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Review

Incentive mechanisms of carbon farming contracts: A systematic mapping study

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ABSTRACT

Despite increasing interest, a lack of comprehensive knowledge regarding the efficient design and implementation of carbon farming schemes remains. These schemes must efficiently achieve higher carbon sequestration, incentivize farmers, and increase farmers' participation in global carbon markets. Our study systematically reviews, describes, and maps available evidence related to carbon farming contracts to assess different incentive mechanisms for carbon farming. We conduct a systematic mapping review of articles extracted from various databases employing the Collaboration for Environmental Evidence method. We shortlist 52 articles and analyze about 40 global case studies, identifying three main incentive mechanisms of carbon farming contracts, namely, result-based, action-based, and hybrid payments. We examine how these incentive mechanisms are designed, in addition to associated payment types, monitoring approaches, and barriers to implementation. Result-based payments include stringent monitoring and can be implemented through auctions, carbon credits, product labels or certificates. Action-based payments are found to be simpler, with lower monitoring requirements for farmers and can be paid upfront or after contract implementation. Hybrid payments combine both techniques, offering low-risk and guaranteed payments for farmers and definite environmental mitigation impacts. Result-based and hybrid payments motivate farmers to innovate to meet environmental objectives while also connecting them to carbon markets. The major challenges to developing a successful carbon farming project include lack of permanence, non-additionality, and the absence of stringent monitoring, reporting, and verification standards, all of which affect farmers' incentives. This study determines that carbon farming contract design and efficiency can be improved by analyzing the lessons learned from previous experiences. By examining and improving the attributes that define different incentive mechanisms, farmers can be better motivated to enroll in carbon farming schemes and benefit from increased access to carbon markets to potentially transform agriculture into a viable tool for climate action.

1. Introduction

The urgency of achieving climate neutrality requires all economic sectors to reduce emissions and advance the capture of greenhouse gases in natural sinks. While reducing the carbon footprint of industries, electricity generation, and transport sectors is a relatively straightforward process, agriculture continues to struggle with its role in combating climate change (Clean Energy Wire, 2023). Since soil and biomass can function as carbon sinks, agriculture can contribute to carbon capture, sequestration, and emissions reduction for climate action efforts. "Carbon farming" refers to a variety of land-use and management practices to facilitate carbon sequestration in the soil (Smith et al., 2008), which can improve agroecosystem health by producing more fertile and resilient farmland. These practices include afforestation, agroforestry, wetland and peatland restoration, biochar application, minimal or no-till farming, limiting livestock grazing, reducing chemical inputs, and using cover crops, among others (McDonald et al., 2021). Carbon farming can also present opportunities for different internal and external sectors in the agri-food chain (McDonald et al., 2021).

Increased interest in carbon farming has been catalyzed by the development of financial instruments designed to incentivize carbon emissions reduction. International agreements such as the Kyoto Protocol and Paris Agreement encouraged emissions reduction through

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mechanisms like carbon trading, green development, and carbon taxes (Gren and Aklilu, 2016). These initiatives introduced a new tradable monetary tool called certified emission reduction units or carbon credits (Wongpiyabovorn et al., 2021). Carbon credits have been applied in carbon markets; these markets are categorized as voluntary or compliant. The voluntary carbon market includes businesses and individuals who voluntarily seek to offset their greenhouse gas (GHG) emissions to accomplish business or personal sustainability goals or enhance their brand image without any legal obligations (Tamba et al., 2021). Conversely, the compliance market serves regulated entities that have been mandated to reduce GHG emissions under regulations like the California Cap-and-Trade program in the United States (US) or the European Union's (EU) Emission Trading Scheme (EU-ETS) (Wongpiyabovorn et al., 2021). These policies have encouraged different sectors to engage in carbon trading, a domain where agriculture has been underrepresented. However, since agriculture accounts for one-third of global GHG emissions, its potential to function as a carbon sink and source of carbon credits has garnered considerable interest from public and the private sectors. This newfound interest in carbon farming has opened new avenues for farmers to adopt related practices, enabling them to benefit from incentives offered by public or private funds (Tang et al., 2016).

Carbon farming has been recognized as an essential policy tool in the EU and beyond. In December 2021, the European Commission (EC) published the *Communication on Sustainable Carbon Cycles* as a component of the EU's Farm to Fork Strategy. The *Communication* outlines short-to medium-term actions for addressing current challenges to carbon farming and upscaling the approach as a *green business model* that rewards farmers and land managers for adopting practices that advance carbon sequestration (McDonald et al., 2021). These actions can be facilitated using various policy instruments under the EU's Common Agricultural Policy (CAP) and other EU-funded programs such as Life, Cohesion, Horizon, and Interreg (McDonald et al., 2021). The CAP has previously been criticized for not effectively reducing carbon emissions (European Court of Auditors, 2021). The new CAP obligates EU member states to identify and prioritize climate needs to support effective carbon farming practices using EU and national funds and specific interventions of Pillar 1 and 2 (McDonald et al., 2021). The EC's interest in promoting carbon farming through existing agri-environmental schemes under CAP is shared by other countries' public institutions (Brockett et al., 2019). Governments worldwide have also implemented or are considering legislation and programs to encourage the development of national carbon markets. For example, the Australian government developed the Carbon Farming Initiative (CFI) as a voluntary carbon offset scheme in 2011, which later evolved into the Emission Reduction Fund in 2014, offering incentives to farmers and landholders for carbon sequestration through carbon credits (Badgery et al., 2021). Similarly, the US Congress introduced the Growing Climate Solutions Act, which established a certification program to encourage farmers' participation in carbon credit schemes (Bomgardner and Erickson, 2021). Additionally, international emissions reduction programs such as Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) support projects that incentivize carbon sequestration actions from farmers in developing countries.

Despite worldwide government interest and legislative efforts to promote carbon farming, limited studies have investigated farmers' willingness to participate in carbon farming contracts and adopt carbon sequestration practices (Dumbrell et al., 2016). The primary challenges in designing effective carbon-based payments include the cost and reliability of monitoring, reporting, and verification (MRV) tools; ensuring "additionality" (that mitigation would not have occurred in the absence of the carbon farming project) of the schemes; and overcoming the barriers to scaling up such projects (McDonald et al., 2021). Many studies have also highlighted a lack of efficient design for carbon-based payment schemes (European Commission, 2021b; Lin et al., 2013; McDonald et al., 2021). Moreover, a comprehensive database that defines and categorizes carbon farming contract elements, like contract duration, payment modes, costs, and barriers has not yet been developed. Peer-reviewed journal research articles on carbon farming contracts are extremely scarce as most cases are private initiatives (e.g., Nori, Indigo Ag, and Truterra). Previous empirical studies have typically analyzed a few successful carbon farming cases, which impedes the extraction of important generalizable lessons from unsuccessful cases. The Interreg North Sea Region Carbon Farming project report (Demeyer et al., 2021) described the lack of evidence as a "patchwork of knowledge," which is fragmented and does not thoroughly present comprehensive insights for policymakers, researchers, and farmers. This knowledge deficit can translate into economic uncertainty and financial unsustainability in all aspects of carbon farming projects, from their design to their outcomes (Demeyer et al., 2021). One such significant gap is understanding how to design an efficient incentive mechanism for enrolling farmers in carbon farming projects. Various approaches have been proposed such as result-based, action-based, and hybrid typologies (e.g., McDonald et al., 2021), as well as cost-based, per-ton (carbon credits), and per-hectare payments (Tang et al., 2016). However, which approach is most efficient for designing and scaling up projects remains unclear.

To advance overall understanding, this study systematically maps the incentive mechanisms of current carbon farming contracts. Using this systematic map (SM), we can determine the state-of-the-art carbon farming schemes globally, analyzing their spread, the diversity of case studies, various incentive mechanisms employed, the nature and structure of the payments to the farmers, the schemes' monitoring processes, and the challenges faced in implementing the different incentive mechanisms.

The main contribution of our study is its review of a broad evidence base, providing a comprehensive catalog of literature concerning carbon farming derived from academic research, policy, and business reports, which highlights potential research avenues and gaps in knowledge. The last comprehensive review of carbon farming, which was conducted by Tang et al. (2016), focused on the economics of carbon farming. Sharma et al. (2021) conducted another systematic review, defining carbon farming in the context of the carbon cycle and carbon sequestration, but the study did not address how carbon farming schemes can be implemented and adopted. Paul et al. (2023) assessed carbon certificates as an incentive for carbon farming but overlooked alternative payment mechanisms. Reed et al. (2022) analyzed the public and private funding mechanisms of different ecosystem markets, including carbon markets; however, our study offers a more comprehensive analysis of global carbon farming projects, examining diverse contract designs and monetary incentives, filling this gap in the existing literature. Our study also explores the crucial connections of different incentive mechanisms with voluntary carbon markets. This multifaceted approach allows us to offer a more holistic understanding of carbon farming, making our study a valuable addition to the field of carbon farming.

The remainder of this paper is structured as follows. Section 2 details our SM method and data analysis methodology. Section 3 presents the results, divided into two sub-sections, 3.1 General and 3.2 Incentive mechanisms for carbon farming. Subsection 3.2 examines incentive mechanisms' design and analyzes carbon farming activities, MRV, and the implementation barriers of these mechanisms. Section 4 investigates the results by highlighting significant economic and policy knowledge gaps and the scope for future research. The discussion section also examines the limitations of our SM. Finally, the study concludes in Section 5.

