

Carbon farming: The foundation for carbon farming schemes – lessons learned from 160 European schemes

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ABSTRACT

Enhancing carbon sequestration while maintaining and improving the soil ecosystem services of agricultural soils, including managed peatland, is an important lever for mitigating climate change in the Land-Use, Land-Use Change and Forestry sector. This can be achieved through the application of a mix of agricultural practices that may reward farmers in a green business model, often referred to as carbon farming (CF). To ensure the credibility of CF and acceptance among farmers, investors, and policymakers, there is a need to design CF schemes that enable the effective implementation of such practices across Europe. The objective of this study is to explore the design of existing CF schemes in relation to quantifying carbon removal, ensuring additionality, long-term storage, and sustainability. Further, to discuss the implications for the design and implementation of CF schemes in Europe, including the basis and potential for developing results-based CF schemes. Our analysis is based on an inventory of 160 CF schemes implemented across Europe, and an in-depth assessment of 40 of them.

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A majority of the schemes we identify are found in Northwestern Europe and are activity-based schemes funded by public expenditure. Further, across schemes, we observe substantial differences in the quality of the carbon removal due to different measures supported, documentation requirements, and years of carbon storage. While result-based schemes provide farmers with a direct incentive to increase carbon sequestration and are emphasized as an important policy objective, our analysis documents that currently, most existing CF schemes in Europe use activity-based incentives.

1. Introduction

Soil organic matter is fundamental to the functioning of Earth's ecosystems, ensuring soil health and supporting essential ecosystem services such as plant productivity, nutrient and water cycling efficiency, and climate balance (Hoffland et al., 2020). Following the signature of the Paris Agreement, sequestration of soil organic carbon (SOC), that is, the carbon content of soil organic matter, has emerged as a significant strategy for climate change mitigation. Soils may be both a source of greenhouse gases (GHG), namely carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) emissions, as well as a sink of carbon (C) as SOC. Carbon farming (CF) is a land management activity that increases carbon storage in living biomass, dead organic matter, and soils, thereby mitigating GHG emissions by enhancing carbon capture and reducing carbon release to the atmosphere and serves as a mechanism for mitigating GHG emissions (EC, 2024a). Further, CF represents an emerging approach to achieving soil health by integrating agricultural management practices with climate change mitigation objectives within a business model that generates economic returns for farmers through incentives. Examples include agricultural practices such as the use of cover and catch crops, the application of soil amendments, reduced tillage, and agroforestry.

In this paper, we conduct a qualitative content analysis of the ongoing policy experimentation being conducted across Europe in the domain of CF. The objectives are, first, to explore how existing CF schemes are designed and second, to address some of the fundamental challenges of their design: Quantifying carbon removal, ensuring additionality, long-term storage and sustainability corresponding to the four Q.U.A.L.I.T.Y (criteria Quantification, Additionality, Long-term storage and Sustainability), specified in chapter 2 of the Carbon Removals and Carbon Farming (CRCF) Regulation (EU/2024/3012) (see Fig. 1) (EC, 2024a). Subsequently, we discuss the implications for the design and implementation of CF schemes in Europe. The analysis is based on the identification of 160 existing CF schemes across Europe in 2022, followed by a more in-depth analysis of a selection of 40 schemes.

1.1. The importance of soil organic matter

The carbon stored in the top 30-cm soil layer represents 44 % of the SOC pool and is affected by changes in land use and soil management

(Batjes, 1996, 2016; R. B. Jackson et al., 2017). Enhancing the potential of soils to store carbon or maintaining existing SOC stocks, especially on peatlands and other carbon-rich soils, is an essential mechanism for climate change mitigation (Bossio et al., 2020). Conversely, continued unsustainable agricultural practices will result in SOC mining, with negative impacts on soil health, productivity, and adaptation to climate change, e.g., through a diminished resilience to extreme climatic events (Keenor et al., 2021; Lal et al., 2018; Smith et al., 2020). CF also offers a range of co-benefits in addition to carbon storage, these include decreasing risk of crop failure, resilience against droughts and heavy rainfall, improved nutrient use efficiency, below-ground biodiversity, and an increase in the supply of agroecosystem services (Paul et al., 2023).

Soil carbon sequestration is driven by complex biological processes that are dependent on soil physicochemical properties, and it is characterised by spatial and temporal variability, which leads to high uncertainty in estimates, even within fields (Basile-Doelsch et al., 2020; Batjes, 1996; Paul et al., 2023). Protection and enhancement of SOC stocks have recently become an important item on the EU political agenda (Heuser, 2022; Van Hoof, 2023; Visser et al., 2019). European soil policy ambitions are, for instance, reflected in the European Union (EU) Soil Strategy for 2030 (EC, 2021a) as well as in the Nature Restoration Law (EC, 2024b) and the Soil Monitoring Law (EC, 2023b). The European Green Deal sets out the ambition to make Europe the first climate-neutral continent by 2050 giving soils a central position in achieving this outcome (Heuser, 2022; Montanarella and Panagos, 2021; Visser et al., 2019) with a 55 % GHG emission reduction target by 2030 compared to 1990 already agreed in the EU Climate Target Plan (EC, 2024a). Agriculture is responsible for about 10 % of total EU GHG emissions (without including soil carbon emission and sequestration) and thus needs to contribute to the overall EU GHG reduction goals (Jacobs et al., 2019). To meet these ambitions, the European Commission (EC) also emphasises that result-based incentives should increasingly be used to encourage farmers to adopt sustainable practices through the Common Agricultural Policy (CAP) (EC, 2020).

In light of this, various schemes promoting CF have emerged as ways to incentivize CF as a green business model that rewards farmers for taking up improved land management practices (Radley et al., 2021; Raina et al., 2024). The EC has proposed a 2030 target of net annual carbon removals of 310 Mt CO₂eq in the Land-Use, Land-Use change and

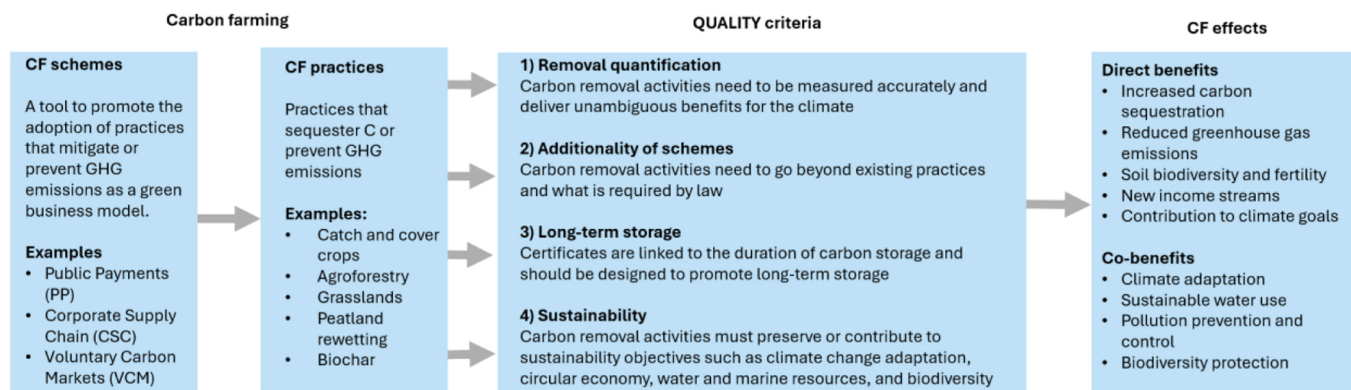


Fig. 1. Conceptual map and definitions employed in the qualitative content analysis.

