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Corporate compensation for carbon sequestration in agricultural soil

Carbon sequestration in soil has gained attention in the EU as a means for farmers to reduce net greenhouse gas emission from agriculture. Corporate funding can serve as an additional resource for these efforts. Currently, several business initiatives in the EU are developing models to attract finance, advance knowledge, and pursue practical solutions. In this Focus, we review the challenges and experiences faced by such initiatives. We find that private business models can be feasible but that their success in climate change mitigation relies critically on system design, verification, and accountability. Public resources are still necessary as healthy soils are a public good. Additionally, a holistic approach is needed to incorporate carbon sequestration into a broader environmental agenda for agriculture.

Introduction

It is urgent to reduce net greenhouse gas (GHG) emissions from the agricultural sector to mitigate climate change (IPCC 2018). In this context, the role of soils in the global carbon cycle has been increasingly acknowledged. Soils are the largest pool of terrestrial organic carbon, with a top meter carbon content estimated to be four times as large as global vegetation, and twice as large as the atmospheric carbon pool (Friedlingstein et al. 2022).

Currently, the organic carbon content of many soils is deteriorating. Underlying causes are deforestation, draining of wetlands and intensification of agriculture. In Europe, evidence from long-term soil-monitoring and field experiments shows an ongoing carbon depletion. For example, around 45 percent of the mineral soils in European agriculture have a low, or very low, soil carbon content (European Commission 2003).

Restoring lost carbon in soils can help to mitigate climate change by removing carbon dioxide (CO2) from the atmosphere (Paul et al. 2023). It may also simultaneously promote soil health, farm resilience and food security due to enhanced soil functionality and water retention capacity (Lal 2004).

It is generally agreed that losses of soil carbon can be reverted by a change to more sustainable agricultural management practices (Rodrigues et al. 2021). In the communication *Sustainable Carbon Cycles*, the European Commission highlights the need to incentivizing practices to sequester carbon from the atmosphere in natural ecosystems. For example, farmers could be encouraged to adopt management practices that increase the organic carbon content in their soil (European Commission 2021b). Also, the Commission intends to promote farmers' participation in market-based soil sequestration initiatives with new legislation on carbon removal certification (European Commission 2022). Private sources of funding are still a novelty in the EU, although several recent initiatives are ongoing. In for example the US, carbon markets for agriculture are more established than in the EU (CRS 2021).

In a review of the literature, the aim of this report is to examine challenges for private funding for soil carbon sequestration in agriculture, and to explore the experiences of three ongoing initiatives in the EU with different scope, scale and product orientation.

Agricultural soils and climate mitigation

Climate change and agriculture are closely connected. Agriculture is a major source of GHG emissions, and the management of agricultural soils are both part of the problem and part of the solution.

Carbon farming

Carbon farming refers to "sequestering and storing carbon and/or reducing greenhouse gas emissions at farm level" (McDonald et al. 2021). The concept of carbon farming is used both for management practices to mitigate climate change, but also to capture a business model in which farmers are paid to sequester carbon and/or reduce emissions (McDonald et al. 2021).

GHG emissions from agriculture stem from biological processes, such as enteric fermentation in livestock and microbial processes in soils, which naturally produces methane, nitrous oxide and carbon dioxide. Carbon farming includes practices to:

- remove carbon from the atmosphere (sequestration of organic carbon in soils and biomass),
- avoid future GHG emissions (including conservation of existing organic carbon in soils), or
- reduce existing GHG emissions.

Hence, carbon farming in its wider definition involves the management of land and livestock, all pools of carbon in soils, materials and vegetation, plus fluxes of carbon dioxide and methane, as well as nitrous oxide (McDonald et al. 2021).

In this report we focus on the soil carbon sequestration part. Carbon sequestration is commonly implied to contribute to climate mitigation by carbon removals from the atmosphere. For this to be true, we follow the definition by Chenu et al. (2019) who emphasize the difference between carbon sequestration and carbon storage, see Box 1.

Box 1: Carbon sequestration and storage

Soil organic carbon sequestration implies a *net removal* of carbon from the atmosphere into the soil of a land unit, through plants, plant residues and other organic solids which are retained as part of the soil organic matter. Retention time of sequestered carbon in the soil can range from shortterm (not immediately released) to longterm (millenia). Sequestration can therefore be quantified for a given duration.

Soil organic carbon storage is a broader concept than carbon sequestration. Although it also entails an increase in organic carbon stocks in a unit of land, it is *not* necessarily associated with atmospheric carbon removal. For example, if carbon is diverted from one storage location to another, the soil carbon stock can increase locally.

Source: Chenu et al. (2019)

In Europe, measures commonly suggested for carbon sequestration are cover crops, residue management, conversion to permanent grassland, reduced tillage and no tillage, and changes in crop rotation (Land et al. 2017, Rodrigues et al. 2021).

Organic carbon in soils

Atmospheric carbon is linked to soil carbon through the carbon cycle. Carbon dioxide is absorbed by plants through photosynthesis and end up in soils through plants, animals and root exudates. Much carbon is released back to the atmosphere when organic material decay, while a small part remains in the soil for a shorter or longer time. The stock of *soil organic carbon* is determined by the balance between carbon inputs and losses, see Box 2. Hereafter, *carbon* is used as a shorthand for *soil organic carbon* throughout the paper.

Box 2: Soil organic carbon

In soil, carbon is present in mineral or organic form. Mineral carbon derives from erosion while organic carbon is present in *soil organic matter*. Soil organic matter includes living and dead components; the living parts are plant roots and soil microbes, like bacteria and fungi, while the dead parts consist of tissues of plants and animals in various stages of decomposition. It can be recent inputs, like plant litter, or highly decomposed materials, like humus.

Soil organic matter is rich in carbon and *soil organic carbon* refers to the carbon content of the matter. The *soil organic carbon stock* is the total amount of organic carbon held in a unit of land at a particular time.