2. Methodology

SM is a review technique for investigating a broad and expansive topic such as *carbon farming* using a step-by-step approach (Haddaway et al., 2016). SM development uses a similar process as systematic reviews (SRs). However, SRs are specific and confirmatory and enable the testing of hypotheses, whereas SMs are generally more broad and narrative and lend themselves to the generation of hypotheses (Pullin et al., 2018). SM generally aims to identify and record policy-relevant evidence, knowledge gaps, and knowledge clusters to describe a topic (James et al., 2016). This study employs the SM methodology based on the standardized Collaboration for Environment Evidence (CEE), which is an open network of international actors that organize and perform systematic research and evaluations using a transparent, precise, and replicable method (Pullin et al., 2018). We use the CEE method version 4.2 (Collaboration for Environmental Evidence, 2013), and reference James et al. (2016) for the methodological framework for CEE mapping for the environmental sciences discipline. Experts in environmental management at CEE produced RepOrting standards for Systematic Evidence Syntheses in environmental research (ROSES) checklists as a reporting standard for systematic review. ROSES checklists include forms to complete during review documentation to ensure that all necessary content required by the CEE Guidelines for SRs in Environmental Management is present and described in detail. We use ROSES templates to report our review findings (downloaded from the official website[1]–ROSES ver 1.0, November 2017), and the ROSES flowchart was accessed online[2] (Haddaway et al., 2018). We constructed the SM in five stages.

2.1. Stage 1: Setting the scope

This review aimed to identify literature focusing on carbon farming contracts and cases. To do so, we established general criteria to include articles from relevant disciplines of agriculture, forestry, agri-environmental, environment, climate change, and agricultural economics. We also identified to the following keywords for the search: “carbon farming schemes,” “carbon farming contracts,” and “agricultural carbon markets.”

2.2. Stage 2: Searching for evidence

Searches were conducted from January 3, 2022 to January 8, 2022. We used keywords such as “carbon farming schemes,” “carbon market,” “soil carbon,” “soil organic carbon,” “carbon sequestration,” “carbon farming,” “agricultural carbon,” and related terms in various combinations with Boolean characters across various databases, as detailed in Table 1. We restricted the search to the period between 2016 and 2021 since outcomes of carbon farming projects were almost non-existent prior to 2016. For example, no results emerged when we used our first search string “carbon farming schemes,” in Scopus and Web of Science for 2015. In addition, the last review of carbon farming was conducted in 2016 by Tang et al. (2016), giving us an opportunity to update previous findings. Additionally, the Paris Agreement (COP21) in December 2015 marked a significant milestone for countries interested in carbon farming and agricultural carbon credits (Rhodes, 2016). A follow-up study of COP21 conducted by the European Parliament’s Committee on Agriculture and Rural Development underscored the importance of adopting carbon farming practices (Hart et al., 2017); therefore, we chose 2016 as the starting point for our literature search.

2.3. Stage 3: Screening evidence

After removing duplicates, we screened the documents using a two-step process at abstract/title (combined) and full-text levels, screening document titles and abstracts to determine whether manuscripts reported on carbon farming or broader terms, including “GHG emissions,” “soil organic carbon,” “agricultural carbon markets,” and other relevant concerns. We then assessed the articles deemed relevant through abstract and title screening at the full-text level using the following peer-reviewed, pre-determined inclusion criteria:

- The document must contain the following keywords and terms aligned with the search and objectives of the review, among others: “carbon farming,” “carbon farming contracts,” “carbon farming schemes,” “agricultural carbon contracts,” “carbon sequestration,” “agricultural carbon credits,” “agricultural carbon markets,” and “voluntary carbon markets”.
- The full text should encompass at least one of the following elements:
  - o Carbon farming cases, schemes, contracts, projects, and policies
  - o Carbon farming actions such as carbon-sequestering or emissions-reducing agricultural or land-use practices
  - o Carbon farming contract elements such as payments, contract duration, financing, intermediaries, monitoring, and farmer acceptance
  - o Agricultural carbon markets or related payment instruments (e.g., carbon credits)

2.4. Stage 4: Coding

We applied generic and study-specific coding to the documents’ full texts (see Table 2). Generic coding was used to describe the spread of the studies, while the specific coding aimed to address our research objectives and construct a SM of the different incentive mechanisms.

2.5. Stage 5: Describing and visualizing the findings

We tabulated all the screened documents, meticulously extracting and organizing coding data using Microsoft Excel. We used Excel to analyze the data via content analysis and text mining (as detailed in Supplementary Material 2). We also used the KH Coder for keyword analysis, referencing the methodologies suggested in previous studies (Baltranaite and Povilanskas, 2019; Blasco Gil et al., 2019; Nattuthurai and Aryal, 2018). The KH Coder can be accessed and downloaded from its official website[3] and its functionalities can be understood through the reference manual authored by Higuchi (2016).

3. Results

The search and screening processes are illustrated through the ROSES flow diagram (Haddaway et al., 2018), as shown in Fig. 1. As indicated in Table 1, we initially identified a total of 120 documents after removing duplicates. Upon screening the abstracts and titles, we scanned 99 articles for full text. Among those, the full text of one document, a book by Walsh (2016), was not retrievable. We accessed the remaining 98 articles in full-text to analyze using our inclusion criteria, resulting in the shortlisting of 52 articles for in-depth analysis. We then employed text mining to extract information about the coding variables from these articles, as detailed in Supplementary Material 2.

3.1. General findings

3.1.1. Study locations

The results in Fig. 2 reveal a global distribution of the evidence base, which is indicative of the worldwide interest in carbon farming. Most of the publications originated from Africa (17), followed by the EU (12), the US (11), Asia (8), Australia (5), the United Kingdom (3), and South America (1) (specifically, Mexico). We further analyzed the cases that were reported as successful from these geographical locations.

[1] RepOrting standards for Systematic Evidence Syntheses in environmental research: https://www.roses-reporting.com/.

[2] ROSES Flow Chart: https://estech.shinyapps.io/roses_flowchart/.

[3] KH Coder: http://khcoder.net/en/.

Table 1
Searching for evidence and data extraction.

Database	Search Date	Search Terms/string	Filters	Studies	Comments
Web of Science	January 3, 2022	"carbon farm* scheme*" OR "carbon contract*" OR "agri* carbon market*" OR "soil Near/2 carbon"	No filters	29	Need to add more terms for a wider search
		"carbon farm* scheme*" OR "carbon agri* scheme*" OR "carbon agr* contract*" OR "carbon farm* contract*" OR "agri* carbon market*" OR "farm* carbon market*" OR soil Near/2 carbon market OR farm Near/2 carbon market OR agr* Near/2 carbon market OR "agr* carbon cert*" OR "agr* carbon credit*" OR "farm* carbon credit*"	No filters	24	Filters need to be added to ensure uniformity of search across different platforms
		"carbon farm* scheme*" OR "carbon agri* scheme*" OR "carbon agr* contract*" OR "carbon farm* contract*" OR "agri* carbon market*" OR "farm* carbon market*" OR soil Near/2 carbon market OR farm Near/2 carbon market OR agr* Near/2 carbon market OR "agr* carbon cert*" OR "agr* carbon credit*" OR "farm* carbon credit*"	Language: English Date of publication: 2016–2021	14	Final output
SCOPUS	January 4, 2022	TITLE-ABS-KEY ("carbon farm* scheme*" OR "carbon agri* scheme*" OR "carbon agr* contract*" OR "carbon farm* contract*" OR "agri* carbon market*")	No filters	5	Need to add more terms for a wider search
		ALL ("carbon farm* scheme*" OR "carbon agri* scheme*" OR "carbon agr* contract*" OR "carbon farm* contract*" OR "agri* carbon market*" OR "farm* carbon market*" OR "soil W/3 carbon" OR "farm W/3 carbon" OR "agr* W/3 carbon" OR "agr* carbon cert*" OR "agr* carbon credit*" OR "farm carbon credit*")	No filters	52	Filters need to be added to ensure uniformity of search across different platforms
		ALL ("carbon farm* scheme*" OR "carbon agri* scheme*" OR "carbon agr* contract*" OR "carbon farm* contract*" OR "agri* carbon market*" OR "farm* carbon market*" OR "soil W/3 carbon" OR "farm W/3 carbon" OR "agr* W/3 carbon" OR "agr* carbon cert*" OR "agr* carbon credit*" OR "farm carbon credit*")	Language: English Date of publication: 2016–2021	39	Final Output
Eur-Lex	January 5, 2022	Text ~ "carbon farming scheme*" OR "carbon agri* contract*"	No filters	6	More keywords need to be added to widen the search
		Text ~ "carbon farming scheme*" OR "carbon agri* scheme*" OR "carbon agri* contracts" OR "carbon farm* contracts" OR "agri* carbon markets" OR "farm carbon credit*" OR "agr* carbon certif*",	No filters	6	Filters need to be added to ensure uniformity of search across different platforms
		Text ~ "carbon farming scheme*" OR "carbon agri* scheme*" OR "carbon agri* contracts" OR "carbon farm* contracts" OR "agri* carbon markets" AND DD≥January 01, 2016≤December 31, 2021	Search Language: English Published in: English Date of publication: 2016–2021	6	Final output
Google Scholar	January 7, 2022	"carbon farming schemes"	Language: English Date of publication: 2016–2021	19	Each term had to be individually searched, constructing a string was not possible
		"carbon agri-environmental scheme"	Language: English Date of publication: 2016–2021	13	
		"Agricultural carbon market"	Language: English Date of publication: 2016–2021	48	
		"Carbon agricultural contract"	Language: English Date of publication: 2016–2021	0	
		"Agricultural carbon contract"	Language: English Date of publication: 2016–2021	10	
		"Agricultural carbon credits"	Language: English Date of publication: 2016–2021	17	
		"Farm carbon credits"	Language: English Date of publication: 2016–2021	2	
		Total from Google Scholar		109	Final output
CONSOLE project database	January 8, 2022	No keywords used; data collected through CONSOLE resources from https://console-project.eu/(Deliverable D2.1)		1	Final output
Final output of all databases				169	
Final output after removing the duplicates				**120**	

Table 2
Coding variables collected from screened articles.

