Lessons learned from existing soil carbon removals methodologies in agriculture to drive European Union policies

Running title: Recommendations for EU methodology on carbon removals

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Abstract

Soil contains the largest existing organic carbon (C) stock on earth and, consequently, plays a central role in the global carbon cycle and in the fight against climate change. For these reasons, the protection of soil organic carbon is fundamental. However, more than 33% of global soils are subject to moderate to severe degradation caused by either natural and/or anthropogenic causes. The stocks of organic carbon in farmland and the extent of wetlands and peatlands are steadily decreasing because of both climate change, which is increasing the incidence of natural causes, and unsustainable agricultural soil management practices. To maintain and increase C stocks in agricultural soils, carbon farming (CF) practices are supported by various forms of incentives. Carbon credits mechanisms represent one of these forms, being tradable credits corresponding to 1 ton of CO_2eq that are issued upon the demonstration of increased soil C stocks over time by the application of C accounting methodologies and standards for each agroecosystem and farming practice. In this study, a detailed and critical analysis of carbon credits methodologies focusing on agricultural soil C is offered by comparing the European Commission proposal of regulation on Carbon removals (COM(2022) 672 final) with relevant certification frameworks implemented in extra-EU countries (Australia, Alberta in Canada, United States). Based on this review, we recommend strengthening the EC proposal by i) expanding the list of eligible agricultural practices ii) setting a permanence time frame for each agricultural practice, iii) setting the GAECs of the CAP as regulatory baseline, iv) including GHG emissions in the calculation of carbon removals, v) prioritizing CF projects on low-SOC lands, vi) requiring the application of a mix of at least 2 CF practices, vii) clarifying the interaction with the CAP and the Soil Monitoring Law, viii) basing the Carbon removals calculation on national or European SOC maps, land use information and modelling, such as the Roth-C, ix) setting a base price for carbon credits to ensure a minimum level of compensation. These recommendations and many more are proposed to guarantee effective environmental protection, technical and bureaucratic feasibility as well as economic affordability for farmers.

Keywords: soil carbon accounting, carbon farming, carbon credits, Voluntary carbon market, regulatory compliance market, certification

Highlights:

- The EC proposal of regulation on carbon removals still needs to define methodological aspects.
- The EC looks for scientific contribution for the definition of a robust and feasible methodology.
- Extra-EU methodologies propose diverse approaches for carbon removals accounting.
- Based on extra-EU initiatives, recommendations are proposed for the final design of the regulation.

1. Introduction

Soils store the largest terrestrial organic carbon (C) pool (1500-2400 PgC, (IPCC, 2014)), around 3 times the content of the atmosphere (589 PgC, (IPCC, 2014)) and of the vegetation (450-650 PgC, (IPCC, 2014)). To mitigate climate change, it appears evident that soil carbon pool should be maintained and possibly increased. In fact, it has been estimated that an annual increase of 0.4% of the global Soil Organic Carbon (SOC) stocks would potentially compensate for the observed increase of CO_2 in the atmosphere (Rumpel *et al.*, 2020).

However, 33% of global soils (FAO and ITPS, 2015), and 12.7% of the European Union (EU) arable lands are subject to moderate to severe degradation (Panagos *et al.*, 2015). The causes of degradation can be either natural (e.g., erosion due to steep slopes, wildfires, high-speed wind, intense rainfall, droughts) exacerbated by climate change, and/or anthropogenic (e.g., fires, land use change, deforestation, unsustainable agronomic practices such as mono-cropping, intense tillage, overgrazing, bad irrigation management and soil sealing).

Loss of SOC in agricultural lands is strictly related to soil degradation and to incorrect soil management. Croplands in the EU are estimated to lose about 7.4 million t of C per year (EC, 2021a) and the extent of wetlands and peatlands is steadily decreasing because of artificial drainage, causing to highest portion of GHG emissions from the Agriculture and Land Use, Land Use Change and Forestry (LULUCF) sectors in countries in Central and Northern Europe, such as Germany (Tiemeyer *et al.*, 2020).

To combat SOC losses and possibly increase SOC stocks in agricultural soils, sustainable agricultural practices (Smith *et al.*, 2016), specifically targeted to sequester carbon (*Carbon Farming, CF*), can be applied.

The European Commission (EC) listed the most effective agricultural practices to sequester carbon in agricultural soils in the "Communication on sustainable C-cycles" (EC, 2021b):

i. afforestation and reforestation;
ii. agroforestry;
iii. use of catch crops, cover crops, conservation tillage and landscape features;
iv. conversion of croplands to fallow or of set-aside areas to permanent grasslands;
v. restoration of peatlands and wetlands.

The effort of the agricultural sector to reduce GHG emissions and increase C stocks is part of the wider effort of the European Union (EU) to become climate neutral by 2050, as established in the European Climate Law (European Parliament & Council, 2021). Moreover, a more specific target for net removals by the LULUCF sector (-310 $MtCO_{2eq}$) by 2030 for the EU has been set by the EC in the COM(2021) 554 final and proposed in the Regulation (EU) n. 2023/839 of the European Parliament and of the Council of 19th April 2023 amending Regulation (EU) n. 2018/841 (EU, 2023).

To achieve these targets, GHG emissions from the agricultural sector must be significantly reduced, and the unavoidable emissions from all sectors (agriculture, cement and steel production, aviation, maritime transport) must be offset. This strategy is in line with the Intergovernmental Panel on Climate Change (IPCC) forecasts that highlight that limiting global

warming to 1.5°C relative to pre-industrial times is possible only if carbon removals are included in the scenarios (IPCC, 2018). In this perspective, the EC has proposed a regulation to establish an EU certification framework for carbon removals to compensate unavoidable emissions (EC, 2022) through:

i) permanent carbon storage (e.g., bioenergy with carbon capture and storage and direct air carbon capture and storage),
ii) carbon farming and
iii) carbon storage in products (carbon stored in long-lasting products or materials, such as furniture made of wood).

Carbon-removals certificates can be used to issue carbon credits that can be purchased on the voluntary carbon market by subjects that *want* to offset their emissions on a voluntary basis. The voluntary carbon market that the proposal of regulation refers to is thought to be established and regulated at the European level. In the case of carbon farming practices, SOC stocks and their variation over time is thought to be assessed through soil carbon accounting methodologies described in the regulation and verified by authorized certification bodies. The resulting carbon credits are thought to be traded to offset emissions from the sectors listed in the Effort Sharing Regulation (ESR), while it is forbidden to sell credits to those sectors under the Emission Trading System (ETS). The ETS is the European regulated carbon market, differing from the voluntary market in that it fixes the number of credits that can be exchanged between energy-intensive sectors to compensate hard-to-abate emissions. Regulated carbon markets exist in other contexts too, such as California (U.S.), Alberta (Canada) and Australia and are concrete outcomes of international agreements such as the Climate Change Convention of the United Nation (UNFCCC), the Kyoto Protocol and successors.

