Biochar

Methodology for CO_2 Removal

Edition 2025 V1

Puro Standard

June, 2025

Document name	Biochar Methodology
Document version	Edition 2025 V1
Date of approval	June 12th, 2025
Status	Approved (pending final copy edit)

Table of contents

Glossary of Terms

> **REMARK:** This glossary provides only the most important definitions for the current methodology. Please note that further definitions are listed in the Puro Standard General Rules.

Activity – A practice or ensemble of practices that take place on a delineated area resulting in emissions or removals taking place. An eligible activity is an activity that meets the qualification criteria in a given certification methodology or protocol.

Biochar – Solid, carbon-rich material obtained from the thermochemical conversion of biomass in an oxygen-limited environment.

Biomass – Organic matter recently derived from the biosphere, including e.g. crops, crop residues, organic municipal waste, forest biomass, sewage sludge, and others.

Carbon dioxide removal (CDR) – Anthropogenic activities removing carbon dioxide (CO_2) from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products[1].

CO_2 Removal certificate (CORC) – A CORC, issued by the Puro Standard, certifies the net removal of one metric tonne of CO_2 equivalent from the atmosphere, accounting for all related emissions.

Carbonization – Process for the thermochemical conversion of biomass into biochar and co-products, in an oxygen-limited environment. Here, the term carbonization is used as a generic term to describe any process used for biochar production along the continuum of thermochemical conditions, from slow pyrolysis to gasification.

Indirect emissions – see *Leakage*

Leakage – An indirect effect associated with a CO_2 Removal activity and dependent on the selected baseline, that may lead to an increase or decrease in greenhouse gas emissions or removals, outside of the system boundaries of the activity, if not avoided or mitigated. It is also called indirect emissions.

Sustainable biomass – Biomass that has been sourced according to the sustainability requirements of this methodology and other Puro Standard Requirements[2], namely the Puro Biomass Sourcing Criteria.

Tonne (t) – A unit of mass equivalent to 1000 kg, also known as 'metric tonne'. In this methodology, the word 'tonne' always refers to a metric tonne.

[1] IPCC AR6 WGIII Report, page 1796
[2] Puro Earth's document library

Acronyms

CDR - Carbon Dioxide Removal

CO_2e or **CO_2-eq** - CO_2 equivalent

CORC - CO_2 Removal certificate

EBC - European Biochar Certificate (trademark owned by Carbon Standards International)

EIA - Environmental Impact Assessment

GHG - Greenhouse Gas

GWP_{100} - Global Warming Potential over 100 years

IBI - International Biochar Initiative

ICVCM - The Integrity Council for the Voluntary Carbon Market

IPCC - Intergovernmental Panel of Climate Change

LCA - Life Cycle Assessment

LCI - Life Cycle Inventories

MSW - Mixed Solid Waste

PAH - Polycyclic Aromatic Hydrocarbon

PTE - Potentially Toxic Element

SDGs - Sustainable Development Goals

VCM - Voluntary Carbon Market

VOCs - Volatile Organic Compounds

VVB - Validation and Verification Body

WBC - World Biochar Certificate (trademark owned by Carbon Standards International)

Note to the reader

REMARK: This methodology provides general information as well as requirements which must be met by all projects seeking certification under the Puro Standard. Across the document, requirements correspond to numbered rules with formatting conforming to the below example. General information is presented without numbering.

0.0.1 This is an example of a numbered rule. The requirements set within numbered rules must be followed by all projects seeking certification under the Puro Standard.

Please note that in addition to the requirements of this methodology document, all projects seeking certification under the Puro Standard must also comply with the Puro Standard General Rules and other Standard Requirements, as well as any applicable local laws, regulations, and other binding obligations. For Puro Standard documents, see https://puro.earth/document-library

Note on public consultation

This methodology was shared for public consultation between April 3rd and 28th 2025. The feedback received has been addressed and edits included in this document. Further details on the outcome of the public consultation are published in the Puro.earth Document Library (https://puro.earth/document-library).

Note on Transition Period

This methodology edition (Biochar, Edition 2025) is meant to progressively replace the previous edition (Biochar, Edition 2022). A transition plan is published separately in the Puro.earth Document Library (https://puro.earth/document-library).

Document history

- **Edition 2025 v. 0.9** (April 3rd, 2025) — Draft for public consultation released.
- **Edition 2025 v. 1.0** (June 12th, 2025) — Version approved by Puro's Advisory Board.

1. Introduction

1.1. Biochar for carbon dioxide removal, climate change mitigation, and sustainability transition

Biochar as a versatile material

Biochar is a solid, carbon-rich material produced through the heating of biomass under reduced oxygen conditions. In the early 2000s, biochar was differentiated from charcoal by its intended use for soil amendment and carbon sequestration (Kwapinski et al., 2010) (Lehmann, 2007). However, the definition has expanded to include various applications beyond agricultural soils, such as the remediation of contaminated soils, serving as an additive in construction materials, or as a filter media in the industrial sector (Bartoli et al., 2020) (Wang et al., 2023) (Yaashikaa et al., 2020). Another possible application of biochar is its use as biocoal or biocoke in steel production and other oxidative industrial processes (Ibitoye et al., 2024), where it serves as a renewable substitute for fossil-based reductants, contributing to the decarbonization of heavy industries but does not contribute to carbon removal (Safarian, 2023).

Biochar for carbon dioxide removal

Renewable biomass, such as plants and algae, grows by capturing atmospheric CO_2 through photosynthesis and converting it into organic matter. In natural ecosystems, this biomass eventually decomposes, releasing carbon back into the atmosphere, maintaining a short-term carbon cycle. Biochar production interrupts this cycle by thermochemically stabilizing biomass. While the co-products of biochar production are typically used for energy, returning carbon to the atmosphere; biochar consists of condensed aromatic structures that are able to resist decomposition in the environment over long time scales. As a result, biochar used in carbon-preserving applications constitutes a form of removal of CO_2 from the atmosphere (Lehmann et al., 2021). More precisely, the persistence of biochar has been a topic of extensive research, including analyses of biochar physico-chemical properties, biochar decomposition experiments in laboratory incubations and field studies, as well as different kind of modelling methods (Azzi et al., 2023). Importantly, not all biochars have similar persistence properties, and feedstock type and production conditions play a key role (Ippolito et al., 2020) (L. Li et al., 2023) (Singh et al., 2012). Environmental factors also have an effect: soil microbial activity alongside other abiotic processes can degrade biochar carbon, or at least some of its least condensed aromatic structures. This said, other soils processes contribute to biochar persistence, e.g. protection by soil aggregates, illuviation in deeper soil layers, and other translocation mechanisms.

Quantifying biochar persistence

Until recently, the quantification of biochar persistence focused on a 100-year time horizon and the use of decay-based models (Woolf et al., 2021), but acknowledged that biochar carbon would likely persist for much longer. These models have been perceived as conservative, were proposed for use in national greenhouse inventory under the UNFCCC as an appendix (IPCC, 2019), and increasingly used in the voluntary carbon market. However, recent scientific advances both in incubation-derived models (Azzi et al., 2024) (Lehmann et al., 2021) (Woolf et al., 2021) and in characterisation of biochar properties (Petersen et al., 2023) (Sanei et al., 2024) are suggesting that previously used models may have been overly conservative, despite certain areas of remaining uncertainty and on-going scholarly discussions. To reflect those advances, Puro.earth decided to increase the durability of biochar carbon removal to several centuries[3], i.e. well beyond 200 years, as represented by CORC200+. This increase does not preclude that further consolidation of biochar persistence science may lead to further increases of durability claims for biochar in the coming years. To enable quantification over several centuries, Puro.earth is also presenting a revised decay-based model. In parallel, Puro.earth also supports the voluntary use of random reflectance measurements, to increase the knowledge around its use in actual certification operations and contribute to the refinement of quantification of persistence based on these measurements.

Biochar risks of reversal

Beyond the expected carbon losses from biochar decomposition, additional risks can lead to unintended carbon re-emissions. These risks can occur at different stages of the supply chain, from production and distribution channels to cascading uses and final application. The primary concern is the diversion of biochar toward oxidative applications, either intentionally or inadvertently. Such risks vary with application type and context but can be mitigated through proper monitoring, collection of evidence, and characterization of biochar applications. Natural risks, such as fires, also play a role, though their impact depends on environmental conditions and management practices. Therefore, ensuring biochar durability involves not only demonstrating its persistence but also implementing safeguards to minimize reversal risks.

Biochar in climate change mitigation & sustainability

Biochar systems are not only a tool for CDR but also a means of reducing emissions and enhancing environmental management (Lehmann et al., 2021). Biochar use across various applications offers co-benefits (Azzi et al., 2021), such as improving agronomic performance, enhancing the properties of materials like concrete and asphalt, and optimizing processes like composting and soil remediation. Additionally, biochar can serve as a sustainable alternative to other products, such as peat. Its co-products can also be valorized for bioenergy or biomaterials, promoting efficient biomass utilization and delivering broader societal benefits. Furthermore, converting certain biomass feedstocks into biochar presents a more suitable treatment option compared to conventional management practices that can be detrimental to human health and pose environmental problems. To maximize its contribution to sustainability (Cowie et al., 2024) (Sundberg & Azzi, 2024), biochar systems should be designed to harness these diverse benefits, while simultaneously minimizing any potential negative impacts throughout the supply-chain.

1.2. Sound biochar supply-chains, from biomass sourcing to biochar use

Origins

The concept of biochar dates back over 2000 years to the Amazonian practice of creating *terra preta*, or "black earth", a type of anthropogenic dark earth which presumably involved adding charcoal to nutrient-poor tropical soils (Glaser & Birk, 2012). While the exact formation processes remain debated (potentially including middens, waste management, and/or intentional soil improvement), these soils demonstrate charcoal's long-term stability in soils and its potential to enhance fertility.

[3] A durability of several centuries, corresponding to at least 200 years, is considered under the EU legislation to be permanent removal.

Today, advanced pyrolysis technologies are being used to produce and apply biochar as a solution for carbon sequestration, soil enhancement and now other applications (Allohverdi et al., 2021). Overall, a well-designed biochar system requires careful planning and implementation across its three fundamental components: the sourcing of the biomass, the biochar production, and the final use of the biochar. Each step must be executed properly to ensure a positive outcome for carbon dioxide removal (CDR), climate change mitigation, and environmental and social benefits.

Biomass sourcing

Biochar can be produced from a variety of biomass feedstocks, including agricultural residues, forestry by-products, and energy crops (Lehmann & Joseph, 2024). Agricultural residues such as crop stalks, husks, and straw are commonly used as they are abundant and often underutilized (Rex et al., 2023) (Ahmed et al., 2024). Forestry by-products, including sawdust, bark, and forest thinning, also serve as excellent feedstocks due to their high lignin content (Kwapinski et al., 2010). Additionally, energy crops like switchgrass and fast-growing trees can be cultivated specifically for biochar production, provided they are cultivated with adequate land use considerations. Each type of feedstock has unique properties that influence the characteristics of the resulting biochar, making the choice of biomass a critical factor in the production process (Jung et al., 2019) (Zhao et al., 2013). Sustainable sourcing of biomass requires a transparent supply chain that ensures environmental and social responsibility. Producers should prioritize feedstocks that do not compete with food production or contribute to deforestation. This involves selecting residues and by-products that would otherwise go unused or be discarded. Additionally, producers should engage with local communities and stakeholders to ensure that biomass harvesting does not negatively impact local ecosystems or livelihoods.

Biochar production techniques

Biochar can be produced through various processes, with pyrolysis being the most common method (Lehmann & Joseph, 2024). Pyrolysis involves heating biomass in an environment with very limited or no oxygen, resulting in the production of biochar, pyrolytic gases, and tars. More generally, biomass carbonization can be classified into slow pyrolysis, fast pyrolysis, and gasification, each differing in temperature, heating rate, and residence time (Gabhane et al., 2020). Slow pyrolysis occurs at lower temperatures (300-500°C) with longer residence times, producing higher yields of biochar. Fast pyrolysis operates at higher temperatures (500-700°C) with rapid heating and short residence times, yielding more liquid products and gases. Gasification, which occurs at even higher temperatures (800-1000°C) and in the presence of a controlled amount of oxygen or steam, primarily produces syngas and a smaller quantity of biochar. The choice of production method influences the properties of the resulting biochar and its suitability for various applications (L. Li et al., 2023) as well as the amounts and nature of co-products. Safe biochar production requires careful selection of equipment and sound operating procedures. Important factors to consider include, e.g. the energy efficiency of the process, the management of co-products and waste streams, the ability to achieve minimal emissions of air pollutants and greenhouse gases, the ability to produce biochar of high environmental quality, and overall the level of automation and control over the equipment.

Management of co-products

During the production of biochar, the management of co-products such as gases and tars is critical. Gases and tars can be combusted to sustain the carbonization process but also converted into heat and power for other uses. In certain systems equipped with condensation, tars can be further processed into bio-oil, an energy-rich liquid that can be used as a fuel or refined into various chemicals and materials via advanced processes. To manage co-products properly, it is essential to implement efficient processing and combustion technologies. Advanced reactors can ensure that gases are collected and fully combusted for energy recovery. These systems should be designed to handle the specific composition and flow rates of the gases produced. Proper design and procedures are also necessary to prevent leaks and ensure safety. Emissions control technologies, including scrubbers and filters, should be employed whenever necessary and depending on the feedstock, to reduce the release of pollutants formed during the combustion and processing of co-products.

Biochar applications and co-benefits

The final component is the use of biochar, which determines carbon storage. Biochar has a wide range of applications beyond soil amendments, including water filtration, construction materials, and other industrial processes (Bartoli et al., 2020). In agriculture, biochar can be incorporated into soil to improve nutrient retention, water holding capacity, and microbial activity, which enhances soil fertility and crop yields (Allohverdi et al., 2021). Biochar can also be used to treat contaminated soils by adsorbing heavy metals and pollutants, thus restoring soil health (Y. Liu et al., 2018). In water treatment, biochar's porous structure makes it an effective medium for removing contaminants from water. Additionally, biochar can be used as a component in building materials, such as bricks and concrete, where it can improve material properties (Rondón-Quintana et al., 2022). As biochar co-benefits depend on the selected applications and material properties, it is clear that they cannot be realized simultaneously and result from conscious design choices.To ensure that the uses of biochar bring the expected climatic, environmental and societal benefits, proper application methods, product formulation, and management practices are key. When used as a soil amendment, only environmentally safe biochar should be applied in reasonable amounts, considering also the local soil types, agricultural practices, and biochar properties, e.g. available nutrients or liming potential. For non-agricultural uses, it is essential to integrate biochar into products and processes in a manner that yields benefits for the product, either in the form of properties or environmental performance.

1.3. Purpose of this certification methodology

This methodology is applicable to certificates issued under the Puro Standard. The methodology sets the requirements for eligibility and quantification of the net CO_2 removal achieved by biochar activities over the time horizon of several centuries, issued as CORC200+ in the Puro Registry.

The scope of this methodology includes the entire biochar supply-chain, from biomass sourcing to the use of biochar, allowing for a diversity of biochar production technologies and applications. The rules are designed to ensure that all steps contribute to the overall goal of durable CO_2 removal, in a socially and environmentally safe manner.

This methodology provides procedures for measuring and monitoring all aspects of biochar production and use, ensuring precise accounting of net carbon removals, and adequate management of reversal, social and environmental risks. It sets the rules for establishing the baseline, which contributes to the determination of additionality and indirect effects (leakage). The methodology also includes rules for the identification and reporting of material sources of uncertainty in quantification.

Note that in addition to the requirements of this methodology document, all projects seeking certification under the Puro Standard must also comply with the Puro Standard General Rules and other Standard Requirements, as well as any applicable local laws, regulations, and other binding obligations.

