gain} + soilC_{rev}}{ops_{loss} + soilC_{exp}} \quad [1]$$

Where ops_{gain} represents the sum of any increases in revenues and decreases in costs in existing operations systems (i.e., total gains from operations), ops_{loss} represents the sum of any decreases in revenues and increases in costs in existing operations (i.e., total losses from operations), soil C_{rev} represents the revenue generated from the soil carbon project, and soil C_{exp} represents the expenses generated from the soil carbon project. Values >1 indicate the investment is financially profitable, whereas values <1 indicate costs outweigh any expected benefits of a given change in management. Changes in existing production practices (e.g., grazing timing, frequency, and intensity, or grassland re-establishment; adjusted tillage rates, crop diversity, or rotation patterns) may induce cascading side effects to existing costs and revenue structures, and therefore, enterprise-level BCR (e.g., reduced animal performance necessitating greater purchased feeds; changes in eligibility of pasture, range, and forage or crop insurance tools).[38] Such uncertainty about potential changes in land productivity worries landowners about implementing unfamiliar management practices they may not want to pay for.[18-21] Production risk also includes the soils' inherent ability to store additional carbon in a given landscape context, such as climate, soil type, and depth.[39] In many rangeland situations, soils possess more than one limitation to long-term nutrient storage, including carbon (e.g., too shallow, too sandy, too steep, too dry).[40]

Carbon price (the supply-curve problem)—As with any market, supply and demand drive the price of carbon credits. The demand for carbon credits comes from the appetite of corporations or organizations to purchase credits to accomplish specific goals, such as becoming carbon-neutral or increasing public perception of being environmentally conscious. Even though these efforts are voluntary, there continues to be significant demand.[6]

The supply-side dynamics reveal a more interesting story. In commodity markets, goods are treated as homogenous and interchangeable (substitutable), which makes differentiation by producers difficult. Producers are described as "price takers" (the market sets the price and rewards the lowest cost producers). Therefore, the change in revenue from a change in production is simply whatever the market price is. In the long run, producers are therefore willing to supply the market where their marginal cost curve (i.e., the change in cost from producing one additional unit) is greater than their average total cost (i.e., above the point where they would financially breakeven and only cover their production costs; Fig. 4A). Initially, when credits were more expensive to create and verify (MC_1) and supply of credits scarcer (S_1), the price (p_1) was favorable, incentivizing many new producers to enter the market, including owners of forest, range, and agriculture land. Over time, efficiency gains in industrial processes have driven down the carbon credit cost (MC_2) and increased the overall supply (S_2), putting downward pressure on price (p_2) as more credits become available (moving from q_1 to q_2; Fig. 4B). Because such processes occur in more controlled settings, the time and cost to generate a carbon credit has declined relative to what it takes to generate the same credit in soil carbon storage. As a result, buyers of carbon credits have simply substituted their sources from land-based to other carbon sequestration sources, which is evidenced by growing proportions of new market credits coming from sources that are not forest, rangeland, or agricultural ones (Fig. 2B). Market dynamics leading to lower prices reduces landowner incentives needed for widespread participation as the declining net benefit of enrollment becomes more difficult to justify (see benefit-to-cost problem).[v]

Measurement protocols and confidence in verification procedures (the confidence problem)—Risk in this area is derived from the unproven nature of new and emerging markets to gain confidence from market participants. Variability and level of complexity between programs, contractual obligations, and legal liabilities associated with carbon credit enrollment are significant barriers landowners must understand before enrolling.[42,43] Significant variability can also be expected in soil test results. This variability is compounded by the variability in soil capabilities across landscapes (see benefit-to-cost problem) as well as varying soil collection and laboratory procedures.[44] This concern aligns with the scientific consensus as to the limited ability to measure year-to-year carbon changes in soil, which is the premise of carbon credit market that makes annual payments.[2,6,10] Additional concern arises from potential liability that if terms are not met (i.e., quantity of carbon sequestered is below the level specified in a contract) despite complying with the enrollment terms, landowners may be

[v] In addition, such market forces may unintentionally discourage carbon emitters from reducing emissions. This is because carbon credit prices decline in comparison to the cost of reducing emissions, and it becomes more cost effective to simply participate in the carbon offset market rather than investing in emission reductions.[41]

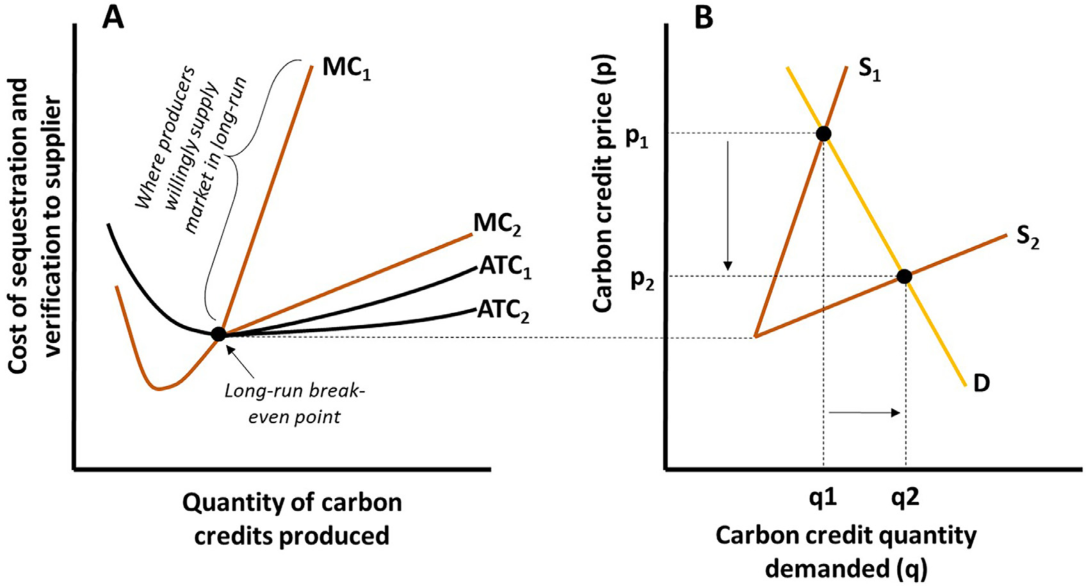

Figure 4. Cost curves for two potential production systems (1 and 2) in a commodity market (A), where ATC_1 and ATC_2 are average total cost per unit for all units produced in system 1 or 2 and MC_1 and MC_2 represent marginal costs per unit (i.e., the change in total cost from changing production level by one additional unit) in system 1 or 2. In the long run, anywhere the MC curve is above ATC, producers are willing to supply the market, generating supply curves S_1 and S_2, respectively (B). The market dynamics of moving from S_1 to S_2 given a certain level of demand (D) result in lowering the price (p_1 to p_2) and greater units demanded (q_1 to q_2).

financially liable to pay back any advanced funds. This lack of confidence in the verification and measurement of soil carbon coupled with added legal liability slows enrollment rates of landowners.