In non-EU contexts, credits issued from carbon farming can also access the regulated carbon market where credits can be purchased by subjects that *must* offset their emissions. For instance, in the case of California, removals quantification, monitoring, verification and reporting (MRV) methodologies developed by private entities to account for carbon removals in agriculture such as the American Carbon Registry (ACR) and the Climate Action Reserve (CAR), have been approved by the California Air Resources Board (ARB) to serve for the California cap-and-trade market (ACR, 2019; CAR, 2020; Government of California, 2018). In Australia, methodologies are defined directly by governmental bodies (Australian Government, 2020; Clean Energy Regulator of the Australian Government, 2021; Minister for Industry Energy and Emissions Reduction of the Australian Government, 2021).

This is evidence of the role that agriculture plays in different countries to offset emissions from other sectors. Nevertheless, the voluntary carbon market is facing two fundamental problems in addressing the carbon removal strategy of climate change mitigation (Boyd *et al.*, 2023):

i. at least 90% of the offsets traded in the voluntary market have been issued upon avoided emissions (e.g., avoided deforestation), therefore they do not correspond to a reduction in atmospheric carbon amounts;
ii. carbon removals estimates based on different methodologies are not comparable for their accuracy as well as for the guaranteed timescale of the carbon storage, and

therefore they differ in their effectiveness in mitigating climate change although they are traded on the same market with the same price.

The European proposal of regulation is working in the direction of solving these two problems by issuing credits upon carbon removals and by proposing one single methodology of quantification and MRV of carbon removals to be sold in the EU market.

The proposal is also motivated by the fact that, to date, at least 156 different carbon removal certification schemes have developed in Europe in the absence of common rules (See: http://reports.crea.gov.it/powerbi/CarbonSchemesInventory.html).

However, the proposal of regulation is currently under review by the European Parliament and the Council, following the standard legislative process, and is still very vague and will be better defined from a methodological point of view in delegated and executive acts that will be defined in the following months.

In this article we aim at comparing extra-EU examples of carbon farming removals quantification and MRV methodologies and certification frameworks with the proposal of regulation of the EC, to learn from success stories and failure to formulate policy recommendations that can contribute to finalize the regulation by guaranteeing both effective environmental protection, technical and bureaucratic feasibility as well as economic affordability for farmers.

2. Materials & Methods

In the present work we selected 7 extra-EU carbon credits initiatives, reported in Tab. 1., which have a methodology dedicated to the estimation of carbon stocks in the soil and their variation due to the application of sustainable agricultural practices. These methodologies have been compared with the European Commission proposal of regulation on carbon removals - COM(2022) 672 (Tab. 1). Five of these methodologies are in use today, while VM0042 Methodology for Improved Agricultural Land Management v 1.0 by Verra is under revision and the Quantification Protocol For Conservation Cropping Version: 1.0 of the Alberta Governments has been withdrawn in December 2021 (Tab. 1).

The analysis of the methodologies listed in Tab. 1 focused on the following aspects:

- **Eligibility criteria** (lands and agricultural practices)
- **Carbon removals estimates:**
    - **Baseline:** reference scenario under which the carbon removal activity was not applied and the corresponding SOC stocks and GHG emissions
    - **Additionality**, a concept that can refer to:
        - the carbon removals, that would not have occurred in the absence of the project activities, that means in the baseline scenarios,
        - the agricultural management activity, that should go beyond the obligations required by law – regulatory additionality – or would not have

taken place if not incentivized by the carbon credits mechanism – financial additionality

- **Soil carbon accounting method** used for the estimate of carbon stocks prior to the carbon removal activity (t0) and after a pre-defined amount of time (t1):
  - Soil sampling at the farm scale (sampling scale and frequency, minimum number of samples, sampling method, analytical method)
  - Default values (e.g., SOC stocks at t0 retrieved from SOC maps or other regionalized information tools; SOC stocks at t1 and GHG emissions estimated through emission factors for each applied measure and possibly pedoclimatic zone)
  - Remote sensing
  - Modelling (with SOC at t0 being estimated by soil sampling or default values)
- **Permanence:** carbon removals should be guaranteed for the long term in order to be effective for climate change mitigation, therefore methodologies set a minimum time frame during which carbon removals activities have to be applied
- **Risk of reversal**: the risk that the carbon that is captured and stored through a carbon removal activity is released back into the atmosphere
- **Risk of leakage:** the risk that higher GHG emissions or SOC losses occur in areas outside the carbon removal project area, as a consequence of the project itself
- **Other carbon pools** accounted for in the calculation of carbon removals (other than SOC, e.g. aboveground and belowground biomass)
- **Other GHG emissions** accounted for (CO_2 fluxes not related to SOC dynamics and non-CO_2 GHG emissions)
- **Other monitored soil qualities**

- **Frequency of monitoring and verification** by a third-party verification body. Upon this activity, carbon credits can be issued by the certification bodies
- **Crediting period:** min and max amount of time, after the beginning of the project, set for the issuing of credits
- **Number of projects, issued credits and market accessibility** (voluntary or regulatory compliance markets).

Information was retrieved online from the organization/program websites and official documentation related to the developed methodologies (Tab. 1).

Finally, a comparison with the approach of the EC proposal of regulation about a certification framework for carbon removals (EC, 2022) has been made for all the aspects listed above.

The review of the methodologies highlighted the diversity of the approaches applied. Given the complexity of the topic, it is appropriate to break down the analysis into transversal principles. The complete analysis of the methodologies is reported in Annex 1.

3. Results and discussion[1]

3.1 Eligibility criteria

3.1.1 Land eligibility

While the EC proposal of regulation on carbon removals doesn't specify which lands are eligible for carbon farming projects development, all other methodologies define the criteria for lands eligibility (Tab. 2).

The two protocols referring to the avoidance of conversion of grasslands, require lands to be grasslands for at least 10 years prior to the start of the project and forbid to develop projects on wetlands. The ACR protocol also requires project developers to demonstrate that the conversion of grassland would have occurred in the absence of the project (Tab. 2).

The protocols referring to soil management in productive lands, show different criteria of land eligibility ranging from simply guaranteeing that the agricultural production is maintained throughout the crediting period (CAR) up to forbidding to develop projects on lands where clearing of native ecosystems occurred, on wetlands, forests and organic soils (VERRA – VCS and the Australian Methodology) and guaranteeing a <5% reduction in crop production (VERRA – VCS) (Tab. 2).