2. Point of creation of the CO_2 Removal Certificate (CORC)

This section specifies the notions of CO_2 Removal Supplier, Production Facility, Crediting Period, and Point of Creation of CORCs, in the context of a biochar carbon removal activity.

2.1. CO_2 Removal Supplier

Biochar supply chains consist of three main types of actors. Biomass providers are responsible for sourcing and supplying the raw biomass material used in biochar production. Biochar producers convert the supplied biomass into biochar using pyrolysis or other thermochemical conversion techniques. The producer is responsible for maintaining the production equipment, adhering to environmental regulations, and ensuring the biochar meets specified quality criteria. Biochar users, whether final users, intermediary users or brokers, are responsible for the proper integration of biochar into the intended application to maximize its benefits and ensure long-term carbon storage.

In most situations, a biochar supply chain is made of a biochar producer receiving biomass from multiple biomass providers, and delivering biochar to multiple users. As such, the biochar producer plays a central role in the supply-chain as well as in the certification of the biochar carbon removal activity. Beyond the direct supply-chain actors described above, other actors can be involved in a biochar carbon removal activity, in particular entities that can assist a biochar producer in developing its activity and conducting the monitoring required for verification of the removal activity.

2.1.1. The CO_2 Removal Supplier is the party contractually authorized to represent the participants necessary to perform the end-to-end activities associated with a biochar carbon removal activity seeking certification under this methodology. Here, the CO_2 Removal Supplier can either be the biochar producer, i.e. the entity owning the biochar production assets, or alternatively, an entity representing the biochar producer via adequate contracts (e.g. parent company, agent, supply aggregator, project developer, or similar). Note that this does not prevent the biochar producer from also being partly or in-full a provider of biomass or a user of biochar.

2.1.2. The CO_2 Removal Supplier is the party responsible for making end-to-end data available and accessible for third-party verification. This includes delivering data needed to assess the eligibility of the activity, as well as monitoring and quantifying the net carbon removal. To enable collection of the necessary data for verification, the CO_2 Removal Supplier must establish clear responsibilities and liabilities with relevant supply-chain partners, external operators, or other involved parties..

2.1.3. The CO_2 Removal Supplier is the party that retains the sole rights to claim CORCs from the biochar carbon removal activity, and must therefore establish, through contracts or similar documents, that any relevant supply-chain partners, external operators, or other involved parties have no such right. *See further details on prevention of double-counting in section 3.8.*

2.2. Production Facility and crediting period

Biochar production equipment encompasses a range of thermochemical processes, configurations and scales. From a certification standpoint, important practical differences arise between stationary (fixed) production equipment and mobile production equipment. In particular, mobile assets are by construction smaller, operate in different locations, and often grouped in fleets, all of which require special attention during certification. Further, whenever several reactors are certified together, attention must be paid to differences between reactors, e.g. in terms of feedstocks processed and operating conditions, potentially affecting monitoring needs.

2.2.1. The **Production Facility** is the ensemble of physical assets necessary to convert biomass into biochar, and subject to the Production Facility Audit. A biochar production facility must be categorized either as **Stationary** (sub-rule a) or **Mobile** (sub-rule b).

a. A Production Facility must be categorized as **Stationary** if it is designed for biochar production at a specific location. The Production Facility may process feedstock from multiple sources, but the reception of the biomass, its pretreatment and thermochemical conversion, and packaging of the biochar take place in a fixed location. In case the Production Facility comprises several reactors (e.g. multiple biochar production lines in the same factory), all reactors must be using similar technology and all reactors must be commissioned and operational at the time of the Facility Audit. The Facility Location is defined as the address or coordinates where the equipment is located.

b. A Production Facility must be categorized as **Mobile** if it is designed for biochar production in multiple locations and where the biochar production equipment is transported to several locations (e.g. based on biomass feedstock availability). The Production Facility may process feedstock from multiple sources. In case several reactors are within the same Production Facility, commonly referred to as a fleet of mobile reactors, all reactors must be using similar technology and must be commissioned and operational at the time of the Facility Audit. Several other properties of the Production Facility must be defined at the time of the Facility Audit:

   i. **Facility Location**: an address or coordinates relevant for the facility, such as a warehouse where the fleet is stored, the headquarters of the biochar producer, or similar.

   ii. **Facility Spatial Extent**: a geographical area in which all biochar production operations take place. This area must be contained within the geographical boundaries of a single country[4], and more commonly a set of sub-national regions. Within this spatial extent, the CO_2 Removal Supplier must be able to demonstrate compliance with all regulations applicable, possibly emanating from different authorities, in particular regarding environmental regulations and stakeholder engagement processes. This spatial extent shall represent an area where production operations actually take place, i.e. an actual space roamed by the reactors in the fleet. The spatial

[4] This is required to enable the determination of a unique and unambiguous Host Country for the removal activity.

extent may be extended during third-party audits, to include new regions where biochar production operations have extended.

iii. **Production Sites**: a list of individual production sites that must all be located within the Facility Spatial Extent. This list can be expanded continuously, as part of normal production operations and reporting activities, provided that adequate documentation is collected in line with the Facility's monitoring plan and environmental and social safeguards (e.g. when moving a reactor to a new farm, adequate stakeholder consultation should have been undertaken and documented; likewise, it must be checked that environmental permits or licenses are also valid in the new location: if licenses for instance require that operations must be at a minimum distance from dwellings, those aspects must be checked and documented as per the monitoring plan). Further, for each individual production site, it is expected that address, coordinates, and other site ownership information are collected by the CO_2 Removal Supplier to enable precise identification of the site and its owners. Different types of production sites can be defined by the CO_2 Removal Supplier, describing the nature of the sites where production operations take place, e.g. warehouse, rice factory, biogas plant, farm, field.

> **EXAMPLE 1:** *Supplier A* operates five mobile biochar reactors across multiple locations in California, Nevada, and Oregon—three contiguous states in the USA—where the reactors frequently cross state boundaries. Additionally, *Supplier A* has ten mobile reactors operating in Maine, with different regulations. *Supplier A* can either register these reactors as two separate mobile production facilities (one for Maine and one for the California-Nevada-Oregon group of states) or as a joint facility covering the entire area.

> **EXAMPLE 2:** *Supplier A* intends to operate a biochar production facility at *Location X* for three years before relocating it to *Location Y* for another multi-year operation. This setup is classified as a stationary facility. However, upon relocation, *Supplier A* must go through an update of the Facility Audit or, if deemed necessary by the Issuing Body, register a new Facility to account for the changes.

2.2.2. The **Crediting Period** of the Production Facility is set to 10 years in this methodology, starting from the first date of the first monitoring period. The Crediting Period can be renewed twice by successfully undergoing a new Production Facility Audit, against the latest version of the methodology and Puro Standard General Rules.

2.3. Point of creation of CORC

2.3.1. The point of creation of the CO_2 Removal Certificate (CORCs) is defined as the earliest point in the CO_2 removal process when CORCs can be claimed. For this methodology, the point of creation of CORCs is the first point in the supply-chain where biochar has been used in a manner that ensures durable carbon storage. Since biochar can have multiple possible uses with different risks of re-emissions and reversals, additional rules apply to demonstrate that those risks do not materialize (see section 3.6 and section 4.2).

3. Eligibility Requirements

This section defines what is an eligible biochar carbon removal activity and defines the associated eligibility requirements that must be demonstrated during audits. Some requirements introduced in this section are then further developed in the following sections.

3.1. Requirements for general eligibility

Eligible activity definition

3.1.1. An **eligible biochar carbon removal activity** is an activity where an eligible biomass source (see section 3.4) is converted through thermochemical processing into biochar under adequate conditions (see section 3.5), and the biochar is subsequently used in eligible applications (see section 3.6) that ensure that carbon is durably stored over several centuries with no significant risk of reversal (see section 4), and resulting in net carbon removal (see section 5).

Audit types, corrective actions and changes

3.1.2. For issuance of CORCs to be possible, the Production Facility must first have undergone a third-party Production Facility Audit, verifying the compliance with this methodology, the Puro General Rules, and related standard documents. As per the Validation and Verification Requirements, the initial Production Facility Audit must be conducted on-site, unless a deviation is granted by the Issuing Body.

3.1.3. During the course of the crediting period, the Issuing Body issues CORCs based on the outcome of the reporting done for the Production Facility, following Output Audits procedures as defined in the Puro General Rules.

3.1.4. During the course of the crediting period, the CO_2 Removal Supplier is required to deploy any corrective actions identified by auditors, in a timely manner, and report on the status of these actions in subsequent audits.

3.1.5. During the course of the crediting period, the CO_2 Removal Supplier must promptly report to the Issuing Body any change affecting the eligibility of the Production Facility, such as any material modifications to the biochar production equipment configuration or any expansion of the production capacity. Such changes must then also be documented by the CO_2 Removal Supplier and verified by the auditor in subsequent audits. A failure to promptly report those changes may lead the Issuing Body to suspend the Production Facility until resolution at the next audit.

a. For expansion of the production capacity, *prompt* reporting to the Issuing Body means notifying Puro.earth in writing within 30 days of the financial decision being taken to expand the capacity.

b. For any other changes, *prompt* reporting to the Issuing Body means notifying Puro.earth in writing within 30 days of the change, and always before the next scheduled audit—whichever occurs first.

Capacity expansion of production facilities

3.1.6. The addition of new reactors to an existing Production Facility is possible during the course of the crediting period without triggering a new Production Facility audit and without affecting the duration of the crediting period, when all the following conditions are met:

a. The added reactors have a similar design to the existing reactors, and their installation follows the necessary environmental and social regulation (e.g. permits or impact studies required by the host jurisdiction have been obtained).
b. The added reactors operate at the same location (Stationary Facilities) or within the defined spatial extent of the facility (Mobile Facilities).
c. The CO_2 Removal Supplier provides an update of all affected facility audit documents and complementary documents as necessary (e.g. permits and licenses, Monitoring Plan, Project Description, Additionality Assessment).
d. The first verification and issuance of CORCs for the added capacity can only take place following i) the *next scheduled* Output Audit for the Facility (i.e. within a year) or ii) an *additional* Output Audit (subject to rule 3.1.7). In both situations, the Output Audit will have a modified scope as specified in rule 3.1.8.

Note that new reactors can also be registered as a separate Production Facility. The decision would depend on the supplier's operational design and preferences, provided that all applicable requirements can be met.

Additional Output Audit following capacity expansion

3.1.7. An additional Output Audit can be organized to verify the information of the added capacity, under the following conditions:

a. All documentation required for verification must be ready and submitted to the Issuing Body prior to the audit organization.
b. The added capacity must have generated a volume of CORC above the minimum defined in the Puro General Rules and Terms and Conditions. For lower volumes, additional fees may apply.

Scope of verification after capacity expansion

3.1.8. Following capacity expansion, the scope of an Output Audit, conducted by a third-party auditor, is defined as follow:

a. Verifying the similarity of the added capacity to the rest of the Production Facility and its compliance with the Puro Standard.
b. Verifying that the monitoring capabilities required by the methodology also apply to the added capacity.
c. Verifying the volume of CORCs reported for existing and additional reactors.

3.2. Requirement for baseline demonstration

The baseline is a conservative scenario or set of conditions that would have happened without the biochar activity and revenues from carbon finance. By establishing a comprehensive baseline, it becomes possible to quantify the additional carbon removal achieved by a biochar activity. The Baseline also affects the determination of i) additionality (see section 3.3), ii) indirect emissions, also known as ecological, market and activity shifting leakage (see section 8), iii) certain land use change emissions (e.g., direct land use change associated with facility construction, counted as part of the project emissions, see section 7), and iv) SDG co-benefits (if certified, see Puro SDG Assessment Requirements). This section defines a set of baseline scenarios for various types of biochar activities.

For biochar activities, the baseline scenario can technically be seen as made of several components, including the baseline about the biochar production assets, the alternative fate of the biomass feedstock, and the alternative to the biochar usage. Among these three components, the biochar production asset baseline is the primary differentiator between biochar activity types. Indeed, since a Production Facility can process multiple and changing types of biomass, baseline aspects related to use of biomass must rather be dealt with alongside monitoring of operations, in line with the Puro Biomass Sourcing Criteria, and verified at each Output Audit (see further section 3.4 and section 9). Further, the alternative to the biochar usage is important for quantifying biochar use-phase effects and therefore must be defined if SDG co-benefits are reported for verification. However, the co-benefits are beyond the scope of carbon removal quantification and certification.

Options of baseline scenarios

3.2.1. The CO_2 Removal Supplier shall select one of the baseline scenarios a-c for its biochar activity:

a. **New Facility**: this refers to activities where a **new biochar production facility** is established, designed from the start of its operation for the production of biochar and possible other bioenergy or biomaterial products. In this context, it is allowed that a share of the biochar output is used for non-eligible purposes, e.g. sold as biocoke or charcoal (but no CORCs can be issued for this share).

b. **Retrofit Facility**: this refers to modifying an **existing bioenergy facility** so that after modifications, it starts producing biochar meant for eligible applications. This scenario can apply in several situations, typically with modified material properties of the char, such as: bioenergy facilities where high-carbon fly ash (HCFA) recirculation is interrupted, bioenergy facilities where the biomass processing conditions are modified to generate a biochar output instead of ash, bioenergy facilities that do not operate at full capacity or could be phased out.

c. **Charcoal Repurpose**: this refers to operational changes at an **existing charcoal production facility** so that after changes, charcoal products or co-products (e.g., fines) are diverted from their historical use or fate (e.g. energy use, activated carbon materials), possibly with modifications of the production equipment and biomass sourcing to comply with the methodology.

Note that the selection of a baseline scenario is performed for the initial Facility Audit, and then remains fixed throughout all crediting periods.

EXAMPLE OF RETROFIT FACILITY: A biomass power plant has been in operation for multiple years, generating electricity and producing carbon-containing ash. Currently, the carbon-containing ash is sent to landfill, contributing to some carbon sequestration. After retrofitting, the plant modifies its process to increase the production of char, which is then used as biochar for soil amendment. This shift increases carbon sequestration, but also results in a reduction in electricity production. *Such a project is classified as Retrofit Facility, and is subject to specific rules for determination of baseline carbon removal and indirect effects on electricity markets.*

EXAMPLE OF CHARCOAL REPURPOSE: A charcoal production facility has been operating for several years, producing charcoal primarily for use as a fuel. The facility generates charcoal, and any excess or low-quality charcoal (e.g. charcoal fines) that does not meet market specifications is currently stockpiled and eventually discarded in surrounding soils. Operators of the facility decide to repurpose charcoal fines for soil use, and divert a fraction of their charcoal production for soil use. *Such a project is classified as a Charcoal Repurpose Facility and is subject to specific rules for determining baseline carbon removal, as well as assessing the indirect effects on existing charcoal markets.*

Selection of appropriate baseline

3.2.2. The CO_2 Removal Supplier shall demonstrate compliance with the selected baseline scenario, based on the following conditions a-c:

a. For a biochar production facility to be classified as **New Facility** (A), the CO_2 Removal Supplier must demonstrate that the biochar production has started concomitantly to or earlier than the production of other bioproducts (e.g. bioenergy, biomaterials, charcoal), if any. The production asset is typically newly built, procured, or manufactured specifically for the CO_2 Removal Supplier. However, in certain cases, it can also be an existing asset that is purchased and re-purposed by the CO_2 Removal Supplier (change of ownership, see rule 3.2.4) as part of a new project.

b. A biochar production facility is otherwise classified as **Retrofit Facility** (B), if it is not specifically a charcoal production facility, and if bioenergy (heat, power, fuels) or biomaterials were already produced prior to the production of biochar.

c. A biochar production facility is otherwise classified as **Charcoal Repurpose** (C), if the facility was already producing charcoal for energy usage or other usage (e.g. activated carbon), and possibly selling or disposing charcoal fines, without the prospect of carbon finance revenues from biochar.

