European Commission

Issues relating to the certification of carbon removal through enhanced rock weathering

Prepared by Zara Popstoyanova, Cato Sandford, Chris Malins & Jonathan Lonsdale under service request CLIMATE-30420

October 2026

ICF

Cerulogy

ecodiversity
climate • people • nature

EUROPEAN COMMISSION

Directorate-General for Climate Action
Directorate C – Innovation for a Low Carbon, Resilient Economy
Unit C.3 — Low Carbon Solutions (III): Land Economy & Carbon Removals

Contact: Fabien Ramos

E-mail: CLIMA-FWC-001@ec.europa.eu

European Commission
B-1049 Brussels

Issues relating to the certification of carbon removal through enhanced rock weathering

26 October 2026

Submitted to:

European Commission

Directorate General for Climate Action

Directorate C – Innovation for a Low Carbon, Resilient Economy

By email: CLIMA-FWC-001@ec.europa.eu

In association with:

Cerulogy

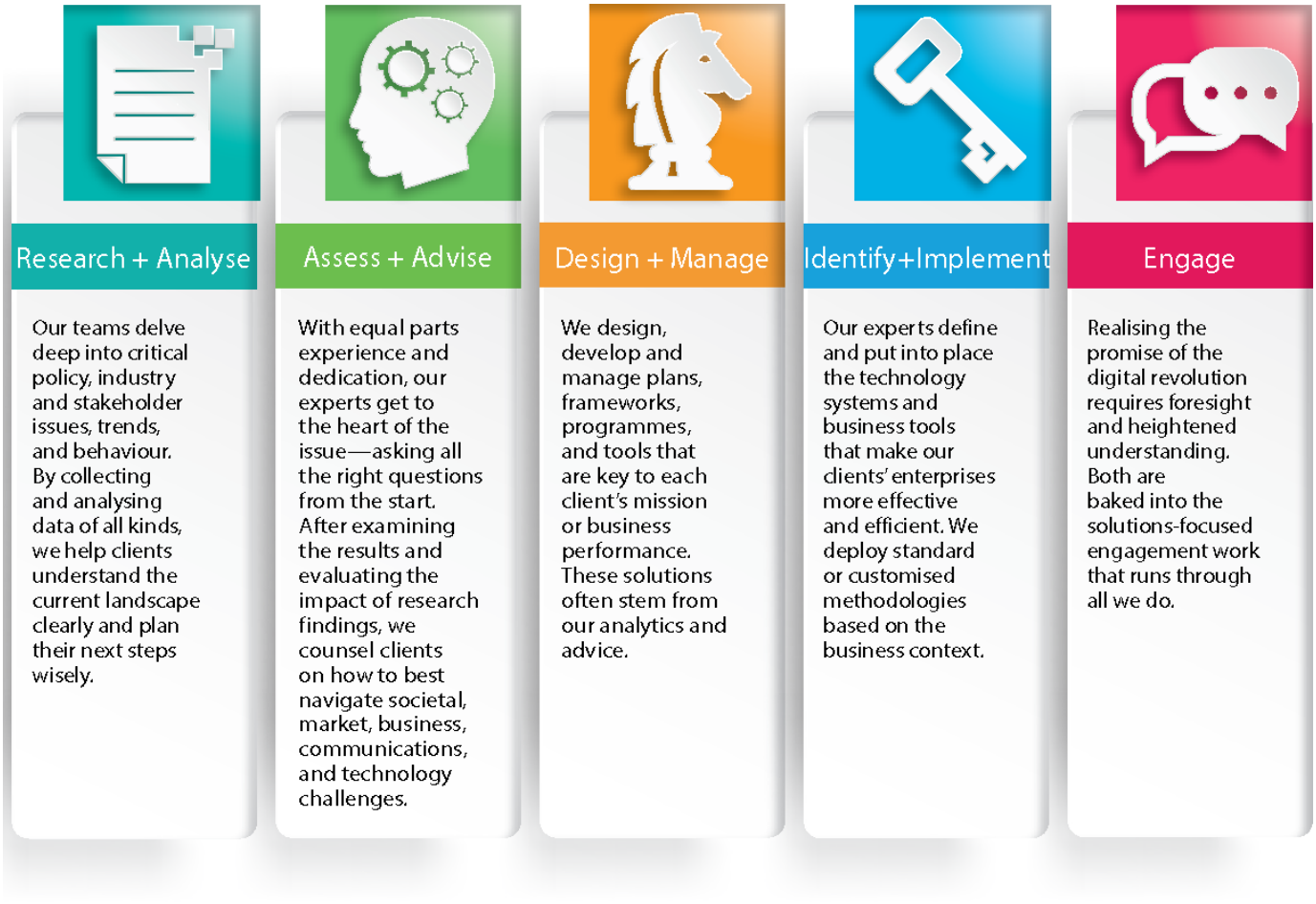
ecodiversity

climate ● people ● nature

Funded by the European Commission

ICF makes big things possible

ICF is a global consulting and technology services provider with more than 8,000 professionals focused on making big things possible for our clients. We are policy specialists, social scientists, business analysts, technologists, researchers, digital strategists, and creatives. Since 1969 government and commercial clients have worked with ICF to overcome their toughest challenges on issues that matter profoundly to their success. Our five core service areas are described below. Engage with us at icf.com.



ICF Cerulogy ecodiversity climate • people • nature

Support to the development of methodologies for the certification of industrial carbon removals with permanent storage

Issues relating to the certification of carbon removal through enhanced rock weathering

A report submitted by ICF

Date: 26 October 2026

Job Number: 330301909

ICF S.A.
Avenue Marnix 17
Brussels
B-1000
Belgium
T +32 (0) 2 275 01 00
www.icf.com

ICF Cerulogy ecodiversity climate • people • nature

Document Control

Document Title	Support to the development of methodologies for the certification of industrial carbon removals with permanent storage: Issues relating to the certification of carbon removal through enhanced rock weathering
Job No.	330301909
Prepared by	Zara Popstoyanova, Cato Sandford and Chris Malins
Checked by	Jonathan Lonsdate
Version	1
Date	26 October 2026

ICF has used reasonable skill and care in checking the accuracy and completeness of information supplied by the client or third parties in the course of this project under which the report was produced. ICF is however unable to warrant either the accuracy or completeness of such information supplied by the client or third parties, nor that it is fit for any purpose. ICF does not accept responsibility for any legal, commercial, or other consequences that may arise directly or indirectly as a result of the use by ICF of inaccurate or incomplete information supplied by the client or third parties in the course of this project or its inclusion in this project or its inclusion in this report. This report is the copyright of the European Commission and has been prepared by ICF S.A. under contract to the European Commission. The contents of this report may not be reproduced in whole or in part, nor passed to any other organisation or person without the specific prior written permission of the European Commission.