--> Recommendations for the EC proposal of regulation on carbon removals:
To set eligibility criteria for land, such as the exclusion of wetlands, peatlands (apart from restoration activities), forests and recently cleared areas and the obligation of continuing agricultural production on mineral soils.
To identify agricultural soils with the highest potential of SOC stocks increase in the short term (areas under risk of desertification, erosion and loss of organic matter). Applying carbon farming to these areas would guarantee a higher effectiveness in mitigating climate change and will increase confidence by farmers and credits buyers.

[1] In the following sections, for communication purposes, the name of the Organization/Program will be shortened to: American Carbon Registry → ACR; Climate Action Reserve → CAR; Verra - Verified Carbon Standard (VCS) Program → Verra – VCS; Standard for Greenhouse Gas Emission Offset Project Developers Technology, Innovation, and Emissions Reductions Regulation, Alberta government → Alberta government; Emissions Reduction Fund (ERF) established by the Carbon Credits (Carbon Farming Initiative) Act of the Australian Government → Australian Government; European Commission → EC.

Likewise, the name of the protocols was shortened to: Avoided conversion of grasslands and shrublands to crop production 2.0 → Avoided conversion of grasslands 2.0; VM0042 Methodology for Improved Agricultural Land Management v 1.0 → Land Management 1.0; Quantification Protocol For Conservation Cropping Version: 1.0 → Conservation Cropping 1.0; Supplement to the Carbon Credits (Carbon Farming Initiative – Estimation of Soil Organic Carbon Sequestration using Measurement and Models) Methodology Determination 2021 → Carbon Credits Methodology 2021; Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals - COM(2022) 672 final → Proposal of regulation on carbon removals

3.1.2 *Eligible agricultural practices*

The EC proposal of regulation on carbon removals doesn't specify yet the agricultural practices eligible for carbon farming projects, but in the recitals of the regulation it is stated that the "*Regulation should take into account farming practices as referenced in the Communication on Sustainable Carbon Cycles"* than can be summarized as: afforestation, agroforestry, use of catch crops and cover crops, conservative soil management, increasing landscape features, conversion of cropland to fallow or of set-aside to grassland, restoration of peatlands (Tab. 2). It is worthed noticing that most of these practices are already incentivized by the Common Agricultural Policy (CAP) 2023-2027 conditionality, that is a set of fundamental obligations of environmental protection that farmers must fulfil in order to access all form of supports[2] and extra incentives for voluntary actions contributing to soil conservation by farmers both in the first[3] and second pillar[4] of the CAP.

In the protocols referring to the avoided conversion of grasslands, this is the only eligible practice.

In the case of soil management protocols in productive croplands a variety of measures are eligible. 4 protocols out of 5 (CAR, Verra- VCS, Nori and the Australian Government) include fertilization, amendments, irrigation, cover crop, improved tillage practices. 3 methodologies out of 5 include residues management, crop rotation (CAR, Verra- VCS and Nori) and grazing (CAR, Verra- VCS and the Australian Government). Other less common practices eligible in the methodologies are fossil fuel use reduction, agroforestry, crop intensity, use of perennial crops, clay spreading, liming, catch crops. The Alberta government protocol focused only on no-till and on shifting from fallow to continuous cropping, if managed with no-till (Tab. 2).

None of the selected methodologies refers to peatlands and wetlands restoration. This is because the selection focused on the management of productive agricultural mineral soils.

[2] GAEC 1: Maintenance of permanent grassland ration on national level; GAEC 2: adequate protection of wetlands and peatlands; GAEC 3: Ban on burning arable stubble except for plant health reasons; GAEC 5: Erosion-reducing measures from a gradient of 10 % on arable land and permanent cropland; GAEC 6: Minimum soil cover on arable land and permanent cropland between January 1 and February 15; GAEC 7: Requirements concerning crop diversification and crop rotation; GAEC 8: Maintenance of the characteristic elements of the landscape; GAEC 9: ban on the conversion or ploughing of permanent grassland in Natura 2000 sites;

[3] Eco-scheme n. 2: Interrow green covers of tree crops; Eco-scheme n. 4: Extensive forage systems with rotations; Eco-scheme n. 5: Specific measures for pollinating organisms

[4] Environmental, climate-related and other management commitments: AECC 3 Minimum tillage, AECC 4 Burial of organic matter, AECC 5 Interrow green cover of tree crops, AECC 6 Cover crops, AECC 7 Land use change from arable land to permanent grasslands, AECC 8 Pastures management, AECC 9 Management of natura 2000 sites, AECC 10 Management of ecological infrastructures, AECC 11 Creation of ecological corridors and belts, AECC 13 Reductions of emissions from farming (organic amendments), AECC 21 Management of crop residues (Action n. 2), AECC 24 Precision farming, AECC 29 Organic farming

--> Recommendations for the EC proposal of regulation on carbon removals:
Expand the list of eligible agricultural practices by including the input of exogenous organic matter (e.g. biochar, livestock manure and slurry, compost and digestate) to soil through sustainable techniques, crop rotation, crop residues management, precision farming, improved irrigation management, perennial crops and sustainable grazing management.

We recommend not to focus on the application of single carbon farming practices, but rather on a mix of two or more practices to promote the overall soil health in accordance with agroecological principles.
The proposal of regulation should clarify on how it relates with:

- *the Common Agricultural Policy (CAP), to avoid double funding for the same practice,*
- *the Soil Monitoring Law, that defines SOC as one of the criteria for healthy soil condition and that forecasts a soil health certification system complementary with the carbon removal one (EC, 2023).*

3.2 Carbon removals estimate

3.2.1 Baseline

In the proposal of regulation, the EC refers primarily to a standardized baseline that includes regional average environmental, geographical, social, economic, and technological aspects and the associated carbon removals for the applied practice (art. 4). This choice has been made to *"ensure objectivity, minimises compliance and other administrative costs*" (recital 7). In case these regionalized reference data are missing, project developers can refer to a baseline directly assessed in their farms (Tab. 3).

In the case of protocols referring to the avoided grasslands conversion (ACR and CAR), the baseline is the reference scenario of conversion of the grassland and in the case of ACR, the conversion agent must be identified, or in case this information is missing, the probability of the conversion must be estimated (Tab. 3).

In the case of soil management protocols in productive lands, most of the methodologies implies the use of historical agricultural information documented at the farm level (CAR, Verra – VCS, Nori Alberta Government, Australian Government) or described in agricultural census and regional databases (CAR, Nori, Alberta Government). Data for the baseline description have to refer to the previous 3 years (CAR, Verra – VCS, Alberta Government), 5 years (Australian Government) or 10 years (Nori). In the Nori methodology, the baseline also includes weather data. The baseline is updated over time in the CAR, Nori and EC methodologies (Tab. 3).

In CAR and Alberta Government methodologies the emissions and C stocks associated with the baseline scenarios are obtained by default values, and in the case of the Carbon Credits Methodology 2021 of the Australian government it also implies the collection of soil samples (t0, Tab. 3).