Forestry sector (LULUCF), of which CF initiatives should contribute 42 Mt CO₂e of the reduction target (EC, 2021b).

1.2. Carbon farming schemes

CF schemes can be a tool to promote the adoption of practices that mitigate or prevent GHG emissions as a green business model (Radley et al., 2021). In Europe, the EC has adopted a broad definition of CF as: “any practice or process, carried out over an activity period of at least five years, related to terrestrial or coastal management and resulting in capture and temporary storage of atmospheric and biogenic carbon into biogenic carbon pools or the reduction of soil emission” (EC, 2024a: 24). Importantly, the activities should result in “a net carbon removal benefit or a net soil emission reduction benefit” and should go beyond common practice (EC, 2024a: p. 7). In the CRCF, carbon farming activities are rewarded when additional carbon removals or soil emission reductions beyond a baseline are documented, after subtracting any lifecycle-related GHG emissions, with soil organic carbon (SOC) as the central focus, in contrast to many other CF initiatives that prioritise increasing tree biomass (McDonald et al., 2021; Raina et al., 2024).

A CF scheme is a contract between two or three parties: a land-user (who implements the CF practice) and a buyer (providing funding for the CF practice or resulting certificate), and sometimes also a certifier (third party certifying the transaction). Sometimes this third party acts as an intermediary between the farmer and the buyer, also taking care of the Monitoring, Reporting and Verification (MRV) (McDonald et al., 2021; Radley et al., 2021). Schemes also contain definitions about the targets, eligible measures, the MRV system, as well as the remuneration. However, CF schemes may differ substantially in how they quantify carbon removals, ensure additionality, define and guarantee long-term storage, and apply wider sustainability criteria. CF schemes may be focused on a certain region (a province, a state, etc.) and/or a particular form of land use (e.g., arable land, forestry) (Demenois et al., 2022; EC, 2024a; Oldfield et al., 2022; Raina et al., 2024). Further, schemes can be established by governmental or private entities (McDonald et al., 2021). Overall, in the analysis, we distinguish between three funding mechanisms for CF schemes, 1) schemes funded by public payments, 2) schemes funded within the corporate value chain and 3) schemes funded via the voluntary carbon market. These different funders have different concerns and considerations when it comes to the requirement for quantification, and this enables us to explore the underlying mechanisms of scheme design.

Regarding public entities, the Paris agreement and the EU climate targets specified legally binding GHG emissions reduction targets for production sectors and Member States (MS). Yet, some emissions of GHGs will be unavoidable or very costly to be avoided, in which case, companies or MS can comply with the reduction target, by e.g., purchasing carbon offsets (EC, 2021b; Huber et al., 2024; van Kooten and Zanello, 2023). Within the Corporate Supply Chain, businesses can engage in carbon in-setting as a way of reducing their emissions and the carbon footprint within their supply chain by investing in GHG emission reductions, favourable contracts, or other forms of rewards to virtuous

producers (Acampora et al., 2023). Conversely, in the voluntary carbon market, offsetting is dominating, where carbon certificates from external projects can be used to compensate for companies' emissions (Criscuoli et al., 2024).

There are different approaches to reward the adoption of CF practices, including action-based, result-based, and hybrid schemes (Raina et al., 2024). Based on previous studies, most existing agri-environmental schemes globally are action-based (Oldfield et al., 2022; Sidemo-Holm et al., 2018; Winsten, 2009). They offer a (per-hectare) payment to farmers for implementing predefined practices on their farmland. Mostly, such schemes are easy to implement and monitor. The effect of the implementation of agricultural practices on soil has been intensely studied in many European countries over the years, both in experimental settings and farm settings (Don et al., 2024; Dupla et al., 2022; Frelih-Larsen et al., 2017; Paul et al., 2023). However, with activity-based schemes, the correspondence between the adoption of a given practice and the actual environmental outcome is only indirect and uncertain (De Cara et al., 2018; Shishlov and Bellassen, 2016).

Result-based schemes provide farmers with a direct incentive to increase carbon sequestration, as payment levels reflect the actual impact of management practices on carbon stocks (relative to a baseline) and could therefore reduce the overall cost to attain environmental benefits (OECD, 2023). However, this requires the implementation of a MRV system that is able to quantify additional carbon sequestration with sufficient accuracy in space and time.

In practice, result-based schemes are rare and often constrained by inadequate monitoring (Nguyen et al., 2022). On top of that, the proliferation of certification protocols has added complexity for buyers (Demenois et al., 2022). Scholars argue that result-based CF schemes are fragmented and risky due to uncertainties in the potential carbon storage achieved through CF practices (Chen and Xie, 2023; Oldfield et al., 2022).

Since CF schemes are voluntary, outcomes can only be achieved if farmers find them attractive and choose to adopt CF practices (Hasler et al., 2022). To ensure attractive schemes, CF schemes must be considered credible, affordable, and incur low administrative burdens (Vainio et al., 2021). The attractiveness of CF schemes also varies across different groups of farmers, and for instance, Hasler et al. (2022) emphasize that farmers with low tolerance to risk are reluctant to enter result-based CF schemes. A recent survey from Finland shows that farmers have a preference for activity-based schemes (Vainio et al., 2021). Further, many farmers do not know the carbon content of their soils, and the basic processes of the carbon cycle, and in the absence of subsidies, they tend to favor practices ensuring high productivity in the short-term, often neglecting soil health, including soil carbon storage (Mattila et al., 2022; Payen et al., 2023).

Despite these challenges, voluntary CF has garnered considerable interest as evidenced by the establishment of the EU carbon removal certification framework and the rapid deployment of a series of private certification protocols (Demenois et al., 2022; Oldfield et al., 2022; Popkin, 2023). Further, in a recent study by Morgan Stanley, the global

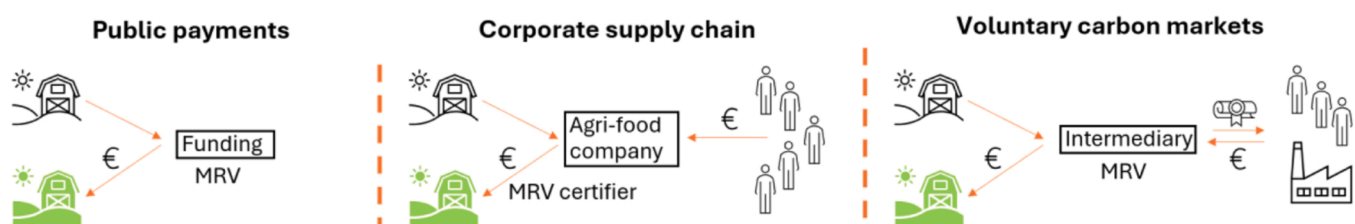


Fig. 2. Typology of schemes applied in the assessment of CF schemes. Farm Payments (FP) represent payments provided in Agri-Environmental Schemes (AES) often from CAP funding, Corporate Supply Chain (CSC) represents payments agrifood companies that offer a premium to producers for C-sequestration and/or other ecosystem services and the Voluntary Carbon Market (VCM) represents payments by companies or individuals in return for certified carbon removals. External certifiers Monitor, Verify and Report that activities deliver the promised effects (adapted from McDonald et al., 2021).

voluntary carbon market is expected to grow from \$2 billion in 2020 to roughly \$250 billion by 2050 (MS, 2023). However, it is uncertain if CF schemes can be designed to ensure that the expectations will be fulfilled. Hitherto, several papers have assessed the challenges and potentials of carbon certification and result-based CF-schemes, but the empirical evidence is scarce.