Further baseline aspects to be specified

3.2.3. Regardless of the selected baseline scenario, the CO_2 Removal Supplier shall further specify the baseline land use of the facility location(s), i.e. the state of the land where the facility is either located (Stationary Facility) or operates (Mobile Facility) prior to project start, for the determination of any direct emissions associated with permanent land cover change due to new construction works, facility expansion works, or other land clearing (see section 7.4). Acceptable data sources include for instance satellite imagery, land registries, primary evidence collected prior to construction, or other similar documents.

Transfer of ownership

3.2.4. In case the biochar production asset was already existing but owned and operated by another entity, the CO_2 Removal Supplier must disclose all information to the Issuing Body relating to the transfer of ownership, any location transfer, repairs and modifications, as well as previous use of the asset (e.g. was it already registered in another registry and receiving carbon finance revenues). On a case-by-case basis, the Issuing Body will evaluate the eligibility of the transfer of ownership.

Unforeseen baseline scenario

3.2.5. In other unforeseen situations, the CO_2 Removal Supplier shall together with the Issuing Body conduct a case-by-case analysis to define an appropriate baseline scenario for this Production Facility. The Issuing Body shall issue a rule clarification prior to certification of any such unforeseen situations.

3.3. Requirements for additionality

Additionality components

3.3.1. The CO_2 Removal Supplier must demonstrate that the biochar activity complies with all three components of additionality, as defined in the latest version of the Puro Additionality Assessment Requirements[5], namely:

a. Carbon additionality, i.e. the activity results in higher volumes of carbon removals than in the selected baseline scenario.
b. Regulatory additionality, i.e. the activity is not required by existing laws, regulations, or other binding obligations.
c. Financial additionality: i.e. the carbon removals achieved by the activity are a result of carbon finance.

Additionality demonstration procedures

3.3.2. To demonstrate additionality, the CO_2 Removal Supplier must answer the latest version of the Puro Baseline and Additionality Questionnaire[6] and provide to the Issuing Body any piece of evidence required in this questionnaire. The information provided must be specific to the Production Facility. Upon successful Facility Audit, the questionnaire must be made public in the Puro Registry; however, supporting pieces of evidence used during verification are not required to be made public.

Biochar-specific financial additionality aspects

3.3.3. Whenever determination of financial additionality requires a cost analysis or investment analysis, in addition to any other rules applicable as per the Puro Additionality Assessment Requirements, the following biochar-specific aspects must be covered:

- Biochar sales revenues: Provide a detailed assessment of current biochar prices and projected trends over the first Crediting Period. Justify these estimates with supporting data and clarify any economic or market trends considered.

[5] Available in the Puro Standard document library: https://puro.earth/document-library?tab=standard_documents
[6] Available in the Puro Standard document library: https://puro.earth/document-library?tab=templates_and_guidelines

- Co-product revenues: If applicable, report on the current and expected pricing of any co-products over the crediting period, specifying how these values were determined.
- Expenses overview: Outline the key cost components involved in biochar production, including biomass, labor expenses, and capital investments, ensuring a comprehensive financial analysis.

Biochar production replacing a waste treatment technology

3.3.4. In the same context as rule 3.3.3, in the event that the biochar activity concerns a biomass feedstock that must be and is already treated or disposed of as per local regulation (e.g. sewage sludge disposal or incineration) and that this treatment represents an existing cost to the entity currently managing the feedstock (whether it is the CO_2 Removal Supplier or not), the financial analysis must adequately compare the financials of the project to the current and projected future treatment and disposal cost of the feedstock. If the implementation of the biochar activity results in significant cost savings, without projected CORC revenues, the activity may be deemed non-financially additional and thereby not eligible.

3.4. Requirements for biomass sourcing

Adequate sourcing and management of biomass is important for the environmental quality of biochar, for air pollutant emission, safety during production, and overall for the integrity of the biochar carbon removal activity. Biomass sourcing must not be allowed to damage natural ecosystems nor entail other indirect effects that would not be mitigated. Further, impurities, micropollutants, potentially toxic elements (PTEs), and biological hazards and pathogens that may be present in the feedstock must be adequately managed during biochar production. Therefore, it is essential for CO_2 Removal Suppliers to monitor the sustainability and eligibility of their biomass on an ongoing basis and have adequate procedures to manage any risks associated with biomass use.

Biomass sources and batches supplied to the facility

3.4.1. The CO_2 Removal Supplier must declare the list of all **biomass sources** that are or will be supplied to the Production Facility, and maintain this list updated throughout the crediting period. A biomass source is here defined as a stream of biomass that shares common properties in terms of biomass feedstock species, geographical origin, category as defined in the *Puro Biomass Sourcing Criteria*[7], required traceability and sustainability information, and other rules applicable in this section.

3.4.2. The CO_2 Removal Supplier must keep records of all the **biomass batches** (also commonly referred to as lots, deliveries, consignments) that have been supplied to the Production Facility. A batch does not necessarily need to correspond to a discrete delivery and may be defined based on time intervals or volume in cases of continuous or bulk supply, provided that eligibility, traceability, and sustainability can be demonstrated. Records must be of sufficient detail to demonstrate and verify the amounts and the eligibility (category, origin, sustainability) of the biomass batches received, and whenever necessary, supported by evidence.

3.4.3. Any biomass source declared must belong to only one of the biomass categories defined in the *Puro Biomass Sourcing Criteria* and must be eligible for biochar production as per rules applicable in this section, with the exception noted in rule 3.4.7.c. Likewise, any biomass batch supplied to the Production Facility must belong to only one of the biomass sources declared for the Production Facility.

Ineligible biomass batches

3.4.4. Any share of biomass feedstock which cannot be demonstrated to be eligible will lead to the resulting biochar not being eligible. Therefore, its share of stored CO_2 must be excluded from the quantification of CORCs.

[7] Available in the Puro Standard document library: https://puro.earth/document-library?tab=standard_documents

Example - Difference between biomass sources, batches, and category

The notions of biomass **source**, **batch** and **category** are introduced to enable smooth and efficient certification operations, while maintaining integrity of the biochar removal activity. The example below illustrates the difference between these notions.

A Production Facility is using forestry residues from FSC-certified Swedish forests, forestry residues imported from non-certified Norwegian forests, and in-field straw residue from nearby farms. This facility should be declaring 3 different biomass sources, belonging to 2 different categories. During operations, many batches will be recorded and reported for the 3 different sources:

List of declared biomass sources and associated categories:

- Source 01: forestry residues from FSC-certified Swedish forests, belonging to the Puro BSC category G.
- Source 02: forestry residues imported from non-certified Norwegian forests, belonging also to the Puro BSC category G.
- Source 03: in-field straw residue from nearby farms, belonging to the Puro BSC category K.

Based on the templates provided by Puro.earth, the supplier must then specify how origin, category, and sustainability criteria will be evidenced for each source of biomass. This should also be part of the monitoring plan of the facility, detailing precisely how operational data will be collected and recorded.

Operational records:

Based on the monitoring plan and declared sources of biomass, part of the operational records can be illustrated by the following table:

Delivery reference	**Date of delivery**	**Amount (tonnes, as received)**	**Source ID**	**Additional evidence of origin, category, sustainability (as needed)**	**…**
AB0232	2024-10-03	25	S01	…	…
AB0233	2024-10-04	33	S01	…	…
AB0234	2024-10-05	50	S03	…	…
AB0235	2024-10-07	20	S03	…	…
AB0236	2024-10-14	60	S02	…	…
AB0237	2024-10-23	25	S01	…	…
…	…	…	…	…	…

In other words:

- All biomass batches belonging to the same biomass source shall be subject to the same eligibility criteria and rules, and
- The eligibility of all biomass batches from the same biomass source shall be possible to demonstrate and verify in the same way, i.e. with the same underlying documents or document types.

Biomass categories for biochar production

3.4.5. The biomass feedstock categories, derived from the *Puro Biomass Sourcing Criteria*, that are allowed or not allowed for biochar production are the following:

Allowed categories for biochar production, potentially resulting in CORCs:

B **Sorted food waste and assimilated**. Post-consumer source-separated food waste, post-production food waste, expired food, residues from food processing, other industrial food-related biowaste (e.g. sugar molasses, cooking oils), other farm-level food-related waste (e.g. spoiled food or feed harvest, expired seeds).

C **Sorted MSW fractions, other than food**. Post-consumer end-of-life paper, end-of-life textile, end-of-life wood materials (of different grades, e.g. untreated and treated), and assimilated biomaterials, from source-separated waste collection.

D **Green waste**. Non-hazardous municipal green waste from urban or rural areas (e.g. park and garden green waste, urban tree cuttings, river debris), including any fraction (e.g. foliage, roots, branches).

E **Animal waste**. Abattoir waste and animal manure and its derivatives (e.g. digestate from manure and abattoir waste).

F **Municipal sludge and biosolids**. Sewage sludge, digested or not, and biosolids from municipal wastewater treatment plants.

G **Forest biomass**, including any primary feedstock (harvested from forest land) or secondary feedstock (generated during processing of primary feedstock).
→ For clarity, note that a biomass feedstock belonging to this category is only eligible if it meets all the traceability and sustainability criteria defined in the Biomass Sourcing Criteria. In particular, harvesting of forest biomass in a manner that does not support forest growth and health is not eligible, as per criteria Regeneration, Carbon stocks, Soil quality. Likewise, use of high-quality timber in a CDR pathway is not eligible, as per criteria Material use.

H **Pulp and paper mill sludge and black liquor**, derived from processing of virgin fibres, recycled fibres or combination of sources.

I **Non-food agricultural crops**. Agricultural crops that are neither food nor feed crop (e.g. energy crops, biomaterial crops), cultivated on agricultural land.
→ Note that the Biomass Sourcing Criteria define explicit land use type restrictions (e.g. degraded land, marginal land),

K **In-field agricultural residues**, originating from the cultivation of a food, feed, or material crop, e.g. cereal straw, rice straw, maize straw, stalks, pruning residues (trees, bushes).

L **Non-field agricultural residues**, originating from the primary processing of a food, feed, or material crop in a factory, e.g. rice husk, maize cob, nut shell and husk, peels, fruit seeds/pits, bagasse, coffee husk, cocoa pods, spent grain.

M **Palm oil biomass and derivatives**. Any biomass from oil palm tree plantations (which are not considered forests but agricultural plantations), e.g. palm oil and its fractions, empty fruit bunches, nuts and kernels, cakes, or other side-streams.
→ In this methodology, such feedstock is limited to residual fractions from palm tree plantations and product processing.

N **Conservation landscape management**. Invasive species whether on land, in freshwater, or in coastal areas, as well as any biomass from landscape management for conservation purposes of protected areas or assimilated, including forest wildfire mitigation

O **Aquatic biomass**. Cultivated or harvested water-based plants or algae, and associated derivatives.

Allowed categories for biochar production, but not resulting in CORCs:

P **Land clearing biomass**, from authorized activities with change in land use (non-renewable biomass), in non-protected and non-high-value ecosystems, with adequate management and compensation measures. Clearing activities can result from, e.g. city urban expansion, pipeline or powerline construction, and similar cases, but does not apply to clearing for agriculture nor plantations. → Limitation: this category is allowed to be processed by a CO_2 Removal Supplier but shall not result in the issuance of CORCs (see details in the Biomass Sourcing Criteria).

Non-allowed categories for biochar production:

A **Mixed municipal solid waste (MSW) and assimilated waste**. The non-sorted organic fraction of mixed solid waste, from normal municipal waste collection service, from collection of assimilated waste from e.g. offices, companies, hospitals, as well as refuse derived fuel and assimilated industrial waste.
→ Note that post-collection sorting of MSW to extract an organic fraction feedstock is also not deemed eligible for biochar due to potential low product quality and higher risks of contamination.

J **Food agricultural crops**. Agricultural crops that are food or feed crops, whether or not used in such applications (e.g. corn or wheat fermented for biofuel, cereals fermented for beverage production), cultivated on agricultural land.
→ Note that e.g. spent grain and similar feedstock residues pertain to *category L* or *K*, and that spoiled food or feed pertain to category B.

REMARK ON THE PURO BIOMASS SOURCING CRITERIA: The *Puro Biomass Sourcing Criteria*, from which the categories above are derived, are defining sourcing criteria in terms of **traceability of origin and type, and sustainability of cultivation and harvesting**. The categories are meant to cover all types of biomass, grouping them in categories that have similar traceability requirements and sustainability risks to be addressed. Note that the biomass sourcing criteria only address the eligibility of the feedstock sourcing, and that the methodology imposes further requirements for eligibility of the feedstock and eligibility for biochar production and use, including other aspects related to e.g. baseline and leakage, impurities and contaminants.

REMARK ON THE EXCLUSION OF MIXED SOLID WASTE: The exclusion of mixed solid waste (MSW) as a feedstock for biochar production is due to several factors.

- Its complex and heterogeneous composition complicates distinguishing between fossil-derived and biogenic carbon in MSW. This makes it difficult to accurately assess the carbon balance and climate benefits of the resulting biochar.
- The diverse materials in MSW, including plastics and metals, may compromise the quality of biochar and pose risks during production and use. Use of such char may be restricted to landfilling. Further, the varying amount of non-biogenic impurities also affects the reliable determination of the biochar mass produced.
- The chemical composition of MSW introduces risks of air pollution from hazardous emissions like dioxins, which require extremely strict flue gas treatment systems and strict regulation, typically not available at the small-scales of pyrolysis systems.
- Additionally, alternative waste management strategies like MSW source segregation, reduction, re-use, recycling, and ultimately waste-to-energy with carbon capture and storage (CCS) offer generally more suitable solutions for handling MSW.

Sequential use of biomass sources

3.4.6. Biochar is allowed to be produced from multiple biomass sources in a **sequential** manner, i.e. different biomass sources are not mixed together but carbonized separately in different production batches. In this case, the CO_2 Removal Supplier shall:

a. Maintain production records specifying the biomass source used in each batch, and
b. Implement a monitoring plan that ensures biochar sampling and analysis adequately capture variations in biochar properties resulting from different biomass sources (see also section 3.5).

Mixing of biomass sources and effects on biochar properties

3.4.7. Biochar is allowed to be produced from **blends** of biomass sources, i.e. different biomass types mixed and carbonized together, only under the following conditions:

a. *Blending of biomass with similar properties.* If the blend is made of feedstock of the same type *and with similar physical and chemical properties, with no foreseeable effect on biochar properties variability*: this is permitted provided that the mixing activities are monitored and described in the monitoring plan.
b. *Blending of biomass with different properties.* If the blend is made of feedstock of different categories, or from the same category but with *different physical and chemical properties* (for example from different plant fractions), or if the blend has foreseeable effects on biochar properties variability: this is permitted only if the mixing activities are monitored and described in the monitoring plan, and the sampling and testing of the resulting biochar is done at a

frequency that capture any significant change in biochar properties, in particular related to changes in blending ratios.

c. *Blend of eligible and non-eligible biomass, with different properties.* In rare cases, eligible and non-eligible biomass may be harvested together (e.g. clearing of invasive species that contains a small but substantial share of native species, as allowed under certain jurisdictions) and have different physical and chemical properties (e.g. a native grass co-harvested with an invasive bush). In such situations, the CO_2 Removal Supplier must propose in the monitoring plan, a procedure to adequately determine the persistence properties and organic carbon content of the biochar produced from the eligible fraction.

No biomass mixing or co-firing with fossil fuels

3.4.8. Biomass is not allowed to be mixed and co-fired with fossil coal nor fossil oil.

Biomass stockpiling at the facility

Biomass stockpiling at the production facility is an important factor to consider because inadequate biomass stockpiling is associated with health and safety risks (e.g. fires and explosions due to self-heating), as well as carbon losses and methane emissions due to microbial decomposition[8]. Ensuring adequate biomass stockpiling conditions is the primary solution to minimise these risks, carbon losses and methane emissions.