The choice to establish a baseline specific for every farm based on historical measured data or to refer to external sources (GIS, photos, regional averages) will impact on the certainty of the reference scenario description, on the administrative burden and costs (Umweltbundesamt, Ramboll, Ecologic, Carbon Counts, 2021) and on the robustness of the application of the additionality principle.

--> Recommendations for the EC proposal of regulation on carbon removals:
An assessment of the baseline choice should be carried out beforehand to identify a good compromise between quantification robustness and feasibility for farmers, to promote both effectiveness in climate change mitigation and high implementation levels.

One option is to consider the Good Agricultural and Environmental Conditions (GAECs) of the CAP (European Parliament and the Council, 2013) as a regulatory baseline. In fact, they are applied as conditionality on 90% of the EU's agricultural land (EC, 2022), and they aim at achieving a sustainable agriculture.

For the initial SOC, we recommend the use of national or European level SOC maps, depending on their availability. We recommend continuing improving the long-term soil monitoring network as foreseen by LUCAS and the Soil Monitoring Law as well as the harmonization of national monitoring data coupled with land use information.

3.2.2 Additionality

The EC proposal of regulation requires the carbon removal activity to be additional in two perspectives: it must go beyond the Union and national law requirements (regulatory surplus test) and it must be applied because of the carbon removal certification incentive (financial additionality). In case the standardized baseline is set, the principle of additionality is considered to be complied with; if the baseline is established at farm level, additionality shall be demonstrated (Tab. 3).

The regulatory surplus test is also required by the ACR, CAR and Verra-VCS methodologies (Tab. 3). These protocols require also the performance standard test that implies, e.g. in the case of the Avoided grassland conversion protocol of CAR:

- a financial threshold (difference in the value of cropland compared to pastureland) to account for the financial barrier to project activities because of the economic incentives supporting the conversion of grasslands to croplands;
- a suitability threshold (suitability of the land to be converted to cropland).

In the case of protocols dealing with soil management in productive lands, additionality refers to the application of a new practice for all protocols (CAR, Verra – VCA, Alberta and Australian Government) apart from the Nori that requires a demonstration SOC increment over the baseline scenario (Tab. 3).

--> Recommendations for the EC proposal of regulation on carbon removals:
If GAECs are set as regulatory baseline, additionality shall be defined as the application of new (additional) practices at the farm level, in comparison with the GAECs.

3.2.3 Soil organic carbon assessment method

The EC proposal of regulation on carbon removals doesn't include yet detailed information on how the monitoring of soil carbon stocks and their variation over time must be done. In article 4(4) the proposal states that *"Carbon removals shall be quantified in a relevant, accurate, complete, consistent, comparable and transparent manner".* According to the art. 8 certification methodologies guaranteeing the robustness of carbon removals, will be established in delegated acts that will be adopted by the EC. In the recital (7) of the regulations, the EC suggests promoting "*the use of available digital technologies, including electronic databases and geographic information systems, remote sensing, artificial intelligence and machine learning, and of electronic maps*" to "*decrease the costs of establishing baselines and of monitoring carbon removal activities*". The proposal of regulation does not mention modelling and soil sampling (Tab. 4).

Six out of the seven extra-EU methodologies analysed in the present article opt for modelling, of which ACR, Verra – VCS and the Australian Government propose modelling as an option alternative to soil sampling and the Soil Enrichment Protocol 1.1 of CAR and the Methodology of the Australian Government require to coupling modelling with soil sampling. The second most frequently proposed method is soil sampling (4 methodologies, of which 2 propose it as optional). The use of default values is proposed by two methodologies while remote sensing only by Verra – VCS (Tab. 4). In case the methodology includes soil sampling, additional information regarding the sampling scale and frequency, minimum number of soil samples, sampling method and C analytical method can be found in Annex 1.

Using simplified methodologies based on readily observable proxy data can streamline carbon removal assessments, reducing transaction costs. However, these approaches require prior scientific knowledge and may introduce project-level uncertainty. It's crucial and complex to find a balance between cost-efficiency and accuracy (Umweltbundesamt, Ramboll, Ecologic, Carbon Counts, 2021).

--> Recommendations for the EC proposal of regulation on carbon removals:
Use of soil maps to infer SOC stocks and land use maps related to the baseline period. Upon these data, the estimate of the SOC dynamics shall be made by modelling, such as the Rothamsted carbon (Roth-C, Farina et al., 2013). Alternatively, the information about land use prior to the beginning of the project can be retrieved from the farm company files.
In an initial phase, while research efforts are put for the best MRV methodology set-up, tying the certification of carbon removals to some priority areas (e.g., areas under risk of desertification, erosion ad loss of organic matter) could ease to fulfill quantification requirements.

It would be ideal to fund research projects where several methodologies are compared to estimate carbon removals and build transfer functions.

We recommend running a beforehand social-economic survey on the feasibility and acceptability of the MRV systems by farmers as well as stimulating the aggregation of multiple enterprise-scale carbon removal projects to mitigate MRV costs and risks associated with leakage and reversal.
For soil cover and agroforestry, we recommend the use of satellite images in MRV.
We recommend continuing reinforcing the long-term soil monitoring network foreseen by LUCAS and the Soil Monitoring Law as well as the harmonization of national monitoring data coupled with land use information and to keep this information open access. This will help assessing soil carbon, improve modeling approaches, align them with on-the-ground farming practice and different pedoclimatic regions.

Finally, we recommend updating the delegated acts of the regulation upon the results of the several research projects funded at the EU level to define MRV methodologies for CF.

3.2.4 Permanence, risk of reversal and leakage

In the proposal of regulation of the EC, permanence, risk of reversal and leakage are mentioned, but not yet defined in an exhaustive way. For the permanence of carbon removals in carbon farming activities, in the art. 6(1), the proposal of regulation states that "*a carbon removal activity aims at ensuring the long-term storage of carbon"* and that *"For carbon farming […] the carbon stored by a carbon removal activity shall be considered released to the atmosphere at the end of the monitoring period"* but there is not any reference to the minimum duration of the monitoring period (Tab. 5).

Six of the seven international methodologies analysed in the present article give a precise reference to the permanence length which is among 5 years (ACR) and 100 years (CAR and the Australian Government). Because 100 years is a very long timeframe, farmers have the option to reduce the permanence time but with some forms of disincentive: 20% discount on the emitted credits in the case of the Australian Government and credits emission ex-post and on an annual base, instead of ex-ante emission, in the case of CAR Soil Enrichment Protocol 1.1. Verra – VCS methodology doesn't refer to a precise time frame but evaluates the non-permanence risk by the VCS AFOLU Tool (Tab. 5).