This document has been prepared for the European Commission. However, it reflects the views of the authors only, and the Commission cannot be held responsible for any use that may be made of the information contained herein.

Contents

1 Introduction 1
2 Issues relating to scope, eligibility, period 2
2.1 Eligibility to be the activity operator 2
2.1.1 Approach under consideration 2
2.1.2 Discussion 2
2.2 Eligible forms of ERW 2
2.2.1 Approach under consideration 2
2.2.2 Discussion 2
2.3 Eligible feedstock types 2
2.3.1 Approach under consideration 2
2.3.2 Discussion 3
2.4 Feedstock characterisation 3
2.4.1 Approach under consideration 3
2.4.2 Discussion 4
2.5 Feedstock batches and sampling 4
2.5.1 Approach under consideration 4
2.5.2 Discussion 4
2.6 Monitoring period 4
2.6.1 Approach under consideration 4
2.6.2 Discussion 5
3 Issues relating to quantification 6
3.1 Baselining 6
3.1.1 Approach under consideration 6
3.1.2 Discussion 6
3.2 Modelled baseline 6
3.2.1 Approach under consideration 6
3.2.2 Discussion 7
3.3 Liming term in modelled baseline, $\mathbf{CR_{baseline,field,liming}}$ 7
3.3.1 Approach under consideration 7
3.3.2 Discussion 7
3.4 Counterfactual natural weathering term in modelled baseline, $\mathbf{CR_{baseline,field,other}}$ 8
3.4.1 Approach under consideration 8
3.4.2 Discussion 8
3.5 Control plot based baseline, $\mathbf{CR_{baseline,field}}$ 9
3.5.1 Approach under consideration 9
3.5.2 Discussion 10
3.6 Natural feedstock weathering term, $\mathbf{CR_{baseline,feedstock}}$ (both modelled and control-plot based baseline) 10
3.6.1 Approach under consideration 10
3.6.2 Discussion 10

3.7 Quantification of total removals 11
3.7.1 Approach under consideration 11
3.7.2 Discussion 13
3.8 Validation checks 13
3.8.1 Approach under consideration 13
3.8.2 Discussion 14
3.10 Role of the certification schemes 15
3.10.1 Approach under consideration 15
3.10.2 Discussion 15
4 Issues relating to long-term storage 16
4.1 Permanence 16
4.1.1 Approach under consideration 16
4.1.2 Discussion 16
5 Issues relating to sustainability 17
5.1 Good agricultural practice 17
5.1.1 Approach under consideration 17
5.1.2 Discussion 17
5.2 Risks of pollution associated with ERW 17
5.2.1 Approach under consideration 17
5.2.2 Discussion 17
5.3 Threshold values 19
5.3.1 Approach under consideration 19
5.3.2 Discussion 20

1 Introduction

Rock weathering is a natural feature of the geochemical cycle, whereby rocks slowly dissolve in the presence of water. The dissolution of certain alkaline minerals in water has the effect of drawing CO_2 out of the atmosphere. Enhanced rock weathering (ERW) promotes this kind of reaction, using crushed and pulverised rock to create the conditions for mineral dissolution, and hence the conditions for an accelerated rate of CO_2 draw-down compared to the baseline. Enhanced rock weathering is identified as a carbon dioxide removal method in the working group III contribution to the IPCC's sixth assessment report *Climate Change 2022: Mitigation of Climate Change*, and will be further addressed in inventory guidelines in the forthcoming *IPCC Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization, and Storage for National Greenhouse Gas Inventories (Additional guidance)*.

This paper presents a series of issues that the project team has identified as relevant to the certification of ERW as a permanent removal. The format of the paper is to present sections of text that our team has developed that could be used as the basis of certifying ERW as a carbon removal activity, informed by our previous review paper on ERW and by consideration of approaches taking by existing certification schemes in the voluntary market, followed by discussion points related to each of these sections. These sections of text could form a significant part of an ERW methodology, but not a whole methodology. Additional requirements would be needed in a complete methodology, but we have focused in this paper on the areas where we think there is most value in discussion with the Expert Group.

2 Issues relating to scope, eligibility, period

2.1 Eligibility to be the activity operator

2.1.1 Approach under consideration

Any involved entity may be the operator of the ERW activity.

2.1.2 Discussion

Carbon removal via enhanced rock weathering can involve quarrying, transporting, and spreading rock, with each step possibly handled by different operators or companies. We are interested in views on whether there is value in specifying which of these entities may be the operator or whether it should be left to the discretion of the participants in each project.

2.2 Eligible forms of ERW

2.2.1 Approach under consideration

ERW activities shall consist of the application of ERW feedstock to agricultural soils at one or more eligible sites followed by monitoring of the delivered carbon removal, or the continued monitoring of carbon removal from ERW feedstock material applied in a previous activity period.

2.2.2 Discussion

Some existing standards specify only agricultural soils, others allow a broader set of managed land (e.g. including forest land or land used for recreational purposes). We understand that agricultural use represents the largest opportunity and that there are synergies between ERW feedstock application and other agricultural activity. There may also be opportunities for ERW at mine sites, brownfield sites and in industrial areas. Extending eligibility to non-agricultural sites might enable consideration of a wider range of feedstocks. Non-agricultural ERW would not have the same potential for productivity co-benefits, but it would avoid risks associated with interventions in the food chain.