Transaction risk (the risk-aversion problem)—Lastly, transactional risk comes from the nature and transparency (or lack thereof) of terms and conditions being proposed within contracts, unanticipated expenses, and lack of regulation.[45] The new and emergent nature of this market does not currently provide a landowner-friendly process to enroll and later verify that contracted terms were met and structured appropriately. The lack of transparency of carbon credit prices and the cost required to verify a credit (see supply-curve problem) further compound transaction risks to landowners. Such transaction risks can lead to potential loss of other land use opportunities because of entering into a carbon contract (benefit-to-cost problem). Combined, all these factors likely create risk above levels many landowners are willing to accept.

The areas of risk (i.e. production, price, and transaction) and lack of confidence in carbon credit protocols are further augmented by the mental models and perceptions about the underlying market structures and dynamics held by landowners and managers.[2,46,47]

Landowner and manager mental models and perspectives

Mental models are the beliefs, assumptions, and models people have about every aspect of themselves, others, and how the world works.[48] They are comprised of peoples' experiences over time that have shaped their view of the world's issues and solutions.[49] Recent research has explored how landowners' and managers' perceptions of carbon credit markets shaped their willingness to participate in the carbon credit program.[19,49-51] In one survey, 64% of respondent landowners identified the current price of carbon credits as not being high enough to incentivize enrollment. Other factors included legal liability (i.e., conformity to terms), lack of confidence in carbon sequestration viability, and the previous use of eligible land management practices that have either disqualified them from participating in prospective programs or reduced potential carbon storage gains and therefore returns.[2] Perhaps surprisingly, only 39% indicated they were aware they could be paid for capturing carbon on their farm, and 82% of these respondents indicated they have not been engaged about potential paid enrollment opportunities.

In another survey using semistructured interviews of both participating and nonparticipating agricultural producers, researchers found producer views were similar and consistent; they found carbon credit programs to be convoluted, burdensome, and unpredictable.[50] Of those participating in carbon markets, all respondents indicated they were doing it for their own business and sustainability interests and not the financial incentives provided by carbon credit programs,[19,49-51] which they described as "gravy on top" of their existing revenue and cost structures. Carbon offset markets will continue to face strong challenges to achieving additionality given these producer-level perspectives.[52]

In fall 2022, we solicited input from three managers who had either participated in carbon credit programs or chosen not to via unstructured interviews. All expressed concern over losing decision-making power of land management decisions because of potential constraints required from enrollment terms. Common sentiments included phrases such as, "It seems better than it really is," and "There are a lot of questions I have, and it doesn't seem like there are many people or companies providing answers." Other concerns included ownership and property rights of data generated by their participation (e.g., Who can see it? Share it? Sell it?), lack of control or input in the verification process and the potential perception they would be viewed as business partners with companies making erroneous claims of the impact on offsetting greenhouse gases.

More importantly, these managers revealed subtler considerations not captured by previous research: the reputation of managers who are early adopters of conservation practices or viewed as innovative managers in their local community as well as the social acceptance among their peer managers. One manger reflected that upon enrollment, "[I] wasn't welcomed into the local community" and was met with comments like "You'll never last, you'll be out of here in three years [out of business]." Many neighbors in their community started using many of the same practices once they saw the benefits, but the process (i.e., from observation to implementing the practices themselves) took decades. When this manager was asked about their thoughts on the carbon credit program in which they enrolled, they responded with, "You don't get credit for what you have been doing," referencing past practices. They also stated, "the program structure is actually incentivizing the landowner to do a bad job managing the land as a resource prior to enrolling so you can be paid more for more practices you additionally implement." Another manager echoed this sentiment: "I will not be getting paid for what I am already doing and the cost of implementing new practices do not outweigh the possible revenue that would come from the partnership." Assuming a maximum level of soil carbon storage given the site's potential, the remaining soil carbon storage capacity represents the earning potential for the landowner. Over time, improperly managed lands consequently have a greater earning potential as the remaining carbon to be stored is greater.

Modeling the system

After investigating the key events, behaviors and trends over time, and the underlying systemic structural forces at work related to slow participation of landowners in carbon credit programs, we developed a conceptual model called a CLD. In systems thinking, a CLD is used to understand how the underlying structures of a problem interact and feedback on one another to thwart the best efforts of management or policymakers to improve the situation at hand. These commonly repeating problem symptoms and structures are known as *archetypes*.[53] We reviewed these archetypes and identified that the enrollment problem uncovered by our focusing question in carbon credits most closely resembled the problem symptom, behaviors over time, and structure of limits to growth (LTG).

The LTG archetype describes a problem situation in which the desired outcome is growth (supported by *reinforcing* feedback processes), but growth eventually stalls or reverses in the face of one or more external limits that act on regulating mechanisms that offset growth (called *balancing* feedback processes). In our case, the desired growth in the market is landowner enrollment rates. Landowners enroll in carbon credit programs when the net benefits of enrollment justify participation, and increasing participation by landowners bolsters the viability of the market and incentivizes benefits for that participation. This is reinforcing the market growth loop, in which *enrollment drives participation benefits* (left side of Fig. 5A). By reinforcing market participation, the market increases the prevalence of favorable land management practices conducive to storing more carbon in the soil. As soil carbon levels increase relative to initial carbon stocks, landowners stand to receive greater net benefits of enrollment. This is illustrated in the second reinforcing loop *long-term carbon storage drives economic gains* (right side of Fig. 5A). As producers begin exploring offset credit opportunities, the initial external limiting constraint is carbon price.