1.3. Quality of carbon removal

In 2024, the EC adopted a regulatory framework on carbon removals, which proposed a set of standards for the certification of future CF activities (EC, 2024a). The objective was to encourage the development of a range of locally or regionally tailored result-based schemes to promote CF (Radley et al., 2021). The four fundamental challenges correspond to the Q.U.A.L.I.T.Y criteria specified in Chapter 2 of the Carbon Removal and Certification Regulation (CRCF) and are further elaborated below, see also Fig. 1.

1.3.1. Quantifying carbon removal

Quantifying carbon removal in CF is challenging due to variability in soil types, climate conditions, management practices, and the lack of standardized, accurate measurement and monitoring methods over time (Smith et al., 2020). The presence of credible MRV is an important enabler for result-based CF, and GHG impact certainty is crucial to enhance CF attractiveness (Paul et al., 2023; Smith et al., 2020).

However, credible quantification of carbon removals comes at a cost to both investors and land managers, including non-monetary costs such as administrative burden and bureaucracy (Smith et al., 2020; van Wijk et al., 2020). Most importantly, direct quantification exposes contracting parties to outcome uncertainties, which discourages the use of the market. To overcome this problem, some scholars have proposed setting a farm-level business-as-usual scenario (i.e., a baseline), combining measurements and modelling to incentivize land managers to ensure that CF becomes an attractive carbon sequestration practices that exceed the baseline (Radley et al., 2021; Shishlov and Bellassen, 2016). This guarantees consistent quantification and controls uncertainty, but operating costs remain high (Don et al., 2024). Quantifying carbon sequestration for result-based schemes is time-consuming, expensive, and prone to high uncertainty, because effects of a change of practice are only visible in a long-term perspective (A. Jackson et al., 2021). MRV of activity-based schemes is cheaper as MRV does not require additional soil sampling and analysis, but can use norm-based figures. Hybrid schemes are a third option, offering upfront compensation for implementing a particular measure and a potential additional payment if objectives for SOC storage are achieved. Accurate documentation of the climate value of CF is difficult to document due to variability across different practices and time, but local climatic and soil conditions, as well as in-field variability, add to this uncertainty too (Basile-Doelsch et al., 2020; Batjes, 1996; McDonald et al., 2021; Paul et al., 2023).

1.3.2. Ensuring additionality

Additionality ensures that the carbon sequestration or emission reductions would not have occurred without the CF project (Batjes et al., 2023). Ensuring additionality is challenging because many practices eligible for credits, such as cover cropping or reduced tillage, are already widespread among farmers for economic or agronomic reasons, making it unclear whether carbon payments truly caused the change (Paul et al., 2023). Additionality implies that to generate carbon credits, the carbon sequestration practice must not have been previously adopted (Don et al., 2024). These factors can undermine the credibility of claimed carbon benefits and reduce the environmental integrity of CF schemes.

1.3.3. Long-term storage

Ensuring long-term storage is essential in CF schemes because the climate benefit of carbon removal depends on keeping it stored in the soil (McDonald et al., 2021). Ensuring long-term storage strengthens the

environmental integrity of CF and ensures alignment with long-term climate targets. The operational contingencies of the agrifood sector (e.g., weather and market fluctuations) and economic constraints constitute a challenge for farmers (Don et al., 2024). Building SOC stocks is slow, while stocks may quickly degrade if management practices change (Janzen, 2006). SOC sequestration rates are typically relatively small compared to the total carbon pool, which makes it challenging to quantify changes over short temporal intervals (Smith et al., 2020).

1.3.4. Sustainability

CF is potentially linked with several co-benefits, including climate adaptation, sustainable water use, pollution prevention and control (EC, 2024a), but also trade-offs, such as potential biodiversity loss, soil and water degradation, or land-use conflicts when carbon gains are prioritized over ecosystem health or food security (McDonald et al., 2021; Paul et al., 2023). These trade-offs can be compounded by weak verification systems, uneven access for smallholders, and the tension between short-term financial incentives and the long-term stewardship required for lasting climate benefits.

2. Materials and methods

We employ qualitative content analysis to systematically examine and interpret the design and implementation of CF schemes across Europe (Mayring, 2015). We adopted this approach to develop a nuanced understanding of the current landscape of CF schemes, highlighting areas of success and opportunities for improvement (Ashley and Boyd, 2006; Mayring, 2015). This methodological choice ensures that the analysis captures the depth and complexity of the subject matter, providing insights for policymakers, practitioners, and researchers interested in the development and implementation of effective CF strategies.

The data for this article were acquired during three steps that were completed in 2024 as part of the Road4Schemes project under the European Joint Programme on soil (EJP SOIL). In a first step, we compiled a comprehensive inventory of all schemes in Europe. In a second step, we conducted an in-depth analysis of the most promising schemes. In the third step, we synthesized the findings of the two inventories. Each step is further detailed below.

2.1. First: Inventory of European carbon farming schemes

Initially, we made a stocktake of the schemes available in all major European countries (EU Member States included in the inventory: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Greece, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden. Non-EU Member States included in the database: Norway, Switzerland, Turkey, UK). We did not identify national CF schemes in Bulgaria, Cyprus, Estonia, Greece, Latvia, Lithuania, Luxembourg, Malta, Romania, and Slovenia, although some of the multinational schemes also apply in some of these countries. In this initial phase of the exercise, the CRCF had not yet been launched, hence we adopted a broad definition of CF schemes, defined as any voluntary agreement in which a farmer or a group of farmers commit themselves to apply CF practices in return for a payment in any form (Smit et al., 2024). This inventory was compiled through a desktop review among publicly available sources like websites, reports, and papers. Ensuring comprehensive coverage, national contact points from the EJP SOIL consortia and expert contacts from agencies and ministries were initially engaged in the identification of schemes. Further, the data collection was undertaken by project partners of the Road4Schemes project, originating from 10 European countries (Denmark, Germany, the Netherlands, France, Switzerland, Austria, Italy, the Czech Republic, Belgium and Turkey), thus representing varied expertise in agricultural systems, practices, land use, and linguistic contexts.

Our selection criteria only included schemes that explicitly aimed at carbon sequestration or maintaining SOC stocks. Data acquisition was based on a protocol for all countries, containing a series of structured questions about the basic characteristics of the scheme identified (scheme characteristics, production systems included, management options, land use type, additional ecosystem services supported, and payment model), further details can be found in [Smit et al. \(2024\)](#). with national representatives from the EJP SOIL national coordinators that represent European countries. This identification process was divided across partner countries primarily based on past experiences and language skills. This identification process resulted in an inventory of 160 CF schemes and can be found as [supplementary material table S1](#).

2.2. *s: In-depth characterization of promising schemes*

In a second phase, we selected 1–5 schemes in each country for a more in-depth analysis. The objective of this phase was to identify how the selected schemes balance the trade-offs involved in CF scheme design, and which elements of the scheme design may contribute to its success in terms of adoption and long-term commitment by farmers. We purposively selected schemes based on maximum variation; this implied that the inventory contained a diverse range of scheme designs, and whereas some were small-scale pilot schemes, others were implemented and in operation. To ensure a broad representativeness and minimise selection biases, the selection was completed by a group of researchers who were not involved in collecting information for the inventory.