Related approaches of river alkalinity enhancement (RAE) and wastewater alkalinity enhancement (WWAE) use the same basic chemistry as ERW, but introduce the alkalinity from the feedstock material directly into a watercourse rather than onto the land. This makes monitoring more straightforward and could reduce uncertainty in carbon removal outcomes. On the other hand, these approaches do not offer the potential agricultural advantages that have been suggested for ERW on farmland.

We are interested in view on whether an initial CRCF methodology should restrict eligibility to the agricultural case or open it more broadly.

2.3 Eligible feedstock types

2.3.1 Approach under consideration

The ERW feedstock utilised shall be material containing silicates and/or carbonates of alkaline earth metals and/or alkali metals (such as Ca, Mg, K, Na).

The ERW feedstock may be sourced from:

- Purpose-quarried rock;
- Quarry fines;
- Mining overburden;
- Mining tailings;
- Other alkaline industrial waste materials, including returned concrete and metallurgical slags.

A single feedstock batch may contain feedstock from only one of these sources.

When feedstock originates from mining or quarrying operations and is considered 'waste', its legal status must be documented. The management and repurposing of such 'waste' products as ERW feedstock must be detailed and documented, with clear evidence provided to show full compliance with all applicable local and national laws and regulations. This includes adherence to the Extractive Waste Directive 2006/21/EC or equivalent requirements.

2.3.2 Discussion

This list of potential feedstock sources includes materials (in particular industrial slags and mining tailings) that may pose a higher risk of contamination if applied to agricultural soils. We are interested in views on whether this list ought to be further restricted, and whether it is possible to set appropriate contaminant thresholds in the sustainability rules that would be adequate to manage any risk from such materials.

2.4 Feedstock characterisation

2.4.1 Approach under consideration

Feedstock characterisation shall be conducted before application at a site. Each batch of feedstock used must be characterised based on representative sampling, and data on each batch used during the certification period must be included in the monitoring report.

Feedstock characterisation consists of the set of ex-ante assessments and records required to demonstrate that weathering materials used in enhanced rock weathering activities are suitable, safe, and capable of delivering durable net carbon dioxide removal, and to identify the associated carbon removal potential.

Feedstock batch characterisation in the monitoring report shall include at a minimum:

- Quantity of feedstock from that batch applied during the certification period.
- Whether the batch consisted of purpose-quarried rock, quarry fines, overburden, mine tailings, or slag from industrial processes
- Origin and nature of feedstock:
  - the geographic origin of the feedstock batch (location of the associated quarry, mine or industrial facility);
  - description of the feedstock based on the geochemical and mineral characterisation;
  - for mining tailings and slags, a description of the process of sampling and recovery. This shall include the location of the facility, the methods used to extract the feedstock, and how it is transported from the source to the ERW project site.
- Composition:
  - Elemental composition, including at a minimum the elements Ca, Mg, K, Na, S, P, Al, Si, Fe, As, Ba, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, Zn, V, Se, Tl*[, C, Ti,*

Sr, Mo, W, Sb, Be and Zr] and any other elements, isotopes or isotope ratios that will be used in the assessment of weathering rate.
  - Mineralogical composition, including bulk mineral abundance for all minerals relevant to the calculation of carbon removal potential and identification of potentially hazardous minerals to environment and human health.
  - Screening for asbestos or asbestiform minerals, and for radionuclides.
- Radiation:
  - Feedstock radiation levels must be assessed to establish compliance with applicable legal restrictions.
- Physical characteristics:
  - Particle size distribution and specific surface area.
- Pre-processing details:
  - Provide a description of any pre-processing that the feedstock has undergone prior to its use. This may involve crushing, milling, drying, washing, sifting, or other forms of treatment intended to prepare the material for its intended application.

2.4.2 Discussion

There is variation in the level of elemental composition reporting required by existing standards. For example, the italicised elements in the list above are required by only one of the Isometric or Rainbow standards but not both. We are interested in views on the final list of elements for which elemental composition should be required by the CRCF methodology, and other observation on the level of feedstock characterisation that might be required.

2.5 Feedstock batches and sampling

2.5.1 Approach under consideration

Feedstock used in an enhanced rock weathering activity shall be grouped into feedstock batches for the purposes of sampling, analysis, traceability and verification. A feedstock batch shall comprise feedstock material of the same origin and extraction or production conditions, for which material characteristics may reasonably be assumed to be uniform. A new feedstock batch shall be defined where a change occurs in feedstock origin, extraction period, production process, or other conditions that may affect material composition.

2.5.2 Discussion

We have not currently proposed any requirements that could be introduced on ERW feedstock storage. We are interested in views on whether it would be necessary for the CRCF to set requirements on storage, with a view in particular to the possibility of weathering occurring during storage after sampling but prior to application at an eligible site.

2.6 Monitoring period

2.6.1 Approach under consideration

The monitoring period for ERW activities is the same as the activity period. Where monitoring at a site is extended into a new activity period, the monitoring period shall be considered to be prolonged to the end of that new activity period.

2.6.2 Discussion

We are interested in views on whether the mandatory monitoring period should be extended beyond the point at which units stop being generated. In general, the rate of unit generation at an ERW site will decline over time (as feedstock dissolves) but may not reach zero for a protracted period. Halting unit generation means that operators would not receive units for the full eventual units delivered, but would avoid the cost of extended monitoring. It is our feeling that ongoing sampling requirements would not be proportionate.

3 Issues relating to quantification

3.1 Baselining

3.1.1 Approach under consideration

ERW activities shall determine the baseline rate of carbon removal either by including a control plot, and monitoring carbon removal delivered on that control plot, or by modelling. The baseline may only be modelled where the certification scheme has provided additional guidance to allow its consistent calculation.