3.4.9. The CO_2 Removal Supplier must have procedures in place at the Production Facility to minimize the risks associated with biomass stockpiling and minimize biomass decomposition during stockpiling. Such procedures shall describe the method of biomass warehousing (including type of container, maximum sizes of piles, whether protected from rain, whether aerated/ventilated), for how long biomass is typically stockpiled before usage, the physical form of the biomass (e.g. chipped, pelletized, logs), and under which temperature and moisture conditions. Such procedures must follow local regulation, if any, and are recommended to follow good industry practice for biomass stockpiling as applicable in the local context.

3.4.10. The CO_2 Removal Supplier must monitor at minimum the average duration of biomass stockpiling at the facility, and under which temperature and moisture conditions and under which form, unless it can be demonstrated that the biomass counterfactual fate also involves similar stockpiling and/or decomposition.

3.4.11. It is considered that biomass decomposition and related methane emissions are considered not relevant if:

a. It can be demonstrated that the biomass counterfactual fate also involves similar stockpiling and/or decomposition.

Otherwise, they can be considered negligible (and thereby set to zero in quantification) if any of the following option can be demonstrated:

b. Biomass is pelleted, with a moisture content below 15%.

[8] IEA Bioenergy, 2013. Health and safety aspects of solid biomass storage, transportation, feeding. https://www.ieabioenergy.com/wp-content/uploads/2013/10/Health-and-Safety-Aspects-of-Solid-Biomass-Storage-Transportation-and-Feeding.pdf

c. Biomass is stockpiling in a coarse form that ensures sufficient natural aeration to prevent anaerobic decomposition. This is typically the case for wood logs, planks, or non-compacted branches stored without leaves.
d. Biomass consists of materials that do not necessarily ensure sufficient natural aeration (including wood chips, sawdust, agricultural residues) but the stockpiling conditions are such that moisture is below 30% and the stockpiles are in a well protected environment.
e. Biomass consists of materials that do not necessarily ensure sufficient natural aeration (including wood chips, sawdust, agricultural residues) but the stockpiling conditions are such that stockpiling time is less than 30 days prior to processing and the stockpiles are in a well protected environment.
f. Biomass is stored in a way that ensures sufficient aeration of the feedstock and/or adequate processing of the air flow emanating from the piles. This can include systems with active aeration, turning of the biomass, or use of air flow in the combustion systems.

Other options to support that biomass decomposition and related methane emissions are negligible can be submitted by a CO_2 Removal Supplier, and can be approved by the Issuing Body via rule clarification, acknowledging that regional or feedstock-specific adjustments may be necessary.

3.4.12. In any other situations not approved under rule 3.4.11 above, methane emissions related to biomass stockpiling at the production facility must be included in quantification. This quantification may take into consideration local climate factors and standardized assumptions.

Management of impurities

Impurities in the feedstock are defined as non-biodegradable, macroscopic particles of **foreign matter** mixed with the biomass feedstock, such as plastics, metals, glass, and other mineral aggregates (e.g. sand, clay). While some impurities can have positive catalytic effects during biomass carbonization, in particular clay and sand minerals in small amounts, the presence of impurities in the feedstock can pose risks during production, negatively affect the biochar quality and the range of applications possible, affect the determination of the dry mass of biochar produced, and project emissions (in particular due to plastics). For impurities that are not volatilized during carbonisation, a 1% impurity level in the feedstock can result in impurity levels of 4% to 10% in the biochar (depending on the biochar yield), if not removed in pre- or post-processing operations. For impurities that are volatilized during carbonisation and subsequently burnt (plastics), a 1% impurity level can affect project emissions significantly.

3.4.13. The CO_2 Removal Supplier must ensure that procedures are in place at the Production Facility to assess the **presence of impurities** in the feedstock received (e.g. visual inspections, measurements) and enable an estimation of the level of impurities present in the feedstock distinguishing between plastics, metals, glass, and other minerals (sand, clay), expressed in % mass (dry basis) for each impurity category. The level of detail and precision of the procedures must be explained in the Monitoring Plan, for each biomass source, and adjusted based on the risks for impurity presence in the feedstock (e.g. forest residues are less prone to presence of impurities than agricultural residues or urban park residues).

3.4.14. The CO_2 Removal Supplier may have additional procedures and equipment in place at the Production Facility to **remove impurities** in the feedstock received, so as to lower the level of impurities in the feedstock actually carbonized. The level of impurities in the feedstock after removal operations (e.g. sieving, magnetic separation) must then also be assessed.

3.4.15. The CO_2 Removal Supplier must report the level of **metal, glass and other mineral impurities** (sand, clay) in the feedstock for each biomass batch received or carbonized, as per the frequency defined in the Monitoring Plan, in line with rule 3.4.13. Both in the Monitoring Plan and in calculations, the CO_2 Removal Supplier must present how the determination of the biochar dry mass and the biochar properties takes into account the presence of these impurities.

3.4.16. The CO_2 Removal Supplier must report the level of **plastic impurities** (in a broad sense, including synthetic rubber) in the feedstock for each biomass batch received or carbonized, as per the frequency defined in the Monitoring Plan, in line with rule 3.4.13. A distinction must be made between plastic materials that are present as impurities (i.e. unintentionally mixed with the biomass during harvesting, storage or transport), and plastic materials intentionally added to the biomass feedstock stream (e.g. agricultural plastic waste). Plastic materials added intentionally may be permitted only if they are composed of thermoplastic polymers that are known to volatilize under pyrolysis conditions (e.g. polyethylene, polypropylene, PET), and the total plastic content must not exceed 5% w/w (dry basis). The inclusion of non-volatilizing plastics, composite materials or synthetic rubbers (e.g. tyres, PVC, neoprene) in the feedstock is prohibited. Both in the monitoring plan and in calculations, the CO_2 Removal Supplier must present how the determination of project emission takes into account the fossil carbon emitted during carbonization of plastic impurities (see rule 3.4.24 to rule 3.4.26).

> **REMARK ON THE IMPACT OF FEEDSTOCK IMPURITIES ON BIOCHAR CALCULATIONS:** The presence of mineral impurities in the feedstock, even in small amounts, can affect the accuracy of the calculations of the dry mass and the carbon storage of the biochar, but also the overall biochar quality.
>
> For example, in a biochar production process with a **20% dry mass yield**, if the biomass feedstock contains **2% (dry mass) of glass and metal impurities**, these impurities could accumulate in the final biochar, reaching **10% (dry mass)**—unless removed either **before carbonization (pre-processing) or after production (post-processing).**
>
> A project measuring biochar dry mass on-site may include these impurities in the recorded mass. However, laboratory analyses determining the organic carbon content of the biochar would likely screen and remove macroscopic impurities from the sample, leading to a discrepancy between the two measured values (dry mass including impurities, and organic carbon content excluding impurities). To ensure accurate reporting, this discrepancy must be identified and corrected.

Management of micropollutants, PTEs, biological hazards, and hazardous biomass

Micropollutants or **potentially toxic elements** (**PTEs**) refer to organic or inorganic substances that, even at low concentrations, can pose significant risks to human health and the environment. Examples include pharmaceuticals, heavy metals, pesticides, paint residues, solvents, preservatives, and asbestos. Such micropollutants can be found in certain biomass feedstock, such as wood chemically treated with preservatives, wood recovered from demolition activities, agricultural residues in fields treated with pesticides. During carbonization of biomass, different micropollutants can either be destroyed by the high treatment temperatures, volatilized and emitted to the atmosphere via flue gases, or remain in the biochar. In some cases, micropollutants can be precursors to other pollutants formed during carbonization. **Biological hazards**, also known as biohazards, refer to biological substances that threaten the health of living organisms. These substances can come in various forms, potentially harming humans, animals, or the environment. Biomass feedstocks like sewage sludge, animal waste, or contaminated agricultural or forest residues can contain biological hazards, including bacteria, viruses, toxins and parasites. These agents must be adequately managed over the biochar supply-chain, and ultimately adequately destroyed during the carbonization process. Depending on the jurisdiction, biomass containing **micropollutants** or **biological hazards** may be classified as **hazardous waste**, and thereby subject to specific regulation for its safe management.

3.4.17. The CO_2 Removal Supplier must declare whether any of the biomass sources received poses environmental or health risks, in relation to its content in micropollutants, biological hazards or due to its classification as hazardous waste. The CO_2 Removal Supplier shall also report any suspicion of contamination of the feedstock, and take preventive action for safe operations whenever necessary.

> **REMARK ON APPLYING THE PRECAUTIONARY PRINCIPLE IN BIOMASS SOURCING:** In waste management, demolition wood is often considered a suitable feedstock for biochar production. However, in some regions, such wood may have been exposed to asbestos, which was once widely used in construction materials.
>
> A biochar producer must exercise due diligence and follow the precautionary principle when sourcing feedstock. If the origin of a biomass batch is uncertain and there is a potential contamination risk that cannot be safely managed by the facility, rejecting the material may be the responsible course of action.

3.4.18. The CO_2 Removal Supplier must comply with any regulation in place for the management of biomass feedstock with high environmental or health risks. In addition, the CO_2 Removal Supplier must also demonstrate that the Production Facility is adequately equipped to manage such biomass feedstock at all stages of the process (from biomass reception and storage, biomass handling and conversion, management of emissions and wastes, to packaging of finished products), and relevant procedures shall be described in the Monitoring Plan.

3.4.19. For feedstocks that contain **biological hazards**, the feedstock must be adequately treated to eliminate the risks. Such treatment can be: i) a processing step prior to the carbonization of the feedstock, e.g. hygienization to eliminate pathogens, either performed by the biochar producer or upstream in the supply-chain, or ii) the carbonization process itself provided that the carbonization temperature exceeds 500°C for at least 3 minutes (Moško et al., 2021) (Ross et al., 2016). This typically applies to e.g. abattoir waste, animal manure, sewage sludge, biosolids, and their derivatives. Note that the carbonization process is normally sufficient in itself to eliminate the risks.

3.4.20. For feedstocks that contain **paints, solvents, or other fossil-derived materials** (which are not possible to separate from the feedstock), an estimation of the fossil carbon content present in the feedstock must be made and reported. Both in the Monitoring Plan and in calculations, the CO_2 Removal Supplier must present how the determination of project emission takes into account the fossil carbon emitted during carbonization of these fossil-derived chemicals.

3.4.21. For feedstock that contain any **high-risk micropollutants** listed in this rule, the CO_2 Removal Supplier can only receive and process such feedstocks if it has been demonstrated prior to the Facility Audit that i) the facility is adequately equipped to manage such biomass feedstock at all stages of the process, ii) the facility has received a permit or authorisation from the local authorities specifically for these substances, and iii) this permit or authorisation requires monitoring of air emissions, water effluents, and product quality. The Issuing Body reserves the right to evaluate whether the permit or authorisation is stringent enough for these high-risk micropollutants. High-risk micropollutants currently identified are: *asbestos and derivatives*, *chromated copper arsenate and derivatives*. This list may be expanded at any time, and the latest list always applies.

3.4.22. Feedstock that contains any **high-risk micropollutants** (as identified in rule 3.4.21) is not permitted to be mixed with other biomass feedstock. Biochar produced from such biomass feedstock must not either be mixed with other biochar batches, and such biochar may only be used in specific applications and authorised by the local authorities (see section 3.6). Sequential carbonization of different biomass feedstock, where one contains high-risk micropollutants, is permitted provided adequate safety provisions are explicit in the operating procedures and Monitoring Plan.

Fossil-derived carbon in sewage sludge, biosolids, and derivatives

Sewage sludge, sometimes called biosolids, contain a large share of biogenic carbon but also a non negligible share of fossil carbon, originating from detergents, pharmaceuticals, and similar chemicals that are discarded in wastewater. In IPCC's 2019 refinement to greenhouse gas inventory guidelines (IPCC, 2019), a basis for future methodological development has been issued (Appendix 6A.1)[9] regarding fossil carbon in wastewater: it appears that some of the fossil carbon in wastewater is degraded during the treatment of wastewater, but that large share also remains in sewage sludge (5-25% depending on sludge type). Further digestion of sewage sludge does not seem to affect the fossil carbon, which remains in digested sludge (Liu et al., 2021). Conversion of sewage sludge or digested sludge to biochar is seen as beneficial from an environmental perspective (volume reduction, energy recovery, destruction of microplastics and pharmaceuticals, sorption of certain heavy metals); however, it also entail emission of the fossil carbon as CO_2 during the carbonization process, which must be accounted for.

3.4.23. For sewage sludge or biosolids, whether digested or not, whether of municipal or industrial origin, an estimation of the fossil carbon content present in the feedstock must be made and reported. Both in the monitoring plan and in calculations, the CO_2 Removal Supplier must present how the determination of project emission takes into account the fossil carbon emitted during carbonization of these fossil-derived chemicals.

[9] IPCC 2019RF. Volume 5. Chapter 6. Wastewater.
https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_6_Ch06_Wastewater.pdf

3.4.24. Direct determination of the fossil carbon content in sewage sludge or biosolids, whether digested or not, whether of municipal or industrial origin is recommended to be performed using either liquid scintillation counting or accelerator mass spectrometry methods[10]. The determination shall reflect variability in the feedstock and be conducted at least four times during the first year of the initial crediting period, to account for seasonal variations. In subsequent years, this direct determination may be replaced with a conservative project-specific fixed value, provided that the measurements have been shown to be stable over time and subject to approval by the Issuing Body. Alternatively, if conservative estimates are available by other means (e.g. country-specific and feedstock-specific data), these may be considered as an alternative to direct determination, subject to approval by the Issuing Body.

Management of fossil carbon

3.4.25. Regardless of the origin of fossil carbon in the biomass feedstock (plastic impurities, paints, solvents, or chemicals in sludges), it is assumed that this carbon is fully re-emitted to the atmosphere, as carbon dioxide, during production, even if the system is equipped with bio-oil condensations (which are likely to be ultimately combusted or otherwise degraded).

Biomass monitoring rules

The rules in this section entail that the CO_2 Removal Supplier must have monitoring procedures that cover various aspects like traceability, sustainability, mixing, stockpiling, impurities, micropollutants, biohazards, and fossil carbon in biomass. Here, the minimum expectations of the monitoring plan and record keeping for biomass sustainable sourcing and safe management are summarized.

3.4.26. The CO_2 Removal Supplier shall implement monitoring for its biomass sourcing activity and on-site biomass management, to fulfill the rules above in section 3.4. This includes covering the following aspects:

a. traceability of biomass batches origin, to the level required by the Biomass Sourcing Criteria
b. sustainability of sourcing, to the level required by the Biomass Sourcing Criteria
c. amounts of biomass received and processed, over the reporting period
d. biomass mixing
e. biomass stockpiling
f. management of impurities, micropollutants and biohazards
g. determination of fossil carbon content in biomass

3.5. Requirements for biochar production

The carbonization of biomass in a reactor is the central part of a biochar carbon removal activity. The rules in this section are meant to ensure the quality of the biochar product, the adequate management of carbonization co-products, wastes and air emissions, the adequate monitoring of production conditions, and other environmental and social safeguards. The rules are also meant to apply to the wide range of biochar production technologies, e.g. slow pyrolysis, gasification, and modified combustion systems. Rules specific to certain technologies are also outlined, whenever necessary.

[10] Liu et al. Behaviour of Fossil and Biogenic Carbon in Sewage Sludge Treatment Processes and Their Impacts on Greenhouse Gas Emissions. Chemical Engineering Transactions, 89, 2021. https://www.doi.org/10.3303/CET2189017

Biochar minimum carbonization degree

3.5.1. Biochar can be produced in any type of carbonization reactor provided that the biochar produced has a molar hydrogen to organic carbon ratio (H/C_{org}) strictly below 0.70. The H/C_{org} is an indicator of the degree of carbonization achieved during production.

