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Public Consultation Summary for the Enhanced Rock Weathering Methodology

This document recalls the development timeline of the Enhanced Rock Weathering methodology and summarizes the main elements raised and discussed by a wide range of stakeholders, including the Puro Advisory Board, the external expert group who contributed to the development process, and external entities who contributed to a public consultation.

The **development timeline** of the methodology is presented in Table 1 below. Overall, the development of this methodology spanned over 9 months. About 10 entities were involved in the expert group and 6 entities contributed to the public consultation. In total, about 40 individuals contributed to the methodology development.

In the rest of the document, the **key points** of debate, the discussion around them, and the choices made by Puro's development team are summarized. This includes the following key points:

- Chapter 1. Introduction
    - An extensive, non-prescriptive, and general introduction
- Chapter 2. General principles
    - Reason for having general principles in a methodology
- Chapter 3. Point of creation of the carbon dioxide removal certificate (CORC)
    - Choice of a full ex-post point of creation and alternatives considered
- Chapter 4. Eligibility and requirements
    - All requirements are this chapter, but some detailed in other chapters
- Chapter 5. Environmental toxicity risks
    - Which weathering materials are allowed?
    - What heavy metals thresholds are used?
    - How is public acceptance dealt with?
- Chapter 6. Quantification of life cycle supply-chain emissions
    - The case of waste weathering materials
    - Economic leakage
    - Direct land use changes
    - Attributional vs consequential life cycle approaches
- Chapter 7. Quantification of carbon dioxide stored and modelling
    - Are simulations enough as of today?

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Table 1. Development timeline of the Enhanced Rock Weathering methodology.

Date	Event
2022-04-01	The methodology development process was initiated. An expert group was established, meeting at regular intervals, to discuss and share knowledge on enhanced weathering and Puro's methodology development procedure.
2022-06-29	**Puro Advisory Board meeting, June** The concept and science of enhanced rock weathering were introduced to the board, with interventions from selected experts, discussing in particular the knowledge gaps and risks.
2022-08-24	The **draft methodology v0** was shared to the Expert group, chapter by chapter, for initial feedback. This was followed up by a series of meetings with the expert group on selected issues. Revisions were then made to the draft.
2022-09-28	**Puro Advisory Board meeting, September** The **draft methodology v1** was submitted for feedback to the Puro Advisory Board. Additional interventions from selected experts were made, on the topics of toxicity risks, removal quantification, and experimental data collection.
2022-10-04	The **draft methodology v1** was shared to the Expert group, for a second round of feedback. Simultaneously, a **public consultation** on the **draft methodology v1** was opened for three weeks.
2022-10-25	The **public consultation** was closed, receiving feedback from 6 independent entities (not involved in the expert group). This was followed up by a series of meetings with the expert group on selected issues. Revisions were then made to the draft.
2022-10-26	**Puro Advisory Board meeting, October** The outcome of the public consultation was presented to the Puro Advisory Board. In addition, selected topics were presented and discussed, namely the requirements for environmental risk assessment, and the point of creation of carbon dioxide removal certificates. This was followed up by a series of meetings with the expert group on selected issues. Revisions were then made to the draft.
2022-11-23	The **draft methodology v2** was submitted to the Puro Advisory Board, for a decision on adoption or further revisions at the next board meeting.
2022-11-30	**Puro Advisory Board meeting, November** The **draft methodology v2** was discussed and adopted by the Advisory Board, leading to the creation of the "Puro Standard for Enhanced Rock Weathering, Edition 2022".
2022-12-09	The **Puro Standard for Enhanced Rock Weathering, Edition 2022** is officially released.

Chapter 1. Introduction

Topic: Why was an extensive, non-prescriptive, and general introduction written in this methodology?

This is indeed different from other methodologies in the Puro Standard. The choice was made here to provide extensive background information because, we realized that the methodology would reach a broad audience. Although our methodologies are mainly meant to guide the certification of enhanced weathering activities, led by experts in enhanced weathering; other non-expert individuals also read our methodologies. This includes third-party auditors, potential buyers and intermediary buyers of removal certificates, as well as the general public. In addition, the working group was under the impression that the public knowledge on enhanced weathering was lower than for other removal methodologies, which stressed the need to spread more accessible information on this removal method.