Source: (Ontl and Schulte 2012)

Land use changes, like the introduction of agriculture on native soils, generally leads to a decline in carbon stocks (Guo and Gifford 2002). It follows from a lessening of root volumes and a reduction of residues returned to the soils, in combination with increased erosion and decomposition from tillage (Lemus and Lal 2005). In a meta-analysis Sanderman et al. (2017) found a global median carbon loss of 26 percent since agriculture was first introduced. The extent of losses differs greatly between places due to differences in soil properties, climate, type of land use change, and agricultural management practices applied.

Net carbon losses can continue when land is farmed (IPCC 2013). For example, it is estimated that arable mineral soils in the EU currently lose 7,4 Mt carbon every year (European Commission 2021a). Organic soils, like former peatlands, have stored large quantities of carbon over millennia. When drained and cultivated, such soils are turned from carbon sinks into large sources of GHG emissions (Tiemeyer et al. 2016). Overall, croplands are estimated to be the largest annual environmental source of carbon loss to the atmosphere in Europe (Smith et al. 2005).

The ongoing depletion of carbon stocks makes it vital to conserve remaining carbon by decreasing the flux of carbon from agricultural soils to the atmosphere, and to restore carbon in soils (Searchinger 2019, Henderson et al. 2022). Forexample, the *EU Soil Strategy 2030* emphasizes the need for decisive action for protecting, restoring and sustainably using EU soils (European Commission 2021a). Research has therefor lately intensified its focus on soil management practices (Costantini et al. 2020, Thompson et al. 2022).

Co-benefits of soil carbon

In addition to climate mitigation, an increased carbon content in depleted soils is commonly argued to provide co-benefits, following from improved soil functionality and water retention capacity (Lal 2004, Baumber et al. 2019, Droste et al. 2020):

- Improved soil health can enhance farm productivity, and reduce soil erosion and nutrient leaching.
- Increased climate resilience as a healthier soil makes farms more resilient against adverse weather conditions like droughts and heavy rainfalls.
- Reduced fertilizer usage as a healthier

soil requires less fertilizer, reducing farmers' costs and lessening environmental impacts.

- Improved biodiversity both above and below ground.[1]

A higher carbon content is valuable for farmers but also for society as a whole; hence by restoring (or conserving) carbon farmers are reducing a negative externality of farming for society.

Costs of carbon sequestration practices

Carbon sequestration is often acknowledged as a cost-effective measure for climate action (COWI et al. 2021). However, farmers will generally adopt such practices at a level below the socially optimal level due to lack of economic incentives (Alexander et al. 2015). Hence, compensation to farmers for adopting carbon sequestration practices can be motivated.

Examples of farmer costs due to carbon sequestration are foregone yield (Droste et al. 2020), decreased profitability in the short run (Antle and Diagana 2003), and investments in new technology (Henderson et al. 2022). As farms are heterogeneous, studies show large variations in costs for adopting carbon sequestration practices, ranging from a few dollars to over $300 per ton CO2 (e.g. Manley et al. 2005, Williams et al. 2005, Tang et al. 2016, Aslam et al. 2017, Bamière et al. 2021). Cost variations depend on region, crop, agricultural practice and time when a measure is applied. The large variation in costs across and within different management practices can make compensation to farmers challenging.

Concluding comment

Soil is a considerable pool of organic carbon. Agriculture can contribute to climate mitigation efforts by increasing carbon content in depleted agricultural soils and conserving existing carbon content, by avoiding practices which cause carbon release, like draining of wetlands for agricultural use and the use unsustainable farm management practices.

Potential for carbon sequestration

Researchers in soil science have studied the potential of sequestering carbon in soils for nearly two decades. From a climate mitigation perspective, it is important to identify the approximate extent to which carbon sequestration in agricultural soil can remove carbon from the atmosphere.

What is achievable?

Common approaches to estimating carbon sequestration potentials in agriculture are bottom–up estimates from long-term field experiments and modelling (Rodrigues et al. 2021). Estimates of the carbon sequestration potential are highly uncertain and depend on estimation approach (Searchinger 2019).

As soil is a large carbon pool that has suffered substantial losses over time, the initial estimates of the sequestration potential were generally very optimistic (Lal 2004). The focus was often on the maximum *biophysical* potential. However, later estimates showed the importance of considering the realistically *attainable potential* taking biological limitations like land suitability as well as economic, social and political constraints into account (Smith et al. 2005, Searchinger 2019). For example, 20 years ago Smith (2004) reviewed the potential in EU15 cropland and noted that the realistically attainable potential could be 10-20 percent of the bio-physical potential. Amundson and Biardeau (2018) conclude that the present status of soil carbon sequestration seems unchanged; the large gap between physically and politically/socially achievable potential still remains, see Figure 1.[2]

[1] Soil contains a large and diverse assemblages of living organisms, underpinning a broad range of key processes and moderating ecosystem service provision (Nielsen et al. 2015).

[2] A large review of 21 meta-analyses found the global potential of soil carbon sequestration to be modest, at best (Moinet et al. 2023).

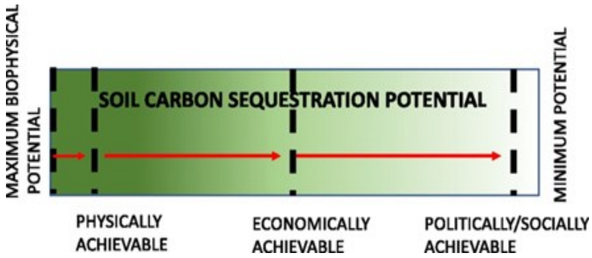

Figure 1: An illustration of the various impediments to maximum versus achievable soil carbon sequestration due to physical and socioeconomic controls.

Source: Amundson and Biardeau (2018) based on Smith et al. (2005)

It can be noted that some recent initiatives, like the 4p1000 initiative launched during the COP21 in 2015t, again point at the physical potential to call for upscaling of carbon sequestration for addressing climate change. According to the 4p1000 webpage:[3]

"If the level of carbon stored by soils in the top 30 to 40 centimetres of soil increased by 0.4% (or 4‰) per year, the annual increase of carbon dioxide (CO2) in the atmosphere would be significantly reduced."