3.5.2. Whenever a carbonization reactor generates multiple streams of char (e.g. primary char from auger and secondary/tertiary chars from flue gas collection systems), each stream of char must be characterised separately and meet the H/C_{org} ratio requirement. An exception to separate characterization is when secondary streams represent an insignificant amount of the total output, i.e. less than 1% of the dry mass of char produced.

Type of reactors allowed

3.5.3. The carbonisation reactors must be categorized according to the following dimensions:

a. **Mode of operation**:
- *Continuous*, i.e. reactors in which biomass can be fed continuously into the process without interruption.
- *Batch*, i.e. reactors in which a fixed amount of biomass is introduced before start-up, and which must be shut-down before reloading with a new batch of biomass.
- *Semi-continuous*, i.e. series of batch reactors jointly operated to mimic continuous operations, certain batch reactors where biomass can be reloaded at specific intervals during operations (e.g. certain containerized flame curtains), or other similar situations.

b. **Carbonization process**:
- *Pyrolysis*, i.e. reactors in which biomass is carbonized in the near total absence of oxygen.
- *Gasification,* i.e. reactors in which biomass is carbonized with a limited amount of oxygen available, favouring formatting of gaseous products.
- *Combustion,* i.e. reactors which are intended, by design, for full combustion of biomass and in which char is recovered due to either incomplete combustion features under normal operating conditions or changes in operating conditions resulting in non-complete oxidation of the biomass (e.g. adjustment of speed of moving grates to reduce residence time).
- *Other*. In rare cases, the carbonization process may not be possible to fit in the categories above. Such situations must be discussed with the Issuing Body during audit preparation.

c. **Heating method:**
- *Indirect heating*, i.e. when heat is supplied to the biomass by conduction through the reactor walls. The heat source is typically hot flue gases from separate combustion of volatile matter generated from the process.
- *Direct heating*, i.e. when heat is supplied to the biomass via an inert heat carrier circulating in the reactor, e.g. hot inert gases or solid carriers like sand, metal or ceramic balls. Solid carriers are typically heated externally, by the combustion of volatile matter generated from the process or by use of electricity.
- *Microwave heating*, i.e. when electrical energy is used to generate electromagnetic waves that heat the biomass.
- *Autothermal process*, i.e. when part of the biomass, the generated volatile matter, and/or the biochar are combusted within the carbonization reactor, due to the presence of a small amount of oxygen, providing sufficient energy to maintain the reaction.

d. **Streams of biochar**:

- Single stream: the biochar is recovered in a single location in the reactor, e.g. the output of a screw auger.
- Multi stream: biochar is recovered from multiple distinct locations in the reactors, with the possibility that the different streams have been exposed to different thermochemical conditions and resulting in different properties.

e. **Co-product fate**:

- All volatile matter (gases and tars) are combusted during production, with energy recovery, i.e. energy is recovered for other purposes than maintaining the carbonization reaction, such as external drying of biomass feedstock, generation of heat or steam, generation of electricity.
- All volatile matter (gases and tars) are combusted during production, without energy recovery, to the exception of energy use to maintain the carbonization reaction.
- Part of the volatile matter is not combusted during production, but recovered for other use or disposal, to be specified. Most commonly, gases are combusted while tars are condensed and refined for further use as biomaterial or bioenergy.

Use of fossil fuels during production

3.5.4. Operation of the biochar production equipment may rely on the combustion of fossil oil products or natural gas, but not fossil coal, as long as i) the use of fossil fuel does not introduce fossil carbon into the biochar product, and ii) the life-cycle emissions associated with fossil fuel usage are adequately included in the calculations. Common acceptable uses of fossil fuels during biochar production include reactor ignition, reactor pre-heating, drying of biomass, external reactor heating, supporting volatile matter complete oxidation (e.g. in thermal oxidisers, or active air curtains), pilot flames (which may be mandatory in certain jurisdictions), or generation of additional energy for other purposes (e.g. upgrading heat to steam for other purposes).

Note that the use of fossil fuels is generally discouraged unless absolutely necessary, and projects should aim to minimize such use in alignment with the broader climate goals, e.g. by making use of renewable fuels instead.

Management of solid and liquid waste

3.5.5. Solid and liquid waste arising during operation of the reactor, during maintenance and cleaning of the reactor, and more generally within the Production Facility, must be adequately managed, i.e. either according to rules specified in this methodology or in line with the local regulation, whichever is stricter. The CO_2 Removal Supplier must monitor the quantity of industrial waste generated, classify this waste according to its environmental and health hazards, and demonstrate, for all waste streams (including non-industrial waste) the fate of such waste streams. The waste management choices must prioritize waste minimization, proper disposal, and, where possible, reuse of byproducts. Industrial waste includes any liquid effluents (e.g. lubricant oils, wastewater, and industrial sludges), residues and spent consumables from the flue gas treatment system (e.g. filter residues, spent filters), and spent materials or reactor parts.

Management of carbonization co-products

3.5.6. Carbonization co-products must be adequately managed, i.e. either according to rules specified in this methodology or in line with the local regulation, whichever is stricter. The CO_2 Removal Supplier must be able to demonstrate the fate of the co-products generated during the production of biochar, e.g. via monitoring and record keeping. This includes the fate of any volatile matter, gases, tars and oils, and wood vinegar or similar solutions.

Management of liquid products

3.5.7. In facilities where tars, oils or wood vinegar are generated, referred to as liquid products (although tars may solidify when cold), either during operations via the use of condensation equipment or during maintenance via the cleaning of pipes, the facility must comply with the following aspects:

a. Once generated, liquid products must not be subsequently mixed with water, unless the mixing is necessary for a certain usage.
b. Liquid products must be collected and stored in tanks, with limited to no risks of leaks or overflow. As such, buried concrete tanks are not acceptable. Closed steel or plastic tanks are usually acceptable.
c. Storage tanks capacity must be able to accommodate for at least 3-months worth of product generation under normal conditions, unless a documented management plan is in place that demonstrates the CO_2 Removal Supplier can operate reliably without this storage capacity.
d. For products intended for use, the equipment must enable monitoring and quantification of products generated from each stream separately (e.g. tars from specific condensers in normal operations). For products meant for disposal, separate quantification is not required.
e. Storage can only be temporary and for up to 12 months, after which the liquid products must either be **used** or **disposed of**. In any case, at the time of the Facility Audit, the operator must have tangible plans for the management of any liquid products generated.
f. Use of liquid products can be done by the operator or another party, provided the use is legal in the jurisdiction of the activity and the use is documented. Usage implies that value is ultimately recovered from the liquid products, either as bioenergy or as biomaterial. Examples of usage include: combustion in specific kilns for thermal energy generation, upgrading for use as biofuel in ships, or upgrading for use as biomaterial.
g. Disposal of liquid products can be done by the operator or sub-contractors, provided the entity is legally authorised to treat such materials and the disposal is documented. Disposal implies that no value is recovered from the oil and tar products. Examples of disposal include: combustion without energy recovery, processing and subsequent landfilling (regardless of whether landfill is recovering landfill gas for energy generation), or suitable liquid waste treatment processes. Dilution and discharge in the environment is not a suitable disposal method.

> **PREFERRED HANDLING OF PYROLYSIS GASES AND TARS:** In the context of **slow pyrolysis**, it is generally recommended to directly combust pyrolysis gases and tars before condensation, ideally with energy recovery. This approach is often preferable to condensing tars and separately combusting non-condensable gases, as slow-pyrolysis tars are highly heterogeneous and present handling challenges due to their chemical properties (e.g., acidity, water content). While it is possible to upgrade or refine slow-pyrolysis oils and tars through thermochemical processes, such methods are not yet well-established or widely available. Direct combustion with energy recovery offers a more practical and efficient solution in most cases.

Design measures to ensure complete combustion of co-products

3.5.8. In facilities where carbonization co-products (gases and/or tars) are combusted, the combustion systems must be designed to i) minimize the amount of unburnt hydrocarbons and methane in the flue gas (i.e. achieving complete combustion), and ii) minimize the formation and emission of air pollutants to the levels required by locally applicable regulation.

Depending on the technology selected, such design features *can* include:

a. Have a single combustion chamber where all carbonization gases and/or tars are channelled and combusted (as opposed to several chambers with different designs or efficiencies).
b. Have a closed combustion chamber with a forced air flow (i.e. using blowers) that can be controlled and adjusted (manually or automatically).
c. Have a combustion chamber that is insulated to maintain sufficient and constant temperature during operations
d. Have a combustion chamber with a shape and internal surfaces designed to increase turbulence in the chamber
e. Have a combustion chamber designed and operated to ensure a residence time of the volatile matter of at least 2 seconds in the combustion zone
f. Have fuel-air injection systems (i.e. burners, nozzles) that are designed to mix carbonization gases and/or tars and air prior to combustion, with primary and secondary air injection points, typically arranged in a manner to create turbulence.
g. Have fuel-air injection systems (i.e. burners, nozzles) that are designed to reduce peak or flame temperature (primarily, to minimize thermal NO_x formation).
h. Have a combustion chamber equipped with tertiary air injection, in addition to primary and secondary air injection near the fuel injection
i. Have a system equipped to measure continuously the temperature in the combustion chamber
j. Have a system equipped for automatic adjustments of the combustion parameters based on monitoring of the flue gas properties (e.g. residual oxygen levels)

Note: the design features listed above are not applicable to all technologies, in particular certain gasification reactors.

Flameout events in combustion systems and flame quality

3.5.9. In facilities where carbonization co-products (gases and/or tars) are combusted, the facility must be equipped with systems to detect any flameout in the combustion systems and have procedures in place to adequately and safely manage flameout events to minimize emission of unburnt hydrocarbons, greenhouse gases and air pollutants. Such systems and procedures must be described in the operating procedures and monitoring plan of the facility. Common procedures include the automatic shut-down of the reactor or manual re-ignition of the flame after automatic detection of flameout.

Operating time of combustion systems

3.5.10. In facilities where carbonization co-products (gases and/or tars) are combusted, for the activity to be eligible, the CO_2 Removal Supplier must monitor the *normal operating time of the combustion systems* and demonstrate that for each monitoring period, this time exceeds 95%

of operating time of the production equipment[11]. Any residual time during which combustion systems were not operational or not operating normally must be reported as an incident and associated greenhouse gas emissions must be conservatively quantified.

Quality of combustion

3.5.11. In facilities where carbonization co-products (gases and/or tars) are combusted, the CO_2 Removal Supplier must monitor the combustion temperature or equivalent parameters, to ensure all combustion systems are operating according to specification. Note that the combustion temperature is different from the carbonization temperature, which can be monitored separately.

Leaks of gases, tars and flue gas

Most technologies channel the carbonization gases and tars and combustion flue gases between components via systems of pipes. At junctions between components and pipes, physical leaks may happen, although rare in well-maintained facilities.

3.5.12. To minimize any losses of fluids throughout the system, the operator of the facility must follow any procedures required by the equipment manufacturer, conduct maintenance operations that ensure tightness of the equipment at a suitable frequency specified in the Monitoring Plan and depending on the technology used, and keep records of these operations.

3.5.13. Technologies that are designed to maintain below-atmospheric pressure levels under normal operating conditions must monitor and keep records of pressure values throughout the system. Any abnormal pressure values must trigger an alarm and a suitable remediation action, and be reported as incidents.

Safety flares and vents

Certain technologies are equipped with safety flares or vents, which can be used in exceptional situations to avoid a risk of explosion. The use of such systems in normal operations should be avoided, to the exclusion of planned start and stop, as they also represent a risk for greenhouse gas emissions and air pollutant emissions.

3.5.14. The CO_2 Removal Supplier must declare any safety flares or vents installed at the Production Facility, have procedures detailing how these systems are to be used, and ensure that their positioning does not cause risks (e.g. floor level release of carbon monoxide via a vent). Further, the CO_2 Removal Supplier must be able to detect and monitor all events when any volatile matter is channelled through these systems, and include any associated greenhouse emissions in its reporting. Any time during which safety flares and vents are used must be excluded from the *normal operating time of the combustion systems*, referred to in rule 3.5.10, and such events must be reported as incidents, to the exclusion of planned start and stop.

Exposure to carbon monoxide

Carbon monoxide (CO) is a hazardous by-product of biomass carbonization. Even at low concentrations, CO poses a serious health risk due to its toxicity and invisibility (it is colorless,

[11] All systems are expected to be able to achieve 100% operating time of the combustion systems. However, the rule is meant to cover for periods of downtime or other technical failures.

odorless, and tasteless). CO can accumulate at low levels in the absence of proper ventilation and must be treated as a critical safety concern.

3.5.15. The CO_2 Removal Supplier shall implement appropriate measures to prevent, detect, and respond to carbon monoxide (CO) exposure at the Production Facility. These measures shall address the design of the facilities and, where relevant, the monitoring of CO. The CO monitoring and safety procedures shall be documented in the Monitoring Plan.

a. Facility design to minimize CO exposure: The CO_2 Removal Supplier shall ensure that facilities are designed to prevent CO accumulation and reentry into occupied areas. This can include measures such as:
    - Installing adequate natural or mechanical ventilation to avoid CO build-up, especially near the floor.
    - Positioning exhaust vents, flares, and safety releases high enough to prevent CO from pooling at worker level.
    - Implementing written procedures for safe opening of enclosed or batch systems, including e.g. forced purging and CO checks before manual access.

b. Monitoring of CO: The CO_2 Removal Supplier must implement CO monitoring wherever leaks or accumulation may pose a risk. This may include:
    - Fixed CO detectors at critical points, including low-elevation zones.
    - Portable CO detectors for staff working near reactors or piping.
    - Alarm-equipped detectors that are regularly tested and calibrated. Any abnormal CO readings or breaches of safety procedures must trigger alarms, prompt immediate corrective action, and be reported as safety incidents.

Emissions of air pollutants during production

In most jurisdictions, air pollutant regulations govern the emissions of the following substances: carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM). For certain biomass feedstocks or larger facilities, regulations may include additional substances (e.g. dioxins and furans, certain heavy metals with high volatility) or have specific testing methods, testing frequencies or limit values. In any case, testing methods, testing frequencies, and limit values are set by the local regulation; and Puro.earth adopts those regulations.

3.5.16. In facilities where carbonization co-products (gases and/or tars) are combusted, the CO_2 Removal Supplier must document which regulation applies to its activity regarding emission of air pollutants, taking into consideration the size of the equipment, the location of the facility, and the biomass feedstocks processed. The CO_2 Removal Supplier must demonstrate compliance with the applicable regulations prior to the Facility Audit, and continued compliance with applicable regulation at each subsequent Output Audit.

Emissions of greenhouse gases during production

Contrary to air pollutants, most jurisdictions do not impose any limits nor monitoring requirements for greenhouse gases (biogenic CH_4 and N_2O) emitted during combustion of biomass or biomass-derived fuels, such as carbonization co-products. However, due to the importance of those emissions for the quantification of net carbon removal, it is essential that all projects be evaluated using a uniform methodological approach.

Context regarding CH_4 emissions

Scientific literature does contain some data on CH_4 emissions from various types of carbonization technologies (primarily, flame curtains and similar technologies with open combustion chambers, various types of retorts, and some more advanced continuous reactor technologies). Overall, CH_4 emissions during normal operations can either be negligible, moderate, or excessive, in relation to the carbon stored in biochar. Most reactors operated continuously and equipped with advanced combustion systems can achieve negligible emissions, i.e. CH_4 emissions are typically well below 1% of the initial carbon stored in biochar, expressed in CO_2-eq using GWP_{100}. Moderate CH_4 emissions, i.e. representing approximately 1 to 5% of the biochar carbon storage value, are most common with batch systems and certain open-air combustion systems such as flame-curtains with forced air flow. In these systems, CH_4 emissions can be lowered by processing relatively dry biomass, i.e. typically with moisture below 20%. Any situations where CH_4 emissions are excessive, i.e. cancelling a large share if not all the biochar carbon storage value, are not eligible for certification.