To acquire data, partners completed at least one expert interview with each scheme holder selected based on a joint protocol, which comprised structured (with closed-ended) and open-ended questions categorizing the scheme design into six thematic areas (general scheme information, payment/buyer information, MRV, safeguards for the society and the environment, transparency and attractiveness for farmers) (for further details, see: [Smit et al., 2024](#)). Further, these fact-finding interviews clarified if and how existing schemes address a set of key design parameters (regional adaptation, farmer responsibility, measures flexibility, robustness, additionality, and transparency). To prevent potential biases in data collection, such as the reliability of self-reported data, interviews focused on clarifying objective characteristics, such as the legal foundation of the schemes that are typically formalized in written documents. Where possible, such information was supplemented with an analysis of publicly available documents provided which specified characteristics. The selected informants were centrally placed in the governing bodies of the schemes or had been involved in their design. Interviews were carried out either face-to-face or online in 2022 and 2023. The themes addressed in interviews are included along with the summarized entries in [tables S1–S3](#). Since the answers given contained sensitive information for some scheme holders (e.g., MRV costs), the results of the second inventory were anonymized in our data processing and presentation.

2.3. *Data analysis and presentation*

Both inventories contain qualitative as well as quantitative elements, thus providing different types of complementary information, offering a rich picture of how the scheme design has managed to address relevant challenges of CF scheme design. The two inventories were analysed in an iterative process of basic descriptive analysis, providing complementary insights between structured and open questions designed to broaden and deepen our understanding of the implementation of CF schemes across Europe ([Creswell, 2014](#)). Where data is presented in tables and figures, a more detailed description of the consolidation process is included in the caption. In [Section 3](#) we present a simple descriptive analysis of the data.

3. Results

3.1. *Carbon farming schemes in Europe – results from step 1*

In terms of spatial distribution, the survey documented that schemes were available in most countries, although the majority of the schemes were found in the northwestern part of Europe. Germany had the highest number of schemes (33), followed by the Netherlands (13), Finland (12), Czech Republic (12), and Switzerland (11), see [Fig. 3](#). In many studied countries – e.g., Slovenia, Romania, Malta, and seven further – no schemes were identified. A range of schemes were recently developed and were only implemented in a pilot phase, while others were in an expansion phase and the interviews indicate that they have greatly increased the number of farmers involved in recent years.

The schemes encompassed a diverse array of CF practices that were mostly implemented on arable farmland, including catch or cover crops, application of organic amendments or reduced tillage. Supporting rewetting of peatlands and agroforestry were also common, while bio-char and forestry schemes were comparatively rare but have been established in certain contexts, see [Fig. 3](#). Co-benefits from these practices were reported from most schemes, primarily in the form of improving soil and ecosystem functions; however, generally, these co-benefits (about 67 %, see [Fig. 4](#)) were not measured or rewarded. An important exception is reported with some of the CSC schemes which provide for a farm-scale approach and support the provision of multiple ESS.

The survey documents that in numerical terms, most of the schemes found across Europe were activity-based (53 %), and the majority of the schemes were funded by private funds (48 %), see [Fig. 4](#). A public payment model of the schemes was less prominent (34 %), and a minority of schemes employed result-based model (20 %). However, it is also important to note that 21 % of the schemes were still under development, see [Fig. 4](#), and several schemes initially adopted an activity-based approach, while at the same time working towards a more elaborate MRV system, facilitating a shift toward result-based result-based payments. This suggests an intent to transition beyond activity-based payment models, while also accepting the challenges of such a transition. Given the number of recent schemes (58 % were implemented, while 21 % were in a concept phase, see [Fig. 4](#)), assessing the performance and implementation status is challenging as little information is currently available documenting such effects (including costs, implementation barriers, and actual sequestration).

3.2. *In-depth analysis of carbon farming schemes – results from step 2*

The in-depth analysis of how CF schemes approach the challenges of CF scheme design indicates that there were notable similarities and differences across the different schemes, see [Fig. 5](#). The scope of initiatives in terms of the number of farmers involved (from just a few, for some pilot schemes, up to more than 87.000 for large-scale initiatives) and farm sizes also varied substantially. Further, there were differences with respect to the practices that farmers could apply: some schemes offered the possibility to apply only a few specific practices, while others offered a suite of practices to choose from. A particularly large proportion of CSC schemes exhibited substantial flexibility in measure selection, see [Fig. 5](#).

Although developing result-based CF schemes has been in focus across Europe in recent years, we observed few genuinely result-based schemes (20 %), and most of the schemes examined in-depth were primarily structured around activity-based payments (70 %) or on hybrid models (17,5 %).

Schemes were either restricted to field level or, more rarely, farm scale (6 % of the schemes). Particularly, for the schemes that operate on the voluntary carbon market, field-scale approach to certification is adopted, while many CSC schemes and schemes relying on public payments focused on farm scale. Schemes that adopt a farm-scale approach

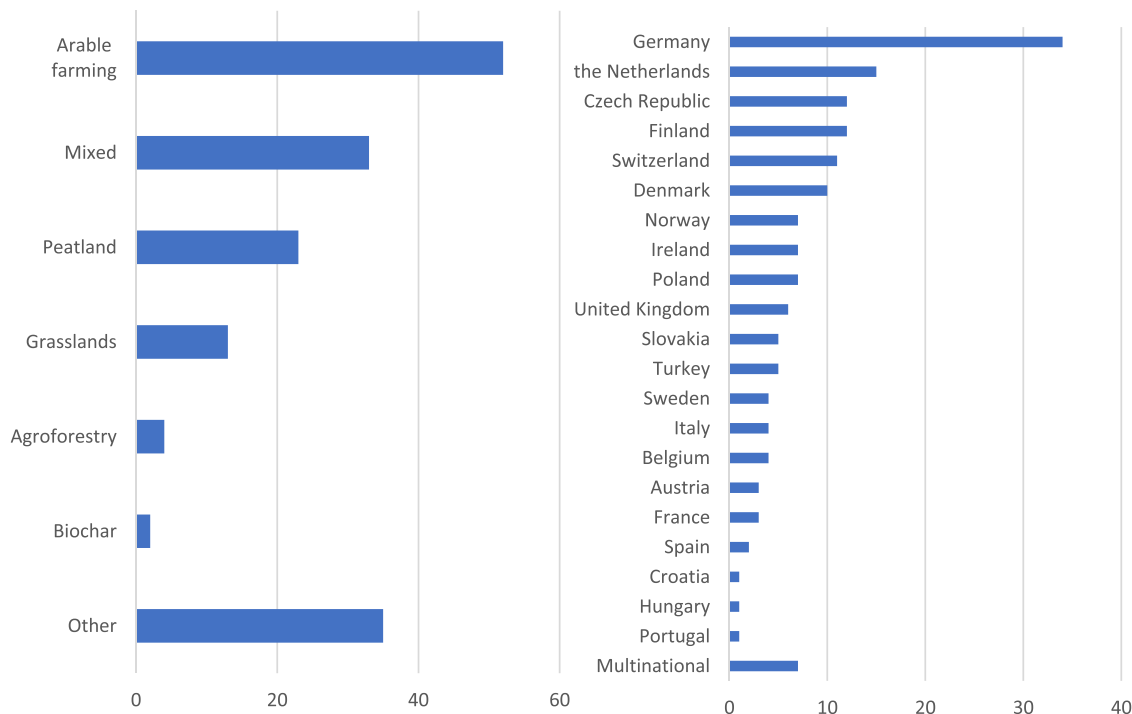


Fig. 3. Results from the first inventory, CF practices implemented on land use type (left) and spatial distribution (right) of the CF schemes. Note: mixed farming systems refer to support for various measures. The category “other” in the left figure refers to schemes that do not prescribe particular measures or land use type (N = 160).

generally do not issue carbon credits, but rather a certificate reflecting broader sustainability outcomes, which is valuable for companies engaged in the value-chain or can be used as a basis for Environmental, Social and Governance (ESG) reports.