The initiative has received sustained criticism (Baveye et al. 2018, Rumpel et al. 2020). Amundson and Biardeau (2018) note that the questions regarding implementation is still ignored; for the 4p1000 initiative to realise its full objective it must be implemented immediately on all lands on Earth, and the practice must be maintained without change for decades. Baveye and White (2020) note that "even supporters of the initiative cannot come up with overall figures that amount to more than about 10% of the target, under the best of conditions."

Further, there is a risk that policymakers can be seriously mislead by the 4p1000 initiative (Baveye and White 2020). Rumpel et al. (2020) point out that the original intention was more of a "thought experiment" or an "aspiration"; never to set an actual, achievable target. However, 4p1000 *could* be interpreted as realistic in the popular debate, especially in the context of slow climate mitigation action in many countries (Baveye et al. 2018). Instead of unpopular decision to reduce GHG emissions, or to support the transition to renewable forms of energy, a suggestion seems to emerge that carbon sequestration in agriculture can compensate for a substantial part of CO2 emissions from fossil fuel use, opening up for the possibility that efforts to reduce GHG emission or transform the energy system largely can be sidestepped (Baveye and White 2020). Such an "utterly unrealistic" target, as presented by 4p1000, is therefore a very real threat to causing further inaction about climate change, observe Baveye and White (2020).

Soil saturation

An additional issue that most estimations of potential do not take into account is soil saturation (Moinet et al. 2023). Instead, estimates of potentials generally show *initial* potentials. In depleted soils, carbon sequestration occurs rapidly at first, but then plateaus at an asymptote (or maximum) level, when the soil is saturated (Stewart et al. 2007, Thamo and Pannell 2016). Hence, sequestration can only occur for a limited time, except in some wetland systems (Bossio et al. 2020). Sink saturation can occur after 10-100 years depending on for example the carbon sequestration measure applied, soil type, and climate zone (Smith 2016).

Another caveat recently noted is that warming and higher precipitation can hamper the ability of soils to sequester carbon, especially in boreal regions. Hence, the potential for storage in an increasingly warmer climate could be rather less than currently suggested (Heikkinen et al. 2022).

Carbon sequestration potential in the EU

So, what could the achievable soil sequestration potential in the EU be? Two examples of the possible EU potentials are the following:

[3] https://4p1000.org. Downloaded 2023-06-13.

For the EU as a whole, Lugato et al. (2014) used an agroecosystem simulation model. Under different management practices like cover crops, conversion to grassland and reduced tillage on 12 – 28 percent of arable lands in EU28, the study estimated the initial annual sequestration potentials to be between 2.7 and 9.1 Mt carbon. This would offset 2.3–7.8 percent of total EU emissions from the agricultural sector.

Box 3: GHG emissions from the agriculture

Currently, 11 percent of total European GHG emissions derive from *the agricultural sector* (EU NIR 2021). This includes GHG emissions from practices managing crops and livestock but excludes GHG emissions from fossil energy use in agriculture, and GHG emissions from land use, land use change and forestry. For example, drainage and agricultural use of organic soils causes substantial carbon dioxide emissions, but these emissions are instead reported under the category Land Use, Land Use Change and Forestry (LULUCF).

Source: (EU NIR 2021) (EEA 2021)

For individual EU countries, Rodrigues et al. (2021) surveyed the literature and provided national estimates of the sequestration potential by local researchers, based on management practices with expected large potentials, see Figure 1. As above, the estimates show initial potentials to offset annual total emissions from the agricultural sector in percent.

The country estimates in Figure 1 are based on different methods, and covers different combinations of management practices. Also, the level of complexity varied regarding the inclusion or not of parameters such as trade-offs in GHG emissions and socio-economic factors, like costs and technical/practical feasibility. Hence, the estimated potentials cannot be compared across countries. Still, the estimate gives an indication of where European countries stand regarding GHG reduction potentials for carbon sequestration in agriculture (Rodrigues et al. 2021).

The estimated potentials in Figure 1 range between 0,3 percent in Italy to 27 percent in France and Estonia, indicating large differences in carbon sequestration potential between countries or large variations due to differences in estimation method. Also, chosen management practices vary between countries suggesting differences in country-specific environmental conditions and agricultural practices. In Sweden, for example, ley farming and cover crops are reckoned to be suitable management options.[4] In other countries, chosen management practices are for example grassland management, no- and reduced tillage, cover crops, agroforestry, organic farming and changes in crop rotation.[5]

Concluding comment

There is an existing, but modest, potential to sequester carbon in agricultural soil in the EU. It is important to distinguish between biophysical potential, and achievable potential, taking economic, social, and environmental constraints into account.

Carbon sequestration as a business model

The concept of carbon farming is commonly used to capture a business model in which farmers are encouraged to reduce emissions or sequester carbon (European Commission 2021b, McDonald et al. 2021). Financial compensation for increased costs can come from private or public sources and be paid through different mechanisms, examples are offsetting, insetting, or public payments for land management.

[4] A more detailed estimations of storage potential and suitable measures for Sweden can be found in (Swedish Forest Agency 2022).
[5] It is possible that the choice of practices in Rodrigues et al. (2021) represents those that are potentially profitable or low cost to farmers. If payments for carbon sequestration are put in place, farmers could have very different incentives to choose between practices.