Baseline removals $\mathrm{CR}_{\mathrm{baseline}}$ are to be calculated according to equation [1]

$\mathrm{CR}_{\mathrm{baseline}} = \mathrm{CR}_{\mathrm{baseline,field}} + \mathrm{CR}_{\mathrm{baseline,feedstock}}$	[1]

where:

$\mathrm{CR}_{\mathrm{baseline,field}}$ = carbon removal due to weathering associated with BAU land management practices including agricultural liming

$\mathrm{CR}_{\mathrm{baseline,feedstock}}$ = weathering of feedstock that would have occurred in the counterfactual scenario

3.1.2 Discussion

In this approach the operator would have the option to either assess the baseline rate of carbon removal by monitoring a control plot, or to calculate baseline removals using modelling based on appropriate assumptions. The modelling approach would only be permitted if the certification scheme has provided more detailed guidance to enable it to be implemented consistently. We are interested in views on whether the methodology should require the use of a control plot for all projects, based on which baseline removals would be calculated, or whether it is possible/appropriate to set a conservative baseline using default assumptions that would alleviate the need for a control plot. As discussed further below, we have suggested that a baseline without a control plot could be proposed that would be divided into three sub-terms – liming, natural weathering and alternative feedstock disposition.

We would see a control-plot based baseline as being a form of activity specific baseline. We would be interested in views on whether a modelled baseline could potentially be treated as a standardised baseline.

3.2 Modelled baseline

3.2.1 Approach under consideration

When calculating the modelled baseline, the term $\mathrm{CR}_{\mathrm{baseline,field}}$ shall be further disaggregated into the baseline removals associated with liming and other baseline removals as indicated in equation [2].

$CR_{baseline,field} = CR_{baseline,field,liming} + CR_{baseline,field,other}$	[2]

where:

$CR_{baseline,field,liming}$ = carbon removal due to weathering associated with BAU agricultural liming;

$CR_{baseline,field,other}$ = carbon removal due to other weathering associated with BAU agricultural land management.

3.2.2 Discussion

If using a control plot, the measured weathering signal would include both carbon removal due to lime application on the control plot and carbon removal due to weathering of other material in the field. For the modelled baseline, we have proposed that these two terms would be calculated separately.

The CRCF Regulation calculates the net permanent carbon removal benefit of an activity as the difference between the gross activity carbon removal benefit, and the sum of the associated GHG emissions and the gross baseline carbon removal benefit. There is no explicit accommodation for the activity's associated emissions credit to be offset by avoidance of emissions in the baseline. The emissions associated with baseline practices (e.g. with the supply of agricultural lime) are not considered in the calculations detailed here, which adds conservatism to the overall calculation. We believe that the legal text of the CRCF may constrain options to consider an 'avoided liming' benefit, but note that an inconsistency is introduced if carbon removal due to liming is included in the baseline but lime production emissions are not.

3.3 Liming term in modelled baseline, $CR_{baseline,field,liming}$

3.3.1 Approach under consideration

The modelled baseline for liming shall reflect the carbon removal associated with business-as-usual application of agricultural lime to a given agricultural area. It reflect the expected carbon removal if all applied lime is dissolved, and the resulting dissolved inorganic carbon is exported in the aqueous phase as bicarbonate with no losses. The operator shall determine the baseline rate of liming as whichever is greater out of: a) the average amount of lime applied annually to the site in question over the last ten years, and b) the amount of lime application that would be considered normal practice for the agricultural context of the site, with reference to local or regional standard practices for comparable farming systems, and to recommended practices for comparable farming systems from agronomists or extension agents. The certification schemes may set additional requirements to specify the calculation of the baseline liming rate.

3.3.2 Discussion

The baseline approach here takes a rather conservative approach by assuming full dissolution of agricultural lime in the counterfactual case and full conversion of the resulting DIC to bicarbonate, without applying the loss terms that are required in the calculation of carbon

removal in the project scenario. In particular, the text above would not require accounting for strong-acid weathering (a potentially important term given that a key purpose of agricultural liming is to manage acidity) and losses/re-equilibration occurring after the point of feedstock dissolution. This gives an inconsistency between the baseline and project cases, and may be excessively conservative. A good case could be made to have more symmetry between the baseline and project calculations.

We are interested in feedback on:

1. How the baseline liming rate should be established;
2. Whether the baseline should treat lime dissolution attributable to strong-acid neutralisation as a 'loss', consistent with the treatment of strong-acid weathering in the calculation of ERW removals?
3. Whether the baseline should account for downstream losses or re-equilibration of bicarbonate, rather than assuming full retention of the maximum theoretical carbon-removal benefit?

The modelled carbon removal baseline has a further asymmetry with the project scenario, because the ERW activity would be expected to calculate its associated emissions but there is no accommodation to offset these against avoided lime production emissions (e.g. due to calcination for quicklime). It would not be appropriate within the CRCF to conflate avoided emissions with delivered removals, but an argument could be made to allow some cancelling out of emissions between the project scenario and baseline scenario (equivalently to treat a quantity of emissions that occurs in both cases as not being emission associated with the activity). We are interested in views on how this could be handled.

We note that IPCC inventory accounting rules for agricultural lime treat liming as a source of emissions assuming that the carbon contained in lime will be released as carbon dioxide following application. The baseline presented here diverges from this treatment by assuming not only that not all carbon in lime is released as CO_2, but that by adding alkalinity to the system liming will deliver a carbon removal benefit. It is the view of the authors that there is a strong technical argument to make the current treatment of agricultural liming in inventory guidelines less conservative, however it is beyond the purview of the current exercise to propose changes to inventory approaches.

3.4 Counterfactual natural weathering term in modelled baseline, $CR_{baseline,field,other}$

3.4.1 Approach under consideration

Weathering of material already present in the soil may occur during the certification period. If the certification body assesses that this may be a significant term, it shall be estimated by the operator in line with best available scientific evidence, and following guidance provided by the certification schemes where it is provided.

3.4.2 Discussion

Where a control plot is used counterfactual natural weathering would be implicitly included in the $CR_{baseline,field}$ term, but where a modelled baseline is used we are interested in views on how this term could be more explicitly defined, and whether its inclusion is necessary.

3.5 Control plot based baseline, $CR_{baseline,field}$

3.5.1 Approach under consideration

Each site shall be divided between the treated area and the control plot. A control plot is used to measure how much carbon removal would take place in the absence of the application of ERW feedstock. The treatment of the control plot must be representative of business as usual agricultural management approaches for the land on which the ERW activity is undertaken (the "treated area"). In particular, this shall include application of mineral fertiliser at the same rate as is applied to the treated area and the continuation or adoption of business as usual liming practices.