In terms of quantifying carbon removals, we also observed substantial differences across the different schemes, see Table 1. The interviews with scheme holders indicate that various combinations of science-based norms (the documented effect of a practice established in field trials), soil sampling, modelling, and remote sensing were used across the schemes. Generally, activity-based schemes used science-based norms (which are sometimes used in combination with remote sensing), while the result-based schemes applied various quantification methods to assess the quantified impact of sequestration or emissions reductions. Internationally approved standards were mostly applied to the documentation of emission reductions in the voluntary carbon market but were also used in the corporate supply chain (a range of operators were used, including VERRA, DNV, SNK, and Indigo, who were mostly certified under ISO 14064/14065 requirements). However, some of the schemes were less advanced, e.g., without independent verification, and multi-annual assessment of practices and commitment periods. Generally, information about the MRV frameworks was available, but farmer-specific data were generally not publicly accessible, although this information was made public in some schemes.

Setting baselines is complex, but very important in result-based schemes to enable the quantification of the actual effect of CF practices and to establish the presence of additionality. Baselines for result-based schemes were either based on the existing stock of carbon (measured or modeled), however, several schemes lacked quantified baselines, but rather allocated payments based on expected SOC balance based on modelling or remote sensing. Additionality was a precondition in 58 % of the schemes during the second phase of the study, meaning that support in these schemes was not provided for sequestration or activities that were also funded elsewhere, see Fig. 5.

Regarding GHG emissions, except for a few schemes that focus on rewetting of peatlands, the majority of schemes only considered the CO₂

flux. This implies that the total GHG accounting and associated environmental trade-offs, including CH₄ and N₂O, and wider ecosystem services, were not considered or included in the scheme design. However, limited information on this aspect was obtained through the interviews, indicating that most of the schemes in the assessment failed to recognize this issue.

In terms of the contract design, there were also substantial differences in the commitment period across schemes. Most of the assessed schemes applied a contractual duration of under 10 years (which may be extended upon contract expiration when deemed appropriate), see Table 1. Particularly, the public payment schemes were often based on annual payments, which fail to ensure long-term engagement to specific practices, although there were also examples of public schemes that offered payments for permanent land use conversion. Interestingly, the prices for CO₂ equivalents (per ton or ha) vary substantially across schemes (€2–500/ton of carbon), high costs represent biochar certificates, indicating a difference in the quality of the carbon removal (certainty, documentation, and duration of storage, especially for SOC vs. biochar) and market demand, see Table 1. Further, it reflects the complexity of designing and comparing CF schemes because of the differences in terms of storage potential (low and short-term, for e.g., cover/catch crops, and high and long-term for biochar and rewetting of peat) as well as costs.

Offsetting was particularly important for the schemes that were funded by the voluntary carbon market, where selling certificates or credits (by either farmers or certifiers) was used to fund CF, see Fig. 6. Schemes that originate in the corporate supply chain have a higher focus on insetting emissions and communicating activities directly to their customers. On the other hand, schemes which were based on public payments were generally not used for insetting/offsetting purposes, although reduced emissions may feature in National Inventory Reports (NIR) and could be part of the countries Nationally Determined Contributions (NDCs). Interestingly, a series of schemes combined public funds (which were allocated for covering MRV costs as a basis for private investments in carbon removal or emission reduction activities) with

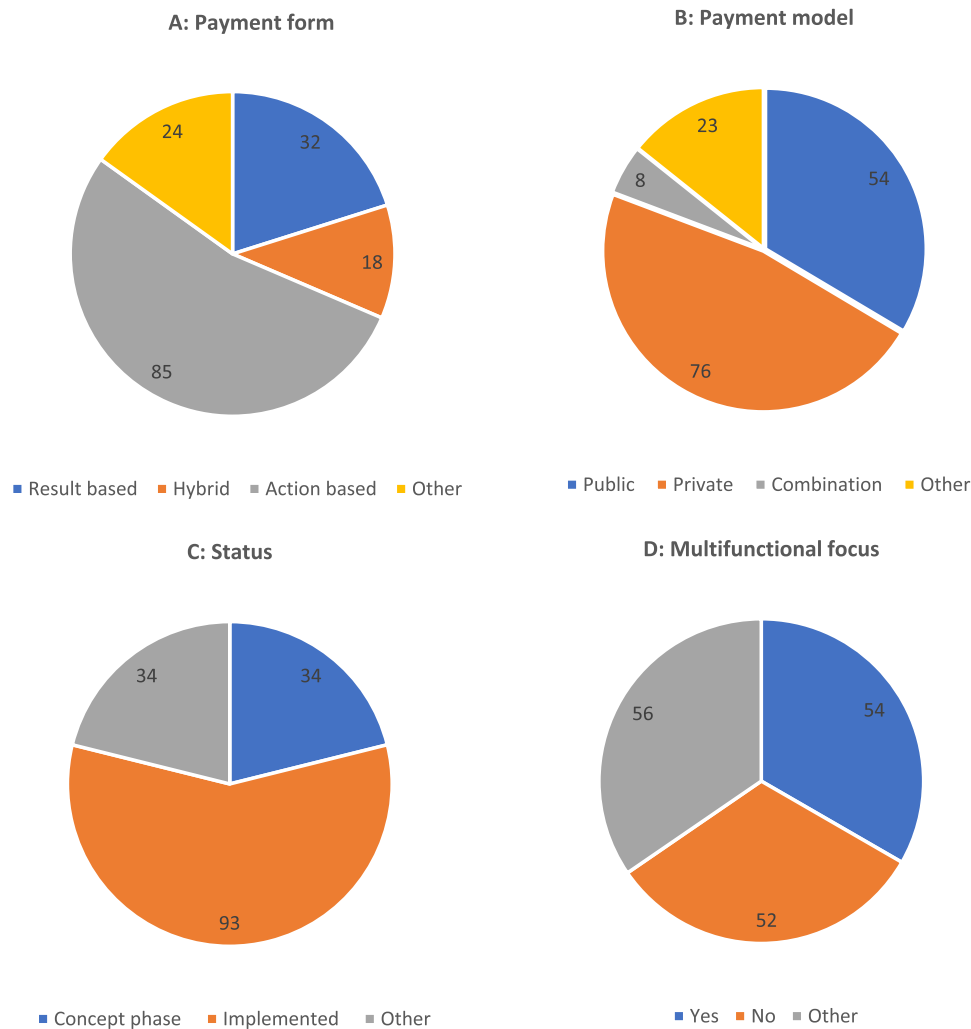


Fig. 4. Results from the first inventory, general characteristics of CF schemes (N = 160) (for full dataset see [supplementary material table S2](#)). Question A: Is this scheme action-based, result-based or hybrid? Question B: Is the payment model of this scheme public, private or a combination of both? Question C: Is this scheme still in a concept phase or is it already implemented? Question D: Does the scheme have multiple focuses/ESS or not? With respect to B, private schemes include both "schemes funded within the corporate value chain" and "schemes funded via the voluntary carbon market".

private funds to incentivize their adoption.

4. Discussion

This paper documents a widespread experimentation with CF scheme design and implementation across Europe. This reflects an increasing focus on developing CF schemes for climate change mitigation in line with a range of other options for a result-based "greening" of production ([van Veelen, 2021](#)) and an increase in public and private funding for CF that has been observed in recent years ([Oldfield et al., 2022](#); [Popkin, 2023](#)). However, the rapid development of a series of pilot schemes should not deceive us into thinking that developing CF schemes is easy. On the contrary, our study indicates that many schemes have only recently been implemented, and in most cases, the uptake and scale of initiatives were limited.

4.1. Scheme design

Initially, we discuss how existing CF schemes are designed with respect to quantification of carbon removal, ensuring additionality, long-term storage, and sustainability. Subsequently, we discuss the wider implications for the design and implementation of CF schemes in Europe.