--> Recommendations for the EC proposal of regulation on carbon removals:
Define a precise permanence time frame for carbon removals in soil, for each eligible carbon farming practice.
If GAEC are set as baseline, the monitoring time of carbon removals shall align with the CAP program's period.
Eliminate the art. 6(3): "For carbon farming […] the carbon stored by a carbon removal activity shall be considered released to the atmosphere at the end of the monitoring period", in fact this is contrast with the requirement of CF to contributing to the national inventories of the LULUCF sector.

Regarding the risk of reversals of carbon removals, the proposal of regulation at the art. 6, paragraph 2 (a) states that "*Operators […] shall monitor and mitigate any risk of release of the stored carbon occurring during the monitoring period*" and in the recitals, the proposal of regulation refers to several liability mechanisms, such as "*discounting of carbon removal units, collective buffers or accounts of carbon removal units, and up-front insurance mechanisms*…" but without opting for one of these liability options in the articles section (Tab. 5).

Outside the EU, 4 methodologies out of 7 (ACR, CAR both protocols and Verra – VCS) account for the reversal risk by estimating the risk and then assigning a % of the issued credits to a buffer pool. The Alberta Conservation Cropping 1.0 protocol applies default discount to the issued credits depending on the types of projects (from 7.5 up to 20% discount) but only if the soil disturbance event concerned more than 10% of the surface area. The Australian Government applies a default buffer value of 5% if the permanence is set to 100 years and a 25% buffer value if the permanence is set to 25 years. The Nori Croplands Methodology 1.3 doesn't account for the reversal risk (Tab. 5).

--> Recommendations for the EC proposal of regulation on carbon removals
We recommend defining how the risk of reversal is taken into account in the article section of the regulation and then provide more details on the methodology in the delegated acts.
We recommend that a % of the issued credits will be assigned to a buffer pool based on a risk assessment.

Regarding the risk of leakage, the proposal of the EC states in the recitals that *"the carbon captured […] should outweigh the emissions […] that can be caused by carbon leakage".* This principle is not mentioned in the following articles section (Tab. 5).

The 2 international methodologies referring to the avoided conversion of grasslands set a default value of 20% discount factor applied to the baseline emissions (ACR: market leakage; CAR: displacement of livestock and crop yields reduction > 5%), while Verra – VCS also considers the GHG emissions linked to the application of extra manure in the field, compared to the baseline. The Alberta Government considered this risk as minimal (Oldfield, 2021). The Nori methodology states generally that "*Verification will establish if SOC stock gains result in losses outside of project boundary*" and, similarly, the Australian Carbon Credits Methodology 2021 states that "*The Regulator notifies the project for non-genuine carbon abatement"* (Tab. 5).

--> Recommendations for the EC proposal of regulation on carbon removals
We recommend defining how the risk of leakage is taken into account in the article section of the regulation and then provide more details on the methodology in the delegated acts.
We recommend that a default % discount factor on issued credits is applied depending on the agricultural practice and on the land use, based on estimation of possible reduced yields.

3.2.5 Other carbon pools, GHG fluxes and soil qualities accounted for

In the calculation of carbon removals, methodologies can account for biogenic carbon pools different from SOC. The EC proposal of regulation include in the organic carbon pools also above-ground biomass, below-ground biomass, litter and dead wood, even if no more technical specifications are provided yet (Tab. 6).
In the framework of ACR it is optional to account for above and below-ground biomass; in the CAR Avoided grassland conversion protocol 2.1 only belowground biomass while in the Verra – VCS and in the Nori Croplands Methodology 1.3, aboveground woody biomass is accounted for. The CAR Soil Enrichment Protocol 1.1, the Alberta Conservation Cropping 1.0 and the Australian Carbon Credits Methodology 2021 do not account for different biogenic carbon pools from SOC (Tab. 6).

> *--> Recommendations for the EC proposal of regulation on carbon removals:*
> *We recommend clarifying how other organic carbon pools such as above-ground biomass, below-ground biomass, litter and dead wood are included in the calculation of carbon removals.*

Regarding the accounting of other GHG emissions (different from SOC-CO_2), the EC proposal of regulation states that when calculating the net carbon removals, "*direct and indirect greenhouse gas emissions, other than those from biogenic carbon pools in the case of carbon farming, which are due to the implementation of the carbon removal activity*", are included, referring for instance to the use of fuel in agricultural machinery (Tab. 6). The exclusion of reduction of GHG emissions from the count is stated in the recital 8: "*A reduction in greenhouse gas emissions resulting from the implementation of the carbon removal activity should not be taken into account to quantify the net carbon removal benefit, but should be considered as a co-benefit towards the sustainability objective of climate change mitigation; by being reported on the certificates, decreases in greenhouse gas emissions (like the other sustainability co-benefits) can increase the value of the certified carbon removals*."

Reversely, all the international methodologies analysed include, in the calculations of carbon removals, other greenhouse gas emissions. Depending on the methodology, the emissions considered are:

- N_2O emissions deriving from fertilizers, amendments, irrigation, fixing crops, tillage, residues;
- CH_4 from livestock and soil, especially in the case of flooded rice cultivation, tillage, residues;
- CO_2 deriving from fuel combustion in agricultural machinery and urea and herbicides production;
- emissions deriving from biomass burning (Tab. 6).

--> Recommendations for the EC proposal of regulation on carbon removals:
In the calculation of net carbon removals, avoided GHG emissions should be accounted for, given that the overall aim of the regulation is climate change mitigation.

Regarding the monitoring of other soil qualities, the EC proposal of regulation refers to six criteria of sustainability, a couple of which might be measured in the soil: *"(e) pollution prevention and control; (f) protection and restoration of biodiversity and ecosystems"* but further explanations will be provided in the delegated acts that will be adopted in the near future (Tab. 6).

Four of the seven international methodologies studied, do not request any other soil quality monitoring (ACR, CAR - Soil Enrichment Protocol 1.1, Conservation Cropping 1.0 of the Alberta Government and Australian Government Determination 2021) and Verra – VCS, if carbon removals are estimated via modelling, requires to directly measure or retrieve from published soil maps the soil characteristics requested in the chosen model. Instead, CAR, in the Avoided grassland conversion protocol 2.1, requires field monitoring of soil/site stability, hydrologic function and biotic integrity with field campaigns for the first 2 years and then once every six years and Nori requires an evaluation of soil health and ability to retain nitrates (optional) and other ecosystem services (e.g. water quality services, etc.), for which farmers can access other markets (Tab. 6).

--> Recommandations for the EC proposal of regulation on carbon removals:
We agree on the necessity to respect sustainability criteria described in art. 7 but monitoring should focus on the main aim of the regulation, which are carbon removals, and not on other soil qualities.