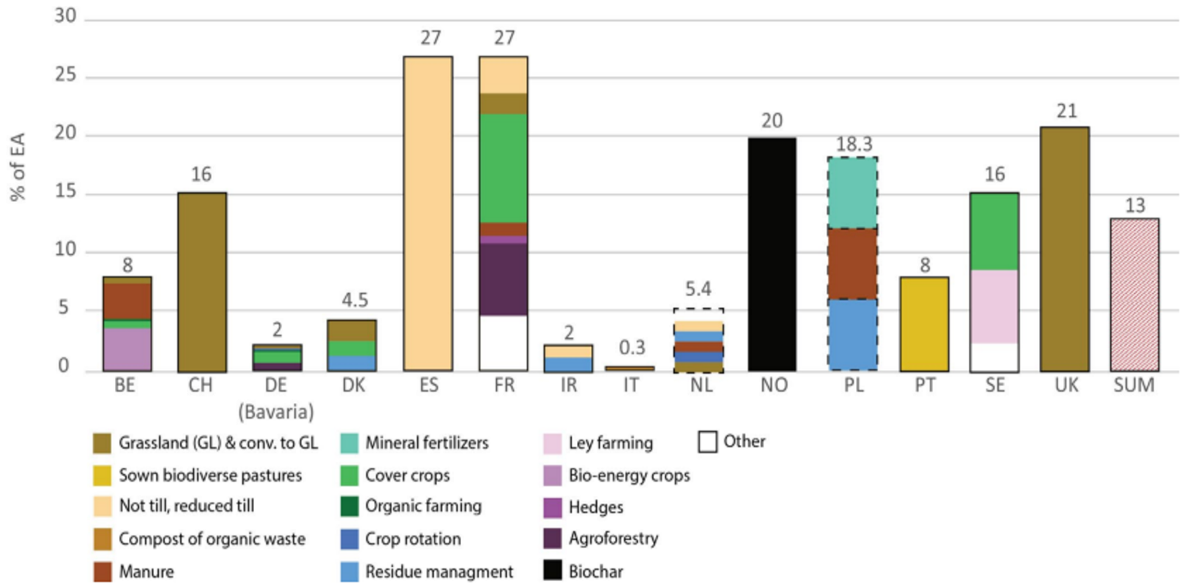

Figure 2: Shares of soil carbon sequestration potentials to offset the annual total emissions from the agricultural sector (EA) per country

Source: Rodrigues et al. (2021)

Offsetting - voluntary carbon markets

One mechanism through which farmers can be compensated is the sales of carbon offsets on a carbon market. In this case, farmers implement approved management practices to sequester carbon and trade offsets, either directly with buyers or through an intermediary.

A *carbon offset* is a reduction in GHG emissions, or an increase in carbon sequestration, that is used to compensate for emissions occurring elsewhere. A *carbon offset credit* is a transferable instrument verified according to a protocol and certified by a government or an independent certification body.[6] The purchaser of an offset credit claims the reduction and use it towards its climate goals (Broekhoff et al. 2019). A *carbon market* is a framework in which buying and selling of carbon offset credits takes place.

The idea with offsetting is to lower the costs for meeting GHG targets. A company or organization has two alternatives to reduce its' climate footprint:

- Reduce its own GHG emissions (or increase carbon removals).
- Pay for someone else's reductions (or increased carbon removals).

As it can be difficult, or very expensive, for an entity to eliminate all its emissions, the idea is to facilitate the use of external, cost-effective mitigation options to balance, or offset, emissions. Entities could then both meet targets and do it less costly than otherwise possible (Broekhoff et al. 2019).

Offsetting is becoming an increasingly popular climate instrument and carbon markets exist under both mandatory (compliance) programs and voluntary programs. Compliance programs are regulated by law, like the EU ETS system. Voluntary markets operate outside compliance markets and enable companies to buy carbon

[6] An offset credit represents the sequestration (or emission reduction) of 1 metric ton of CO_2, or CO_2 equivalent for other GHG emissions.

offset credits to meet their own climate objectives. So far, carbon sequestration in agriculture caters for voluntary GHG reduction strategies.

Currently, most land-related carbon offset credits are generated through tree planting and improved forest management (Von Unger and Emmer 2018). Presently, however, business interest in soil carbon is rising (Buck and PalumboCompton 2022).

Insetting - carbon action in the supply chain

Insetting are initiatives taken by a company to reduce GHG emissions within its own supply chain. For example, retailers or processors can provide education, technical assistance and financial support to farmers in their supply chain to encourage carbon sequestration (Thompson et al. 2022).

Non-agrifood corporate funding

Companies from outside the agrifood chain can be motivated to engage in climate action. For example, companies can work with and compensate farmers for carbon sequestration practices (Van Colen and Lambrecht 2020).

Public payments for land-management

Public payments for landmanagement practices are provided within for example the Common Agricultural Policy (CAP). The payments are intended to compensate farmers for additional costs when adopting voluntary measures.

Below, we focus on private market initiatives where farmers interact with different stakeholders. First, a wide range of challenges are discussed. Thereafter, the experiences of three ongoing initiatives: Swedish carbon sequestration (offsetting), Valio (insetting) and Windpark Krammer (corporate funding) are considered.

Challenges for corporate funding

There are several challenges to consider for corporate funding of carbon sequestration in agriculture. Below, the focus is on offsetting. However, we start with the willingness of farmers to adopt carbon sequestration practices.

Farmer adoption of sequestration practices

If carbon sequestration in agricultural soils shall increase, farmers must be willing to change what they do on a daily basis on their farms (Buck and Palumbo-Compton 2022). Is this the case, and is financial compensation a sufficient condition for such a change?

For farmer adoption of carbon sequestration practices, a strong motivator throughout the literature is the presence of environmental co-benefits such as soil fertility, reduced erosion risk or water holding capacity. Such benefits are often a much more important factor than the compensation the farmers receive (Buck and Palumbo-Compton 2022). Also, farmers have a range of different environmental and economic concerns; for example yields, soil health and resilience which are commonly more important for farmers than climate change mitigation efforts (Von Unger and Emmer 2018).

Also, several barriers to farmer adoption of carbon sequestration practices have been identified. As carbon sequestration is still a novelty, it requires methodological developments, time and effort (Von Unger and Emmer 2018). Unfamiliarity with carbon sequestration practices, uncertainties about policies, and lack of information contribute to hesitancy among farmers to adopt new farming practices (Kragt et al. 2017).