The operator shall determine the baseline rate of liming as whichever is greater out of: a) the average amount of lime applied annually to the site in question over the last ten years, and b) the amount of lime application that would be considered normal practice for the agricultural context of the site, with reference to local or regional standard practices for comparable farming systems, and to recommended practices for comparable farming systems from agronomists or extension agents. The applied business as usual liming rate shall at the minimum be consistent with maintaining the long-term productivity of the land. The certification schemes may provide further guidance to operators on acceptable approaches to set the business as usual liming rate for the control plot.

In the case that the treated area is subject to more than one agricultural management regime and these regimes may be expected to lead to different rates of carbon removal, it may be necessary to divide the control plot into two or more sub-areas, each representative of a specified agricultural management regime. Certification schemes may provide additional guidance to operators in relation to:

- Requirements to ensure that the control plot is adequately comparable to the treated area;
- When differences in agricultural management on the treated area are significant enough that the control plot shall be sub-divided;
- The minimum size required for each sub-area of the control plot;
- Requirements to avoid the control plots being affected by the ERW treatment;
- The set of practices that must be consistent between the treated area and the relevant sub-area of the control plot.

The control plot must be subject to the same measurement and calculation regime for carbon removal as the treated area. $CR_{baseline,field}$ shall then be calculated in accordance with equation [3]:

$$CR_{baseline,field} = \left(\sum_{A} k_A * CR_{control,A}\right) * \frac{Area_{treated}}{Area_{control}} \quad [3]$$

where:

$CR_{control,A}$ = carbon removal measured on each sub-area A of the control plot. This shall be calculated in accordance with equation [4];

k_A = the ratio of the size of the part of the treated area that corresponds to each sub-area A of the control plot to the whole of the treated area;

$\text{Area}_{\text{treated}}$	=	the size in hectares of the treated area;
$\text{Area}_{\text{control}}$	=	the size in hectares of the control plot;
A	=	an index of the sub-areas of the control plot.

3.5.2 Discussion

We are interested in views on whether there are preferable alternatives to a control plot requirement for the establishment of detailed activity specific baselines.

We are not aware of other certification standards that currently have an explicit requirement to divide the control plot in order to ensure that part of the control plot is representative of each of the agricultural practices used on the treated area. As different crops and soils may be associated with quite different fertilisation rates and liming requirements, we felt it was appropriate to require differentiation. In the case that a project involved application to land all of which is under a uniform agricultural management regime, the control plot would require no subdivision. However, in the case of application across an area with several different crops and management regimes, the number of subdivisions required could become large.

3.6 Natural feedstock weathering term, $\text{CR}_{\text{baseline,feedstock}}$ (both modelled and control-plot based baseline)

3.6.1 Approach under consideration

In the case that ERW feedstock is produced from material quarried specifically for this purpose, $\text{CR}_{\text{baseline,feedstock}}$ shall be set as zero. In the case that ERW feedstock is produced by reducing the particle size of material that consisted predominantly (at least [98%] by mass) of grains with a size of [10 cm] or more, $\text{CR}_{\text{baseline,feedstock}}$ shall be set as zero. In the case that the ERW feedstock would not be exposed to moisture in the counterfactual scenario or would be stored in a way that prevented dissolved material from reaching watercourses, $\text{CR}_{\text{baseline,feedstock}}$ shall be set as zero. Otherwise, the carbon removal that would result from natural dissolution of the ERW feedstock over a period of [200 years] from the date of implementation of the activity shall be calculated following guidance from the certification scheme.

Where the term $\text{CR}_{\text{baseline,feedstock}}$ is estimated this estimation shall be based on an appropriate model of feedstock dissolution and alkalinity transport. The model shall be informed by a characterisation of the storage conditions of the feedstock, and where relevant the assumptions for this modelling shall be consistent with assumptions used in the estimation of carbon removals by the activity. Certification schemes may set additional requirements on the estimation of this term.

3.6.2 Discussion

We have suggested that the formulation of requirements for the natural feedstock weathering element of the baseline could be devolved to the Certification Schemes. This reflects a feeling that more technical work may be needed to establish robust baseline estimates, and the suggestion noted in the introduction that it is appropriate to defer more to the Certification Schemes at points in an ERW methodology proposal. We are interested in views on this, and on whether it would be appropriate to differentiate rules between the modelled and control-plot based baseline cases.

3.7 Quantification of total removals

3.7.1 Approach under consideration

Operators may use one of two approaches for the calculation of the total carbon removals (CR_{total}):

a) The soil-based method, which measures the loss of base cations in treated soil over time;
b) The porewater-based method, which evaluates the accumulation of relevant anions and/or cations in soil porewater.

Certification schemes shall set further requirements on the implementation of the quantification approach. These requirements shall have due regard to developments in the scientific understanding of ERW and ERW quantification, and should be consistent with evolving good practice in the field. If permitted by the certification scheme operators may designate a sub-part of the treated area as the area on which quantification is to be undertaken and calculate the overall carbon removal by scaling up the results for this quantification area.