3.3 Frequency of monitoring and crediting period

The EC proposal of regulation on carbon removals doesn't specify yet the required frequency of monitoring nor the length of the crediting period.

Five of the seven extra-EU methodologies set an annual frequency of monitoring, while the crediting period ranges from 5 up to 50 years. It is relevant to notice that the Alberta Government states in the methodology that the crediting period for conservation cropping using no-till management is set to 20 years because "*it takes approximately 20 years for soil reservoirs, managed under conservation cropping, to reach saturation, that is the point where soils reach equilibrium and no new incremental carbon will be stored*" (Tab. 7).

--> Recommendations for the EC proposal of regulation on carbon removals
If GAEC are set as baseline, the monitoring time of carbon removals shall align with the CAP program's period.

3.4 Level of implementation and market accessibility

The EC regulation on carbon removals is still a proposal, therefore no projects have been approved yet and no credits have been issued (Tab. 8).

The highest number of projects approved are registered within the Carbon Credits Methodology of Australia (454), but credits have been issued only for one project, being the methodology very recent. The highest number of credits has been issued in the framework of the Conservation Cropping 1.0 of the Alberta Government, now withdrawn (around 7 million credits issued) after another very successful initiative was applied (Tillage System Management Protocol, around 10 million credits issued) (Tab. 8).

According to Oldfield (2021) the high level of implementation of the Alberta's program can be explained by two driving factors. First, the emission offsets issued in the framework of the Conservation Cropping 1.0 protocol can be used by industrial facilities with emissions higher than 100,000 t CO_2e/y to meet their reduction requirements (regulated market, Tab. 8). Even though we are aware of the possible driving force of binding carbon removals from carbon farming to the regulated emissions sector (Directive 2003/87/EC), we believe that trading carbon removals only on the voluntary carbon market is a beneficial choice to the European climate policy. Second, the Alberta's protocol is action-based and refers to default values to estimate the increase in SOC due to no-till management.

Opting for an action-based approach might be an advantage because of i) the high cost of soil monitoring if based on soil sampling, ii) the lower level of reliability of other methods, iii) the low accumulation of SOC over a short time, iv) the lower risk borne by farmers compared with a result-based certification scheme, where farmers face upfront costs in view of uncertain outcomes (Derissen and Quaas, 2013; Drechsler, 2017; White and Hanley, 2016).

The European Union is turning towards a result-based approach also in the CAP, considering that this is the only way to guarantee that the carbon farming, and more in general environmentally friendly practices for which farmers get paid for, are effective in achieving the expected results for climate mitigation and avoid greenwashing (EC, 2022).

--> Recommendations for the EC proposal of regulation on carbon removals:
We recommend keeping building a MRV system which is scientifically sound but not too demanding for the farmers, as it is foreseen in the proposal of regulation, in order to guarantee that farmers are rewarded for their actions but proportionally to predicted results.

We recommend setting a base price for carbon credits to ensure a minimum level of compensation for carbon agriculture. Compensation should be a combination of fixed payments for the implementation of measures and additional rewards based on the results of carbon sequestration (Demeyer et al. 2021).

Conclusions

Mitigating climate change through carbon farming is an uncertain approach due to the difficulties in SOC monitoring and the risks of reversal and leakage. Reducing GHG emissions should be the main aim of the EU policy on climate. Given the necessity to compensate the hard-to-abate emissions, in order to encourage a wider participation in carbon offsetting projects and guaranteeing to comply with the EU GHG targets, it is necessary to set-up a reliable and feasible MRV methodology, keeping in mind also that carbon farming practices can bring co-benefits such as climate change adaptation.

Based on a review of 7 extra-EU carbon credits initiatives, focusing on methodologies for carbon accounting in agricultural soils, we realized the diversity of approaches and we recommend that the proposed European Union regulation on carbon removals (COM(2022) 672 final):

- Set eligibility criteria for land.
- Prioritize the application of carbon farming projects on low-SOC lands.
- Uses the GAECs of the CAP as a regulatory baseline.
- Define additionality as the application of new practices in comparison with the GAECs.
- Expand the range of eligible agricultural practices.
- Set a permanence time frame for each agricultural practice.
- Require the application of a mix of at least 2 CF practices.
- Clarify the interaction with the CAP and the Soil Monitoring Law.
- Base the carbon removals calculation on national or European SOC maps, land use information and modelling, such as the Roth-C.
- Include GHG emission in the calculation of carbon removals.
- Clarify how other carbon pools are included in the calculation of carbon removals.
- The monitoring period shall be aligned with the CAP program.
- Update the MRV methodologies based on research projects already running on the topic, in Europe.
- Promote research on the comparison of MRV methodologies.
- Promote aggregation of farm-scale initiatives to mitigate MRV costs and risks.
- Set-up a buffer pool to account for the risk of reversal.
- Apply default-value discount to account for leakage risk.
- To set a base price for carbon credits to ensure a minimum level of compensation.

These recommendations are designed to ensure a harmonized combination of environmental conservation, technical and administrative feasibility, and economic viability for farmers.

Conflict of interest

The authors have no conflicts of interest to declare.

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Country	Region	Organization/Program	Protocol	Status	Website	Documental sources
U.S.A.		American Carbon Registry (ACR)	Avoided conversion of grasslands and shrublands to crop production 2.0	Active	https://americancarbonregistry.org/	ACR, 2019
U.S.A.		Climate Action Reserve (CAR)	Soil Enrichment Protocol v 1.1	Active	https://www.climateactionreserve.org/	CAR, 2022
U.S.A.		Climate Action Reserve (CAR)	Avoided grassland conversion protocol 2.1	Active	https://www.climateactionreserve.org/	CAR, 2020
U.S.A.		Verra - Verified Carbon Standard (VCS) Program	VM0042 Methodology for Improved Agricultural Land Management v 1.0	Approved but under revision	https://verra.org/	VCS, 2020
U.S.A.		Nori	Nori Croplands Methodology, v 1.3	Active	https://nori.com/	Nori, 2021
Canada	Alberta	Standard for Greenhouse Gas Emission Offset Project Developers Technology, Innovation, and Emissions Reductions Regulation, Alberta government	Quantification Protocol for Conservation Cropping Version: 1.0	Withdrawn on December 31, 2021	https://open.alberta.ca/publications/9780778596288	Government of Aberta, 2012
Australia		Emissions Reduction Fund (ERF) established by the Carbon Credits (Carbon Farming Initiative) Act of the Australian Government	Supplement to the Carbon Credits (Carbon Farming Initiative - Estimation of Soil Organic Carbon Sequestration using Measurement and Models) Methodology Determination 2021	Active	https://www.legislation.gov.au/Details/F2021L01696	Minister for Industry Energy and Emissions Reduction of the Australian Government, 2021 Clean Energy Regulator of the Australian Government, 2021
Europe	European Union	European Commission	Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals - COM(2022) 672 final	Proposal	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0672	EC, 2022

Tab. 1: Extra-EU and EC carbon credits initiatives considered in the present article which have a methodology dedicated to the estimation of carbon stocks in the soil and their variation over time due to application of sustainable agricultural practices; description of their status of implementation, websites and documental sources used for the analysis.