The introduction chapter was written with this objective in mind: providing an accessible general overview of enhanced weathering as a carbon removal method, for a broad audience. Therefore, some simplifications were made and not all technical details are discussed. It also introduces the key concepts and challenges of enhanced weathering, which are needed to appreciate the rest of the methodology document.

The several rounds of revisions allowed to find the right level of balance between conciseness and accuracy of the description. Here, the public consultation was particularly helpful in reducing the emphasis placed on some weathering materials rather than others. The public consultation also stressed the need to present important mechanisms like strong acid weathering to better understand some risks and limitations.

Chapter 2. General principles

Topic: Why was a chapter on general principles added to this methodology and not to the Puro General Rules?

The chapter on General principles is new and not necessarily specific to Enhanced Rock Weathering, but echoes to several principles already laid out in the Puro General Rules. The new chapter outlines principles, based on the new best practices suggested by the Integrity Council for the Voluntary Carbon Market (ICVCM).

It was suggested (by the Puro Advisor Board and other reviewers) that this chapter could be moved to the Puro General Rules, or presented as a standalone document. However, it was decided to keep the chapter in the ERW methodology, at the moment, for the following reasons:

- Including the chapter in the methodology is a way to introduce these general principles to the ERW project proponents.
- An update of the Puro General Rules follows its own process and schedule. An update of the General is scheduled in 2023. Adding the chapter in this methodology requires a first approval by the Puro Advisory Board. This can be seen as a first step, to its way of being included in the General Rules at a later stage.

Chapter 3. Point of creation of the carbon dioxide removal certificate (CORC)

Topic: During the development of the enhanced rock weathering methodology, several options for the point of creation of the carbon removal certificates (CORCs) were considered. These options ranged from fully *ex-post* issuance (CORCs issued only once the sequestration

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has *already happened and was empirically demonstrated*) to various methods of issuance based on simulated results. **In the end, why was the fully ex-post issuance chosen? What implications does it have for project finance?**

The main problem with CORC issuance in the context of ERW is that weathering is a slow process with an expected completion time ranging from months to decades or more. This presents difficulties for commercial ERW endeavors due to the resulting long return periods for investments. Hence, from a commercial perspective, it would be convenient if CORCs could be issued *ex-ante* (before sequestration has happened) based on simulated results on ERW sequestration over time—after all, once the weathering material has been spread to the application site, the weathering reactions cannot reasonably be stopped from happening.

With the commercial angle in mind, several different simulation-based crediting options were considered in the methodology. These included a 50/50 split between *ex-ante* and *ex-post* credits, and an option a year-by-year issuance of *ex-ante* credits base on validated simulation performance thus far observed. However, all the simulation-based crediting approaches faced significant backlash from both the academic community as well as from some commercial operators. The main difficulty in issuing *ex-ante* credits is that there is currently no scientific consensus on the best ways to model of experimentally validate the CDR associated with ERW. Hence, any approach to issue *ex-ante* credits would come with significant uncertainties, which would damage the credibility of the methodology as a whole. Furthermore, as CORCs come with the possibility to make CO_2 removal claims, it would be troublesome if buyers were to make removal claims based on simulated results, which have not happened yet, and might not ever happen (for example if the simulation were flawed or due to some unforeseen change in circumstances).

Due to the difficulties associated with ERW modelling with today's knowledge and *ex-ante* credits, it was ultimately decided that any CORCs issued for and ERW project need to be based on the amount of CO_2 *already sequestered*, as verified by on-site measurements. In short, the CO_2 Removal Supplier is obligated to monitor the application site after the spreading of the weathering material (at least annually for the duration of the project) and produce experimental evidence quantifying the sequestration happened thus far. This is the only way to ensure a robust and credible methodology, which is ultimately more important than commercial gains. The downside is the funding gap thus produced: the grinding and spreading of weathering material requires upfront capital expenditure, but the CORCs are issued gradually over the lifetime of the project, which might be decades. While the methodology does not outright require or endorse any particular funding methods for commercial projects, it is noted that the funding gaps associated with the long return periods need to be bridged with e.g. pre-CORCs (essentially prepayments for possible future CORCs, for which no removal claims can be made), the project's own equity, or various other means of funding.

Chapter 4. Eligibility and requirements

Topic: Are the requirements listed in this chapter the only requirements to be met by a project?