Because landowner net benefits of participation are driven by the change in soil carbon, several additional limits begin to exert themselves. Each soil possesses an inherent ability to store carbon in the form of organic matter, which is not infinite. This is the *soil carbon storage capacity* variable. Therefore, as the *actual carbon levels* stored increases, the *remaining carbon storage capacity* decreases (Fig. 5B). Over time, the *carbon accumulation rate* also decreases due to carbon saturation effects,[54-56] slowing the observable *change in soil carbon* and reducing landowner *net benefits of enrollment* because it will take more work at a greater cost over a longer period of time to see significant carbon storage gains to garner credit payments[vi] (shown as the balancing loop in Fig. 5B, *soil carbon saturation constrains growth in long-term storage*).

Even when landowners may be confident their respective land has the potential to store significantly more soil carbon, the variability in soil sampling protocols and subsequent test results requires large and intensive sampling efforts to statistically verify changes have occurred. Such considerations erode landowner confidence in the detectability needed to generate payments from enrollment. These natural biological limitations, coupled to payment structures based in soil carbon gained relative to beginning carbon content, unintentionally reward landowners with historically poor management and degraded soil organic matter. Furthermore, this situation disincentivizes early conservation adopters who would be willing to implement additional practices, but their soils may have less carbon storage potential remaining.

[vi] Increasing terminology such as "soil carbon sequestration" and "increasing soil organic matter storage" are used interchangeably, which is problematic given the evidence that without increasing organic inputs most soil carbon is depleted within only a few years (i.e., not sequestered), a fact discussed by Baveye et al.[56]

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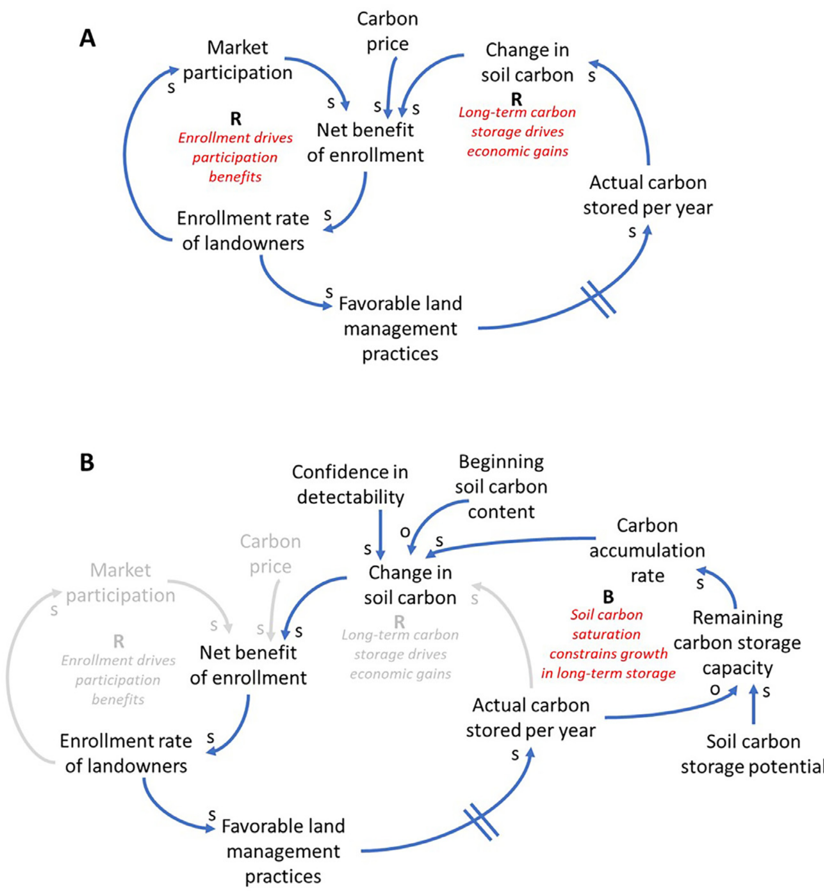

Figure 5. Feedback processes that support continual growth in enrollment rates driving participation benefits and long-term soil carbon storage driving economic gains (loops denoted R in top panel A). Links denoted S represent the same relationship whereby variables at the arrowhead move the same direction as their causal predecessor at the arrow tail. For example, as enrollment rate of landowners increases (decreases), favorable land management practices increase (decrease), leading to actual soil carbon stored per year increasing (or decreasing) after practices have time to take effect (denoted by the delay ≠ link). Biophysical limits to these growth processes arise through the influence of soil carbon storage potential, beginning soil carbon levels, and confidence in detectability (bottom panel B). For example, the higher the beginning soil carbon content, the lower the change in soil carbon (denoted O link), which drives down the net benefit of enrollment. Likewise, as the actual carbon stored per year increases, the remaining carbon storage capacity declines (O link), thereby reducing the carbon accumulation rate and, hence, the change in soil carbon level which drives net benefits of enrollment. Finally, as confidence in detectability declines due to sampling size requirements, the detectable change in soil carbon that can be assigned to the carbon project also declines, reducing net benefit of enrollment. The result is a balancing process (labeled B) that acts to balance or offset the growth processes via soil carbon saturation that constrains growth in long-term soil storage.

Besides these economic and biological limits, we also identified a social constraint to carbon credit market participation by landowners: acceptance among their peers and in their communities. If greater *market participation* means their *acceptance among peers* declines, then landowners are less likely to implement the full suite of *favorable land management practices* needed to maximize carbon storage in soils (Fig. 6A). Without proper implementation of favorable management practices, the *long-term carbon storage driving economic gains* loop (Fig. 5A) cannot express itself, and *net benefits of enrollment* are further constrained. This social constraint may be powerful enough to reverse the *long-term carbon storage loop* from a desirable growth process to an undesirable downward spiral that serves to push producers away from even considering enrollment possibilities (shown as the loop entitled *fear of losing peer acceptance strengthens the limits hindering enrollment*; Fig. 6A).