Organization	Protocol	Land eligibility	Eligible agricultural practices
ACR	Avoided conversion of grasslands 2.0	Grassland or shrubland at least for 10 years before. Conversion to cropland would occur in the absence of the project. Organic soils, peatlands, wetlands are not eligible.	Avoided conversion of grasslands and shrublands to croplands
CAR	Avoided grassland conversion protocol 2.1	Grassland or shrubland at least for 10 years before, with available data for modelling and baseline. Wetlands and government land not eligible.	Avoided conversion of grasslands to croplands
	Soil Enrichment Protocol 1.1	Cropland, grassland, or pastureland remaining in agricultural production throughout the crediting period	Fertilization, amendments, irrigation, tillage, residues management, crop rotation, cover crop, fossil fuel, grazing.
Verra - VCS	Land Management 1.0	Cropland or grassland at the project start date and throughout the crediting period. No clearing of native ecosystems within the 10-year. No reduction > 5% in productivity. Wetlands are not eligible.	Fertilization, amendment, irrigation, tillage, residues management, crop rotation, cover crop, agroforestry, grazing.
Nori	Nori Croplands Methodology 1.3	Croplands	Fertilization, amendments, irrigation, tillage, residues management, crop rotation and crop intensity, cover crops, perennials
Alberta Government	Conservation Cropping 1.0	Lands producing annual crops or first year of seeding of a perennial crop.	No till + Shifting from fallow to continuous cropping if managed with no till
Australian Government	Carbon Credits Methodology 2021	Pastureland, cropland, or bare fallow for 5 years before the project. Forests and organic soils not eligible. No illegal clearing of a native forest or illegal draining of wetlands.	Fertilization, amendments, irrigation, inversion tillage, clay spreading, liming, catch crops, cover crops, re-establishing grazing, etc.
EC	Proposal of regulation on carbon removals	Not specified yet	*"Should take into account farming practices as referenced in the Communication on Sustainable Carbon Cycles"*: afforestation, agroforestry, use of catch crops and cover crops, conservative soil management, increasing landscape features, conversion of cropland to fallow or of set-aside to grassland, restoration of peatland

Tab. 2: Land eligibility and eligible agricultural practices in the different agricultural soil carbon credits methodologies analysed in the present article

Organization	Protocol	Baseline	Additionality
ACR	Avoided conversion of grasslands 2.0	Scenario of conversion to croplands and associated practices. Updated every 5 years. Identification of the conversion agent or probability.	Regulatory surplus test Performance standard test
CAR	Avoided grassland conversion protocol 2.1	Scenario of conversion to croplands and associated practices. Valid for up to 50 years. Default emission factors developed through a probabilistic approach.	Regulatory surplus test Performance standard test
	Soil Enrichment Protocol 1.1	Min. of 3 years of historical management information. Use of regional average allowed after quality check by CAR.	New practice Regulatory surplus test Performance standard test
Verra - VCS	Land Management 1.0	Scenario of continuation of pre-project agricultural management practices. Min. of 3 years.	New or change in practices (at least 5% delta) Regulatory surplus test Performance standard test
Nori	Nori Croplands Methodology 1.3	Prior 10 years of historical agronomic practices and past weather data. Historical management data for at least 3 years + proxies taken from databases (such as USDA/NRCS) by Nori. Dynamic baseline updated based on new weather data.	Must show SOC increment over baseline scenario
Alberta Government	Conservation Cropping 1.0	Conservative tillage management: Census of Agriculture + carbon seq. default values. Summerfallow reduction: use a historic project baseline based on 3 years records.	New practice
Australian Government	Carbon Credits Methodology 2021	Scenario describing 5 years historical data where the land was used for pasture, cropping or bare fallow + soil sampling (t0).	New practice
EC	Proposal of regulation on carbon removals	"*The standard carbon removal performance of comparable activities in similar social, economic, environmental and technological circumstances and take into account the geographical context. Where duly justified, the baseline may be based on the individual carbon removal performance of that activity*." *"The baseline shall be periodically updated"*.	Regulatory surplus test Due to the incentive effect of the certification

655 **Tab. 3:** Baseline and additionality criteria set in the different agricultural soil carbon credits methodologies analysed in the present article.

656

Organization	Protocol	Soil organic carbon assessment method			
		Modeling	**Default values**	**Remote sensing**	**Soil sampling**
ACR	Avoided conversion of grasslands 2.0	**Y** e.g. DAYCENT	**N**	**N**	**Y** Alternative to modeling
CAR	Avoided grassland conversion protocol 2.1	**N**	**Y** Probabilistic approach	**N**	**N**
	Soil Enrichment Protocol 1.1	**Y** + sampling	**N**	**N**	Y t0 + t5 + t10… + modeling
Verra - VCS	Land Management 1.0	**Y** optional	**N**	**Y** optional	**Y** optional
Nori	Nori Croplands Methodology 1.3	**Y** Tier-3 DAYCENT	**N**	**N**	**N**
Alberta Government	Conservation Cropping 1.0	**Y** Empirical model based on default factor	**Y**	**N**	**N**
Australian Government	Carbon Credits Methodology 2021	**Y** optional	**N**	**N**	**Y** mandatory
EC	Proposal of regulation on carbon removals	Not mentioned	Mentioned in the recitals	Mentioned in the recitals	Mentioned in the recitals but considered not applicable due to analytical costs

Tab. 4: Soil carbon assessment methods proposed in the agricultural soil carbon credits methodologies analysed in the present article (Y = YES, N = NO).