3.7.1.1 Soil-based method

Where the soil-based method is used, the operators shall calculate the total carbon removals (CR_{total}), and where the activity specific baseline is used the carbon removals from the field in the baseline ($CR_{baseline,field}$) in accordance with equation [4], in which all the CR terms shall be expressed in units of tCO_2.

$$CR_{total} \text{ or } CR_{baseline,field} = \left(CR_{Weathering} - CR_{BiomassLoss} - CR_{NetNewCarbonate} - CR_{NetNewSilicates} - CR_{NetSorption} - CR_{NonCarbonicNeut}\right) * \eta_{RiverOcean} \quad [4]$$

where:

$CR_{Weathering}$ = the maximum potential for carbon removal due to release of base cations from feedstock dissolution through weathering, based on measurement of the change of Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} concentration identified by soil sampling;

$CR_{BiomassLoss}$ = in the case of the calculation of $CR_{baseline,field}$ this term is zero; in the case of the calculation of CR_{total} the decrease in carbon removals due to base cations taken up by plants (i.e. annual crops or perennial crops), based on a comparison of measurement of cation content in samples of annual biomass growth in the treated area against samples of annual biomass growth in the control plot (where available) or produced prior to the commencement ERW activity;

$CR_{NetNewCarbonate}$ = the decrease in carbon removals due to the net formation of new carbonate minerals in the soil (i.e. carbonate precipitation) based on measurement of samples;

$CR_{NetNewSilicate}$ = the decrease in carbon removals due to net formation of new silicate minerals in the soil (e.g. clay formation) based on measurement of samples;

$CR_{NetSorption}$ = the decrease in carbon removals due to the net sorption of base cations to cation exchange sites (other than in the first certification period this value may be negative, indicating a net release of cations that had accumulated in previous certification periods) based on measurement of samples;

$CR_{NonCarbonicNeut}$ = the decrease in carbon removals due to the neutralisation of acids other than carbonic acid, to be determined by direct measurements of anions in porewaters (e.g. NO_3^-, PO_4^{3-}, Cl^-, SO_4^{2-}) or estimated based on documented fertiliser application;

$\eta_{RiverOcean}$ = total retention factor for all relevant processes in rivers and oceans that lead to a reduction of CO_2 that ends up durably stored in the ocean. This factor is dimensionless with value between 0 and 1, and must be based on modelling.

Operators shall follow additional guidance provided by the certification scheme in calculating these terms.

3.7.1.2 Porewater-based method

Where the porewater-based method is used, the operators shall calculate the total carbon removals (CR_{total}) in accordance with equation [5]:

$$CR_{total} = CR_{Aqueous} * \eta_{RiverOcean} \quad [5]$$

where:

$CR_{Aqueous}$ = carbon removal potential as determined from the measurement of carbonate alkalinity leaving the NFZ, either directly or by appropriate proxy measurements;

$\eta_{RiverOcean}$ = total retention factor for all relevant processes in rivers and oceans that lead to a reduction of CO_2 that ends up durably stored in the ocean. This factor is dimensionless with values between 0 and 1.

The term $CR_{Aqueous}$ shall be calculated in accordance with equation [6]. The calculation of $CR_{Aqueous}$ shall account for the removal of base cations due to plant uptake. If plants absorb alkalinity below the porewater sampling depth of 20 cm, this uptake should be quantified.

$$CR_{Aqueous} = \sum_{i}^{n} \left(\overline{Alk_i} * Q_i\right) * \frac{molCO_2}{molAlk} * M_{CO_2} \quad [6]$$

where:

n = total number of samples taken in a certification period, to be summed;

$\overline{\mathrm{Alk}_i}$ = interval-average alkalinity over interval i, $\frac{\mathrm{Alk}_{i-1}+\mathrm{Alk}_i}{2}$, in eq/L;

Q_i = volumetric water flux over interval i, in L;

$\frac{\mathrm{molCO_2}}{\mathrm{molAlk}}$ = molar ratio of CO_2 removed per mole of alkalinity;

$\mathrm{M_{CO_2}}$ = molar mass of CO_2, tonnes/mol.

Operators shall follow additional guidance provided by the certification scheme in calculating these terms.

3.7.2 Discussion

The suggested requirements on soil- and porewater-based measurements are broadly aligned to existing approaches within the voluntary Certification Schemes. The text is predicated on additional requirements being specified by the Certification Schemes, which would reflect developing understanding but may also reflect differences in detailed approaches. We feel that there may be value in supporting further knowledge development through deployment of the two different approaches and variation thereof. Our team has engaged extensively with the community on the measurement question during the development of the review paper and subsequent period, and we recognise that there are challenges for both approaches. Soil-based measurement has advantages in terms of implementability but may still be subject to significant uncertainty. Porewater-based approaches provide a more direct measurement of carbon removal outcomes, but may be challenging in practice and impose greater costs. We would anticipate that in due course the community may converge on one approach, perhaps supported by the development of improved modelling approaches, but felt that if a CRCF methodology was to be adopted in the relatively short term it would be appropriate to follow the current practice of offering the two approaches as options, while knowledge development continues.

3.8 Validation checks

3.8.1 Approach under consideration

Certification schemes may require operators to undertake a validation check, by assessing carbon removal on some part of the treated area (and from the control plot if a control plot is used) using the other of the two quantification methods, or by some innovative alternative measurement approach.

If the amount of carbon removal identified by the validation approach is significantly lower than that under the main quantification approach, then the certification scheme may choose to reduce the number of units issued (based on a defined protocol) and may require additional sampling in subsequent certification periods.

Certification schemes may set additional guidance and requirements in relation to the validation check, which may include requirements on the size of the validation area, further specification of what constitutes a 'significantly lower' measurement, further specification of how the results from the validation area should be extrapolated, and any other relevant details.

3.8.2 Discussion

Some existing certification schemes have required validation checks. We have discussed the utility of validation measurements with certification schemes and experts in the field, and it is our understanding that measurements taken with the solid and aqueous phase approaches generally do not show good alignment. This may in part be an indicator of the level of uncertainty in the current measurement approaches, but can also reflect temporal delays between the disappearance of cations from the ERW feedstock (identified by solid state measurement) and the appearance of cations/DIC in porewater (aqueous measurement). We have therefore not proposed to make a validation measurement a mandatory requirement at this time, but have also preferred not to preclude its use, instead leaving it to the discretion of the certification schemes. We are interested in feedback on this approach.