Coding Variable	Information to be recorded
General	
Study locations	The country where the study was conducted
Keywords	Extracted from studies
Existing cases	Cases reporting carbon farming contracts and projects across studies
Incentive Mechanisms	
How they pay	Types of carbon-based payments to farmers and their contract elements
What they pay for	Farming practices for mitigating GHG emissions and carbon sequestration
How they monitor	Tools for MRV and certification mechanisms that exist
Barriers	Challenges and barriers to the adoption and implementation of these incentive mechanisms

3.1.2. Keywords: Co-occurrence network

We extracted keywords from the included studies and plotted them into a multi-dimensional co-occurrence network using the KH Coder application (see Fig. 3). This co-occurrence network measures the similarities between sets of words, resulting in a network of interconnected terms that enable calculating the similarities between the different word combinations. The illustration links the keywords that commonly occurred in all the studies, notably “carbon,” which is associated with numerous terms, including “soil,” “sequestration,” “storage,” “organic,” and “forest.” These terms are further interconnected to words such as “market,” “emission,” “management,” and “farming.” These connections highlight keywords that are pivotal for inclusion in further research on topics related to carbon farming. For example, the keyword “credit” is linked to both “carbon” and “market,” whereas “market” is associated with the terms “voluntary,” “carbon,” and “agricultural.” Identifying these links provides insights for future research exploring the topic of carbon credits or agricultural carbon markets in search databases. The keywords also highlight broader themes such as “carbon storage,” “climate change and mitigation,” “smallholder farmers,” and “sustainable land management,” which can be investigated further.

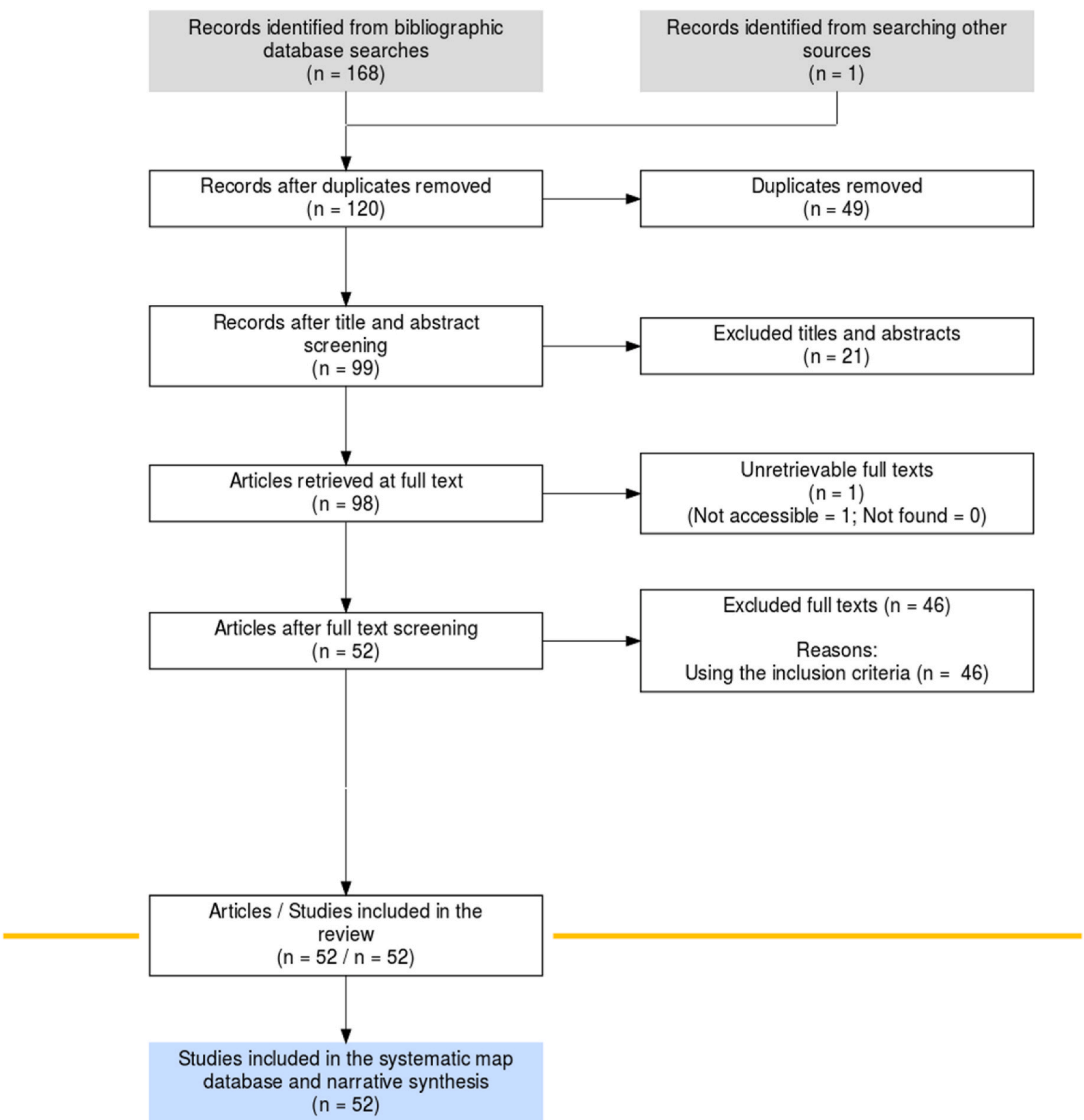

Fig. 1. ROSES Flow diagram, made online on ROSES official website[41].

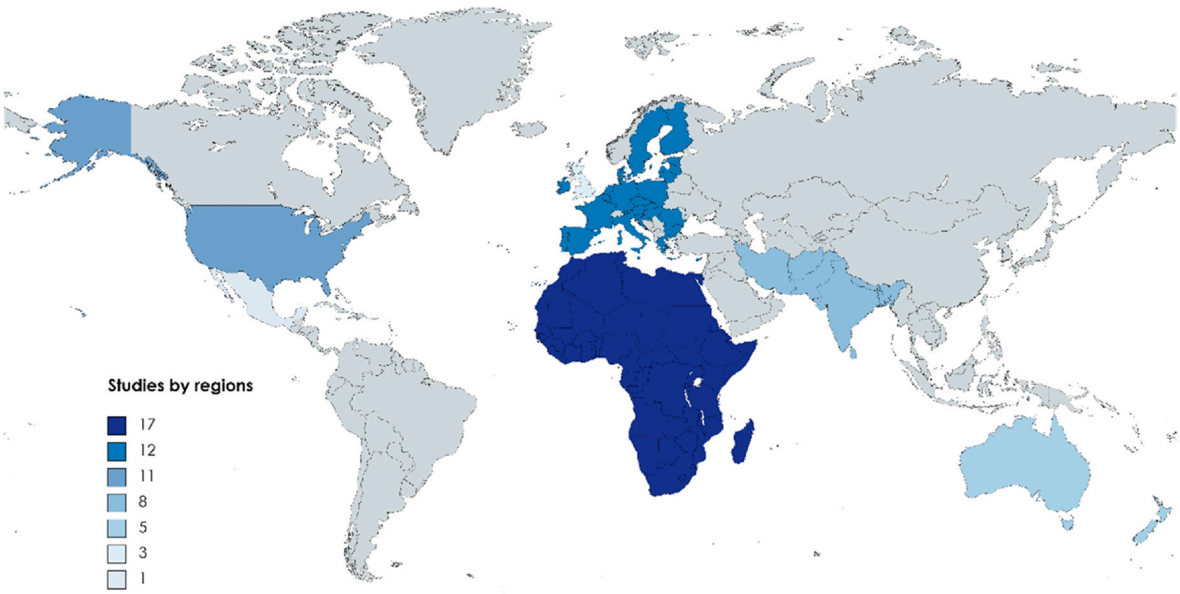

Fig. 2. Geographical distribution of study countries.