Maximum acceptable amount of residual CH_4 emissions

3.5.17. Residual CH_4 emissions from the carbonization process must not exceed 15% of the initial carbon stored in biochar[12] when expressed in CO_2-eq using GWP_{100}.

Negligible residual CH_4 emissions

3.5.18. Residual CH_4 emissions during normal operations can be deemed negligible (i.e. typically well below 1% of the initial carbon stored in biochar, expressed in CO_2-eq using GWP_{100}) whenever the technology complies with the following conditions, as applicable:

a. **For continuous reactors**, all following conditions are met:
   i. The reactor design clearly exhibits that all volatile matter to be combusted is adequately channelled to combustion systems.
   ii. The reactor design is equipped with advanced combustion systems that enable complete combustion of volatile matter. To be considered an advanced combustion system, the reactor must have at least 6 of the design features identified in rule 3.5.8.
   iii. The reactor is monitoring continuously (i.e. at a minimum of 1-min intervals) at least one parameter that indicates the quality of the combustion of volatile matter, e.g. the temperature in the combustion chamber(s).
   iv. Measured values for monitoring parameters identified in iii) are consistently in their expected range during normal operations (e.g. temperature consistently above a given threshold value in the combustion chamber during normal operations). Whenever monitoring parameters are not within their expected range, the CO_2 Removal Supplier must exclude this time from the normal operating time of the combustion systems as defined in rule 3.5.10 and estimate conservatively CH_4 emissions during non-normal operations.

   If the conditions i) to iii) above can be demonstrated, residual CH_4 emissions are set to a conservative default value of 0.5 kg CH_4 per dry metric tonne of biochar produced, *for normal operations*. Note that all facilities should strive for achieving negligible CH_4

[12] This maximum threshold is deemed achievable by most technologies, provided they are operated according to their specification.

emissions at all times. Facility-specific measurements of CH_4 emissions are then not required, but can still be provided and used in quantification.

If the conditions i) to iii) above cannot be demonstrated, residual CH_4 emissions must be measured as per rule 3.5.19 for normal operations.

b. **For batch reactors of various types, including semi-continuous reactors**: at the moment, it is not possible to confidently evaluate whether CH_4 emissions are negligible only based on technology design and monitoring of combustion parameters. This is related to the fact that batch reactors may have significant emissions during start-up and shut-down phases, and that the carbonization phase can be variable, due to e.g. feedstock moisture. CH_4 emissions must be measured as per rule 3.5.19.

Options for residual CH_4 emission measurements

3.5.19. Measurement of residual CH_4 emissions from the carbonization process, whenever required, can be either:

a. *conducted specifically for the facility being certified*
b. *reused from a previously certified facility*, from the same CO_2 Removal Supplier, using the same technology type from the same equipment manufacturer, similar operating conditions and similar feedstock type
c. *reused from academic literature*, provided that the results were derived from the same technology, similar operating conditions and similar feedstock type
d. *reused from equipment manufacturer testing*, provided that the results were derived from the same technology type, similar operating conditions and similar feedstock type

For situations b), c) and d), the Issuing Body and its auditors have the right to determine whether measurement results correctly apply to the facility being certified.

Methods for residual CH_4 emission measurement

3.5.20. Measurement of residual CH_4 emissions from the carbonization process, whenever required and for any of the options in rule 3.5.19, must be done according to industry-best practice and the following guidelines:

a. Residual CH_4 emissions shall be calculated by measurements of the flue gas flow rate and measurements of the residual CH_4 concentration in the flue gas, at all the points of release of flue gases. In most cases, the chimney or stack is the single release point.
b. Measurements must be conducted by a third-party, complying with international testing standards (e.g. ISO, ASTM, AS, D, HJ) and approved by authorities to conduct air emission testing. If available in the country of operations, such testing bodies shall follow quality standards such as ISO 17025, ASTM D7036, or equivalent.
c. Measurement of CH_4 concentration in the flue gas can be performed via e.g. flame ionisation detection (FID, see e.g. ISO 25140:2010) or gas chromatography (see e.g. ISO 25139:2011). The setup can either be continuous measurements or sampling of a fixed number of representative gas samples. Lower detection limits must be made explicit.
d. Measurement of the flue gas flow rate and its conditions (pressure, temperature) must be performed in a way that is appropriate for the reactor technology to be representative of all the

flue gas generated. In particular, whenever flue gases are not channeled through a single stack (e.g. in flame-curtains), a temporary stack and fan may be installed during testing. Measurement method shall be selected according to the properties of the flue gas flow and dimensions of the stack.

e. To ensure results are reliable and representative of normal operations, the following criteria must be met or exceeded: i) flow rate measurements must be conducted for at least 60 minutes, ii) flow rate and concentration must be measured and/or sampled at the same time, iii) at least 3 measurements of CH_4 concentration must be made, if not measured continuously, iv) if CH_4 emissions are determined to be non-negligible (> 1% of biochar carbon storage value), but the variation between CH_4 concentration values exceeded 20%, the sampling frequency has to be doubled to obtain a more representative value.
f. The amount of biomass feedstock used during the test, its type and moisture must also be recorded. Ideally, the amount of biochar produced and its moisture shall also be recorded.
g. **For batch systems only**, additional measurements must be made in order to estimate CH_4 emissions during the start-up and shut-down phases of the batch process. Further, CH_4 concentrations are required to be measured continuously over the duration of the test, due to their expected high variability in batch systems.
h. The outcome of the emission testing must be consigned in a report signed by the third-party testing body. All supporting data must also be made available upon request.
i. The calculation of CH_4 emissions factors must be made available, in a spreadsheet format enabling verification of calculations. The emission factor for normal operation must be expressed in *kg CH_4 emitted per dry metric tonne of biochar produced. For batch systems only,* start-up and shut-down emission factors must be expressed in *kg CH_4 emitted per reactor start-up* and *kg CH_4 emitted per reactor shut-down*.
j. In case the measured CH_4 concentrations are below the lower detection limit, the calculation of emission factors shall be based on the value of this lower detection limit.

Context regarding N_2O emissions

When it comes to N_2O emissions, the scientific literature available is limited to few carbonization technologies (e.g. technology with complete oil condensation and combustion of non-condensable gases only) and few feedstock types (e.g. wood). In fact, most knowledge on N_2O emissions is derived from combustion technologies, which can be seen as a conservative proxy for carbonization.

N_2O emissions depend primarily on the feedstock type and its nitrogen content (e.g. sewage sludge has higher N content), whether tars are condensed or combusted (e.g. N is found in tar molecules rather than in non-condensable gases), the combustion temperature (e.g. higher temperatures above above 900°C tend to decrease N_2O formation), the combustion technology (e.g. fluidized bed reactors have generally lower NO_x but can have higher N_2O emissions due to lower temperature), and the flue gas treatment system installed (e.g. certain selective non-catalytic reduction system reduce NO_x but increase N_2O emissions; flue gas recirculation can reduce N_2O emissions).

This said, unlike CH_4 emissions which heavily depend on the reactor design to be moderate or negligible, N_2O emissions are less variable and there are no expected situations where N_2O emissions would be excessive, i.e. cancelling the entire biochar carbon storage value. Puro.earth observed data ranges from below 1% up to approximately 5% of the biochar carbon storage value, primarily for woody biomass. Hence, while supporting the biochar industry in conducting further measurements of N_2O stack emissions, the methodology pragmatically allows for the use of conservative default values.

Option for determination of N_2O emissions

3.5.21. Determination of N_2O emissions from the carbonization process is always required, and can be either:

a. *derived from an emission factor available in table 3.1*, as applicable for technology and biomass types (currently not available for all types of feedstock).

b. *derived from an emission factor provided by a local authority for statutory reporting of greenhouse gas emissions*, as applicable for technology and biomass types.

c. *derived from peer-reviewed scientific literature*, as applicable for technology and biomass types.

d. *measured specifically for the facility being certified.*

e. *reused from a previously certified facility*, from the same CO_2 Removal Supplier, using the same technology type from the same equipment manufacturer, similar operating conditions and similar feedstock type.

f. *reused from equipment manufacturer testing*, provided that the results were derived from the same technology, similar operating conditions and similar feedstock type.

For situations c) to f), the Issuing Body and its auditors have the right to determine whether measurement results apply to the facility being certified.

Table 3.1. Default factors for direct N_2O emission from biomass combustion, used as proxy data in the context of biochar production. Additional default factors may be added in the future, for other biomass types.

Technology	Biomass feedstock	kg N_2O	Unit	Source	Applicable to (unless otherwise determined)
Combustion, conventional technology	Wood biomass	15	per TJ biomass, LHV basis	Volume 2, Chapter 2, Table 2.2, upper value, in IPCC 2006	Carbonization of wood biomass
	Sewage sludge	0.99	per tonne sewage, dry weight	Volume 5, Chapter 5, Table 5.6, default value, in IPCC 2006	Carbonization of sewage sludge

Methods for N_2O emission measurement

3.5.22. Measurement of N_2O emissions from the carbonization process must be done according to industry-best practice and the following guidelines:

a. N_2O emissions shall be calculated by measurements of the flue gas flow rate and measurements of the N_2O concentration in the flue gas, at all the points of release of flue gases. In most cases, the chimney or stack is the single release point.

b. Measurements must be conducted by a third-party, complying with international testing standards (e.g. ISO, ASTM, AS, D, HJ) and approved by authorities to conduct air emission testing. If available in the country of operations, such testing bodies shall follow quality standards such as ISO 17025, ASTM D7036, or equivalent.

c. Measurement of N_2O concentration in the flue gas can be performed via e.g. non-dispersive infrared measurements (NDIR, see ISO 21258:2010). The setup can either be continuous measurements or sampling of a fixed number of representative gas samples. Lower detection limits must be made explicit.

d. Measurement of the flue gas flow rate and its conditions (pressure, temperature) must be performed in a way that is appropriate for the reactor technology to be representative of all the flue gas generated. In particular, whenever flue gases are not channeled through a single stack (e.g. in flame-curtains), a temporary stack and fan may be installed during testing. Measurement method shall be selected according to the properties of the flue gas flow and dimensions of the stack.
e. To ensure results are reliable and representative of normal operations, the following criteria must be met or exceeded: i) flow rate measurements must be conducted for at least 60 minutes, ii) flow rate and concentration must be measured and/or sampled at the same time, iii) at least 3 measurements of N_2O concentration must be made, if not measured continuously, iv) if N_2O emissions are determined to be non-negligible (> 1% of biochar carbon storage value), but the variation between N_2O concentration values exceeded 20%, the sampling frequency has to be doubled to obtain a more representative value.
f. The amount of biomass feedstock used during the test, its type and moisture must also be recorded. Ideally, the amount of biochar produced and its moisture shall also be recorded.
g. For **batch systems** only, additional measurements must be made in order to estimate N_2O emissions during the start-up and shut-down phases of the batch process, following the same guidelines stated in this rule. Further, N_2O concentrations are required to be measured continuously over the duration of the test, due to their expected high variability in batch systems.
h. The outcome of the emission testing must be consigned in a report signed by the third-party testing body. All supporting data must also be made available upon request.
i. The calculation of N_2O emissions factors must be made available, in a spreadsheet format enabling verification of calculations. The emission factor for normal operation must be expressed in *kg N_2O emitted per dry metric tonne of biochar produced. For batch systems only,* start-up and shut-down emission factors must be expressed in *kg N_2O emitted per reactor start-up* and *kg N_2O emitted per reactor shut-down*.
j. In case the measured *N_2O* concentrations are below the lower detection limit, the calculation of emission factors shall be based on the value of this lower detection limit.

Emissions when reactor is started by a wood fire

3.5.23. Whenever a reactor (of any type) is started by a wood fire, the amount of wood used during the start-up phase must be estimated and recorded. Associated CH_4 and N_2O emission related to start-up by wood fire must be determined. This can for instance be done using the values of 350 g CH_4 per GJ biomass and 5 g N_2O per GJ biomass (based on the lower heating value of the biomass) for open fireplaces, derived from the Swedish Environmental Protection Agency[13].

Biochar safe cooling

[13] National Inventory Report, Sweden 2022: Annexes. Swedish Environmental Protection Agency. Available at: https://unfccc.int/documents/461776 (Table A2.11, Table A2.20)

3.5.24. The production facility must be equipped with systems that enable the safe cooling of biochar after production, whether this is achieved by quenching with water (immersion), spraying with water, retention in an environment without oxygen until sufficiently cooled, or other methods.

> **EFFECTS OF BIOCHAR COOLING METHODS:** After pyrolysis, biochar must be cooled to ensure safety, prevent further oxidation, and allow for safe handling. Cooling methods vary in duration and resource intensity, and can also affect the biochar's physical and chemical properties. For example, quenching hot biochar by immersing it in water is a rapid method that cools the material thoroughly, including its core. This approach also typically increases friability and may activate the biochar's surface—features that can be beneficial for certain applications.

Biochar safe stockpiling on-site

3.5.25. The operator of the production facility must have procedures in place to ensure safe stockpiling of biochar at the site of production or any other warehouse used by the operator, to minimize risks of biochar self-heating, fire, and dust explosions. These procedures must be documented in writing and workers must be trained to implement those procedures.

3.5.26. The operator of the production facility must have procedures in place to prevent biochar dust from becoming airborne during handling, stockpiling, and transport. These procedures can include, e.g. using enclosed conveyors, regular water spraying of biochar, bagging of biochar, dust suppression systems, and protective barriers in biochar processing areas.

Occupational health and safety measures

3.5.27. The operator of the production facility must ensure a safe working environment for all personnel, adhering to occupational health and safety standards and local regulations. Those procedures must be documented in writing and workers must be trained to implement those procedures. Workers should be trained in handling biochar and related byproducts, and personal protective equipment (PPE) must be provided to minimize exposure to dust and hazardous materials.

Material safety data sheets

3.5.28. The operator of the production facility must have material safety data sheets (MSDS), or other similar statutory documents if applicable, presenting occupational safety and health information relating to the production and handling of biochar and related by-products, as well as any other chemical substance or product used in the biochar production process.

Post-processing of biochar for impurity removal or resizing

3.5.29. The CO_2 Removal Supplier may have additional procedures and equipment in place at the Production Facility to remove impurities in the biochar produced or resize the biochar produced (e.g. grinding, sieving). If existing, such procedures must be described in the monitoring plan, emphasizing how calculation of the biochar dry mass is affected by post-processing.

Post-processing of biochar for altering properties

3.5.30. The CO_2 Removal Supplier may have additional procedures and equipment in place to modify the properties of the biochar (e.g. activation). If existing, such procedures must be described in the monitoring plan, emphasizing how biochar sampling and laboratory analyses are conducted in a way that ensures correct calculation of biochar dry mass, persistence properties, and environmental quality.

Engineering design of the facility

3.5.31. The CO_2 Removal Supplier must provide engineering designs and technical specifications for the carbonization reactor and associated equipment installed at the Production Facility. These elements are considered confidential and are not meant to be made public. This should include, as applicable:

a. Technical drawings, specifications and pictures of the end-to-end biochar production system, including biomass preprocessing and feeding systems, biomass dryer, carbonization reactor, biochar processing equipment, co-product and waste processing equipment, combustion systems, safety flares, safety vents, and flue gas treatment systems. In particular, the documents provided must clearly identify the available design features listed in rule 3.5.8 and other safety measures. *Note this subrule can be limited to a high-level technical package.*
b. A flowchart illustrating the flows of materials throughout the end-to-end biochar production system, clearly presenting the flows of biomass, biochar, volatile matter, flue gases, side-products, and other residues and waste.
c. For Stationary Production Facilities only, technical drawing and pictures presenting the overall layout of the Production Facility (e.g. with buildings, storage areas, offices).