4.1.1. Quantification

The current European CF schemes differed substantially in terms of the measures that were supported as well as the approaches to quantify their sequestration potential. For some practices, documentation is quite well developed, and international standards are being developed (e.g., biochar, forestry, and peatland rewetting). As seen in this paper, different MRV systems were employed to quantify carbon removals, but the majority of schemes relied on norm-based averages for design. Therefore, in line with [Smith et al. \(2020\)](#) we argue that the lack of credible, efficient MRV systems remains a key barrier to developing result-based CF schemes ([Smith et al., 2020](#)). Alternatively, (agri-environmental payments by modelled results (PAMR), see for instance: [Bartkowski et al., 2021](#)) could be an alternative. Using a combination of public and private payment in a blended system may also be an approach forward that was also seen in several schemes ([Moxey et al., 2021](#)).

In the absence of cost-effective and credible MRV systems, a substantial share of the costs for CF schemes (~20 %) is allocated to certifiers for administration and certification, which does not directly contribute to climate change mitigation ([Oldfield et al., 2022](#); [van Kooten and Zanello, 2023](#)). This is particularly challenging if CF schemes only provide short-term storage. This does not mean that CF schemes only generate low-quality sequestration or that they are



Fig. 5. Results from the in-depth inquiry into 40 European CF schemes highlighting key design features and differences in scheme implementation across different categories (CSC: Corporate Supply Chain, PP: Public Payments, VCM: Voluntary Carbon Market). Question A: Is this a regional scheme, or is it also used in other countries, EU-widely or even globally? Question B: Are farmers involved in the governance of this scheme, directly or through e.g., a board of stakeholders? Question C: Are all farmers under this scheme obliged to take the same measure(s) or can they select one or more measures for their own farms that they prefer most? Question D: Is the scheme certified or registered in another official document? (N = 40) (for full dataset see [supplementary material table S2](#)).

Table 1

Results from the in-depth inquiry highlighting key differences in scheme characteristics (N = 40) (for full dataset see [supplementary material table S2 and S3](#)).

	Farm payments	Corporate Supply Chain	Voluntary Carbon Market
Contract duration	Typically 1 yr	1–10 yr	5–15 yr
CO ₂ e price	NA	€20–€50	€30–€500
Ownership to reduction	Government	Value chain	Farmer
Co-benefits	NO	Some schemes	NO

superfluous, but the lack of rigorous standards makes it difficult to ensure a well-functioning carbon market that provides positive climate outcomes and especially in the design of result-based schemes.

For certainty, the measures used for CF vary substantially. Biochar schemes are result-based and mostly centred around the production of biochar and the monitoring of the biochar application to soil. As decay of biochar in the soil is widely independent of soil type and management, the amount of carbon stored in a long-term perspective can be certified ex-post once the biochar is applied to the soil (Camps-Arbestain et al., 2015). Additionally, peatlands are an important source of GHG, and rewetting offers a relatively certain opportunity for reduction (Bossio et al., 2020; ECA, 2021). However, for other practices, the effects of the measures and ex-ante documentation is associated with a higher degree of uncertainty and variability, which makes the application of average science-based norms for certification problematic (e.g., agroforestry and carbon sequestration on mineral soils).

Data availability, standardization, and access are other important aspects to address in the years going forward. Given the large spatial and temporal variability of CF practices, there are still important gaps in European soil monitoring systems, and comparability across countries is difficult, for instance, concerning SOC stocks and biological parameters, such as carbon mineralisation rates (Thorsøe et al., 2023; van Leeuwen et al., 2017). Although the proposal for a Soil Monitoring and Resilience directive (EC, 2023b) in a long-term perspective may improve soil monitoring, there will still be a substantial variation in monitoring systems across countries, and in the short-term data availability will not improve.

4.1.2. Additionality

With respect to additionality, most schemes in the inventory have adopted a field-based approach in calculations of baseline and effect. When single fields are certified in a scheme, as opposed to the entire farm or landscape, the additionality of the carbon sequestration can be questioned, e.g., farmers may focus the application of manure or other inputs on the plots under certification. The lack of reliable MRV systems and thus credible CF schemes is therefore a barrier for implementing SOC management schemes (Smith et al., 2020), which is also relevant for national reporting of GHG emissions and emission trading. Without such systems, changes to the SOC stocks cannot be quantified for farmers, policy makers, and the market (Radley et al., 2021).

When assessing the effects of CF, a systemic or landscape perspective is important; otherwise, there is a risk of leakage by providing an incentive for relocating carbon in the landscape (Paul et al., 2023; van Kooten and Zanello, 2023). Thus, the increase of SOC measured in-field