Previous research has shown that it can be difficult to get farmers involved in voluntary agro-environmental schemes in general (Liu et al. 2018). This is especially the case if a scheme is complex or in conflict with other farmer objectives (Sharma et al. 2021). Farmers who rent their land have less incentives to invest in measures with long-term pay-offs, such as carbon sequestration; the same is true for older farmers (Amundson and Biardeau 2018). It is also unclear whether farmland prices accurately reflect improvements in soil quality (Amundson and Biardeau 2018).

Regarding insetting, some farmers are reluctant to collaborate with firms in the food chain regarding carbon sequestration measures, as they are concerned that new measures will eventually become a new standard, meaning that the initial payment will vanish (Demeyer et al. 2022).

To conclude, a payment for additional cost may not be sufficient to attract farmers. Instead, other nonmonetary motivators than climate mitigation are important to keep in mind when designing programs, as well as barriers farmers face to adopt carbon sequestration practices.

Carbon offset credits quality

Carbon offset credits face particular challenges (Broekhoff et al. 2019). Primary concerns are i) the quality of the carbon offset, and ii) how the carbon offset credit is used.

Offset quality means that a carbon offset credit must be a valid substitute for an organization's own internal GHG reductions (Broekhoff et al. 2019). Important features for offset quality are additionality, permanence, and non-leakage. As stated by (Thamo and Pannell 2016):

"If carbon sequestration is to be a cost-effective substitute for reducing emissions, then it must occur under a framework that ensure that the sequestration is additional to what would otherwise have occurred, the carbon is stored permanently, and any leakage is properly accounted for."

The criteria can be captured in three questions:

1. *Would the carbon have been sequestered without the carbon offset credits?*

Additionality is necessary as carbon credits are sold to offset existing sources of emissions. Additionality implies that the carbon removals would not have been implemented without the revenue from the offset (McFarland 2011). That is, for an applied management practice to be additional, the opportunity to sell carbon offset credits must play a pivotal role in farmers' decision to implement the carbon sequestration measure (Broekhoff et al. 2019).

2. *Will the carbon remain in the soil?*

Permanence is essential as sequestered carbon can be released (Smith, 2005). Concern that sequestered carbon could be easily lost is one reason that carbon sequestration projects were not included in early carbon offset markets, as those created under the Kyoto Protocol (Von Unger and Emmer 2018).

3. *Is it certain that the amount of carbon to be sequestered really was?*

A radically smaller amount of carbon than reported can be sequestered due to double counting, leakage or over-estimation.

Double counting occurs when two or more parties claim credit for the same emission reductions.

Leakage, or displacement, occurs if an activity within a carbon sequestration program has consequences outside a program. Leakage takes place if emissions are transferred to another location, time or form. For example, if cropland is converted to grassland to promote carbon sequestration, compensatory conversion of grassland, or forest, to cropland could be triggered elsewhere, resulting in leakage (Garnett et al. 2017).

Over-estimation happens when offsets have less of an impact than reported (Broekhoff et al. 2019). In addition to being a consequence of leakage, overestimation can result from:

- overestimation of baseline emission,
- underestimation of actual emissions,
- forward crediting, that is using credits that is *expected* to be issued in the future.

Does monitoring, reporting and verification (MRV) help to guarantee the quality of the offsets? The of quality issue is addressed in protocols which standardize the MRV requirements for generating carbon offset credits (CRS 2021). However, MRV has proven difficult and costly to undertake (Smith et al. 2020). An evaluation of 14 existing MRV protocols for soil carbon offsetting show that robust crediting of soil carbon is difficult to achieve and that none of the protocols is doing enough to guarantee good outcomes (Zelikova et al. 2021).

Evaluations show that the quality of offsets in existing carbon sequestration programs indeed can be low due to non-permanence, leakage, lack of additionality and over-estimation (CRS 2021, Runge-Metzger et al. 2022). An evaluation of California's forest offset program, for example, highlights problems with a systematic over-crediting of offsets (Badgley et al. 2022). They conclude:

"Rather than improve forest management to store additional carbon, California's forest offsets program creates incentives to generate offset credits that do not reflect real climate benefits."

Carbon offset credit usage

Carbon offsets are devised to facilitate investment in cost-effective mitigation options that organizations would otherwise not have access to. As such, they are not supposed be used as a justification for continued GHG emissions. However, a risk highlighted by both scholars and NGOs are the presence of so called perverse incentives (Broekhoff et al. 2019, Dyke et al. 2021). Several problems could arise:

- As they are easy to use, it could be tempting to use carbon offset credits instead of making needed investments to reduce ones' own emissions.
- Offsets could cause a lock-in of high-carbon infrastructure if they allow firms to continue with high-emitting activities and invest in high-emitting equipment.
- The presence of carbon offsets may hinder the introduction of more stringent regulation.[7]

Finally, it can be noted that some oppose carbon offsets in general, as CO2 emissions from fossil fuels must be reduced to a very large extent, and they argue that there is hardly no room to "net out" emissions using someone else's reductions (Broekhoff et al. 2019).

Farmer participation in carbon markets

The question of whether farmers will *adopt carbon sequestration practices* differ from whether they will *participate in carbon markets*. Experiences from carbon markets in the U.S. show that many farmers can be skeptical to take part. Questions commonly raised are (Thompson et al. 2022):

- How much will I get paid?

[7] For example, the introduction of needed and more stringent regulation may deprive current producers of carbon offsets credits of their revenue, by ensuing that their reductions are no longer additional as they are now mandatory by law. Both sellers and intermediates are likely to resist such changes (Broekhoff et al. 2019).

- What are the impacts on yields and farm productivity?
- Do I qualify if I already use eligible practices?
- What are my contractual obligations as a producer to continue the practices?

Overall, uncertainties regarding carbon offset demand and costs serve to deter farmers from participating in carbon markets (Sharma et al. 2021). A concern is also increased paperwork related to the gathering of records and data for the carbon market system, and some farmers are worried about loss of control of what they can do on their land (Rochecouste et al. 2017).