This collection of documents must be made available for the Facility Audit, and updated at each Output Audit in case of major changes.

Mass and energy balance

3.5.32. The CO_2 Removal Supplier must provide a **mass and energy balance** for the end-to-end biochar production system, as described in rule 5.3.31.a. This should include all inputs (feedstock, fuel, electricity, water, chemicals, consumables) and outputs (biochar, syngas, bio-oil, ash, flue gas, liquid effluents, spent consumables), as well as an evaluation of the energy efficiency of the process. This mass and energy balance must be made available for the Facility Audit, and updated at each Output Audit with operational data.

Uniformity of treatment conditions during carbonization

To ensure uniform biochar properties and complete carbonization, it is important that biomass is exposed to uniform carbonization conditions for a sufficient amount of time. This is primarily controlled by the temperature reached in the carbonization zone of the reactor, the residence time of the biomass in this zone, and heat transfer properties of the reactor (e.g. inertia, speed and homogeneity). Although monitoring of carbonization temperature and residence time are highly recommended, they cannot be required for all technologies. This said, facilities equipped with continuous monitoring of carbonization conditions can reduce the frequency of laboratory analyses of biochar's properties and be subject to different sampling rules.

Sampling and laboratory analyses per biochar type

3.5.33. The CO_2 Removal Supplier must sample and analyse biochar separately for each type of biochar produced, taking into consideration the differences in *biomass feedstock type or blend*, different *operating conditions during carbonization* (temperature, residence time), and any *post-production treatment of biochar*, according to one of the following regimes (further detailed in the following rules):

a. Regime A. Biochar sampling and analyses under monitored and uniform carbonization conditions
b. Regime B. Biochar sampling and analysis under other conditions

Sampling for biochar analyses and sample retention

3.5.34. For each biochar type produced (as defined in 3.5.33) and sampling regime, the CO_2 Removal Supplier must follow a biochar **sampling plan** that ensures a representative sample of biochar is collected and stored for further laboratory analyses.

More specifically, for both sampling regimes:

a. The sampling plan shall be based on grab sampling over multiple days of production to form a composite sample.
b. The sampling plan shall include homogenisation by mixing prior to laboratory analysis of the composite sample.
c. In case carbonization conditions are temporarily unstable, sampling procedures must be adjusted to adequately address the instability (e.g. conserving separate samples for affected batches).
d. If the Production Facility is composed of several reactors (with similar design as per rule 2.2.1), whether co-located or not, sampling can either be done separately for each reactor or done in a representative manner across the reactors.
e. The plan must also include retention and archiving of composite samples sent for analysis, with adequate labelling information (sampling datetime, production batches, feedstock, production conditions), for at least two years.

More specifically, for each sampling regime:

Regime A. The sampling procedure must follow the following items:

f. The composite sample that is sent for analysis must not represent *more than 6 months of production (i.e. minimum 2 analyses per year).*
g. *For continuous production processes*, grab sampling to form a composite sample shall be performed *at least every 15 days of production*, from a random selection of batches produced under stable conditions (see rule 3.5.37) during this period, taking care of sampling from different locations and depth within the bags or containers used.
h. *For batch and semi-continuous processes*, grab sampling to form a composite sample shall be performed daily, taking care of batch homogenisation prior to grab sampling.

Regime B: The sampling procedure must follow the following items:

i. The composite sample that is sent for analysis must not represent *more than 3 months of production (i.e. minimum 4 analyses per year)*.
j. *For continuous production processes*, grab sampling to form a composite sample shall be performed *at least every 7 days of production*, from a random selection of batches produced during this period, taking care of sampling from different locations and depth within the bags or containers used.

k. *For batch and semi-continuous processes*, grab sampling to form a composite sample shall be performed daily, taking care of batch homogenisation prior to grab sampling.

Each Production Facility must develop a detailed sampling and analysis plan, which can be appended to the Monitoring Plan, where the above elements are further detailed and applied to the specifics of each facility.

Auditor right to request sampling for analysis

3.5.35. During Audits, the CO_2 Removal Supplier must provide the auditor with the detailed biochar sampling procedure used at the Production Facility as per its Monitoring Plan. Further, during a site visit, the auditor is allowed to request demonstration of the biochar sampling procedure, and to send this sample or any retained sample for laboratory analyses. This may be requested in case there are suspicions of inaccurate implementation of the sampling procedure or analyses.

Frequency of laboratory analyses for permanence properties and carbon stored

3.5.36. For each biochar type produced (as defined in 3.5.33), the CO_2 Removal Supplier must conduct laboratory analyses of the *biochar permanence properties* and *carbon content* (see analytical methods and laboratory requirements in section 6) at the following minimum frequencies:

a. **Regime A**. At least 2 times per year per biochar type produced, from the composite samples, under uniform carbonization conditions; and possibly additional analyses for biochar produced under deviating conditions.

b. **Regime B**. At least 4 times per year per biochar type produced, from the composite samples.

Note that if the Facility is not producing biochar during a given time period (e.g. due to seasonality of production), no testing is required during that period.

Uniform carbonization conditions

3.5.37. Under the monitoring and sampling regime A (see rules 3.5.33 and 3.5.34), carbonization conditions are deemed continuously monitored and uniform if the following conditions are met:

a. Monitoring records at 1-minute intervals are reported for indicators of carbonization temperature (i.e. the highest temperature to which biomass/biochar is exposed to).

b. Monitoring records at 1-minute intervals are reported for calculation of the biomass/biochar residence time in the carbonization reactor (excluding residence time in any cooling screws).

c. The monitored data shows uniform carbonization conditions, in one of the following ways:

i. *Standard option*. Carbonization temperature and residence time values for all contributing samples (within a composite sample) or for individual production batches (matched to a composite sample) fall within ±10% of the average values observed for that composite sample. Data records may exclude startup and shutdown phases, as well as sensor anomalies.

ii. *Custom option*. The CO_2 Removal Supplier may propose a facility-specific approach based on parameters relevant to their carbonization process. This approach must be supported by laboratory analysis demonstrating that biochar properties remain consistent within the defined parameter range. The proposal must be described in an annex to the Monitoring Plan, approved by the Issuing Body prior to the Facility Audit, and made publicly available.

Reporting of biochar properties for verification

3.5.38. When reporting biochar properties for Output Audits, the following distinctions are made between the two sampling regimes:

a. **Under Regime A**, the following applies:
   i. For biochar production batches that have contributed to a composite sample, the reported properties are those of the analyzed composite sample.
   ii. For production batches that did not contribute to a composite sample yet but were produced under carbonization conditions demonstrably similar to those of a previously analyzed composite sample (dated no more than 6 months prior), as per rule 3.5.37, the properties of that analyzed sample may be assigned to those batches.
   iii. For batches produced under carbonization conditions that deviate from all available composite samples (from the past 6 months), the properties may not be inferred and must either be excluded from reporting or analyzed separately—unless they represent a marginal share of the total reported production (i.e., less than 1% of the total dry mass of biochar produced).
   iv. The data used to demonstrate similarity of carbonization conditions must be documented and made available for auditor verification.

b. **Under Regime B**, the following applies:
   i. In the absence of continuous monitoring and documentation of stable production conditions, each reported batch must be supported by a completed laboratory analysis to enable full verification. Properties may not be inferred from prior analyses if the associated composite sample has not yet been analyzed.
   ii. For affected batches (i.e., those lacking completed laboratory analysis), verification may need to be deferred to the next Output Audit, once the missing analysis results become available. The CO_2 Removal Supplier may adjust the timing of laboratory analyses or increase analysis frequency to better align with auditing cycles.

(in production) Figure 3.1. Illustration of the interlinkages between biochar production records, biochar sampling and analysis, and auditing schedules, under different sampling regimes.

Minimum records of biochar production batches

3.5.39. The CO_2 Removal Supplier must keep records of biochar production batches, including at minimum the following information: a unique identifier, production date or range, feedstock type used, production parameters, identifier of corresponding sample(s) sent for analyses, and dry mass of the batch. Beside this minimum identification information, additional information is necessary to comply with other rules in this methodology. A Facility-specific definition of biochar production batches must be defined by the CO_2 Removal Supplier in its Monitoring Plan and used for reporting, as relevant for the operations of the Facility (e.g. bag level, volume-based, time-based) and compliance with the methodology.

Linking of biochar production records

3.5.40. The CO_2 Removal Supplier must be able to link the biochar production records to:

a. Upstream: a monitoring period or subset of a monitoring period during which the batch was produced, thereby enabling association with parameters needed during verification.

b. Downstream: the records of biochar used, thereby enabling demonstration of end-use and suitable environmental quality (see further rules in section 3.6).

> **REMARK:** The method for linking biochar production and usage records may vary depending on the complexity of the biochar activity. For cases involving a single feedstock and uniform production conditions, a strict first-in/first-out (FIFO) approach can be used. In more complex scenarios—where multiple feedstocks, varying production conditions, and diverse end-uses are involved—tracking can be implemented at the bag level using individual identification systems.

3.6. Requirements for eligible biochar uses

Biochar carbon removal is only secured once biochar has been used in an application that preserves its carbon storage potential with minimal risks of reversal. Biochar use is also the phase when several co-benefits can take place, provided the use is well designed and the biochar is environmentally safe. Additionally, biochar use also affects quantification of project emissions and carbon stored. Hence, monitoring is an important aspect during this phase, yielding the last pieces of evidence required to demonstrate the eligibility of the removal activity. It should be noted that the level of detail of the monitoring may vary with the complexity of the activity, as affected by the number of use types, the multiplicity of end-users and geographical areas, the split of biochar batches in different units, or any intermediaries processing the biochar.

A key aspect of ensuring the permanence of carbon removal is minimizing the risk of reversal. Monitoring during the biochar use phase is particularly important for addressing two main risks: reversals due to diversion of the biochar from its intended uses, and reversals due to cascading uses of biochar where the final fate is difficult to predict.

Biochar applications are grouped in three categories with respect to eligibility. First, applications that are eligible for CORCs, where the biochar use meets the eligibility requirements. Second, applications that are allowed but do not qualify for CORCs, where biochar is used in a legal and environmentally sound manner but does not meet eligibility requirements. This includes e.g. oxidative applications or applications where reversal risks cannot be demonstrated to be low. Finally, some applications are explicitly forbidden, including any form of disposal or application that is illegal or environmentally harmful.

Records of biochar use

3.6.1. The CO_2 Removal Supplier must keep records of biochar use batches, including at minimum the following information: a unique identifier, a date of use, a category of use, the dry mass of the batch, a link to the biochar production records and the biochar properties. Beside this minimum information, additional evidence is necessary to comply with other rules in this section and the methodology. A Facility-specific definition of biochar use batches must be defined by the CO_2 Removal Supplier in its Monitoring Plan and used for reporting, taking into consideration the different categories of uses and distribution chain details (e.g. individual bag tracking, truckloads, deliveries).

Combinations of end-uses

3.6.2. The CO_2 Removal Supplier can use biochar from the Production Facility in multiple applications, even combining applications that are eligible for CORCs and non-eligible for CORCs (see table 3.2). Only biochar batches for which it can be proven that they were used in eligible applications can result in CORCs. However, all biochar leaving the Production Facility must still be managed or used in a legal and environmentally safe manner. If a CO_2 Removal Supplier is found to make illegal use of biochar, its Production Facility can be suspended.

Eligible and allowed end-use categories

3.6.3. An eligible application or end-use is defined as an application where biochar has been used in a manner that ensures durable carbon storage, with demonstrated low risks of reversals, and in a legal and environmentally safe manner. For each batch of biochar used, the CO_2 Removal Supplier must report which use category applies from the list in Table 3.2.

a. If the use is eligible for CORCs, the CO_2 Removal Supplier must provide the associated evidence required to demonstrate that end use has taken place, reversal risks are mitigated, and use is environmentally safe.
b. If the use is not eligible for CORCs, but is an allowed use, the CO_2 Removal Supplier must still provide the associated evidence to demonstrate that the use is legal and environmentally safe.

Other categories may be added to Table 3.2 by the Issuing Body via rule clarifications, in case unforeseen biochar applications emerge.

Mitigation of reversal risks prior to final use

3.6.4. In order to address risks of reversals prior to final use of the biochar, the CO_2 Removal Supplier must further specify for each batch of biochar used how the following risks have been addressed:

a. **Diversion from intended use**: this refers to situations where intermediaries or users of the biochar have an incentive to divert biochar from the reported intended use, to instead make use of it in an application that does not preserve its carbon storage. The biochar use records must specify whether:
    i. Biochar is delivered to users in **pure** form, i.e., with no other product added to the biochar after it has been produced, except water. In this case, diversion risks are generally higher. *Hence, the required proof of end-use must comply with rule 3.6.5.*
    ii. Biochar is delivered to users in **mixed** form: in this case, diversion risks are generally lower. *Hence, the required proof of end-use must comply with either rule 3.6.5 or rule 3.6.6.*
b. **Cascading uses**: this refers to situations where biochar or a biochar containing-product is used in a first application before being reused or disposed of in one or several subsequent applications. Cascading uses are opposed to final uses. The biochar use records must specify whether:
    i. Biochar use is **final**: in this case, no additional evidence is required besides proof that the end-use has taken place (sub-rule a).

ii. Biochar use is **cascading**: in this case, risks can be low or high depending on the actual cascade of use and project-specific information. *Hence, the required proof of low-risk cascading use must comply with [rule 3.6.7](#).*

c. **Handling by intermediaries**: this refers to situations where biochar or a biochar-containing product is not directly delivered to its user, but handled by intermediaries such as wholesaler, reseller, or product manufacturers. Intermediaries may e.g. keep biochar in stock at their premises before it is sent to users, mix biochar into certain products that are then delivered to a user, or may treat biochar in ways that may alter its properties. Note that transporters that simply collect and deliver biochar batches are not considered an intermediary in the context of this rule. The biochar use records must first specify whether:

i. There are **no intermediaries** between producer and users: in this case, no additional evidence is required besides proof that the end-use has taken place (sub-rule a) and proof of low-risk cascade (sub-rule b, if applicable).

ii. There are one or several **intermediaries** between producer and users: in this case, risks can be low or high depending on the role of intermediaries. *Hence, the monitoring of the end-use (sub-rule a) must be extended to include handling by intermediaries, following [rule 3.6.8](#).*

In the context of the methodology, the term biochar user or user means the first user from which sufficient evidence can be collected for the Point of Creation of the CORCs (see section 2.3) to be established. The identity of the user may vary depending on the *subrules a, b, c*, and the selected category of use (e.g. for retail to individuals, the retailer is considered the user; for certain urban uses, a municipal office in charge of urban greenings can be considered the user rather than its subcontractors).

Biochar delivered for use in pure form

Biochar can be sent to an end-use in pure form, i.e. without being mixed with other products except water. In this case, evidence of shipment to the user and signed attestations of use from the user are not necessarily sufficient to guarantee low risk of reversal. In particular, diversion from its intended purpose is a reversal risk that must be addressed more carefully when biochar is delivered pure. This risk materializes primarily in regions where the use of charcoal for energy is still prevalent and that there are incentives to divert biochar for energy use.