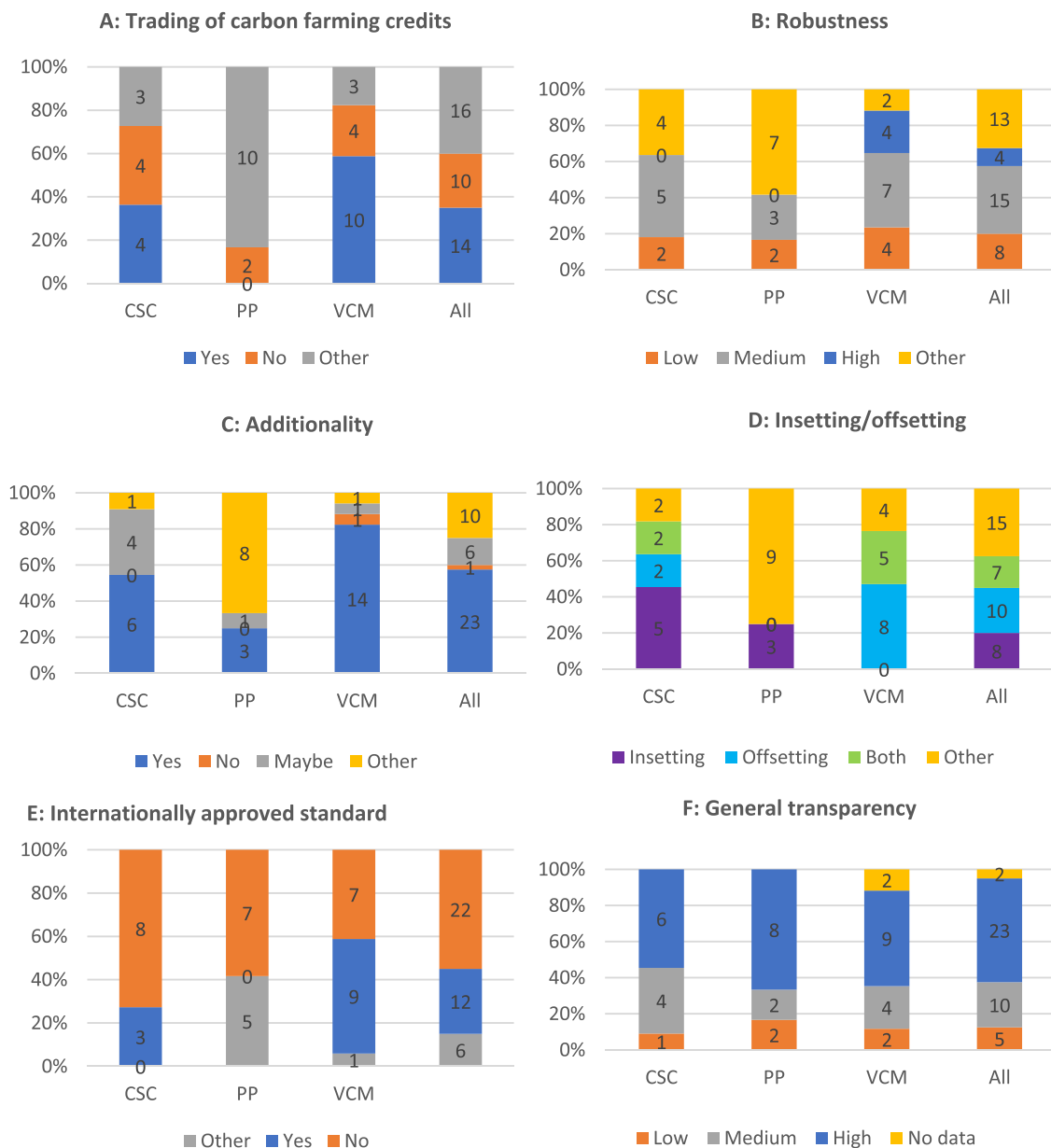


Fig. 6. Results from the in-depth inquiry into 40 European CF schemes highlighting key scheme design features and assessment characteristics across scheme categories (CSC: Corporate Supply Chain, PP: Public Payments; VCM: Voluntary Carbon Market) Question A: Are there opportunities for trading CF outcomes across sectors or national borders? Question B: How robust is the scheme? Question C: Is additionality addressed by the scheme? Question D: Is the scheme meant for in- or off-setting or both? Question E: Is the scheme conforming to an internationally approved standard? Question F: Is there transparency about the scheme, specifically how many farmers are involved, whether MRV-data are publicly available, about administrative and MRV-cost and, in the case of a result-based or hybrid scheme, about the risk of not reaching initial goals of scheme and how to deal with that? (N = 40) (for full dataset see [supplementary material table S3](#)).

may not truly be additional if the activities that sequester carbon in this field result in leakage elsewhere (e.g., manure can only be applied once in one location) (McDonald et al., 2021). Although a field-based approach is simple to administer, it does not directly incentivize long-term storage but rather increases competition for organic matter between fields.

The regulatory baseline varied substantially across contexts, indicating that additionality is context-dependent. For instance, the use of catch crops is partly mandatory in some countries (e.g., Sweden and Denmark), while it is considered an additional practice in others (e.g., Germany and France) (Thorsøe et al., 2022). Further, as most CF schemes were activity-based, they do not take the underlying trends in the carbon content of the soils into account, which may lead to misinterpretations and unrealistic expectations of the capacity of

agricultural soils to mitigate climate change (Don et al., 2024).

4.1.3. Long-term storage

Concerning the timeframe of carbon storage, the inventory documented widespread support for practices that do not provide long-term carbon storage and are associated with various uncertainties. Scheme operators work with different timescales and methods for documenting the outcome of removal activities. For investors, this makes it difficult to fully understand what a CF scheme. Further, long-term storage cannot be guaranteed, so CF schemes should not claim to generate certificates that allow for compensation of CO₂ emissions (Paul et al., 2023). Except for peatland rewetting and biochar application, other CF practices have a non-permanent storage effect. Further, most contracts were short-term (<10 years; see Table 1) with low incentives or possibility for project

renewal, which implies that only short-term storage is supported. In addition, only limited schemes provided incentives for the protection of existing stocks, implying that farmers with high existing carbon stocks have limited incentives to maintain them beyond public activity-based payments. However, in mitigating climate change, protecting existing carbon stocks is equally as important as sequestration (Bossio et al., 2020). Long-term commitments may also be problematic for farmers with short-term lease contracts; European farmers increasingly lease their farmland, and leaseholds today account for about 50 % of European farmland (FADN, 2021). This implies that farmers who manage fields may lack the ability to enter into long-term contractual agreements, and in effect, it is difficult for farmers to enter longer-term contracts for carbon sequestration. In effect, CF contracts may need to be negotiated also with the landowner, so that long-term storage becomes feasible to overcome shift problems to new land users.

Given the short-term storage of agricultural CF practices as of now, certificates under the CRCF are not designed to be transferable in the same way as traditional carbon credits in voluntary or compliance markets (EC, 2024a). This is also reflected in the inventory of schemes, where opportunities to transfer certificates are typically not provided. Further, the CRCF foresees robust liability rules and buffer or insurance requirements for temporary removals (Criscuoli et al., 2024). Given the activity-based incentives applied across most schemes in the inventory, this aspect is often overlooked. A few schemes apply buffering using various approaches, including insurance mechanisms, standardized buffer rates based on activity type (e.g., 10–20 % for soil carbon), or pooled buffer accounts where contributions from multiple projects go into a shared buffer pool.

4.1.4. Sustainability

Most CF schemes identified in the inventory only focus on SOC; GHGs other than CO₂ and co-benefits were frequently excluded from contemporary scheme designs. Potentially, several co-benefits are associated with CF, including decreasing risk of crop failure, resilience against droughts and heavy rainfall, improved nutrient use efficiency, below-ground biodiversity, and an increase in the supply of agroecosystem services (Paul et al., 2023). Those co-benefits are critical in motivating farmer engagement and prioritizations, particularly when payments only cover the costs of the practices (Graversgaard, 2024). Further, when practitioners are only provided with incentives to increase SOC, but not for other ESS, this may lead to sub-optimal outcomes for society and a carbon centric focus that risks marginalizing other critical aspects of soil health—such as biodiversity, nutrient balance, and water retention—that are also essential for sustaining long-term agricultural productivity and ecosystem resilience, but not incentivized in schemes. Trade-offs, for instance, include the application of manure and other organic fertilizers, which might result in higher SOC sequestration compared with green manure, but with higher risks of nutrient leakage and lower improvement of biodiversity. Minimizing or preventing such tradeoffs is important to maintain legitimacy in the CF schemes, particularly in result-based schemes, where payments are contingent upon specific environmental outcomes (Hasler et al., 2022; Vainio et al., 2021).

The inventory also points to lessons that could inform future CF initiatives in terms of wider sustainability concerns. Several schemes (particularly corporate supply chain schemes) adopt a whole farm approach and provide farmers with a comprehensive suite of support services, for CF but also support practices including training, capacity building, and facilitation. This includes several schemes in the value chain that offer complementary training for farmers and investment support, which may continue beyond the project duration.

4.2. Improving the basis for carbon farming schemes in Europe

CF practices are associated with management changes that entail costs for farmers, thereby creating barriers to the widespread voluntary

adoption of CF practices (Tang et al., 2016). Historically, activity-based schemes have constituted the foundation for most AES (Hasler et al., 2022), result-based schemes are now emphasized in the European Green Deal as a fairer way to provide support to farmers with a direct incentive for achieving environmental outcomes such as carbon sequestration (EC, 2020). Especially for measures with long-term environmental impacts, result-based incentives may also be a cost-effective approach, considering transaction costs. However, for practices with a short-term effect, activity-based schemes may be a preferred option as the current MRV costs will not guarantee a good payment to farmers for these practices in light of result-based standards and the associated MRV and transaction costs. Further, there are ways in which the implementation of activity-based schemes can be targeted, which may also be used for CF scheme implementation, e.g., by targeting areas where high mitigation potential is predicted for superior performance (Bartkowski et al., 2021; Thorsøe et al., 2016).

In addition to the payment, some of the CF activities, such as rewetting of peatlands, require coordination beyond field and farm scales to be effective (Nguyen et al., 2022); thus, result-based carbon sequestration schemes are insufficient in isolation. Rather, a more systemic landscape approach and a mix of measures and instruments are needed, including capacity building, land consolidation, and facilitation. Thus, in terms of the wider enabling environment for CF schemes, policies need to be adjusted, considering the primary barriers to adoption, including concerns over carbon leakage and competitive advantage, the need for a just transition, and structural issues in the food value chain (Van Hoof, 2023).