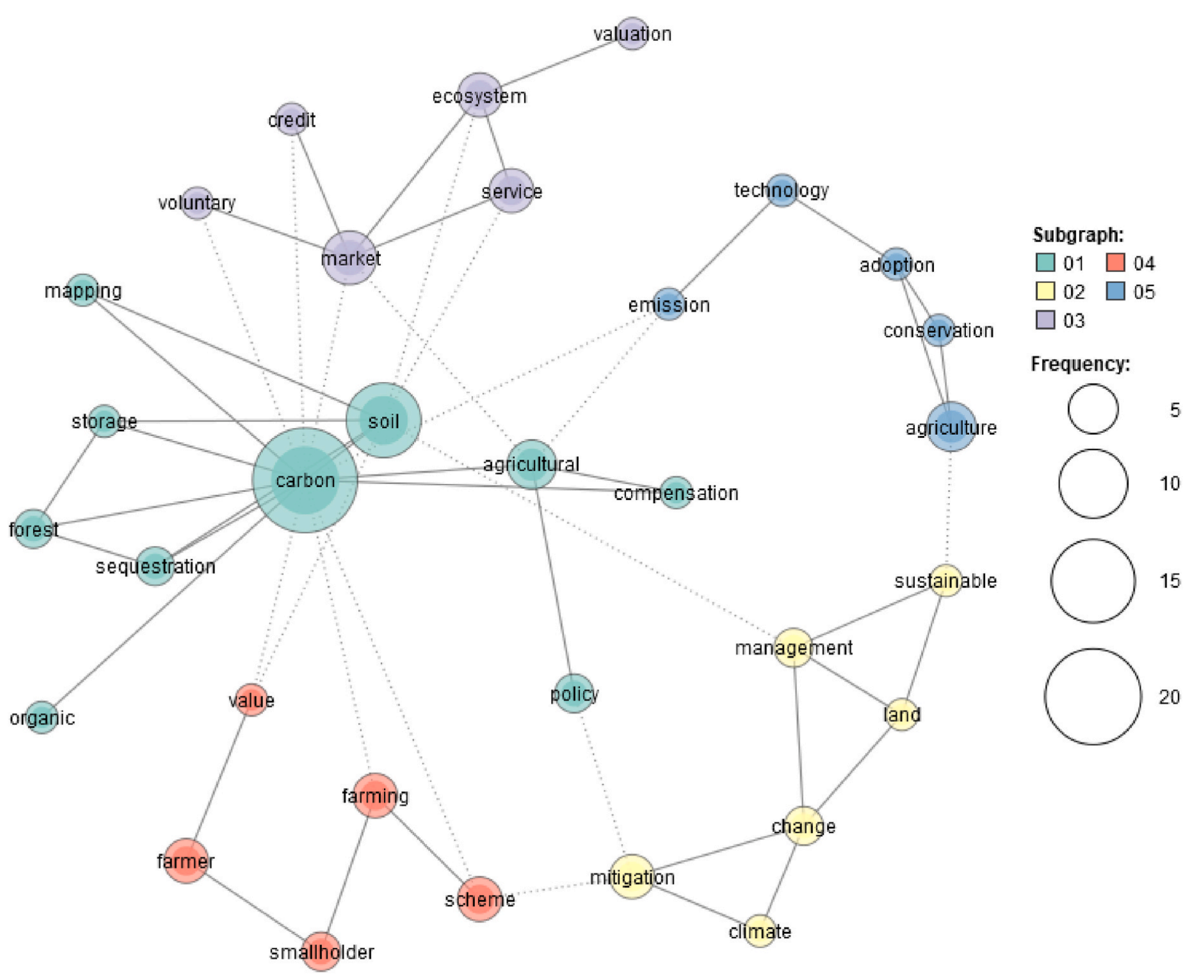

Fig. 3. Co-occurrence network of keywords.

3.1.3. Existing cases across studies

We extracted almost 40 cases from the selected 52 documents, and organized them based on the frequency of their occurrence in the studies

[4] ROSES Flow Chart: https://estech.shinyapps.io/roses_flowchart/.

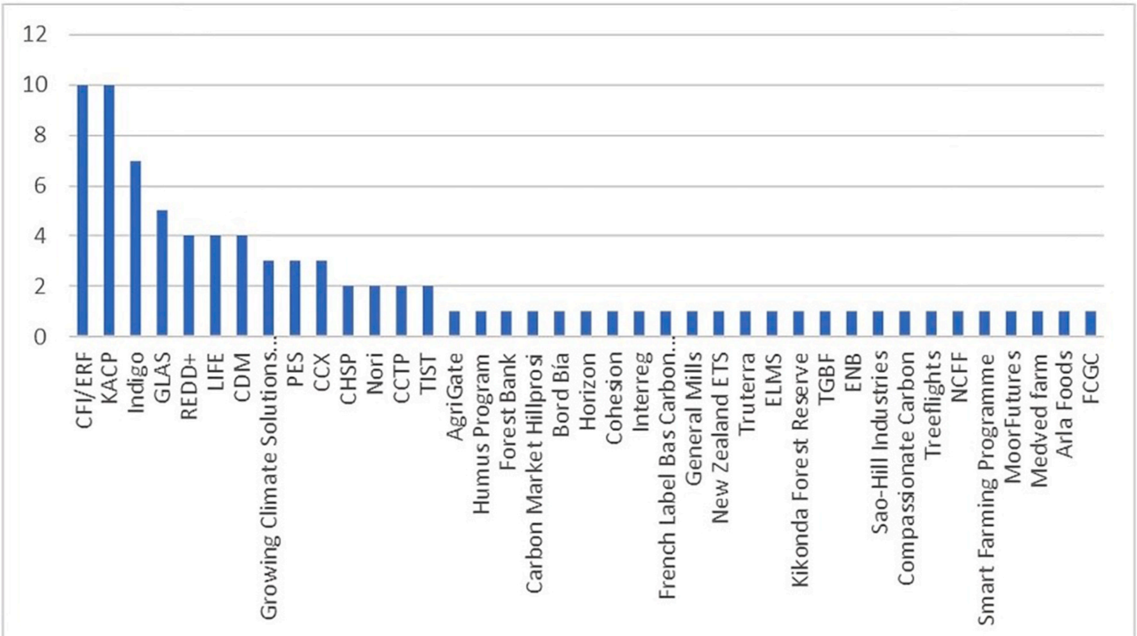

Fig. 4. Distribution of case studies across 52 documents.

(Fig. 4). The CFI in Australia, which is now called the Emission Reduction Fund (ERF) and the Kenya Agricultural Carbon Project (KACP) were the most frequently cited cases in the studies (N = 10). We assume that the prevalent citation of the CFI/ERF and KACP is because these are some of the oldest implemented cases and are still being analyzed ex-post. The general attributes of the cases are noted by observational analysis provided in Supplementary Material 1, including the forms of compensation that classify various incentive mechanisms.

The cases extracted encompassed a wide array of practices and approaches, ranging from private schemes that compensate farmers for carbon offsets or facilitate farmers' access to carbon markets, to government-funded initiatives that incentivize farmers to apply sustainable and carbon-negative practices on farms, or policies that support the adoption of carbon-sequestering practices and financially support or encourage private and public ventures in carbon farming. Frequently studied cases (those appearing in more than two studies) are detailed in Supplementary Material 1. A notable example of an early voluntary carbon project is the Chicago Climate Exchange (CCX) that was the first major voluntary cap-and-trade scheme involving agriculture in the US (Havens, 2021). However, the CCX ceased operations within 7 years, which has primarily been attributed to an oversupply of carbon offsets and a decline in carbon prices (Wongpiyabovorn et al., 2021). Our analyses of the identified cases also revealed the different incentive mechanisms employed in carbon farming contracts, which will be discussed in the sections ahead.

3.2. Incentive mechanisms

3.2.1. How are incentives designed? Defining the different incentive mechanisms

We extracted information regarding how different carbon farming contracts incentivized farmers from the identified cases. 41 articles cited some incentive mechanisms and associated structures. We categorized the extracted incentive structures referencing the EC's study on carbon farming (McDonald et al., 2021). We classified the cases into three main categories, including result-based payments, action-based payments, and hybrid payments, based on specific characteristics (as depicted in Fig. 5 and Table 3). Fig. 5 illustrates how these three incentive mechanisms operate and how payments connect farmers, intermediaries, and buyers (of carbon-based products) to carbon markets. A detailed description of the primary categories (and subcategories) of contract types is provided in the following sections.

3.2.1.1. result-based payments for carbon offsets. In result-based payments, farmers are compensated based on the actual outcomes they achieve in terms of carbon mitigation, whether through sequestration or emissions reduction (COWI, Ecologic Institute, & IEEP, 2021). These payments can be either in the form of carbon credits or product labels. The reviewed studies demonstrated that carbon credits can be paid variably post-contract or at a fixed rate via auctions. Result-based payments can also be in the form of certifications for products or associated labels that are contingent upon stringent MRV to ensure that carbon mitigation objectives were met (McDonald et al., 2021), as shown in Fig. 5 (I). Farmers can also sell credits issued by intermediaries post-MRV in carbon markets.

Although MRV requirements can pose challenges, particularly amid fluctuating market prices, uncertain mitigation strategies, and regulatory policies, result-based contracts produce measurable and quantifiable outcomes, enhancing environmental credibility of the carbon farming project (McDonald et al., 2021). Moreover, the contract flexibility that is inherent in result-based payments can encourage farmers to innovate and adopt mitigation measures according to unique local contexts (COWI, Ecologic Institute, & IEEP, 2021). Most REDD+ and Improved Forest Management projects are result-based, and offer farmers instant incentives when carbon offsets are issued or payment on delivery for projects under development (Gren and Aklilu, 2016).