In short, no. In Chapter 4, the main eligibility rules and requirements are presented by categories (activity eligibility, additionality, double-counting prevention, environmental safeguards, social safeguards, carbon removal quantification). However, several requirements listed in Chapter 4 also point at the following chapters (5, 6, and 7) where further details and sub-requirements are defined. More precisely, the Chapters 5, 6, and 7 give details about the requirements on environmental and social safeguards, life cycle assessment, and carbon removal quantification, respectively.

There are also additional general requirements defined in the Puro General Rules.

Chapter 5. Environmental & Social safeguards

Topic: Weathering materials are different, with respect to potentially toxic elements. Can a positive list (accepted) or a negative list (non-eligible) of weathering materials be provided?

Having positive/negative lists of weathering materials accepted/excluded by the methodology would simplify the assessment of ERW projects. However, an attempt of establishing such lists of materials was made during meetings with the expert group and revealed that reaching a consensus is difficult. Some of the reasons are listed below:

- Even within one type of rock, e.g. basalt, olivine, waste concrete, there are ranges of concentrations of potentially toxic elements (PTEs). Even within material extracted from the same mine, there will be variability.
- The environmental risk associated, e.g. with heavy metals applied to soil, does not only depend on the rock type and the concentration of PTEs in the rock, but also on other factors: the type of soil, the type of soil use, the application rate of the weathering material, and pre-existing background levels.

Among other factors, this is why a *project-specific environmental risk assessment* analysis is required from for all ERW activities planned by project proponents. Guidance on how to perform a risk assessment is provided, with specific information regarding heavy metals, asbestiform minerals, and radionuclides.

Topic: Heavy metal accumulation in soil is a key area of concern. What limit values are included in the methodology and why?

The topic of heavy metals was discussed multiple times by the working group. At first, the methodology included only limit values on the maximum concentration of heavy metal allowed in the weathering material, which were derived from the EU directive on fertilizer (product category of inorganic soil improvers).

However, the validity and relevance of these threshold values for enhanced weathering was argued by several experts to not be sufficient. Therefore, the compulsory environmental risk assessment was extended to require the analysis of a second metric, namely maximum concentrations of heavy metals *in the soil*. Guidance values are provided in the methodology, derived from the Finish governmental decree on the Assessment of Soil Contamination and Remediation Needs. While this decree is often used as a guide in the European context, it must be noted that other more stringent soil concentrations limits may exist locally (e.g. in other countries, or in particularly sensitive areas). Therefore, the compulsory environmental risk assessment analysis (which is project and site specific) will have to analyze both criteria (rock and soil concentrations) as well as demonstrate the relevance of the limit values considered for the specific application site.

In addition, this approach was deemed to provide the needed flexibility to deal with special cases.

The public consultation also suggested that the presence of (some) heavy metals, even at high levels, is not necessarily an environmental or human threat if the metals are not *bio-available*. Options to include bio-availability of metals were considered. It was however deemed more conservative and less variable to not consider bio-available fractions at this stage.

Topic: How is the public acceptance of ERW activities tackled in the methodology?

The topic of public acceptance of ERW activities was raised both during the September Advisory Board meeting, and during the public consultation.

During the meeting, the board discussed the topic of public acceptance of enhanced weathering in general as well as the involvement of local communities for specific projects, and whether requirements on stakeholder consultation should be included in the methodology. An expert present at the meeting argued that in surveys performed so far, stakeholder acceptance was good, when the co-benefits of enhanced weathering for agriculture were put forward. It was noted that it is equally important to present the risks and how the risks are managed.

The public consultation called for a more explicit requirement, in addition to the elements already included in the general principles. As a result, requirements for stakeholder consultation and involvement of local communities were made more explicit.

Chapter 6. Quantification of life cycle supply-chain emissions

Topic: What supply-chain emissions should be included when the weathering material is a waste or a by-product of another activity?

To deal with the case when the weathering material is a waste or a by-product of another activity, the LCA must applies the so-called "cut-off rule for waste and secondary products" approach. This terminology, derived from the LCA jargon, was deemed unclear by multiple stakeholders, and further clarified in the methodology.