For instance, familiarity with CF practices and access to resources, including advice and equipment, are a precondition for successful adoption. Assessments by Thorsøe et al. (2023) have documented that stakeholders perceived a lack of knowledge about SOC management as a key barrier to upscaling sustainable soil management. Improved knowledge creation and exchange are identified as key enablers for scaling up adoption. Thus, CF scheme design should also look beyond merely changing economic incentives, as other important enabling factors have received insufficient attention in the current development of most CF schemes. This paper, in line with previous research, documents that current schemes place limited emphasis on structural adaptation and capacity-building initiatives (Ingram and Mills, 2019; Ingram et al., 2022; Vanino et al., 2023). Besides, CF provides farms with a range of benefits, including yield stability, improved soil structure, and greater resilience. These additional benefits may be more important to the farmers than the financial compensation for the practices, which often fail to offset the implementation costs (Dumbrell et al., 2016).

The economic interest of certifiers and a lack of qualifications have hitherto been reported as a problem of CF schemes, particularly pertaining to the carbon offsetting market (van Kooten and Zanello, 2023). To prevent such issues, a robust regulatory framework is essential to protect investor interests, the environment, and the long-term legitimacy of CF as a contribution to climate mitigation (van Kooten and Zanello, 2023). Current development of the CRCF and the Green Claims Directive (which prevents claims based on offsetting with carbon certificates) may provide such a basis (EC, 2023a, 2024a). However, it is important to note that most of the schemes and projects that we have assessed in the inventory are unlikely to meet the requirements of the CRCF. This misalignment potentially limits access to official carbon markets and related funding mechanisms and could also compromise the credibility and environmental integrity of CF efforts. Further, the risk of fragmented implementation hampers the EU's broader climate goals and disadvantages farmers in regions lacking compliant schemes.

The uneven geographical availability of CF schemes across EU member states presents significant distributional challenges, potentially exacerbating regional disparities in access to climate finance, favoring more developed agricultural regions while potentially marginalizing areas with a mitigation potential but limited institutional capacity (Günther et al., 2024; Paul et al., 2023). This also may undermine the

environmental effectiveness of EU-wide carbon mitigation efforts, with suboptimal uptake of schemes.

In line with [Demenois et al. \(2022\)](#), in this paper, we observed that current certification protocols for carbon removals were highly diverse and do not provide the same level of effect and certainty across certifiers and practices. Therefore, it is unclear to what extent CF can guarantee carbon sequestration because of different shortcomings in the design of certification protocols, mainly related to a lack of consideration of additionality and permanence. Although attracting private and corporate funds for climate mitigation is generally a positive outcome of CF schemes, it is important to emphasize that current CF schemes cannot directly offset emissions in other sectors (and thus be applied to substitute emission reductions), due to the inherently non-permanent nature of sequestration. Although CF schemes may not be able to ensure long-term storage (decades to centuries) ([Paul et al., 2023](#)), long-term contractual commitments could be introduced as safeguards to CF contracts that could help address the problem.

While our paper has provided an in-depth analysis of CF schemes in Europe, certain limitations should also be acknowledged. The analysis is primarily qualitative and focused on the current state of the CF schemes, an area that is rapidly evolving in Europe. In the data collection, we tried to cover Europe and collect a representative sample of the current situation for a better public understanding. Limited availability of quantitative data constrains opportunities for ex-post analysis of scheme performance. Further exploration of CF schemes would also benefit from further analyzing how co-benefits are measured and verified, as such aspects are an important component of multifunctional or whole-farm schemes.

5. Conclusion

In this paper, we have explored how CF schemes manage the challenges of CF scheme design (quantifying carbon removal, ensuring additionality, long-term storage, and sustainability) and discussed the implications for the design and implementation of CF schemes across Europe. We have observed the rapid development and implementation of a range of diverse CF schemes across Europe in recent years, primarily in the Northwestern parts of Europe. No single scheme design performs better across all aspects; rather, different design options offer distinct opportunities and challenges for advancing CF. Although result-based schemes deliver direct incentives for farmers to increase carbon sequestration and developing result-based schemes are an important policy objective, this analysis documented that most existing CF schemes in Europe are designed with activity-based incentives. Further, most result-based schemes have only been implemented in a pilot phase, therefore, assessing the performance of these schemes is challenging at present.

This assessment has highlighted some general issues in the foundational elements of current CF schemes, such as substantial differences across schemes on reporting of carbon removals, variation in the temporality of carbon storage, and in the CF practices supported; these issues affect the overall quality of the carbon removal activities. Further, cross-regional and cross-practice comparisons of carbon removal outcomes is challenging and involve a series of tradeoffs, including the emission of nitrous oxide and methane, which were omitted in most of the schemes examined in this study.

Maintaining the credibility of CF as a solution to climate change mitigation is a key challenge in a rapidly evolving carbon market. Although CF holds potential as a climate change mitigation strategy, realizing this potential requires a robust regulatory framework that provides incentives to farmers, mitigates adverse trade-offs, and protects investors from purchasing certificates that fail to deliver the promised outcomes. Adherence to the Q.U.A.L.I.T.Y criteria (Quantification, Additionality, Long-term storage and Sustainability) in the CRCF may pose challenges for farmers and scheme owners, particularly among stakeholders with constrained resources or technical capacity. However,

setting ambitious criteria for environmental performance is essential for effective climate change mitigation and for building trust in CF schemes, but the complexity of certification and the large number of bottom-up initiatives that each work with different certification protocols make this challenging.

For policymakers, we highlight the importance of integrating multiple support mechanisms, which is critical to ensuring farmer participation, particularly when the costs of implementation are high. Policies should integrate CF into broader frameworks by offering technical assistance, risk-sharing tools, and bridge financing, also targeting smallholders who might otherwise be excluded. Besides, a shift beyond a climate-centric approach is needed to highlight co-benefits, including enhanced soil health, biodiversity, and farmer learning, which can enhance adoption and strengthen the broader environmental effects of CF. Market coordination must continuously be fostered to reduce fragmentation and promote scalable implementation, with strong standards that are crucial for building trust in CF schemes. CF scheme credibility hinges on accurate removal quantification. Lastly, regional customization is essential but remains challenging in a unified carbon market, as soil organic carbon (SOC) dynamics vary significantly with soil types, climate, and farming practices, necessitating flexible, context-specific scheme architectures to ensure environmental integrity and economic viability.

CRedit authorship contribution statement

Stephane de Cara: Writing – review & editing, Conceptualization. **Jana Poláková:** Writing – review & editing, Conceptualization. **Ennio Facq:** Writing – review & editing, Conceptualization. **Morten Grøvegaard:** Writing – review & editing, Conceptualization. **Irene Criscuoli:** Writing – review & editing, Conceptualization. **Laura B. Martínez-García:** Writing – review & editing, Conceptualization. **Claudia Heidecke:** Writing – review & editing, Conceptualization. **Leonardo Amthauer Gallardo:** Writing – review & editing. **Andrea Martelli:** Writing – review & editing, Conceptualization. **Nikolas Hagemann:** Writing – review & editing, Conceptualization. **Bert Smit:** Writing – review & editing, Writing – original draft, Conceptualization. **Jennie van der Kolk:** Writing – review & editing, Conceptualization. **Francesco Galioto:** Writing – review & editing, Conceptualization. **Martin Hvarregaard Thorsøe:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Martin Thorsøe reports financial support was provided by Aarhus University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.landusepol.2025.107747](https://doi.org/10.1016/j.landusepol.2025.107747).

Data Availability

is provided in supplementary material

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