Result-based payments have been implemented using the following mechanisms.

a) **Auctions.** In this case, multiple buyers bid in an auction to purchase carbon abatement results from a single seller at a fixed price. The seller is typically the farmer, and the buyers can be government or private entities. The auctions are competitive and set a fixed price to incentivize farmers for pre-defined projects to ensure efficient allocation of public funds while maximizing the volume of carbon sequestration per hectare per dollar. Under Australia's ERF scheme, farmers engage in reverse auctions for carbon abatement contracts with the Clean Energy Regulator, the government of Australia

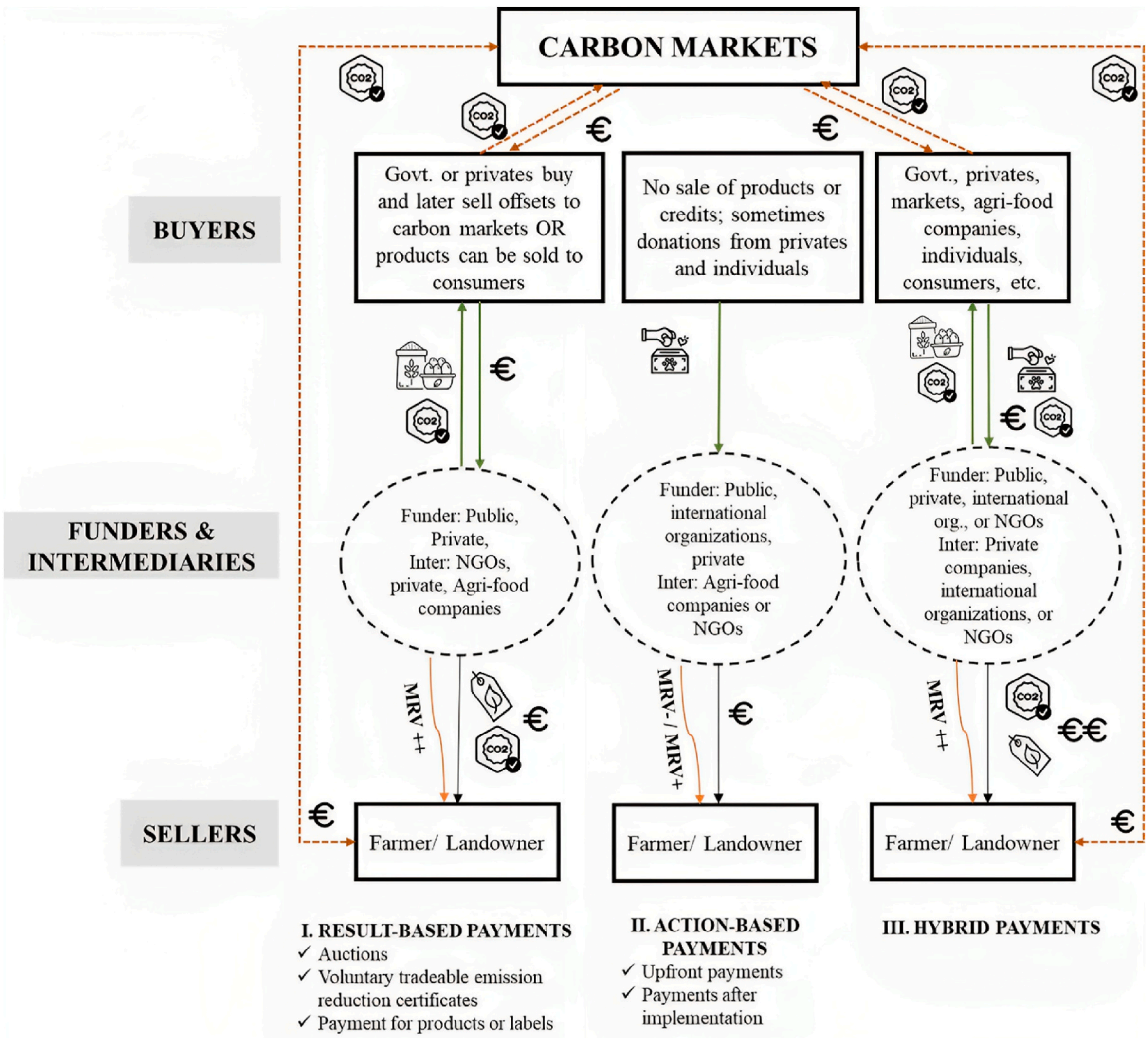

Fig. 5. Different incentive mechanisms for carbon farming contracts: (I) Result-based payments, (II) Action-based payments, (III) Hybrid payments.

(Verschuuren, 2016). Farmers are paid per generated Australian carbon credit units (ACCUs), which the government buys at a fixed price that is agreed during the auction; alternatively, farmers are also free to sell the ACCUs to private buyers for more lucrative prices (Salas Castelo, 2017).

b) **Payments in voluntary tradable emissions reduction certificates.** In this case, farmers implement agricultural practices that can generate voluntary tradable emissions reduction certificates or carbon credits based on the amount of reduced or sequestered GHG emissions. Each carbon credit typically represents removing one metric ton of carbon dioxide equivalent (MT CO_2eq) from the atmosphere that is sequestered into farms or forests. In this incentive mechanism, farmers sell credits directly on the market or to an intermediary (e.g., NGOs or private companies), who then sells them on the market in which other stakeholders can buy credits. For an efficient market exchange, credits must be additional, verified, and certified. Some private intermediaries facilitate this exchange between farmers and the market. From our review, private companies such as MoorFutures, Nori, and Indigo Ag contract with farmers as intermediaries to sell farmers' result-based carbon offsets to other big corporations such as McDonald's, NorthFace, and JPMorgan Chase & Co (Cruz et al., 2020; Havens and Havens, 2021; Lal, 2020; McDonald et al., 2021; Wongpiyabovorn et al., 2021).

c) **Payment for products (certificates or eco-labels).** Farmers participating in carbon farming projects receive payments for agricultural products that are certified as carbon-neutral or carbon-negative. This certification indicates that the production and life-cycle of these products have caused minimal or no net greenhouse gas emissions and rely heavily on stringent MRV. The certification process involves assessing the entire supply chain, from farm to market, to ensure emissions have been effectively reduced or offset. State and federally-funded programs, such as US Department of Agriculture (USDA), Certified Organic labeling, and Beyond California's Healthy Soils Program encourage producers to implement conservation practices through product certification (Buckley Biggs et al., 2021; Cruz et al., 2020).

3.2.1.2. Action-based payments. Action-based payments offer farmers fixed compensation for implementing or adopting specific environmentally-beneficial actions within their business-as-usual farming practices (McDonald et al., 2021). In the case of carbon farming, action-based payments are specifically awarded following concrete actions undertaken to sequester carbon or reduce emissions. A common example is the CAP payments (e.g., direct payments under Pillar 1 or agri-environmental-climate payments under Pillar 2), which have predominantly been action-based. Cho et al. (2021) determined that direct payments to forestowners and landowners effectively

Table 3
Detailed characterization of different incentive mechanisms.

Payment types		Payment characteristics						Case study examples	No. of papers
		Funder	Intermediaries	MRV and certification	Contract Flexibility	Risks	Payment mode		
Result-based payments	Auctions and Reverse auctions	Government and privates	Private companies – conduct MRV, connection to markets, training and advisory	Very high due to pre-defined project objectives Certification mechanism: Yes	Very low since the project is pre-defined	Low risk since the buyer fixes the price of carbon sequestered before the project starts	Mainly cash sometimes carbon credits to sell in the market	CFI/ERF	**8**
	Voluntary tradeable emission reduction certificates or carbon credits	Mostly private companies or international organizations, rarely government	Private organizations or NGOs – provide extension services, conduct audits and MRV, connect farmers to the markets	Very high to ensure high quality of credits Certification mechanism: Yes	Low flexibility since the payments are result-based	High risk since voluntary carbon markets could be volatile	Carbon credits	KACP, CCX, Indigo Ag, Moor Futures,	**41**
	Payment for products or labels	Run by private companies like agri-food industries with accreditation usually by the government	Agri-food companies, other private companies, or NGOs – conducting MRV and ensuring certification and labeling and creating new supply chains	Very high to ensure high quality of products Certification mechanism: Yes	Medium flexibility, since companies want to attract voluntary participation of farmers	Medium risk since labeled products act as a bonus to farmers	Product price	Clean Development Mechanism (CDM) projects; Forest Bank, Virginia (The Nature Conservancy); USDA Grass Fed programs and labels	**8**
Action-based Payments	Upfront payments	Mostly, Public financing or international organizations	Privates or NGOs –extension services for farmers	Low MRV requirements Certification mechanism: No	High flexibility	Low risk since farmers are paid upfront	Generally, cash	Many PES and REDD + programs, TIST, ENB, TGBF,	**11**
	Payments after implementation	Mostly public financing, sometimes private, international organizations or NGOs	Privates or NGOs – extension services, MRV processes	Medium MRV requirements to validate the actions taken Certification mechanism: No	Medium flexibility: Actions are predetermined	Low risk since farmers are compensated for yield loss	Generally, cash	Forest Gardens for Closing the Global Carbon Cycle (FCGC), GLAS	**23**
Hybrid Payments	A mix of result-based payments and action-based payments	Public, private, international organizations, or NGOs	Private companies, international organizations or NGOs – extension services, MRV, new supply chains, labeling, connecting to the markets, linking to government	Medium to High MRV requirements to guarantee different funding sources Certification mechanism: Yes	Low to medium flexibility since contracts are more complex and fixed	Low risk since multiple payments are provided	Cash or credits or product labels, mixed payments	TIST, ENB, TGBF, Nori, Indigo Ag	**10**

advance the preservation and restoration of private forest lands. These payments are relatively straightforward, with low monitoring requirements for farmers and project administrators, compensating farmers for their efforts, even ex-ante. However, the actual impact of such payments on emissions mitigation is uncertain since such payments rely on the promise of achieving results rather than tangible outcomes. The payment modes can be categorized into two sub-types, as described below and illustrated in Fig. 5 (II).