Also, carbon offset credit prices are commonly assessed to be too low to encourage a general uptake of carbon sequestration among farmers (Demeyer et al. 2022, Thompson et al. 2022). Frontrunner farmers may accept a low price but stable and high enough prices are needed to attract mainstream farmers (Demeyer et al. 2022).

Not only the price for an offset credit *per se* may matter. Some carbon sequestration practices, like cover crops or conversion to grassland, generate biomass to be used as feedstuff or substrate for biogas production. Therefore, sufficient market demand for this output may be needed too, if farmers shall adopt the management practices (Swedish Forest Agency 2022).

A concern has been the risk of a "wild west" market situation for carbon offsetting in the EU. In the US, for example, many different carbon offset credit protocols have emerged with different rules, obligations, and prices, making it difficult for farmers to participate as providers (Ben Lilliston 2022). It is also difficult for buyers to assess the quality of an offset (Broekhoff et al. 2019). The EU proposal for new legislation establishing a Union framework for carbon removals is therefore a step in the right direction (European Commission 2022).

Finally, the need for additionality means that sales of carbon credits can raise questions about fairness, since such payments would provide income to farmers who have depleted their soil, and disregard past efforts made by farmers having high carbon content today due to a previous use of more sustainable production methods (Henderson et al. 2022).

Will there be a demand for soil carbon offset credits?

The overall market for offsets from carbon sequestration is currently small (Von Unger and Emmer 2018). Many companies have recently committed to achieving net zero emissions; to offset some emissions with carbon credits could be seen as a viable alternative for them, suggesting a potential surge of future demand (Kreibich and Hermwille 2021).

Size and scalability may, however, present challenges as a large number of heterogeneous farmers with different circumstances and preferences need to be covered if carbon sequestration in agriculture shall be accomplished at a larger scale via private funding (Von Unger and Emmer 2018).

A concern for buyers, and thus important for market growth, are the quality issues discussed above. Buyers (usually) require that the offset credits have a measurable benefit, due to concerns over the reputational impact of buying ineffective credits (BCG 2022). Corporate demand for offsets with poor effectiveness is likely to be low (Thompson et al. 2022).

Of interest is the example Arla Foods, see Box 4, where the validity of a climate neutrality claim,

Box 4: Climate neutrality for Arla Foods

Background: Milk and beef production are large emitters of GHG. Livestock farming has a significant potential to reduce emissions from its´ production (Gerber et al. 2013).

The case: In Sweden, the dairy cooperative Arla Foods has bought carbon offset credits and claimed climate neutrality for dairy products in consumer marketing campaigns. In 2021, the Consumer Ombudsman at the Swedish Consumer Agency sued Arla Foods and asked the Patent and Market Court in Sweden to prohibit Arla from using the claim "net zero climate footprint" or other similar claims that give the impression that dairy production does not affect the climate, as the Consumer Agency argues that Arla fails to demonstrate that their milk production does not harm the climate. Following the lawsuit, Arla Foods has decided to cease buying offsets.

Source: (Swedish Consumer Agency 2021).

based on offsetting, was challenged in court.

Concluding remarks

Farmers may not be willing to adopt carbon sequestration management practices even if they are compensated for additional costs if other barriers they face, and non-monetary motivators they have, are not sufficiently addressed.

For carbon offset credits to be a viable option, a well-designed system is needed where criteria regarding additionality, permanence and leakage are fulfilled, and with standardized monitoring, reporting and verification in place.

Carbon initiatives in the EU

The interest in soil carbon sequestration is growing among corporate buyers. The challenges are significant, but efforts are being made to address them. For example, several pilot projects and programs have recently taken off in Europe. Below, three initiatives in the EU are presented.

Swedish Carbon Sequestration (offsetting)

The platform *Swedish Carbon Sequestration*[8] is a non-profit organization developing a market-based solution for carbon sequestration in agricultural soil. The aim is to enable compensation to farmers who apply carbon sequestration measures by developing an infrastructure for sales of carbon credits to companies and organizations.

During 2020-2022, the organization conducted a pilot study involving 40 Swedish farms and 12 partners, the latter including private companies in the food chain, commercial banks, farmer cooperatives and consultants (Svensk kolinlagring 2022). The management practices applied included for example the use of seed varieties with a higher potential for carbon storage than traditional seeds, agroforestry, less or no-till and the use of catch/cover crops.

The farmers' participation was funded by the partners with 130 Euro/ha, of which the farmer received 100 Euro/ha and 30 Euro/ha financed measurements and analysis of the results.[9] The pilot tested management practices, monitoring, reporting and verification at the farm level, and the interaction between farmers and offset credit buyers.

The buyers' motivation to participate in the pilot study was a desire to work for a more sustainable food production in cooperation with farmers. The potential buyers asked for:

- **Verification**, quantification and transparency regarding carbon sequestration.

[8] Svensk Kolinlagring
[9] Additional funding was received from Vinnova, the Swedish Board of Agriculture (EIP-Agri) and Svea Green Foundation.

- **Permanence** over time.

- **Synchronization** between buyer/sellers, as large companies in the food chain often are interested in buying large quantities of offset credits. Since several of the farms in the pilot were small, an intermediary was deemed to be needed.

In addition to compensation for extra costs the farmers highlighted the need of:

- **Knowledge and inspiration**. The farmers stressed that advisory services do not have enough expertise for carbon sequestration practices.

- **Networks**. Farmers emphasized the need to meet colleagues working with carbon sequestration practices.

- **New seeds**. Many farmers wanted to try perennial cereals, like kernza, but had difficulties finding seeds.

- **Better measurements** of soil health and soil carbon content. Farmers wanted to know the soil status at the farm.

The farmers were generally concerned whether a demand with sufficient willingness-to-pay would exist if they decided to continue with carbon sequestration management practices; and how, if this would be the case, they would be able to take advantage of this demand. They also noted that the CAP framework sometimes is at odds with suggested practices. Many practical questions surfaced in the pilot, see Box 5.