3.9 Associated emissions

3.9.1 Approach under consideration

The greenhouse gases associated shall be calculated in accordance with equation [7].

$$\mathrm{GHG}_{\mathrm{associated,Y}} = \mathrm{GHG}_{\mathrm{operations}} + \begin{cases} \dfrac{\mathrm{GHG}_{\mathrm{feedstock}} + \mathrm{GHG}_{\mathrm{transport}} + [\mathrm{GHG}_{\mathrm{leakage}}]}{T} & \text{if } Y \leq T \\ 0 & \text{if } Y > T \end{cases} \quad [7]$$

where:

$\mathrm{GHG}_{\mathrm{feedstock}}$ = total GHG emissions associated with feedstock sourcing, processing and application across the activity period, in tCO_2e;

$\mathrm{GHG}_{\mathrm{transport}}$ = total GHG emissions associated with ERW feedstock transport from the production facility to the point of application or incorporation across the activity period, calculated following the rules in Section XXX, in tCO_2e;

$\mathrm{GHG}_{\mathrm{operations}}$ = total GHG emissions associated with operational processes during the certification period, in tCO_2e;

$\mathrm{GHG}_{\mathrm{leakage}}$ = total GHG emissions associated with project's impact on activities outside the system boundary, in tCO_2e;

T = the amortisation period for associated emissions;

Y = the number of years since certification.

3.9.2 Discussion

Unlike the CDR activities in the existing delegated regulation for which associated emissions occur more or less contemporaneously with carbon removal, for ERW activities the associated emissions primarily occur prior to ERW feedstock application (due to feedstock extraction and transport), after which carbon removal occurs progressively over several years. We have not yet proposed a specific basis for setting the period on feedstock-emission amortisation. We are interested in feedback on how these emissions should be amortised across the lifetime of a project, in particular given that removals from one application may continue to be generated across multiple activity periods. This includes feedback on whether this could be deferred entirely to the Certification Schemes. We are also interested in views on whether the methodology should allow for a second (etc.) application of ERW, later in the activity period, as part of the same activity. Some existing standards give operators a choice to 'pay off' the feedstock emissions immediately or to amortise them over some defined period. There is also the possibility of estimating total removals and allocating emissions annually in proportion to removal reported, though the case that measured and estimated removals diverged would need to be managed.

3.10 Role of the certification schemes

3.10.1 Approach under consideration

The approach presented above would defer to the Certification Schemes to add detail and clarify requirements more broadly than was done in the adopted CRCF permanent carbon removal methodologies. This reflects a feeling that the ERW field is still in a development and data gathering phase to a greater extent than those activities, and that therefore there would be value in having some diversity of approaches among the certification schemes, which would be able to inform further tightening and harmonisation of the rules as knowledge develops.

3.10.2 Discussion

We are interested in views on whether utilising the expertise of the certification schemes in this way would be appropriate for an ERW methodology.

4 Issues relating to long-term storage

4.1 Permanence

4.1.1 Approach under consideration

Carbon removals delivered by ERW are considered permanent once units have been issued. The risk of reversal is addressed through conservative quantification of the total carbon removal benefit.

4.1.2 Discussion

As discussed in the review paper, ERW delivers storage of carbon in the form of dissolved bicarbonate and carbonate that is carried from the field to the watershed and thence to the ocean. In the ocean, bicarbonates and carbonates provide carbon storage over significantly longer periods than the several centuries required for permanent storage by the CRCF. There is no way to directly monitor carbonates from any given origin once they enter the river system and ocean, and therefore potential reversals can only practically be handled through the inclusion of loss terms in the initial calculation rather than through monitoring.

5 Issues relating to sustainability

5.1 Good agricultural practice

5.1.1 Approach under consideration

Operators of ERW activities shall demonstrate that the local context has been considered and that it is reasonable to expect no overall negative effect on biomass production, site condition or soil health and no reductions in the storage of soil organic carbon or increase in soil emissions of methane or nitrous oxide. Where significant loss of other soil organic carbon, significant increase in methane or nitrous oxide emissions or significant deleterious impacts on agricultural productivity, on biodiversity, on ecosystems receiving the ERW feedstock or the ones located downstream in the watershed, soil health, or on any other environmental aspects are considered likely by the certification body, no carbon removal units shall be issued in relation to that applied quantity. Certification schemes may provide additional best practice guidance or soil health monitoring guidance on ERW feedstock application to soils.

To promote scientific advancement and facilitate collective progress in the field of ERW, operators shall share relevant data and information that is not commercially sensitive upon request by certification schemes, competent national authorities or the European Commission, and without creating undue administrative burden for farmers. Certification schemes shall enable knowledge sharing between operators by providing platforms to allow the dissemination of data gathered in the course of any post-application monitoring activities undertaken by operators.

5.1.2 Discussion

The suggested requirement echoes a similar requirement in the adopted BCR methodology.

5.2 Risks of pollution associated with ERW

5.2.1 Approach under consideration

Operators shall comply with threshold levels in this section. When setting monitoring requirements, certification schemes shall take a risk-based approach to the level of sampling and testing that is necessary, requiring at a minimum a frequency of sampling consistent with the requirements of Regulation (EU) 2019/1009.

Accumulation of heavy metals in soils and crops must be assessed at a minimum of once per certification period. The concentrations and cumulative inputs of heavy metals shall remain below the applicable threshold values throughout the crediting period. Where monitoring demonstrates that a threshold value has been exceeded in the feedstock, soil, or through cumulative application rates, units shall not be issued for carbon removal by the activity. Unit issue may only recommence if and when subsequent measurements demonstrate that concentrations have returned below the applicable threshold values and the source of non-compliance has been addressed.

5.2.2 Discussion

ERW feedstocks may potentially be labelled as fertilising products and subject to the Fertilising Products Regulation (FPR), but it is our understanding that this would not be mandatory (if the ERW feedstock was never marketed as a fertilising product). We would welcome views on

what other existing EU and Member State regulation would apply to an ERW activity and whether such regulation would be uniformly applicable and binding. We believe that it is appropriate (in line with the “do no significant harm” requirement in the CRCF) to set explicit requirements on contaminant levels through the methodology, and that these should require both testing of the ERW feedstock and monitoring of the status of soils to which ERW feedstock is applied. The suggested requirements are informed by consideration of the limits in the Sewage Sludge Directive. We welcome feedback on whether specific requirements may be too weak or too stringent, and on any other contaminants we should consider controlling. As an example, Puro has added a requirement for conservative mass-balance calculations estimating the maximum loading of potentially toxic elements (PTEs) in soil resulting from feedstock application. These calculations assume that all applied feedstock fully dissolves and that no PTEs are removed from the soil system, and account, at a minimum, for baseline PTE concentrations in soil, PTE concentrations in the feedstock, feedstock application rates, and soil bulk density. The resulting maximum soil PTE concentrations are compared against applicable regulatory limit values, and feedstocks are not to be used where such limits would be exceeded under these conservative assumptions.