a) **Upfront payments.** Subsidies or upfront payments are financial compensation provided by the government or other entities to support and encourage farmers to adopt low-carbon farming practices or alter current practices to increase carbon sequestration in soil (Bithas and Latinopoulos, 2021; Klauser and Negra, 2020; Lee et al., 2016). Payments are provided upfront to motivate farmers to enroll in the carbon farming scheme and compensate them based on opportunity and conversion costs. However, these payments may not always be sufficient to cover farmers' transaction or opportunity costs for adopting new practices. For instance, several REDD+ and Payment for Ecosystem Services (PES) projects offer landowners upfront payments for achieving the objectives of a contract (Bakkegaard et al., 2016; Gren and Aklilu, 2016; Keenor et al., 2021; Klauser and Negra, 2020); however, many REDD + projects in Africa, for example, the International Small Group & Tree Planting Program (TIST), provided farmer groups with initial payments of US$0.018 per tree to help with planting costs (Lee et al., 2016; zuDrewer, 2019), while others such as the Emiti Nibwo Bulora program (ENB) and the Trees for Global Benefit Program (TGBF) gave farmers a portion of the carbon payment upfront with the support of donor funds and in accordance with the trees that needed to be planted (Lee et al., 2016).

b) **Payments following implementation.** Farmers receive compensation based on actions to implement specific carbon farming practices which also brings additional co-benefits such as improved soil health, enhanced biodiversity, and other advantages (Lal, 2020). For example, the Green Low-Carbon Agri-Environmental Scheme (GLAS) in Ireland is an action-based agri-environmental scheme (AES) that compensates farmers based on specified adopted practices that are scored on a tier system based on the expected environmental benefits of each practice (McGurk et al., 2020). GLAS promotes carbon sequestration and also encourages advancing public goods like improving the agroecosystems' water quality, soil quality, climate, and biodiversity (Mc Guinness and Bullock, 2020). California's Healthy Soils Program (CHSP) Incentives Program, funded by state cap-and-trade proceeds, similarly incentivizes farmers to implement conservation management practices to improve soil health, sequester carbon, and reduce GHG emissions (Buckley Biggs et al., 2021; Cruz et al., 2020). In Nepal, REDD + programs also incentivize carbon sequestration through action-based schemes like the TGBF Program, in which farmers were incentivized through cash-carbon per-tree payments and paid an average of €132 per year per farmer for 3 years for growing approximately 171 trees (derived from 2015 planting data by zuDrewer, 2019).

3.2.1.3. Hybrid payments. Hybrid payments combine aspects of result- and action-based payment schemes, offering farmers low-risk, upfront, and guaranteed payments for implementing specific farm management actions, with additional compensation based on actual measured mitigation results (McDonald et al., 2021). For example, the TIST program in Kenya provides farmers with upfront payments of US$0.018 per tree to offset planting costs during the contract period and further pays them carbon credits generated per household according to the sequestration measured at the end of the contract period (Lee et al., 2016; Salas Castelo, 2017; Tamba et al., 2021). Similarly, private initiatives such as Indigo Ag and Nori provide upfront payments when farmers join, with subsequent payouts based on actual outcomes. Nori also rewards farmers with one NORI token (cryptocurrency) as an additional incentive for their actions and the subsequent results (Cruz et al., 2020). Hybrid payments are similar to result-based incentives, except that they cover farmers' conversion costs to change practices, making these incentive mechanisms more profitable and less risky for farmers. As illustrated in Fig. 5 (III), hybrid payment mechanisms provide farmers with payments for actions and results from sellers and funders and through participation in the carbon market by selling carbon credits. In some cases, hybrid contracts can establish a supply chain with an agri-food company, from which the farmer earns additional revenue through product sales while receiving incentives for environmental actions. Hybrid payments can be more persuasive than a result-based mechanism as they can create multiple benefits for farmers, project partners, and other stakeholders.

3.2.2. What are the incentives for? Carbon farming activities

Through our comprehensive review, we extracted various management practices related to carbon farming and analyzed their frequency of occurrence (as shown in Table 4). As defined in the Technical Guidance Handbook produced by COWI, the Ecologic Institute, and IEEP (2021), carbon farming involves "*management of both land and livestock, all pools of carbon in soils, materials, and vegetation, plus fluxes of carbon dioxide (CO_2) and methane (CH_4), as well as nitrous oxide (N_2O).*" Consequently, carbon farming contracts incentivize farmers for actions that sequester and store carbon in the soil and biomass, implement land management actions to avoid carbon emissions, and manage livestock to reduce non-CO_2 GHGs that are common to agriculture such as CH_4 and N_2O. Carbon farming also yields other co-benefits, as noted in at least seven articles (Bithas and Latinopoulos, 2021; Cruz et al., 2020; Dumbrell et al., 2016; Emmet-Booth et al., 2019; Fleming et al., 2019; Keenor et al., 2021; McDonald et al., 2021). Dumbrell et al. (2016) reported improved soil quality and reduced soil erosion among the most recognized potential co-benefits by farmers. Table 4 summarizes the different practices under carbon farming contracts, how they mitigate GHG emissions, the co-benefits that these actions provide to the agroecosystems and society, and examples from case studies that incentivize these practices.

"Reducing chemical inputs and fertilizer use" was the most frequently cited practice across the reviewed studies (29 articles), followed by "forest management" (27 articles), and "tillage management" (25 articles). Seven articles did not mention any specific management practices, and 36 articles referenced other unique practices that are usually case-specific and related to the case countries' social and geographic context. For example, in humid tropical areas like India, the traditional method of increasing soil organic carbon in a field is through "shifting cultivation," in which previously used farmland is left fallow for long periods to regain soil fertility (Morton et al., 2020). Similarly, in the US, "forest fire hazard management" is an important practice, as highlighted by Gren and Aklilu (2016), since wildfires can negate all the carbon offsets provided by the forests (Galik and Jackson, 2009). Other less frequently cited practices included grassland management, pest management, water management (e.g., altering irrigation practices), and landscape management (e.g., protecting hay meadows).

Dumbrell et al. (2016) observed that farmers who primarily rely on cropping preferred implementing no-till cropping techniques. Conversely, practices that do not easily integrate with current farm operations such as using biochar, were ranked lower in their survey. Bithas and Latinopoulos (2021) highlighted the economic value of maximizing CO_2 sequestration through best practices in agriculture to support sustainability in rural areas such as tree plantations. Farmers in the study were incentivized to grow olive trees, which are capable of sequestering CO_2 with a value of €256.9 per ton. In addition, Simone et al. (2017) observed that the combination of no-till and crop rotation achieved higher carbon sequestration levels and increased soil carbon stocks.

Table 4
Overview of carbon farming practices in various studies and case reports.

Carbon farming practices	Frequency of citation	Mitigation mechanism	Co-benefits of other ecosystem services	Reference case studies	Selection of case study citations
Reducing chemical inputs/adding organic matter	29	Soil carbon sequestration	Soil health, biodiversity	ERF projects, LIFE Carbon Farming Scheme, Indigo Ag, Medved farm, Humus-Program	Dumbrell et al. (2016); Salas Castelo (2017); McDonald et al. (2021); Cruz et al. (2020); Havens (2021); Eichhorn et al. (2020); etc.
Forest management (afforestation, reforestation, agroforestry, etc.)	27	Soil and biomass carbon sequestration + avoiding land use emissions	Soil health, erosion prevention, biodiversity, microclimate	CDM projects, REDD + projects, CFI projects, LIFE ClimaTree, TNC Forest Bank, French Label Bas Carbon, FCGC, TGBF, TIST	Gren and Aklilu (2016); (2021); Badgery et al. (2021); McDonald et al. (2021); Lee et al. (2016); zuDrewer, 2019; etc.
Tillage management (no till, conservation tillage, strip till, etc.)	25	Soil carbon sequestration	Soil health, biodiversity, water management	ERF projects, Indigo Ag, KACP, Medved farm, Humus-Program, CHSP, Nori, GLAS	Buckley Biggs et al. (2021); Lee (2017); McDonald et al. (2021); McGurk et al. (2020); Cruz et al. (2020); Havens (2021); Eichhorn et al. (2020); etc.
Cover cropping	17	Soil carbon sequestration	Erosion prevention, soil health, biodiversity	KACP, Indigo Ag, Humus-Program, CHSP, Nori	Cruz et al. (2020); Havens (2021); Eichhorn et al. (2020); Lee (2017); Nyberg et al. (2020); etc.
Intercropping or Crop rotations	12	Soil carbon sequestration	Prevention of soil erosion, soil health, biodiversity	KACP, Indigo Ag, Humus-Program, CHSP, Nori	Cruz et al. (2020); Havens (2021); Eichhorn et al. (2020); Lee (2017); Nyberg et al. (2020); etc.
Livestock management (feed, emission management, etc.)	11	Emission reduction of non-CO_2 GHGs	Animal health, product quality, human health	GLAS, Bord Bía's Origin Green programme, CHSP, Nori	Emmet-Booth et al. (2019); Mc Guinness and Bullock (2020); McGurk et al. (2020); Schulte et al. (2016); Cruz et al. (2020);
Pasture and grazing management	9	Emission reduction of non-CO_2 GHGs + avoiding land use emissions	Animal health, product quality, soil health, biodiversity, water management	GLAS, ERF projects,	Badgery et al. (2021); Buckley Biggs et al. (2021); McGurk et al. (2020); Schulte et al. (2016); etc.
Peatland restoration	5	Avoiding land use emissions	Improve water retention and quality, biodiversity	MoorFutures, Carbon Market (Hiilipörssi)	Eichhorn et al. (2020); McDonald et al. (2021); etc.
Others	36			CDM projects, REDD + projects	Simone et al. (2017); Xiong et al. (2019); Yang et al. (2018); Appiah et al. (2016); Gren and Aklilu (2016); Møller et al. (2016); etc.
No management practices	7				

3.2.3. How are farmers monitored? Exploring MRV and certification mechanisms

The review revealed two primary MRV methods that are used today, namely, direct on-site measurement of carbon storage and modeling GHG emissions using proxy data and scientifically tested values, which is more cost-efficient and less time-consuming than the former (McDonald et al., 2021). Directly measuring highly variable soil organic carbon distribution is a costly and complex endeavor, which poses challenges to implementing such measurements in smallholder carbon projects. Direct measurement requires high MRV costs that funders, farmers, or both must bear. In particular, in developing countries (where cases such as REDD+, KACP, and others are piloted), high MRV costs lead to the projects relying solely on process-based models over on-site sampling to determine soil organic carbon fluxes. As a less resource-intensive alternative, projects may focus on implementing agricultural interventions that focus on simpler monitoring requirements such as quantifiable tree biomass carbon (zuDrewer, 2019); however, such restrictions can limit farmers' ability to innovate practices for increasing soil organic carbon, potentially reducing the environmental benefits of a carbon farming project. Notably, some studies cited emerging tools that could simplify MRV processes such as earth-observation-based remote sensing and blockchain data sources (Lal, 2020; Paquel et al., 2017; Tziolas et al., 2021).