In short, the life cycle assessment shall include the greenhouse gas emissions associated with sourcing the waste from the point where the waste is created. For instance, in the case of mining, emissions associated with extraction of the primary product do not need to be included; the waste or by-product is created free of any burdens. In the case of an urban waste like spent concrete, emissions associated with the previous production and use of the material do not need to be included. However, in both examples, any subsequent handling, transportation, or storage of the material must be included in the LCA (and this, even if similar emissions would have happened in an alternative waste management scenario).

Topic: How are possible direct land use changes (dLUC) dealt with in the LCA?

Thanks to the public consultation, the notion of dLUC was added to the scope of the LCA. Impact from dLUC refers here to a change in soil greenhouse gas emissions (biogenic carbon, methane and dinitrogen monoxide) after application of weathering material relative to a non-application baseline.

We reckon that dLUC is not straightforward to calculate and requires on-site measurement of soil characteristics, but also a non-amended control. To date, no generic values of dLUC can be used for enhanced weathering, the literature being scarce. We thereby hope that this requirement in the Puro methodology will help advancing knowledge.

It must be noted that dLUC can lead to both positive (reduced emissions) and negative impacts (increased emissions). For the sake of CORC quantification, i.e. Puro's carbon removal metric and digital asset, it was decided that only negative dLUC should be included in the LCA. In other words, if dLUC leads to increased emissions, then it must be included in the quantification of CORCs; if dLUC leads to decreased emissions, then dLUC must not be included in the quantification of CORCs, but can be presented as co-benefits of the activity.

This reasons for this dichotomy are mainly related to the fact that dLUC are an unresolved issue in LCA theory which require e.g. an allocation timeframe for carbon stock changes. In addition, potential carbon stock gains via positive dLUC do not have the same permanence and reversibility risks as the carbon stored via enhanced weathering.

The solution adopted is deemed conservative, in the sense that it penalizes for emissions and negative impacts of dLUC, but does not over-credit for temporary and uncertain removals in the case of positive dLUC. Potential dLUC, if demonstrated to take place, remain a valuable co-benefit to the long-term removal from enhanced weathering.

Topic: How is risk for economic leakage dealt with in the LCA?

Compared with other carbon removal methodologies, the risk for economic leakage in enhanced weathering projects is considered to be relatively low. The main risk for economic leakage is in the situation when the weathering material was already used to deliver another useful product or service, and thereby possibly entail the extraction of additional primary material, if demand persists. This is dealt with in the scope of the LCA by the requirement to include primary material extraction in the accounting when the absence of economic leakage cannot be demonstrated.

Topic: Should the LCA be attributional or consequential?

In the public consultation, it was suggested that Puro apply a consequential, project-level LCA framework, to account for the system-wide climate change impact of ERW activities, to quantify the amount of CORCs than a project can issue.

Puro recognizes that several types of LCA frameworks exist and are suited for different goals:

- consequential (aka changed-oriented) LCAs are suited to attempt determining the net climate change mitigation impact of an activity A relative to an activity B, in a context Z and using so-called marginal data whenever relevant, for a specific functional unit.
- attributional (aka accounting) LCAs are suited to identify hotspots within a supply-chain, but also to determine the net-negativity of a carbon removal activity A within given system boundaries, in a context Z and using so-called average data, for a specific functional unit.

As presented in the CDR literature, "CDR research acknowledges the importance of carbon accounting, and often refers to the use of life cycle assessment to *guarantee that supply-chain emissions do not outweigh the amount of CO2 captured*. CDR research also reckons *that only system-wide change in greenhouse gas emissions and sinks actually leads to climate change mitigation* (Tanzer and Ramirez, 2019; Brander et al, 2021)" (quote from Zakrisson et al. 2022).[1]

Puro believes that the "net-negativity of an activity" (as determined in an attributional LCA) and the "climate change mitigation impact of an activity" (as determined in a consequential LCA) are **two different but complementary metrics**. Puro also acknowledges the fact that, in many instances, "removing carbon dioxide today" is not necessarily the most efficient "climate change mitigation" measure today. This is why consequential assessments of e.g. DACCS, biochar, or BECCS would often conclude that they do not mitigate climate change as long as energy systems are relying on coal power. However, as it is also recognized in the IPCC AR6 reports and elsewhere, efforts for scaling CDR are needed today so that they can possibly reach the scale needed in a decade from now.