Valio (insetting)

Valio is a dairy cooperative in Finland owned by 4 000 Finnish milk producers. Valio aims at creating a carbon neutral milk chain by 2035.

Box 5: Questions from farmers in the Swedish carbon sequestration pilot study

Farmer questions (examples)

- Which carbon sequestration practices can I adopt without risking my CAP payments?

- How can I integrate cover crops in my current crop rotation scheme?

- Can cover crops turn into weeds?

- Which new feed seed varieties can be used to simultaneously reach targets regarding carbon sequestration and biodiversity, without compromising feed quality?

- How can I boost soil micro-organisms?

- How do I see the result of the new management practices?

Source: (Svensk kolinlagring 2022)

Here, carbon sequestration is part of a broader climate initiative covering all GHG emissions in the supply chain (Valio 2022).

Valio notes that 85-95 percent of all climate impacts from milk production are generated at the farm and conclude that action must primarily be taken there (Valio 2023). Valio do not currently buy carbon offset credits. Juha Nousianien, in charge of the carbonneutral milk function says:[10]

"Offsets play a role in global emissions reduction, but if all companies simply bought offsets, developing ways to reduce their own emissions and improving their carbon sinks could be neglected."

[10] Downloaded from the Valio homepage 2022-09-01.

The farm level tools used by Valio are:

- the Valio Carbo Calculator, a tool for monitoring GHG emissions at the farm level,
- farm training, and
- an extension, from mid-2023, of the existing bonus payment programme for animal welfare to include efforts to reduce GHG emissions.

The actions are voluntary for the farmers. So far, management practices to restore or conserve carbon is only included in the training part, which is ongoing since 2019. Soil impacts are not included in the Calculator or the bonus program due to lack of research data on how much carbon can be sequestered with year-round grass farming, and how much carbon is emitted from peatland cultivation (Valio 2023).

Examples of recommended soil management practices in the training sessions are crop rotation, the use of deep-rooted grass varieties in grasslands, and cover crops. Dried peatland fields are common in Finland. As organic soils under cultivation tend to lose a lot of carbon, farmers are recommended to avoid the clearing of new peat fields, end farming on the poorest-condition peat fields and raise groundwater levels on peat fields.[11]

The Valio initiative has been evaluated by Puupponen et al. (2022). They focused on farmer engagement, but also found that a motivation for the program was Valio's concerns about negative consumer attitudes towards dairy farmers.

Puupponen et al. (2022) interviewed farmers who supply milk to Valio; both participants and non-participants in the climate program. In general, the farmers believed that the initiative was beneficial for their management practices and their businesses. They noted that most of the recommended practices did not increase costs, nor required large investments. If costs were to increase, they emphasized that compensation would be necessary but perhaps not sufficient for farmers to participate. Also, the low profitability in the agricultural sector in general was highlighted; the farmers argued that farming needed to be profitable to enable the uptake of new environmental practices. Finally, the farmers were skeptical to the carbon offsets business model.

Windpark Krammer (corporate funding)

In the Netherlands, a five-year pilot study is ongoing since 2020, in which actors outside the agrifood chain are involved; Zeeuwind and Deltawind – two energy cooperative producing renewable energy (Demeyer et al. 2022).

Box 6: Available management practices

Soil measures	Above-ground measures
Reduced tillage No tillage Cover crops Compost animal manure Permanent grassland Herb-rich grassland Crop residue	Flower borders Agroforestry

Source: (Demeyer et al. 2022)

The cooperatives dedicate parts of the earnings from Windpark Krammer to support local carbon sequestration. The cooperatives want to compensate for unavoidable emissions and to link the energy transition to the broader social agenda, such as a more circular agriculture. The director of Zeeuwind emphasizes that they rather support local actors than buy carbon offsets generated far

[11] Clearing of new peat fields is driven by dairy farm expansion, as farms need to have enough fields to spread manure.

away from where the company is operating (Demeyer et al. 2022).

A farmers' association (ZLTO) serves as intermediary between the cooperatives and the farmers, taking care of contracts and monitoring, reporting and verification. During the pilot, 15 farmers apply two soil measures and one aboveground measures out of a set of optional measures, see Box 6. The farmers are organized in groups, guided by ZLTO, for self-monitoring and knowledge transfers.

Payments are based on a hybrid of effort-based and result-based rewards. If measures are implemented according to an individual carbon plan, the farmer receives a yearly effort-based payment (70 percent of the total). By the end of the five years, samples will be taken. If an increase in carbon stock has been realized, the farmer receives the result-based part of the payment for the 5 years (30 percent of the total payment).

Discussion

Mitigating climate change and promoting healthy soils are highly complex endeavours, requiring joint efforts from farmers, scientists, policymakers, NGO:s and the business sector to find solutions to the different challenges presented.

Reflections on the three initiatives

The three examples above illustrate the wide range and scope of initiatives. They can be local (Krammer), national (Swedish carbon sequestration) or product oriented (Valio). They can focus on carbon sequestration (Swedish carbon sequestration, Krammer) or carbon farming in general (Valio). One trend is a growing corporate interest in locally produced carbon offsets, as shown by Krammer. This is partly fueled by questions regarding the quality of 'far away' compensation projects, like reforestation projects in developing countries, but also strengthened by an interest in buying local to support the local environment and local farmers (Demeyer et al. 2022).

Size and scalability present a challenge, and many projects have a limited duration, like Krammer. However, farmers may try new practices during the project period which could affect how they choose to manage their land in the future. Valio, on the other hand, aims at permanently reducing the carbon footprint of its supply chain.

Different solutions for addressing additional farm costs are tried. Krammer uses a hybrid solution for payments, while Valio focuses on training and practices that do not increase farm level costs.

Overall, the initiatives can be seen as testing grounds, which bring together stakeholders to tackle the challenges present in search of practical solutions.