Different carbon farming practices require different monitoring and verification methods. For example, the technical report produced by COWI, Ecologic Institute, & IEEP (2021) asserted that soil organic carbon can be determined more accurately through direct measurement than modeling, while manure management can be cost-efficiently measured through modeling. Most MRV tools and strategies in a carbon farming scheme are specific to the project and payment type, which is pre-defined for farmers. For example, MRV data for the KACP are collected through Activity, Baseline, and Monitoring Surveys, conducted by farmers who record data annually such as acreage, number of tree species, and crop types (Chemarum, 2015; zuDrewer, 2019; Shirley, 2018). Efficient MRV mechanisms require externally collected data and farmer data that are usually self-reported by farmers or collected via third-party farmer surveys. Similarly, in Ireland's Bord Bía's Origin Green program, monitoring is conducted through regular livestock and data collection on the participating farms, incentivizing farmers with certifications signaling higher quality meat plus a bonus from the meat plant.

Generally, result-based incentive mechanisms employ stringent MRV strategies, whether on-site or modeled measurements, particularly when the objective of the contract is to generate offset credits (McDonald et al., 2021). In addition, for result-based payments, it is often necessary to involve a certifying body to ensure the validity of credits as buying or selling carbon credits in a marketplace requires each credit to be equivalent and uniform in all terms, regardless of the source of the credit (Cruz et al., 2020). Several verifying bodies currently operate such as Verra,[5] Plan Vivo,[6] Scientific Certification Systems Global,[7] and Gold Standard[8] (Tamba et al., 2021). Verra's Verified Carbon Standard is the most commonly used standard for voluntary offset projects (Gren and Aklilu, 2016). Conversely, action-based payments rely on on-site measurement and data gathered from farmers to validate actions implemented on farms (Havens, 2021). While the limited MRV approach of action-based payments can reduce project costs, it may result in lower mitigation impacts (McDonald et al., 2021).

[5] https://verra.org.
[6] https://www.planvivo.org.
[7] https://www.scsglobalservices.com/.
[8] https://www.goldstandard.org.

3.2.4. Barriers: Identifying the challenges of different incentive mechanisms

Out of the 52 articles reviewed, 33 highlighted specific barriers, challenges, and issues in adopting and implementing carbon farming projects (see Fig. 6). The most frequently cited challenge (which was noted in 16 articles) was the lack of universal and robust standards for MRV and certification that can hinder tangible, additional, measurable, and permanent carbon offsetting (McDonald et al., 2021). Another common challenge faced by farmers is the high cost of enrolling in carbon farming projects. Carbon farming projects usually incur high transaction costs for farmers, including administrative, legal, and technical expenses, in addition to the time and effort required to complete paperwork and MRV (Bhattacharyya et al., 2020; European Commission, 2021c; Klauser and Negra, 2020; Torabi, 2019). Farmers also encounter higher opportunity costs, which can affect potential earnings (Bhattacharyya et al., 2020; Gren and Aklilu, 2016; Salas Castelo, 2017; zuDrewer, 2019). Insufficient knowledge about carbon market operations (as noted in 10 articles) is another significant barrier to farmers' participation in these projects (Lal, 2020; Lee et al., 2016; Wongpiyabovorn et al., 2021, etc.). This lack of understanding can lead to farmers, particularly smallholders, feeling uncertain about how the carbon market works as well as carbon-based payment timing, amounts, and variances (Lee et al., 2016). Additional barriers to adoption include low carbon-based payments, limited access to land rights and tenure, fluctuating carbon market prices, uncertainty regarding credit buyers, insufficient advisory and training services, and potential yield declines (McDonald et al., 2021; Salas Castelo, 2017; Wongpiyabovorn et al., 2021, etc.).

We further investigated this topic by summarizing the main barriers associated with each payment mechanism, which were identified by their frequency of occurrence in the reviewed articles (Table 5). Permanence, additionality, and the lack of robust MRV and certification mechanisms were reported as commonly occurring barriers across all payment types. As observed in Table 5, result-based payments face the most challenges, including high project and opportunity costs, low-carbon payments, land tenure issues, and the absence of baseline data crucial for certifying the validity of carbon offsets. In addition to the three common barriers, action-based incentives also incur high project costs. Furthermore, barriers to implementing auctions primarily concerned uncertainty related to current policy conditions, project details, and buyers in the market. Payments for product certifications or labels encountered the least challenges as this mechanism was only cited in a limited number of cases in our review. Similarly, hybrid payment type was also noted to have a low number of barriers.

4. Discussion

We extracted 52 documents in our review, mapping the current state-of-the-art in carbon farming contracts worldwide. Analysis of approximately 40 cases from these articles revealed three different incentive mechanisms, namely, result-based, action-based, and hybrid payment schemes. These mechanisms, as illustrated in Fig. 5 (I, II, and III), depict farmers' connections with funders, intermediaries, buyers, and carbon market. Overall, while result-based and hybrid payments incentivize farmers and connect them to carbon markets, action-based payments solely compensate farmers for conversion costs. However, result-based payments can be riskier for farmers than action-based payments due to social, environmental, and political uncertainties such as fluctuating weather patterns or changes in emissions reduction policies (McDonald et al., 2021). In contrast, result-based payments can potentially increase farmers' profitability, whereas action-based payments can minimize participation risk. Given the volatility of carbon markets and the modest incentives that farmers have received in some carbon farming cases, adopting new practices and changing current practices necessitates additional financial support beyond a single type of incentive mechanism (Buckley Biggs et al., 2021).

Reed et al. (2022) provided novel mechanisms for integrating public and private payments to incentivize ecosystem services. One such mechanism, the *carbon floor price guarantee mechanism*, suggests using public funds to provide farmers guarantees through reverse auctioning to ensure that low-cost projects are being implemented, with the option to sell these guarantees back to the government if the carbon market price becomes volatile. Australia's ERF scheme also uses a similar mechanism to address market-based carbon price risks, incentivizing farmers with a guarantee called the Australian Carbon Credit Unit (Badgery et al., 2021; Salas Castelo, 2017). These solutions can help farmers absorb carbon market shocks when they have entered into a result-based contract. The EC (European Commission, 2021a) has also recommended that member states should compensate farmers with result-based payments and invest in private carbon markets. However, result-based mechanisms are new in the EU, and there are currently no mechanisms in place to address uncertainties about the outcomes of result-based payments. Our review suggests that carbon payment-based agri-environmental schemes might be more efficient in a hybrid format, combining various incentive mechanisms to reduce farmers' risk,

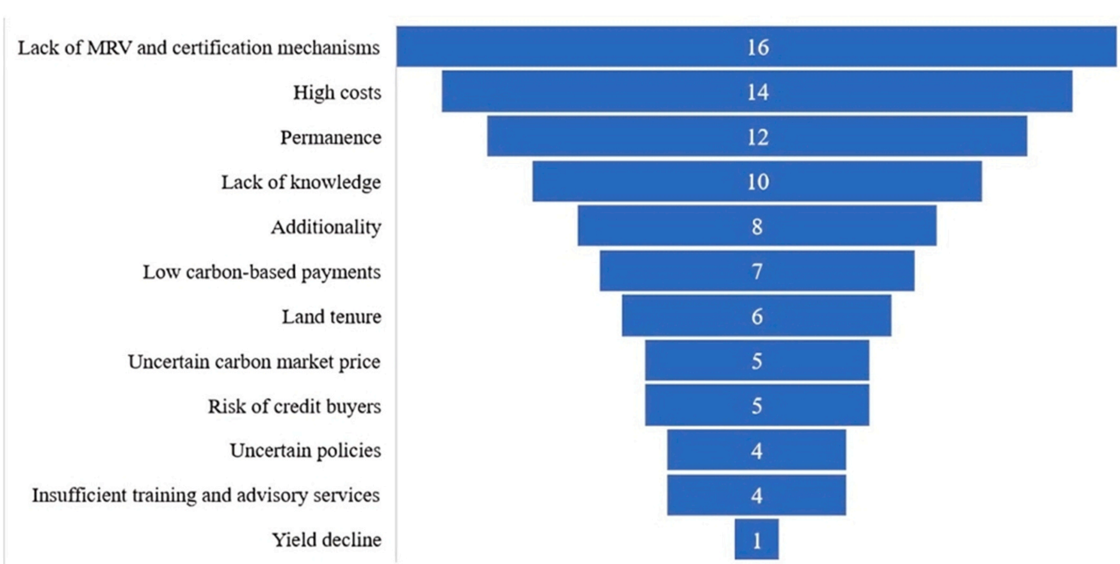

Fig. 6. Identified barriers to carbon farming in reviewed studies.