Places of leverage in the system

With these underlying feedbacks mapped into a CLD and being informed with the best available data about the problem including landowner mental models, we set out to identify possible interventions following guidelines for addressing LTG-related problems. Generically, these intervention strategies include raising or removing a limit, anticipating limiting forces and addressing them before they begin to dominate (i.e., restrict growth), or identifying links between the growth processes and limiting factors to find ways to manage the balance between the two.[53]

Raise or remove a limit

Within this strategy, we identify two limiting factors needing to be raised: *carbon prices* and the *confidence in detectability*

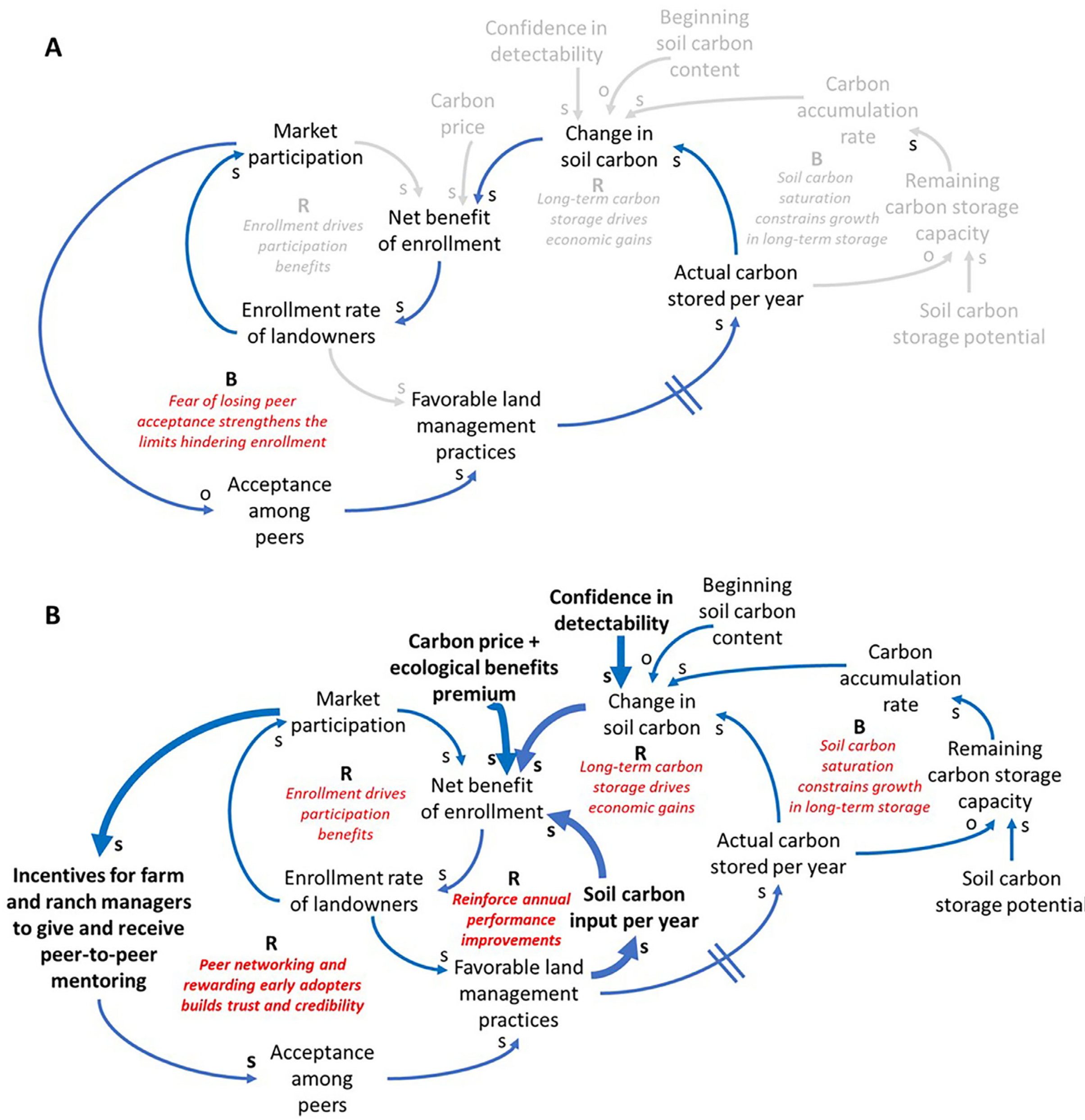

Figure 6. Expanded model to include the social limits that constrain growth of landowner enrollment rates (A), namely the fear of losing acceptance among peers. Links denoted O represent relationships where the cause variable at the arrow tail leads the effect variable at the arrowhead to move in the opposite direction, S links represent relationships where the cause variable leads the effect variable to move in the same direction, while delays are shown as ≠ links. For example, as market participation increases, acceptance among peers erodes (O link). As acceptance erodes, willingness to implement more favorable land management practices also declines (S link). This results in a new balancing loop acting to constrain enrollment rate of landowners (denoted B, fear of losing peer acceptance strengthens the limits hindering enrollment). A modified feedback loop structure (bottom panel) to include possible intervention strategies or leverage points (shown as bold links and variable names) that would enhance landowner participation in carbon credit programs: increasing confidence in the measurement and verification process and carbon prices (including possible prorated payments or ecological benefits premiums) to increase net benefits of enrollment (raising the limits), adjusting payment structures so that benefits are derived or partitioned between both the change in long-term soil carbon as well as the annual carbon inputs (adding a positive reinforcing loop, R, for annual performance improvements), and incentivizing mentorship opportunities so that early conservation adopting producers typically ineligible for carbon credit programs can be paid to mentor and support newcomers (reversing the original balancing loop grounded in social peer acceptance to a positive reinforcing loop, R, grounded in building trust and credibility).

of change during sampling and verification processes. Because of the commodity market nature of carbon credits, carbon price will be driven by supply and demand. However, land-based enterprises have unique auxiliary or complementary benefits of generating carbon credits that many industrial processes lack. These include but are not limited to improved hydrologic function and watershed health, reduced soil erosion, increasing biodiversity and its habitat, and/or improved aesthetic values. To improve the net rate of return for landowners who may wait years before seeing any new

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revenue, carbon credit programs could incorporate an "*ecological benefits premium*" which is added on top of the commodity carbon price (Fig. 6B). Such premiums are not unprecedented in the commodity markets (e.g., beef is often marketed on a "grid," which begins with the reported negotiated commodity prices and adds premiums or subtracts discounts from the base price given changes in quality and yield grades). This strategy widens the net of potential landowners willing to enroll, especially those early adopters of conservation practices who may not have as much carbon credit revenue potential given their initial soil carbon levels.