Organization	Protocol	Permanence	Reversal	Leakage
ACR	Avoided conversion of grasslands 2.0	= crediting period 5 - 40 years	Risk assessment via an ACR tool % of credits issued goes to a buffer pool	Default value of 20% market leakage
CAR	Avoided grassland conversion protocol 2.1	100 years after credits issuance. Monitoring and verification period > crediting period	Risk assessment % of credits issued goes to a buffer pool	20% leakage effect due to displacement of livestock and crop yields reduction
	Soil Enrichment Protocol 1.1	100 years: credits issued ex-ante. If less: credits are 1% of the tCO2e stored/year. Issued ex-post	Risk rating % of credits issued goes to a buffer pool	Accounts for displacement of livestock and decline in crop yields (>5%).
Verra - VCS	Land Management 1.0	Non-Permanence Risk calculated by the VCS AFOLU Tool	Risk assessment % of credits issued goes to a buffer pool	Extra manure + productivity decline (>5%) + displacement of livestock (emissions as if steady number).
Nori	Nori Croplands Methodology 1.3	10 years	-	"*Verification will establish if SOC stock gains result in losses outside of project boundary*"
Alberta Government	Conservation Cropping 1.0	20 years	Discount factors due to tillage events = 7.5 - 20% of credits (if <10% of the field area, not considered).	Based on ISO 14064:2, activity shift deemed minimal
Australian Government	Carbon Credits Methodology 2021	100 years Or 25 years with 20% discount on credits issued	Buffer: 5% if 100-year permanence 25% if 25-year permanence	The Regulator notifies the project for non-genuine carbon abatement
EC	Proposal of regulation on carbon removals	Long-term storage and undefined monitoring period	*"Operators […] shall monitor and mitigate any risk of release of the stored carbon occurring during the monitoring period"* + in the recitals it mentions liability mechanisms	*"the carbon captured […] should outweigh the emissions […] that can be caused by carbon leakage"*

659 **Tab. 5:** Permanence, risk of reversal and risk of leakage in the different agricultural soil carbon credits
660 methodologies analysed in the present article.

661

Organization	Protocol	*Other (different from soil) carbon pools accounted for*	*Other GHG fluxes (different from SOC-CO_2) accounted for*	*Other soil qualities monitoring*
ACR	Avoided conversion of grasslands 2.0	Optional: above and below-ground biomass.	• Direct N_2O emissions from synthetic fertilizers and organic N amendments • CO_2 emissions from fossil fuel combustion optional • CH_4 emissions only if livestock are present	None
CAR	Avoided grassland conversion protocol 2.1	Belowground biomass	• soil and fertilizer N_2O emissions default factors from IPCC • N_2O and CH_4 from burning and grazing from monitored data; N_2O emissions from irrigation • fossil fuel from agricultural equipment	• Soil/site stability; • Hydrologic function; • Biotic integrity field campaigns for the first 2 years and then every 6 y.
	Soil Enrichment Protocol 1.1	None	CH_4 and N_2O	No. Only attestation of project compliancy with environmental regulations in the verification period.
Verra - VCS	Land Management 1.0	Aboveground woody biomass (if highly impacted by the project activities) with CDM A/R Tools*	• fossil fuels if highly impacted • CH_4 emissions from soil if highly impacted, livestock, manure, biomass burning • N_20 from manure, fertilizers, fixing crops, biomass burning • mainly based on default values derived from IPCC (2019)	If carbon removals are estimated via modelling, the soil characteristics requested in the chosen model (different from SOC and bulk density) must be directly measured or retrieved from published soil maps
Nori	Nori Croplands Methodology 1.3	Organic carbon sequestration in woody biomass (orchard and vineyard crops)	• Direct N_2O) emissions from synthetic fertilizer and organic matter additions • CO_2 emissions from urea fertilizer use and liming • CO and CH_4 from biomass burning • CH_4 and N_2O from flooded rice cultivation	• Compliance with existing laws and regulations • evaluation of soil health and ability to retain nitrates (optional) and other ecosystem services (e.g. water quality services, etc.) can be sold on other markets
Alberta Government	Conservation Cropping 1.0	None	Overall farm's GHG footprint: • N_2O emissions from soils • emissions from fossil fuel use in agricultural machinery • herbicide production	None
Australian Government	Carbon Credits Methodology 2021	None	N_2O and CH_4 – from: livestock, synthetic fertilizer use, tillage events, soil modification activities, residues, and irrigation if emissions from these activities exceed average levels during baseline period	None
EC	Proposal of regulation on carbon removals	above-ground biomass, below-ground biomass, litter, dead wood	When calculating net carbon removals, *"direct and indirect greenhouse gas emissions, other than those from biogenic carbon pools in the case of carbon farming, which are due to the implementation of the carbon removal activity"*, are included. Recital 8: "*A reduction in greenhouse gas emissions resulting from the implementation of the carbon removal activity should not be taken into account to quantify the net carbon removal benefit, but should be considered as a co-benefit*"	*"co-benefits for;* *[…]* *(e) pollution prevention and control; (f) protection and restoration of biodiversity and ecosystems"*

Tab. 6: Other carbon pools, GHG emissions and soil qualities accounted for or monitored in the different methodologies analysed in the present article. *A/R CDM tool = methodology developed by the United Nations Framework Convention on Climate Change (UNFCCC) for an Afforestation or Reforestation project activity under the Clean Development Mechanism (CDM)

Organization	Protocol	Frequency of monitoring	Crediting period
ACR	Avoided conversion of grasslands 2.0	Annual	At least 5 years and no more than 40 years
CAR	Avoided grassland conversion protocol 2.1	Annual	No more than 50 years
	Soil Enrichment Protocol 1.1	Annual	10 years, renewable 2 times up to 30 years
Verra - VCS	Land Management 1.0	At least every five years, or prior to each verification event if less than five years	Not specified
Nori	Nori Croplands Methodology 1.3	Annual farm monitoring but verification of credits is issued every three years.	At least 10 years with credits issued after verification every 3 years
Alberta Government	Conservation Cropping 1.0	Annual	20 years
Australian Government	Carbon Credits Methodology 2021	Minimum of a 6-month period and a maximum of 5 years	25 years
EC	Proposal of regulation on carbon removals	Not specified yet	Not specified yet

665 **Tab. 7:** Frequency of monitoring and crediting period in the different soil carbon accounting
666 methodologies analysed in the present article

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Organization/Program	Protocol	Number of projects	Credits issued	Market accessibility
ACR	Avoided conversion of grasslands 2.0	1 project	166,197	Voluntary Regulated (California Cap-and-Trade + CORSIA)
CAR	Avoided grassland conversion protocol 2.1	20 projects	241,330	Voluntary Regulated (California Cap-and-Trade)
	Soil Enrichment Protocol 1.1	3 projects	133,646	
Verra - VCS	Land Management 1.0	60 projects	0	Voluntary
Nori	Nori Croplands Methodology 1.3	18 projects	123,607	Voluntary
Alberta Government	Conservation Cropping 1.0	122 projects (active, inactive and closed)	17,000,000*	Regulated
Australian Government	Carbon Credits Methodology 2021	454 projects	1,904 issued only from 1 project	Voluntary Regulated
EC	Proposal of regulation on carbon removals	None	None	Voluntary

668 **Tab. 8**: Number of projects, credits issued up to 29th March 2023 and market accessibility in the
669 framework of the different programs

670 *The data reported is cumulative of the Tillage System Management (10 million credits issued) and
671 Conservation Cropping protocols (7 million credits issued) (Van Wyngaarden, 2022).

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