Puro sets limits for metal concentrations in soils based on the Sewage Sludge Directive. The directive specifies three categories of contaminant threshold values:

Annex I A: Sets limits on how polluted the soil is allowed to be - could be applied for site eligibility for ERW.

Annex I B: How polluted the applied material is allowed to be - could be applied for feedstock eligibility for ERW.

Annex I C: How much metal is allowed to be added per year. Will the metal build over time? - to be considered for total ERW application rate.

The current proposal implements threshold on all three of these bases. Puro currently sets the limits on contaminants in feedstock much lower than the Annex I B requirements of the Sewage Sludge Directive, by aligning these thresholds to the threshold in soil. The current proposal follows Puro in this regard by setting a single set of thresholds for soil and feedstock. We are interested in feedback on whether it would be appropriate to relax the requirements on feedstock concentrations, if soil concentrations will be regularly monitored. We are also interested in feedback on whether there are fundamental differences in expected bioavailability of metals in ERW feedstock as compared to sewage sludge or mineral fertilisers, and whether this should be reflected by adjusted some or all of the threshold values.

The Directive includes a rule for acidic soils (pH < 6), where heavy metals become more mobile and are more-readily absorbed by plants. This is relevant for ERW, as it often targets acidic soils suitable for weathering. It may be appropriate to vary limit values on ERW feedstock depending on the pH of the soil to which it is applied - we are also interested in feedback on this point.

Finally, we note that although the Sewage Sludge Directive remains in effect, it is regarded as a foundational baseline; typically, national contaminant thresholds may be more stringent.

5.3 Threshold values

5.3.1 Approach under consideration

5.3.1.1 Limit values on metals in soil and feedstock

Operators shall demonstrate by lab analysis that concentrations of the following substances (in units of milligrams per kilogram dry matter [mg/kg dm]) do not exceed the stated threshold values in either the soil at the application site or in the ERW feedstock:

(a) Antimony (Sb); 2 mg/kg dm
(b) Arsenic (As); 5 mg/kg dm
(c) Cadmium (Cd); 1 mg/kg dm
(d) Chromium (Cr); 100 mg/kg dm
(e) Cobalt (Co); 20 mg/kg dm
(f) Copper (Cu); 100 mg/kg dm
(g) Lead (Pb); 60 mg/kg dm
(h) Mercury (Hg); 0.5 mg/kg dm
(i) Nickel (Ni); 150 mg/kg dm
(j) Vanadium (V); 100 mg/kg dm
(k) Zinc (Zn); 200 mg/kg dm
(l) hexavalent chromium (Cr VI) for feedstocks; 2 mg/kg dm

Operators shall also assess the concentrations of the following substances (in units of milligrams per kilogram dry matter [mg/kg dm]):

(a) Barium (Ba)
(b) Beryllium (Be)
(c) Manganese (Mn)
(d) Selenium (Se)
(e) Thallium (Tl)
(f) Uranium (U)

Certification schemes may set threshold values on these substances, and certification bodies may refuse to issue units to an activity if the rate of application of these substances is not consistent with local good practice.

5.3.1.2 Limit value on radionuclides

(a) radionuclides for feedstock; 1 kBq/kg

In addition, the activity shall comply with any relevant national or local requirements.

5.3.1.3 Limit values on total application of metals

The annual input of heavy metals to agricultural land resulting from the application of ERW feedstock shall not exceed the maximum loading rates specified below, calculated as a rolling ten-year average. Compliance with these limits shall be demonstrated through feedstock characterisation, application records, and soil monitoring. Application rates shall be managed

to prevent the long-term accumulation of heavy metals and to ensure that heavy metal concentrations in soil remain below the threshold values specified in section 4.2.1.

(a) Cadmium (Cd); 0.15 kg/ha/yr

(b) Copper (Cu); 12 kg/ha/yr

(c) Nickel (Ni); 3 kg/ha/yr

(d) Lead (Pb); 15 kg/ha/yr

(e) Zinc (Zn); 30 kg/ha/yr

(f) Mercury (Hg); 0.1 kg/ha/yr

(g) Chromium (Cr); [10] kg/ha/yr

5.3.2 Discussion

The limits in section 4.3 rely on a number of sources.

The concentration limits in section 4.3.2 for metals in soil and ERW feedstock are informed by the Sewage Sludge Directive's soil and sludge-limit structure. The approach follows Puro in suggesting a conservative treatment by applying one set of thresholds to both soil and feedstock, rather than adopting the higher applied-material limits in Annex I B. Chromium requires separate justification because the Sewage Sludge Directive identifies chromium as relevant but does not provide a numerical annual loading limit.

Ba, Be, Mg, Se, Tl and U do not have a soil concentration limit set in the Puro standard, but operators are nevertheless required to measure and report those concentration. The approach would empower certification schemes to set thresholds on these concentrations should they see fit, and empower certification bodies to withhold unit issuance if the concluded that the rate of application was inappropriate.

The radionuclide limit in section 4.3.2.1 is sourced from the Puro Enhanced Rock Weathering Methodology, which references Commission Delegated Regulation (EU) 2022/973.

The annual metal loading limits in section 4.3.2.2 for Cd, Cu, Ni, Pb, Zn and Hg are based on Annex I C of the Sewage Sludge Directive, which sets maximum average annual inputs to agricultural land over a ten-year period.

The Sewage Sludge Directive anticipates the agreement of a chromium limit but does not yet contain one. We have therefore proposed a value of 10 kg/ha/yr as the total application limit, which is informed by the suggested chromium feedstock concentration limit, which is based in Puro, and on the ratio between the feedstock concentration limit and total application limits for the other metals listed in 4.3.2.2.

We are interested in views on whether the suggested thresholds are appropriate and any other sources of data that should be considered.