The second limit that could be raised is the landowners' *confidence in detectability* of change in soil carbon levels (Fig. 6B). Existing standardized protocols are not always transparent to landowners, and in some cases, verifiers' methodologies are considered intellectual property and not publicly accessible to evaluate or compare. Financial support to generate large enough sample sizes for statistical confidence at acceptable intervals around observed measurements, which can be prohibitively costly, may help boost the confidence of interested landowners. The limit is that these processes and parameters have not been clearly communicated in a way that landowners can intuit the feasibility of enrollment.

Anticipate limiting factors before they dominate

Even when such limits in prices or confidence are raised, there still exists the impact of the balancing loop, which is the *soil carbon saturation constraining growth in long-term storage*. No soil can continue to accumulate organic matter in perpetuity. Even when soil has reached its carbon storage potential and carbon inputs are reduced or stopped, biological activity in soil food webs will naturally consume and deplete organic matter levels within only a few years. Thus, short-term efforts to increase soil organic matter levels can be easily negated without long-term support to maintain those levels given the high input rates over long periods of time needed achieve organic matter levels capable of escaping microbial consumption.[56] In other words, maintenance of soil carbon *inputs* (i.e., in the form of root exudates below the surface and/or plant residues and litter above the surface) becomes more important the closer the *actual carbon stored per year* gets to its maximum *soil carbon storage potential*. Anticipating that limit and the continuous carbon input needed to maintain accumulated amounts in the soil, credit programs may seek to diversify their payment structure to account for the accumulated soil carbon as well as the carbon input needed to maintain it (e.g., adding multispecies cover cropping, leaving increased crop residue after harvest or increased residual standing forage after grazing). This approach is represented by adding a new feedback loop to the structure between *favorable land management practices* and *net benefit of enrollment* to re*inforce annual performance improvement and maintenance of stored soil carbon* (Fig. 6B). Such a payment structure also provides incentives for landowners to remain in programs after their initial contracts are closed out. Although their additional soil carbon potential may be exhausted, they could still receive some benefits by maintaining those levels and thereby increasing the probability of actual carbon sequestration success via long-term commitment to favorable land management practices.

Manage the links between growth processes and limiting factors

The primary link either negating or amplifying the limiting processes is the social loop representing *acceptance among peers* and other community members. A potential strategy to manage this link and use it to the market's advantage would be to convert this balancing loop (Fig. 6A) into a reinforcing loop to support *enrollment rate* and *market participation*. The addition of *incentives for farm and ranch managers to give and receive peer-to-peer mentoring* strengthens rather than quenches *acceptance among peers* and provides a reinforcing network of *peer mentoring and rewarding early adaptors to build trust and credibility* (Fig. 6B). Funds could be provided to early adopters to serve as mentors to landowners thinking about enrolling into carbon credit programs. As paid mentors to new enrollees they can provide management experience and moral support as new participating landowners learn to incorporate new practices into their existing land management strategies.

Discussion and Conclusions

The systems thinking approach provided the framework, processes, and language (e.g., behavior-over-time graphs, mental models, CLD's, archetypes) necessary for exploring the complex and dynamic problem pertaining to landowner enrollment in carbon credit programs. Systems thinking tools such as these are widely used in many scientific and management disciplines and are particularly useful to systems where the ecological or natural elements of the problem overlap and provide feedback with the human dimensions of the problem.

As we illustrate, there are multiple limiting factors that constrain growth of landowner participation in carbon credit exchanges, their willingness to enroll or explore such programs, and the required changes in land management and soil carbon content (Figs. 5 and 6). Market prices are likely too low to entice new entrants and keep them motivated in participating (the supply-curve limit). The market is highly fragmented, and there is a lack of standardized procedures and incentives across various landowner programs, which has caused confusion and lowered landowner confidence (the confidence limit). Contract terms vary significantly based on land conservation or agricultural practices put into management to possibly restrict the ability to make certain land-management decisions. Some limits interact; more degraded land has a greater opportunity for increased carbon storage than land that has been managed favorably, which disadvantages innovative landowners because it will take longer time and greater cost to see significant increases in soil carbon storage (the benefit-to-cost limit) which alters their perception of the motivations of market participants downstream in the supply

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chain (the confidence limit). Some fear participating in carbon programs will alienate them among their peers (the social acceptance limit).

For enrollment rates of landowners to increase, several intervention strategies aligning with the places of leverage (described previously) need to be explored by registries, developers, and landowners. First, registries need to develop more clear, consistent, and reliable frameworks by which landowner confidence and market transparency is ensured and supported in the long term.[57] For example, a mix of annual or short-term soil physical, chemical, and biological indicators combined with longer-term soil carbon measurements would address the scientific consensus pertaining to the limited ability to measure annual carbon changes in soil, which is the current premise of carbon credit validations.[6,10,58,59] In addition, all landowners would benefit from rigorous and technical education and information outreach to facilitate navigation of the carbon credit exchange process. Landowners should be aware that even in the same program, all contracts will differ depending on soil and landscape characteristics, management history, and developer and enrollee conditions. Potential enrollees should consult an attorney and read the entire contract before deciding. Registries could support these efforts by exploring ways to simplify the enrollment frameworks.

Second, developers who recruit landowners should not exclude early adopters of conservation practices conducive to enhancing soil carbon storage from the market. For the landowner who has historically maintained favorable management practices and restored and maintained soil carbon values near their maximum potential, there is currently little incentive compared to the landowners with degraded soils or currently employing practices with little to no carbon storage potential. Developers could explore prorating carbon credits values or providing other forms of payment (e.g., *ecological benefits premium*), which would more fairly compensate landowners who proactively restored soil carbon in the long term. This would also bolster confidence and reduce the stigma among peer landowners who are potential participants that the developers wish to enroll.