Table 5
Barriers in implementing different incentive mechanisms with their frequencies in reviewed studies.

	Auctions	Payment in voluntary tradeable emission reduction certificates	Payment for products (certificates or eco-labels)	Action-based payments	Hybrid payments
Lack of robust MRV and certification mechanisms	1	9	1	6	3
High project costs	1	5	0	5	2
High opportunity costs	0	3	0	2	2
Permanence	2	10	2	5	3
Additionality	2	10	2	4	3
Low carbon-based payments	1	4	0	0	0
Land tenure issues	2	5	1	2	0
Uncertainties	4	6	1	0	1
Insufficient training and advisory services	0	2	0	2	1
Lack of baseline data	1	3	0	1	0

increase profitability, and provide flexibility for farms to implement optimal actions that allow farmers to cover opportunity costs. Hybrid payment mechanisms also offer funders the flexibility to choose from different modes of funding, including action-based, carbon credit-based, or product-based payments. This versatility in hybrid mechanisms establishes a safety net for farmers while also guaranteeing tangible environmental results for society because monitoring is mandatory in hybrid contracts estimating impact. Additionally, carbon farming practices also yield co-benefits for the environment and society, which should be monetarily valued to capture the total profitability of carbon farming contracts.

Our review also analyzed the challenges and barriers to implementing carbon farming projects. Two recurring challenges are ensuring the permanence of carbon stocks and the additionality of projects. Permanence ensures that the carbon sequestered during the project remains sequestered for a significant duration, ideally beyond the project's lifetime, without leakage (Gren and Aklilu, 2016). Additionality verifies that a project adds value to the environment by reducing emissions beyond what would occur in business-as-usual scenarios (Gren and Aklilu, 2016). These concepts are essential for trading emissions reduction certificates in a carbon market, ensuring that these certificates or credits are awarded only for genuine actions that lead to real emissions reduction, and not emissions reduction that would have occurred regardless of the project's existence (e.g., naturally in the agroecosystem). Reed et al. (2022) also observed that if farmers are enrolled in more than one AES, it is difficult to prove that mitigation would not have occurred without carbon finance, which is a challenge that has not been extensively examined. The current solution that the UK AES employs is to spatially separate the delivery of ecosystem services from different schemes. However, Reed et al. (2022) advocated using a "financial additionality test" to quantify how much carbon finance ensures that the project is additional. For example, their study noted that the projects, the Peatland Code and Woodland Carbon Code, require a minimum of 15% carbon finance to be additional (Reed et al., 2022).

Lack of standardized and reliable certification and MRV methodologies can lead to false accounting of carbon credits, also affecting farmers' payments. For example, studies have reported how the complexity of MRV procedures can lower final payments, particularly for smallholder farmers (zuDrewer, 2019; Lee et al., 2016; Tamba et al., 2021). The role of the government, particularly to ensure compliance in carbon markets, is to standardize private carbon credit markets and certify third-party verifiers. For example, the Growing Climate Solutions Act (2021) allows the USDA to certify third-party verifiers to motivate farmer participation in these schemes (Bomgardner and Erickson, 2021). The EC is also designing a similar framework to reliably certify high-quality carbon offsets and establish verified carbon markets for the EU by 2023 (McDonald et al., 2021).

Uncertain carbon market prices and policies primarily impact result-based payments. Further research could explore issues of low carbon-based payments, uncertain market prices, knowledge gaps in best practices for carbon farming, and yield decline related to enrolling in carbon farming projects. Unclear policies regarding carbon credits, carbon pricing, and voluntary carbon markets create uncertainties and risks for farmers investing in carbon farming projects (Dumbrell et al., 2016; Salas Castelo, 2017; Torabi, 2019). A possible explanation for these challenges is the novelty of the cases analyzed and the lack of comprehensive ex-post studies. One of the early carbon farming projects was the KACP, which was recently concluded and has been subject to ex-post academic analysis; however, its funder (the World Bank) has not released any official ex-post analyses of the project. Peer-reviewed studies analyzing the project at the field level have thoroughly criticized it for issues such as non-transparent project results, failure to account for the additionality in credits, and paying inadequate incentives to farmers in exchange for considerable efforts to alter practices (Cavanagh et al., 2017). In addition, the fluctuating nature of carbon market prices has resulted in participants of the KACP receiving only nominal carbon-based incentives, roughly amounting to US$3 per hectare annually (Cavanagh et al., 2021).

These challenges in implementing carbon farming projects present potential research avenues for designing more efficient incentive mechanisms. Such research can guide policymakers on the impact of carbon farming on local communities and ecosystems, revealing how carbon farming models can be scaled up, the potential environmental benefits, and overall effectiveness in reducing atmospheric carbon.

Despite the challenges, carbon farming is gaining momentum worldwide, supported by new national policy regulations. In the US, President Biden enacted the Growing Climate Solutions Act in December 2022, linking farmers with experts and the market and ensuring stringent certification of carbon credits. Concurrently, the EU proposed the Carbon Removal Certification Framework, a regulation for independent certification of carbon removals (European Commission, 2022). The regulation amends the existing Land Use, Land-Use Change, and Forestry regulations, incorporating a carbon removal target of −310 Mt CO_2 eq by 2030 through carbon farming approaches (European Commission, 2022). In Australia, the ERF was also updated in July 2023 and was renamed the ACCU Scheme. Additionally, the Australian government is pursuing the establishment of a stock exchange called the Australian Carbon Exchange to boost its carbon market. With global carbon markets expanding, there is an urgent need to integrate local farmers into these markets and fully leverage agriculture as a potential tool for climate action. Reed et al. (2022) argued that public funding must be adapted to emerging private carbon markets. The authors also advocated blending public and private schemes to deliver multiple public goods while integrating diverse markets for these goods. This approach can also be used to monetize the co-benefits of carbon farming and foster innovative business models to strengthen the carbon farming incentive mechanisms.

Our SM has some limitations. First, we considered only published documents, which do not represent the full spectrum of information on carbon farming; however, the study extended beyond academic databases to gather more comprehensive information. Second, applying filters during our database scan limited the scope of our search and data collection. Filters like language and year of publication eased our search; however, they also limited the breadth of the information collected, particularly from non-English sources like studies in China, a popular location for carbon cultivation under numerous Clean Development Mechanism schemes, for which a significant body of literature is only available in Chinese. Additionally, using specific inclusion criteria and coding variables may have excluded articles that matched our criteria but differed in the research context. For example, a study by Cavanagh et al. (2021) addresses global political ecology and inequalities faced by farmers in carbon farming projects. Similarly, Eichhorn et al. (2020) emphasized that measuring co-benefits in carbon sequestration projects is crucial for efficient payment models. However, our study does not explore these themes, as they were beyond the anticipated scope of our review. Hence, future exploratory studies should analyze these articles through a different lens to encompass a wider range of concepts and evaluate additional pros and cons of carbon farming contracts.

5. Conclusions

This review provided a systematic and structured analysis of various types of incentive mechanisms for carbon farming contracts, combining the knowledge from academic repositories and practical databases of carbon farming. The review revealed the current landscape of carbon farming contracts, elucidating ways to incentivize farmers and identifying the barriers associated with each type of incentive mechanism. Carbon farming is beneficial for the environment not only through emissions reduction but also through providing additional co-benefits such as increased soil health, enhanced water quality, erosion prevention, and biodiversity improvement. However, carbon farming has evolved beyond publicly funded agri-environmental schemes into a monetary instrument used by businesses to demonstrate commitments toward climate neutrality, boost green branding, or participate in the mandatory or voluntary carbon markets. Carbon markets are pivotal for ensuring the global economy's circular flow of carbon credits by guaranteeing that only verified credits are traded in the market and effectively regulating carbon market prices.

Carbon farming incentive mechanisms must be effectively designed and regulated to ensure farmers' profitability and the agroecosystems' sustainability. Our case study analysis demonstrated that carbon farming projects must include high transparency, standardized methodologies for verification and certification of emissions reduction or offsets, and regulated corporate offset claims to ensure equitable benefits for the society and the environment.

We conclude that the success of carbon farming relies on understanding the complexities of contract design attributes and fostering collaboration among farmers and other stakeholders. Contract attributes that address barriers to adoption such as non-additionality, lack of permanence, and the absence of standardized MRV systems must be tested and applied. Designing contracts with novel attributes such as *third-party auditors*, *farmer-(self-)reported data*, and *standardized MRV* could enhance the quality of carbon removal and boost farmers' profitability. Changing agricultural practices for carbon farming must be efficiently incentivized, whether through result-based, action-based, or hybrid solutions. Ex-ante and ex-post analyses of successful cases can provide valuable insights for the future design of carbon farming projects and methods to connect farmers to carbon markets. In summary, this study reveals that carbon farming contracts can be efficiently designed by ex-post analysis of successful cases, focusing on the attributes that define different incentive mechanisms so that carbon farming can be employed as a potential tool to fully leverage agriculture's contribution to climate action.

CRediT authorship contribution statement

Nidhi Raina: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Matteo Zavalloni:** Conceptualization, Resources, Validation, Writing – review & editing. **Davide Viaggi:** Funding acquisition, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have shared my data in the attach file step

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2024.120126.

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