To measure carbon content in soils

A starting point for a business model for compensating farmers for carbon sequestration, is the extent to which soil carbon can be measured. It is straightforward to measure the organic carbon content in an agricultural soil, but it is not possible to measure *annual* changes of the stock with statistical reliability. This is because the carbon content will generally only change in small increments from one year to another, which makes annual measurements of sequestration susceptible to impacts of random weather events and error margins of measurement techniques. Rather changes in carbon can only be reliably detected after several years. On the other hand, the impacts of different management practices can be predicted with the help of models given basic information about soil characteristics, current carbon content and climate zone (Bartkowski et al. 2021) Thus, it could be feasible to base compensation of carbon sequestration on a hybrid results-based payment scheme through utilizing a combination of measurement and modelling to estimate sequestration.

Soils for carbon or carbon for soils?

The *EU Soil Strategy for 2030* emphasizes that EU soils are subject to "severe degradation processes such as erosion, compaction, organic matter decline, pollution, loss of biodiversity, salinisation and sealing" and subsequently calls for protection, restoration and a sustainable use of soil (European Commission 2021a). In this perspective, the current trend to concentrate foremost on *soils for carbon*, could be too narrow a focus (Searchinger 2019, Moinet et al. 2023).

An alternative is to flip the perspective – food security, climate resilience and improved biodiversity, are worthwhile for their own sake, not just co-benefits from carbon sequestration (Amundson and Biardeau 2018, Searchinger 2019, Moinet et al. 2023). That is, a healthy, productive and resilient agricultural soil is the primary goal for farmers and society, and carbon sequestration is a mean to this end, instead of the other way around. For example, Moinet et al. (2023) argue that a shift from *climate-smart* soils to *soil-smart* agriculture is needed; carbon sequestration may occur along the way and should be seen as a co-benefit.

Such a change of perspective is helpful as the multiple functions of soil, like productivity, water regulation/purification, climate regulation, soil biodiversity and nutrient cycling, are context-specific, and several trade-offs exist (Zwetsloot et al. 2021). For example, carbon sequestration is sometimes promoted as a win-win solution to both climate change and food insecurity (Lal 2004). However, in a review of 21 meta-analyses Moinet et al. (2023) find that yield effects of increased soil carbon content is variable, ranging from negative, to neutral, to positive. They conclude that a win-win solution for increased carbon content and yield exist only for specific land management practices under specific conditions. Hence, carbon sequestration is *not* a win-win solution for all soil related challenges.

A more holistic approach could be further appealing as neither farmers nor corporates are solely interested in climate mitigation. For farmers a wide range of environmental and economic priorities generally rank higher, while corporates may also be interested in animal welfare, healthy food, and biodiversity.

Finally, it is important not to forget other promising options for carbon storage, like i) avoiding conversion of forests and other native landscapes to agricultural land, but instead producing food on existing agricultural land, and ii) rewetting of drained peatlands (Searchinger 2019).

Conclusions

Climate action is urgently needed, and both reductions of existing GHG emissions and removal of carbon from the atmosphere is called for. Soils are a considerable pool of organic carbon and agriculture can contribute to climate mitigation efforts by absorbing atmospheric CO2 through carbon sequestration.

A healthy soil has large benefits for farms and society. Within the EU, there is a need to increase the carbon content in depleted agricultural soils and conserve existing carbon stocks by avoiding practices that cause carbon release, like the use of unsustainable farm management practices or draining of wetlands for agricultural use.

There is a real, but modest potential to increase the carbon content in agricultural soil in the EU by carbon sequestration. Carbon sequestration cannot, however, significantly alleviate carbon dioxide imbalances, or serve as an alternative to emission reductions.

Private funding for carbon sequestration in agricultural is still a novelty in the EU, but several recent initiatives exist, developing infrastructures, channeling resources, and exploring feasible ways forward. Examples are:

- *Offsetting* in which carbon offset credits are sold to offset GHG emissions by other entities,
- *insetting* in which agrifood corporates reduce emissions in their supply chain, and
- *private funding* to farmers from non-agrifood entities.

Carbon offset credits must meet several criteria to guarantee their efficacy and cost-effectiveness. These criteria are:

- *Additionality*, or that the scheme results in less emissions of GHG globally.
- *Permanence*, or guarantees that the carbon stays in the ground for a pre-determined period.
- *Measurement* of sequestration, or that the amount sequestered can be reasonably estimated.
- *Standardized* monitoring, reporting, and verification.

In addition, *emission leakages* to different locations, time or type of GHG emissions need to be properly accounted for and *over-estimation* and *double counting* must be avoided.

Farmers are found to be primarily motivated by environmental co-benefits of carbon sequestration, like soil health and biodiversity, rather than climate mitigation per ser or financial compensation. Several barriers to farmer adoption of carbon sequestration practices have been identified. Farmers may be reluctant to commit as such practices may conflict with other economic and environmental objectives they have. Farmers face a lack of suitable advisory services, and they raise concern about costs. Further, farmers can be hesitant to enter carbon offset markets, as carbon prices and obligations are uncertain, as additional paperwork can be required, and as they are worried about loss of control of what they can do on their land.

Carbon sequestration in soils is not a silver bullet for climate mitigation; it is potentially volatile and temporary, sensitive to human actions and natural disturbances, and can be lost again. Carbon sequestration finite, though this time can be many decades, while improved management needs to be maintained to sustain the improved soil carbon stocks.

Private initiatives and funding can help to overcome the barriers present to preserve and restore soil carbon in agriculture, to stimulate climate action and to pursue wider societal goals. It is important to note, however, that private initiatives are only one of many tools, which is currently developing from a small scale. Public policies wills still be of fundamental importance for soil health and carbon sequestration objectives in the EU.

To conclude, the corporate interest in soil carbon sequestration is a positive sign as private and public actors need to join forces for climate action in agriculture. Overall, it seems that private models can be feasible but their success for climate change mitigation will be critically dependent on system design, verification and accountability.

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