A third strategy would be to align the payment structure modifications with the first two strategies. Registries and developers working collaboratively could incentivize enrollment through a variety of payment mechanisms, such that payments could be warranted not only for the long-term change in soil carbon levels but also the annual soil carbon input needed to achieve and maintain these levels. Such payment structures would strengthen commitment to carbon credit programs because landowners would see financial benefits annually and in the long term for implementing and maintaining preferred management practices as well as benefits for maintaining desired soil carbon storage levels once they are reached.

Finally, early adopters should be given a seat at the table given their knowledge and experience. If they cannot be paid for previous carbon stored in soils, they should be paid to help guide new landowners via peer-to-peer mentoring. Besides alleviating the social stigma around participation for new enrollees, such a program could shorten the time delay between when a new landowner enrolls and when a credit is verified because the learning curve for implementation will have shifted closer to best practices using early adopters' experiences.

Some weaknesses or omissions of the model include geographic variability. Carbon credit programs may possess greater environmental or financial advantages to those located in regions of greater precipitation. In these more humid environments, soils have greater probability of infiltrating and storing more water, which in turn can increase biomass that gets converted and stored into organic matter.[60] On the other hand, landowners in more arid regions with highly variable precipitation are exposed to increased risk to sequester contracted quantities of carbon. Other omissions were the interaction between landowners and other stakeholders in the carbon credit supply chain and the perceptions many landowners and managers hold about the true underlying motivation of carbon credit programs. For example, although corporations can purchase carbon credits to offset their own emissions, they are not incentivized to significantly reduce their emissions. To address the root cause of carbon emissions would mean implementing changes to industry processes which lead to actually reducing emission rates. Some will perceive the concept of carbon offsets (i.e., an *indirect* tool of mitigating climate change) as a mechanism for corporations to avoid emission reductions while also marketing their public image towards one that *directly* invests in climate change mitigation. From a corporation's viewpoint, carbon credit offsets represent a cost to the company with no direct monetary return other than appeasing stockholders, public perception, and minimizing additional government regulations.[2,61] We excluded these factors from the model because of the size and complexity of these concerns.

Critics agree carbon offsets fall significantly short of reducing threats of climate change,[41] but there are ecological, environmental, and agricultural benefits of rebuilding soil carbon levels.[8,12,34] Public and corporate appetites for perceived positive action toward mitigating climate change will ensure carbon credit exchanges remain by offering financial opportunities to forest, rangeland, and agricultural landowners.[62-64] We have discussed many of the decision-making factors and limitations associated with carbon credit exchange enrollment. Every landscape and property are unique, and carbon credit programs are not a one-size-fits-all solution. Moving forward, landowners need a user-ready framework to assist in evaluating the risks and benefits of carbon credit programs with respect to their specific situation to make the most ecologically sound and financially profitable decision. Registries communicating clearer frameworks inclusive of a mix of short- and long-term indicators will provide clear incentives and measurable outcomes that landowners and managers can objectively manage. Developers and registries should not prematurely exclude early conservation adopters from the market. Instead, they should find ways to include these leaders in unique ways. Given the respect among local peers, this approach can reduce the negative perception and add trust to market participants among potential landowner enrollees. Finally, potential enrollees should seek the experience of existing participants and get advice from legal counsel to ensure they understand all terms and conditions in proposed contracts.

Declaration of competing interests

None.

CRediT authorship contribution statement

Landon R. Schofield: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Micayla E. Pearson:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Samuel Newell:** Methodology, Writing – original draft, Writing – review & editing. **Nathan Clackum:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Benjamin L. Turner:** Conceptualization, Methodology, Project administration, Writing – review & editing.