[1] Tanzer, S.E., and Ramírez, A. 2019. When are negative emissions negative emissions? Energy Environ. Sci., 12, 1210-1218. https://doi.org/10.1039/C8EE03338B
Brander, M., Ascui, F., Scott, V., and Tett, S. 2021. Carbon accounting for negative emissions technologies. Clim. Policy, 21(5), 699-717. https://doi.org/10.1080/14693062.2021.1878009
Zakrisson L., Azzi E.S., Sundberg C. 2022. Bioenergy with or without carbon dioxide removal: influence of functional unit choice and parameter variability. Pre-print, submitted for publication in the International Journal of Life Cycle Assessment. https://doi.org/10.31223/X5ZK9C

Therefore, Puro's LCA metrics are solely focused on determining net-negativity of a given removal, using an accounting approach, in a conservative manner. Being conservative implies that Puro's LCA metrics will not capture other positive climate effects that removal activities may have (e.g. see comment above on direct land use changes); but it will account for and penalize projects for any negative climate effects (e.g. land use change and economic leakage). As such, the CORCs are a metric representing removals, netted from supply-chain emissions and relevant other negative climate effects. In addition, the LCA metrics defined in the Puro Standard to calculate CORCs are metrics that allow, for a given methodology, to compare removal projects against one another.

Puro believes that consequential assessments of CDR technologies are needed, e.g. at a higher-level, led by extensive research work, to inform policies on the right technologies to support. However, consequential LCA seems less appropriate than a *well-defined attributional scope* to support the creation of a removal metric that can lead to scaling the CDR industry[2]. Puro's quantification approach is similar to the EU approach for carbon foot-printing of biofuels in the RED policies, or any other product environmental footprint scheme.

As of today, it seems challenging and not pragmatic to require projects to perform both attributional and consequential assessment of their activity without providing them with the right tools for it.

Chapter 7. Quantification of carbon dioxide stored and modelling

Topic: During the public consultation, most comments relating to the calculation, modelling, and validation of enhanced weathering suggested the addition of further requirements and information to ensure a robust and accurate simulation and validation approach. **How was this implemented?**

- Modelling
    - Emphasis was added on the uncertainties and challenges regarding current ERW models
    - Guidelines for ERW modelling were added, including suggestions for factors to consider in the models.
- Validation
    - Empirical validation of simulated results was explicitly added as a requirement
    - Annual on-site follow-up measurements were added as a requirement
    - Information and guidelines for validation methods were expanded including pros/cons lists and details of the various experimental validation techniques
    - Emphasis was placed on the importance of controlled experiments and quantifying the weathering *due to carbonic acid*, which is what drives CDR (instead of e.g. weathering due to strong acids in the soil).

The public commentary also included some comments that were not included in the methodology. There were three main points that were ultimately not included in the methodology, namely

- Request to simplify and add some general rules to modelling and verification approaches

[2] This can be explained with the case of biochar, another removal method. Biochar systems have been assessed in multiple consequential LCAs, in research and in various parts of the world. These consequential assessments of biochar conclude that deploying biochar systems lead to more climate change mitigation than e.g., conventional bioenergy, through multiple effects (carbon storage and material uses of biochar), unless when energy systems are heavily reliant on coal and simultaneously biochar is not put to useful usage. These results being established, the use of well-defined attributional LCA to issue removal certificates is, we believe, beneficial to scaling biochar production and use globally. Obviously, scaling any CDR technology must go hand-in-hand with coherent policies to decarbonize our global economy.

- While certain overarching principles concerning the modelling and validation approaches were explicitly added, the modelling and verification of ERW remains a challenging topic for which scientific consensus has not yet been reached. At the moment, it is not possible to create modeling and verification approached that are very simple, yet accurate enough to capture all aspects of the ERW process in enough detail.

- Request for compulsory publication of simulation approaches
  - Instead of compulsory publication, a strong suggestion for the use of peer-reviewed, open-source models was added as well as the additional suggestion that the core components of the models should be publicly available.
- Request for additional validation approaches
  - There is currently no scientific consensus on the best way to validate ERW results in field. Thus, the methodology does not require the use of any particular experimental method, but instead includes several suggested methods and emphasizes the need for a robust quantification approach, preferable based on several different kinds of measurements. The methodology already makes it clear that the experimental methods suggested are not the only ones that can be utilized for validation.

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