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References

1. US Environmental Protection Agency (EPA). Inventory of U.S. greenhouse gas emissions and sinks: 1990-2021. 2023. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021, Accessed September 26, 2022.
2. Thompson N, Hughes M, Nuworsu E, et al. Opportunities and challenges associated with "carbon farming" for U.S. row-crop producers. 2021. Purdue University, Center for Commercial Agriculture. Accessed September 26, 2022. https://ag.purdue.edu/commercialag/home/resource/2021/06/opportunities-and-challenges-associated-with-carbon-farming-for-u-s-row-crop-producers/.
3. Griscom BW, Adams J, Ellis PW, et al. Natural climate solutions. *Proc Natl Acad Sci USA*. 2017; 114(44):11645–11650. doi:10.1073/pnas.1710465114.
4. Broekhoff D, Gillenwater M, Colbert-Sangree T, Cage P. *Securing climate benefit: A guide to using carbon offsets*. 2019 Stockholm Environment Institute & Greenhouse Gas Management Institute; 2019:60.
5. Parkhurst R, Moore LA, Wright R, Perez M. *Agricultural carbon programs: from chaos to systems change [white paper]*. Washington, D.C.: American Farmland Trust; 2023.
6. Sawyer J, DeLaney D, Anderson D, Dowell-Lashmet T, Mathis C. Should I sell carbon credits? A decision guide for ranchers - King Ranch Institute for Ranch Management. Published August 19, 2022. Accessed September 26, 2022. https://krirm.tamuk.edu/carbon-credits.
7. UN Environment. Emissions Gap Report 2019. United Nations; 2022.
8. Newell-Price P, Bhogal A, Aller F, et al. Is sequestering carbon in agricultural soils a viable option for climate change mitigation? *Sci. Parliam.*. 2022; 78:10–12.
9. Dodson B. These 7 major companies are pledging to go carbon neutral—here's when (and how). Brightly. Published July 23, 2021. Accessed September 26, 2022. https://brightly.eco/when-big-companies-are-going-carbon-neutral
10. Sawyer J, Schofield L. The carbon question. 2022. The East Foundation. Accessed September 26, 2022. https://eastfoundation.net/media/annual-report/2022/2022-east-foundation-annual/.
11. Brody G. 2020. Farming to capture carbon & address climate change through building soil health. How well-managed grazing and continuous living cover benefit the climate, our waters, farmers and taxpayers through improved soil health. 2020. Land Stewardship Project white paper. Accessed December 1, 2023. http://www.landstewardshipproject.org/carbonfarming.
12. Conant RT, Cerri CEP, Osborne BB, Paustian K. Grassland management impacts on soil carbon stocks: a new synthesis. *Ecol Appl*. 2017; 27(2):662–668. doi:10.1002/eap.1473.
13. Zomer RJ, Bossio DA, Sommer R, Verchot LV. Global sequestration potential of increased organic carbon in cropland soils. *Scientific Reports*. 2017; 7(1). doi:10.1038/s41598-017-15794-8.
14. Bai X, Huang Y, Ren W, et al. Responses of soil carbon sequestration to climate-smart agriculture practices: A meta-analysis. *Glob Chang Biol*. 2019; 25(8):2591–2606. doi:10.1111/gcb.14658.
15. Reinhart KO, Hilaire Rinella MJ. Ruminating on the science of carbon ranching. *J Appl Ecol*. 2021; 59(3):642–648. doi:10.1111/1365-2664.14100.
16. Fletcher LS, Kittredge D, Stevens T. Forest landowners' willingness to sell carbon credits: a pilot study. *N J Appl Forest*. 2009; 26(1):35–37. doi:10.1093/njaf/26.1.35.
17. Lokuge N, Anders S. Carbon-credit systems in agriculture: a review of literature. *School of Public Policy Publications*. 2022; 15:12.
18. Kragt ME, Dumbrell NP, Blackmore L. Motivations and barriers for Western Australian broad-acre farmers to adopt carbon farming. *Environ Sci Pol*. 2017; 73:115–123. doi:10.1016/j.envsci.2017.04.009.
19. Buck HJ, Palumbo-Compton A. Soil carbon sequestration as a climate strategy: what do farmers think? *Biogeochemistry*. 2022; 161:59–70. doi:10.1007/s10533-022-00948-2.
20. Feliciano D, Hunter C, Slee B, Smith P. Climate change mitigation options in the rural land use sector: Stakeholders' perspectives on barriers, enablers and the role of policy in North East Scotland. *Environ Sci Pol*. 2014; 44:26–38. doi:10.1016/j.envsci.2014.07.010.
21. Gramig BM, Widmar NJO. Farmer preferences for agricultural soil carbon sequestration schemes. *Appl Econ Perspect Pol*. 2017; 40(3):502–521. doi:10.1093/aepp/ppx041.
22. Rhoades RD, McCuistion KC, Mathis CP. A systems thinking approach to ranching: finding leverage to mitigate drought. *Rangelands*. 2014; 36(6):2–6. doi:10.2111/rangelands-d-14-00017.
23. Wayland T, West L, Mata J, Turner BL. Why are proposed public land transfers a source of extreme conflict and resistance? *Rangelands*. 2018; 40(2):53–64. doi:10.1016/j.rala.2018.01.001.

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24. Ritchie H, Roser M, Rosado P. Greenhouse gas emissions. Our World in Data. Published June 10, 2020. Accessed September 26, 2022. https://ourworldindata.org/greenhouse-gas-emissions.
25. US Environmental Protection Agency (EPA). Overview of greenhouse gases. US EPA. Published April 13, 2023. https://www.epa.gov/ghgemissions/overview-greenhouse-gases, Accessed September 26, 2022.
26. USGCRP. Climate science special report. Washington, DC: U.S. Global Change Research Program, 2017. Accessed September 26, 2022. https://science2017.globalchange.gov/.
27. O'Neill BC, Dalton M, Fuchs R, Jiang L, Pachauri S, Zigova K. Global demographic trends and future carbon emissions. *Proc Natl Acad Sci USA*. 2010; 107(41):17521–17526. doi:10.1073/pnas.1004581107.
28. Smoot G. 2020. The history of carbon offsetting: the big picture. Impactful Ninja. Published June 9, 2021. Accessed September 26, 2022. https://impactful.ninja/the-history-of-carbon-offsetting.
29. Bohringer C. The Kyoto protocol: a review and perspectives. *Oxford Rev Econ Pol*. 2003; 19(3):451–466. doi:10.1093/oxrep/19.3.451.
30. European Commission. Development of EU ETS (2005-2020). Accessed September 26, 2022. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/development-eu-ets-2005-2020_en.
31. United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement. United Nations Framework Convention on Climate Change. Published 2016. Accessed September 26, 2022. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.
32. Savaresi A. The Paris Agreement: a new beginning? *J Energ Nat Resources Law*. 2016; 34(1):16–26. doi:10.1080/02646811.2016.1133983.
33. So IS, Haya BK, Elias M. Voluntary registry offsets database v8. 2023. Berkeley Carbon Trading Project. Accessed December 20, 2023. https://gspp.berkeley.edu/faculty-and-impact/centers/cepp/projects/berkeley-carbon-trading-project/offsets-database.
34. Aryal DR. Grazing intensity in grassland ecosystems: implications for carbon storage and functional properties. *CABI Reviews*. 2022; 2022. doi:10.1079/cabireviews202217032.
35. Eldridge DJ, Macintosh A, George DA, Butler D. 2023. 3 reasons why removing grazing animals from Australia's arid lands for carbon credits is a bad idea. The Conversation. Published November 27, 2023. Accessed December 20, 2023. http://www.theconversation.com/3-reasons-why-removing-grazing-animals-from-Australias-arid-lands-for-carbon-credits-is-a-bad-idea-218129.
36. Teague WR, Apfelbaum S, Lal R, et al. The role of ruminants in reducing agriculture's carbon footprint in North America. *J Soil Water Conserv*. 2016; 71(2):156–164. doi:10.2489/jswc.71.2.156.
37. Stanley PL, Rowntree JE, Beede DK, DeLonge MS, Hamm MW. Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. *Agr Syst*. 2018; 162:249–258. doi:10.1016/j.agsy.2018.02.003.
38. Harmel RD, Smith DR, Haney RL, et al. Transitioning from conventional continuous grazing to planned rest-rotation grazing: A beef cattle case study from central Texas. *J Soil Water Conserv*. 2021; 76(6):534–546. doi:10.2489/jswc.2021.00159.
39. Maillard É, McConkey BG, Angers DA. Increased uncertainty in soil carbon stock measurement with spatial scale and sampling profile depth in world grasslands: A systematic analysis. *Agr Ecosyst Environ*. 2017; 236:268–276. doi:10.1016/j.agee.2016.11.024.
40. Herrick JE, Whitford WG. Assessing the quality of rangeland soils: Challenges and opportunities. *J Soil Water Conserv*. 1995; 50(3):237–242. Accessed January 2, 2024. https://www.jswconline.org/content/50/3/237 .
41. Kilgore G. How The Nature Conservancy sparked a global investigation into carbon offsets. 8 Billion Trees: Carbon Offset Projects & Ecological Footprint Calculators. Published June 21, 2021. Accessed September 28, 2022. https://8billiontrees.com/carbon-offsets-credits/best-programs-providers-companies-2021/nature-conservancy.
42. ISAP. An overview of voluntary carbon markets for Illinois farmers. 2023. Illinois Sustainable Ag Partnership. Accessed December 20, 2023. https://ilsustainableag.org/ecomarkets
43. Zelikova J, Chay F, Freeman J, Cullenward DA. A buyer's guide to soil carbon offsets. 2021. CarbonPlan.org. Accessed December 20, 2023. https://carbonplan.org/research/soil-protocols-explainer.
44. Bettigole C, Hanle J, Kane DA, et al. Optimizing sampling strategies for near-surface soil carbon inventory: one size doesn't fit all. *Soil syst*. 2023; 7(1):27. doi:10.3390/soilsystems7010027.
45. Ferguson M. Lessons on managing risk in emerging markets. *J Account*. 2011. Accessed September 26, 2022. https://www.journalofaccountancy.com/news/2011/jul/20114177.html.
46. Kreye M. 2021. What is selling forest carbon like? Three landowners' experiences. 2021. Penn State University Extension. Accessed September 28, 2022. https://extension.psu.edu/what-is-selling-forest-carbon-like-three-landowners-experiences.
47. Miller KA, Snyder SA, Kilgore MA. An assessment of forest landowner interest in selling forest carbon credits in the Lake States, USA. *Forest Pol Econ*. 2012; 25:113–122. doi:10.1016/j.forpol.2012.09.009.
48. Sence PM. *The Fifth Discipline*. New York, NY: Doubleday; 1990.
49. Denzau AT, North DC. *Shared Mental Models: Ideologies and Institutions*. Cambridge University Press eBooks; 2000:23–46.
50. Cook SL, Ma Z. The interconnectedness between landowner knowledge, value, belief, attitude, and willingness to act: Policy implications for carbon sequestration on private rangelands. *J Environ Manage*. 2014; 134:90–99. doi:10.1016/j.jenvman.2013.12.033.
51. Torabi N, Mata L, Gordon A, et al. The money or the trees: What drives landholders' participation in biodiverse carbon plantings? *Glob Ecol Conserv*. 2016; 7:1–11. doi:10.1016/j.gecco.2016.03.008.
52. Barbato CT, Strong AL. Farmer perspectives on carbon markets incentivizing agricultural soil carbon sequestration. *npj Climate Action*. 2023; 2(1):1–9. doi:10.1038/s44168-023-00055-4.
53. Senge PM. *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization*. Currency, Doubleday; 1994.
54. Stewart CE, Paustian K, Conant RT, Plante AF, Six J. Soil carbon saturation: concept, evidence and evaluation. *Biogeochemistry*. 2007; 86(1):19–31. doi:10.1007/s10533-007-9140-0.
55. Stewart CE, Paustian K, Conant RT, Plante AF, Six J. Soil carbon saturation: Evaluation and corroboration by long-term incubations. *Soil Biol Biochem*. 2008; 40(7):1741–1750. doi:10.1016/j.soilbio.2008.02.014.
56. Baveye PC, Berthelin J, Tessier D, Lemaire G. Storage of soil carbon is not sequestration: straightforward graphical representation of their basic differences. *Eur J Soil Sci*. 2023; 74:e13380.

57. Dowell T. Understanding & evaluating carbon contracts. Texas A&M Agrilife Texas Agriculture Law. Accessed September 28, 2022. https://agrilife.org/texasaglaw/2022/01/24/understanding-evaluating-carbon-contracts/.
58. Peltoniemi M, Heikkinen J, Mäkipää R. Stratification of regional sampling by model-predicted changes of carbon stocks in forested mineral soils. *Silva Fennica*. 2007; 41(3). doi:10.14214/sf.287.
59. Sanderman J, Baldock J, Hawke B, Macdonald L, Massis-Puccini A, Szarvas S. National Soil Carbon Research Programme: field and laboratory methodologies. https://csiropedia.csiro.au/wp-content/uploads/2016/06/SAF-SCaRP-methods.pdf, Accessed October 9, 2022.
60. Ramanujan K. Rain helps carbon sink. earthobservatory.nasa.gov. Published September 3, 2002. Accessed October 9, 2022. https://earthobservatory.nasa.gov/features/CarbonHydrology.
61. Downar B, Ernstberger J, Reichelstein S, Schwenen S, Zaklan A. The impact of carbon disclosure mandates on emissions and financial operating performance. *Rev Account Stud*. 2021; 26:1137–1175. doi:10.1007/s11142-021-09611-x.
62. Fuss S, Lamb WF, Callaghan MW, et al. Negative emissions—Part 2: Costs, potentials and side effects. *Environ Res Lett*. 2018; 13(6). doi:10.1088/1748-9326/aabf9f.
63. US Department of Agriculture. Partnerships for Climate-Smart Commodities Fiscal Year (FY). 2022 Partnerships for Climate-Smart Commodities National Funding Opportunity (NFO). Accessed December 20, 2024. https://www.usda.gov/sites/default/files/documents/climate-smart-nfo-usda-nrcs-comm-22-nofo0001139-02062022-web-final.pdf.
64. Kennedy SP, Kennedy K. Why the US should establish a carbon price either through reconciliation or other legislation. Brookings Institute. Published October 7, 2021. Accessed September 27, 2022. https://www.brookings.edu/research/why-the-us-should-establish-a-carbon-price-either-through-reconciliation-or-other-legislation/

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