3.6.5. Whenever biochar is delivered to a user in pure form, the CO_2 Removal Supplier must collect sufficient evidence to demonstrate no diversion from its intended purpose (e.g. application to soil). The evidence shall be made of:

a. Evidence of delivery to the user, with at minimum explicit mentions of region of delivery, amounts used, category of use and date of delivery.

b. Evidence of no risk of diversion from intended purpose, which can be one or a combination of the following options:

i. Evidence that charcoal use for energy is not prevalent in the country of biochar use.

ii. Evidence that biochar, although pure, has been processed in a way that reduces the risk of diversion, either at the production site or at the user location, e.g. grinding to fine powder and mixing with water to moisture content above 50%.

iii. Attestation of use from the user, with explicit mention of location of use, date of use, and identification of the biochar batches used.
iv. Photographic evidence of the use (e.g. incorporation to soil), including timestamp and georeference, and identification of the biochar batches used.
v. Other forms of evidence, to be approved by the Issuing Body.

POST-APPLICATION VERIFICATION OF BIOCHAR IN SOIL: The feasibility of using soil measurements to verify biochar application has been explored. However, current methods are neither sufficiently reliable nor cost-effective to precisely quantify the amount of biochar applied. While some analytical techniques can detect increases in pyrogenic carbon content in soils after biochar application, for a limited period of time (years), they do not provide an accurate measure of the quantity introduced.

As a result, while research and advancements in this area are encouraged, post-application soil measurements cannot be mandated as a requirement for certification at this time. Instead, verification of biochar use must rely on alternative forms of documentation, such as records of biochar production, transport, and use.

REMARK ON BIOCHAR DELIVERY FOR AGRONOMIC USE: The timing of biochar delivery to farms should, when feasible, align with the planned application period. While timely delivery is not mandatory, long-term storage on farms can increase the risk of fire, misplacement, or unintended use. CO_2 Removal Suppliers are encouraged to support end-users by promoting safe storage practices and providing guidance or assistance where needed.

Biochar product mixing minima

3.6.6. Whenever biochar is mixed with other constituents to form a product, the delivery of the product to the user can be considered to be sufficient proof of use, with low diversion risk, only if all the following conditions are met:

a. The biochar content of the product is below 50% (v/v) on a volume basis.
b. The product has a clear declared use in the context of an eligible application listed in Table 3.2.
c. Evidence of delivery is available (i.e. if the product is still in-stock at the production site or in-stock at a reseller, it is not sufficient), with at minimum explicit mentions of region of delivery, amounts used, category of use, and date of delivery.

This implies that monitoring of the biochar-containing product is not necessary beyond the delivery to the user, unless required by another rule (e.g. cascading uses). If one of the conditions cannot be demonstrated, the monitoring of the biochar-containing product must continue until the conditions are met, if CORCs are to be reported for those volumes. Further, the auditor is allowed to request a visit to the mixing sites for verification of the composition of the biochar-based product.

Biochar cascading uses

Biochar can have cascading uses. Cascading uses refer to situations where biochar is first used in an application for a given amount of time, before being re-used in one or several other intermediary applications, and ultimately used in a final application from which it cannot be recovered anymore. Two examples are given below:

1. Biochar is used as animal feed in dairy farms (use 1), which is then recovered in animal manure that is sent to an anaerobic digester (use 2), from which biochar-containing digestate is applied to soil (use 3, final). *This is normally an eligible cascade of uses*.
2. Biochar is used as a filter (use 1), which is then recovered and re-activated for re-use as a filter once (use 2), after which it is finally treated and either sent for disposal in landfill or incineration (use 3, final). *This is a cascade of uses that is ineligible due to the reactivation process that likely re-emits biochar carbon and the unknown end-use that could entail incineration of the filter.*

3.6.7. Whenever biochar or a biochar-containing product is used in an application that does not constitute a **final use**, but instead is used in an application that is part of a **cascade**, the CO_2 Removal Supplier must document and report the nature of the cascading uses. If CORCs are to be reported for those volumes, the documentation must provide sufficient project-specific evidence that the cascade entails low risks of reversals. Depending on the category of use selected, Table 3.2 identifies the most common evidence to be provided to demonstrate a low-risk cascading use. For accounting of project emissions in the case of cascading use, see rule 7.3.14.

Biochar intermediaries

3.6.8. Whenever biochar or a biochar-containing product is sent from the Production Facility to biochar **intermediaries, brokers, resellers**, i.e. entities who are not the user of the biochar or biochar-containing product, monitoring of the use must continue until it reaches the user of the biochar or biochar-containing product. Hence, the CO_2 Removal Supplier must have procedures and agreements in-place with its intermediaries to collect the necessary traceability information. Further, whenever the intermediaries are also manufacturing biochar products, mixing different sources of biochar, or even altering the properties of the biochar (e.g. chemical or thermal treatment), those possible actions must be clearly described and reported to the CO_2 Removal Supplier, as per the procedure and agreements above-mentioned. For accounting of project emissions in the case of intermediary activities see rule 7.3.14.

Table 3.2. Categories of biochar applications, their eligibility for CORCs, rules applicable for management of potential re-emissions and reversal risks, and environmental quality thresholds in the absence of local regulation.

ID	Biochar used in [sector]	Biochar used as [product type]	Most common form of use	Final or Cascading use	Eligible for CORCs	Potential re-emissions and reversal risks and associated rules	Conditions for low-risk cascading use, complementing rule 3.6.7, and other use-specific conditions	Minimum Environmental Quality Level[14]
AF1	Agriculture & Forestry	Soil amendment, applied pure and incorporated into the topsoil (e.g. on arable land, grazeland, forest land).	Pure	Final	Yes	- Diversion risks: proof of end-use as per rule 3.6.5 - Cascade risks: not applicable - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (forest or agriculture): deemed not a threat to biochar carbon, see section 4.	Not applicable.	WBC Agro
AF2	Agriculture & Forestry	Soil amendment, mixed with other amendments (e.g. with compost, manure, organic fertilizer, slurries) prior to soil application (e.g. on arable land, grazeland, forest land), and biochar-fertilizers.	Mixed in product	Final	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6 - Cascade risks: not applicable - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (forest or agriculture): deemed not a threat to biochar carbon, see section 4.	Not applicable	WBC Agro
AF3	Agriculture	Cultivation substrate, pure or mixed with other constituents. Cultivation substrate here refers to substrate used for crop production in a non soil environment (e.g. potting soil, growing media, substrate for horticulture), and where the substrate is discarded after one or several cultivation cycles.	Pure or Mixed in product (to be specified)	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6 - Cascade risks: **applicable** (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (forest or agriculture): deemed not a threat to biochar carbon, see section 4.	Evidence that spent cultivation substrates are used or discarded in a manner that preserves the carbon storage (e.g. composting and soil amendment). Evidence can be based on common practice for substrate management in the project area (showing no incineration risk) or primary evidence from the users of the biochar product.	WBC Agro

[14] According to the WBC (2023): World Biochar Certificate – Guidelines for a Sustainable Production of Biochar and its Certification.' Carbon Standards International, Frick, Switzerland, version 1.1 from 20th December 2024

AF4	Forestry	Planting substrate, pure or mixed with other constituents, for tree seedling and sapling production.	Pure or Mixed in product (to be specified)	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: **applicable** (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (forest or agriculture): deemed not a threat to biochar carbon, see section 4.	Evidence that unused or spent substrate alongside any failed or discarding seedlings are managed in a manner that preserves carbon storage (e.g. re-use, composting, soil amendment). Evidence can be based on common practice for spent planting substrate management in the project area (showing no incineration risk) or primary evidence from the users of the biochar product.	WBC Agro
AF5	Agriculture & Forestry	Seed coatings, for seeds used in agricultural context (e.g. arable land)	Mixed with product (although mixing here not addressing risk of reversal)	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 only - Cascade risks: **applicable** (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (forest or agriculture): deemed not a threat to biochar carbon, see section 4.	Evidence that the coated seeds have been used in the agricultural sector on arable land, entailing that biochar reaches a final site of use. Measurements or conservative estimations of the share of any expired or damaged seeds that are discarded by the users. Unless otherwise demonstrated, it is assumed that discarded seeds are sent for incineration and therefore the share of biochar they contain is not eligible.	WBC Agro
AH1	Animal husbandry	Additive to manure in on-farm storages	Pure	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 - Cascade risks: **applicable** (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (forest or agriculture): deemed not a threat to biochar carbon, see section 4.	Cascading use: manure storage is periodically emptied, for subsequent management, which can include e.g. i) direct application to soil, ii) anaerobic digestion or composting with subsequent soil application of digestate or compost, or iii) incineration. Evidence that biochar-containing manure, digestate or compost is not sent to incineration in the region of use, but instead applied to land. Evidence can be based on common practice for manure management in the project area (showing no incineration risk) or primary evidence from the actual users.	WBC Agro

AH2	Animal husbandry	Additive to animal bedding	Pure	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 - Cascade risks: **applicable** (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (forest or agriculture): deemed not a threat to biochar carbon, see section 4.	Similar to "Additive to manure in on-farm storages"	WBC Premium
AH3	Animal husbandry	Animal feed additive (at industrial scale; i.e. not retail to individuals for pet feed)	Pure or Mixed in product (to be specified)	Cascading	Yes	Similar to "Additive to manure in on-farm storages"	Similar to "Additive to manure in on-farm storages"	WBC Premium
WM1	Waste management	Additive to industrial composting or anaerobic digestion facilities	Pure	Cascading	Yes	Similar to "Additive to manure in on-farm storages"	Similar to "Additive to manure in on-farm storages"	WBC Agro
WM2	Waste management	Landfill intermediary or final cover material, mixed with soil other constituents (note: this does not include landfilling of biochar, but use of biochar as part of landfilling operations to cover other waste processed)	Pure or Mixed in product (to be specified)	Final	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: not applicable - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (landfill context): intentional or unintentional fire can take place in certain landfills	Evidence that biochar is delivered to the landfill, in mixed or pure form, and if in pure form, is mixed at the landfill with other constituents before use as cover or during application as a cover material. Evidence from the landfill operator on how biochar or biochar product is handled and used in normal operations, in the form of a standard operating procedure. Evidence from the landfill operator that the landfill has procedures in place to minimize unintentional fires, and that the landfill does not conduct intentional open-burning of waste.	WBC Material

							The landfill must also be classified as a sanitary landfill (which contributes to mitigation of those fire-related risks).	
EM1	Environmental management	Soil additive for remediation of contaminated soils	Pure or Mixed in product (to be specified)	Final or Cascading (to be specified)	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: depends on the subsequent use of the remediated soil, to be documented (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (soil context): deemed not a threat to biochar carbon, see section 4.	Each situation of biochar use for soil remediation must be documented individually. This brief documentation must include: i) a description of the soil remediation activity, ii) demonstration of the legality of the activity, iii) information on the type of contamination to be remediated with biochar, and iv) the subsequent use of the remediated soil. In particular, the subsequent use of the remediated soil must be documented in a way that allows to evaluate the cascade related reversal risks. In the case of in-site soil remediation, where the soil is not excavated but remains in place, cascade risks are considered low by default.	WBC Agro, although deviations can be commonly accepted
EM2	Environmental management	Soil amendment, for reclamation of mines and quarries	Pure or Mixed in product (to be specified)	Final (in most cases)	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: not applicable - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (soil context): deemed not a threat to biochar carbon, see section 4.	Each situation of biochar use for reclamation of mines and quarries must be documented individually. This brief documentation must include: i) a description of the reclamation activity, ii) demonstration of the legality of the activity (e.g. authorisation by competent authorities, following adequate engineering studies), iii) information on the types and volumes of biochar used and how it is mixed with other constituents (a maximum of 50% v/v biochar content is expected), and iv) information on the planned fate of the reclaimed area.	WBC Agro

BE1	Built environment	Urban soil, roadbeds or landscaping soil mixes (long-lived soil uses)	Pure or Mixed in product (to be specified)	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: deemed low by default - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (soil context): deemed not a threat to biochar carbon, see section 4.	Biochar used as a soil amendment in a built environment context (e.g. urban soils, roadbeds, or landscaping) is usually considered to stay in place for several decades, and may only be moved in the built environment when construction, renovation or demolition works take place. Biochar is then contained in soil masses resulting from those works, and is not considered to be at risk of reversal, because such soil masses are either re-used for other landscaping works or discarded in landfill for soil masses. Hence, cascading risks are deemed low, and no additional evidence is required beside proof of use.	WBC Agro
BE2	Built environment	Planting substrate, used in temporary or short-lived greenings (e.g. green roofs, green walls, raised planting beds, planting pots)	Pure or Mixed in product (to be specified)	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: applicable (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (in-product): possible risk of fire in buildings or built environment, considered exceptional or part of disaster regime, see section 4.	Planting substrate in the built environment can have variable product lifetimes (from years to decades) and the management of the spent substrate can vary by type of product and project area. Hence, each biochar product type must be documented individually. This brief documentation must include: i) a description of the product, including composition and average lifetime, ii) a description of the common management of the product at end-of-life in the area of use, demonstrating low risks.	WBC Agro

BE3	Built environment	Long-lived construction material (e.g. concrete, bricks, cement mortar)	Mixed in product	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: deemed low by default - Intermediaries risks: as per rule 3.6.8 - Exposure to fire (in-material): possible risk of fire in buildings, considered exceptional or part of disaster regime, see section 4.	Biochar is typically delivered in pure form to manufacturers of long-lived construction materials, who then mix biochar into their products. Biochar is then delivered in mixed form to the user of the product. The products normally have long lifetimes, in the range of several decades, after which renovation or demolition works may entail movement of the biochar containing product. Most recycling technologies available today for concrete, bricks, or cement, do not pose a risk to biochar carbon. Re-use of aggregates from demolition does not pose a risk either. Hence, cascading risks are deemed low, and no additional evidence is required beside proof of use.	WBC Material
BE4	Built environment	Road surfacing materials (e.g. biochar-containing asphalt) and assimilated	Mixed in product	Cascading	Yes	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: deemed low by default - Intermediaries risks: as per rule 3.6.8 - Exposure to fire (in-material): possible risk of fire in buildings, considered exceptional or part of disaster regime, see section 4.	Biochar is typically delivered in pure form to manufacturers of asphalt, who then mix biochar into their products, either as a pre-mix or directly on-site of use. Hence, the biochar product must be proven to be used. The products normally have lifetimes in the range of years to decades, and some minimal wearing also occurs during use. At end-of-life, surfacing material can either be covered with new material or removed for re-use or recycling. To date, none of these management options seem to pose risks. Hence, cascading risks are deemed low, and no additional evidence is required beside proof of use.	WBC Material
NE1	Natural environment	Soil amendment in natural areas, protected areas, areas of high ecological values, wetlands and peatlands, and similar environments	Pure or Mixed in product (to be specified)	Final	Yes, under conditions	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: not applicable - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (natural environment): deemed not a threat to biochar carbon, see section 4.	This use is eligible for CORCs only if it is also authorised by competent authorities, e.g. as part of a restoration or remediation project. Unauthorised application of biochar in such areas or environments are not eligible and not allowed.	WBC Premium

<table>
<tr><td>NE2</td><td>Natural environment</td><td>Addition to water systems (rivers, lakes, sea, oceans)</td><td>Pure or Mixed in product</td><td>Final</td><td>No & not allowed use</td><td colspan="2">This type of use is not eligible for CORCs and certified Facilities are not allowed to make use of biochar in such applications, even if not resulting in CORCs. The primary reason for this is the unknown environmental effects on water ecosystems of such uncontrolled additions of biochar.</td><td>Not applicable</td></tr>
<tr><td>R1</td><td>Retail to individuals</td><td>Pet feed supplement</td><td>Pure or Mixed in product</td><td>Cascading</td><td>No, but allowed use</td><td colspan="2" rowspan="2">This type of use is not eligible for CORCs because of high risks of reversals and traceability challenges relating to the cascading use in the context of retail to individuals. Pet feed and other consumer products have a high risk of being disposed of in common waste management facilities, including solid waste incinerators, and face traceability challenges. The level of risk is deemed higher than for gardening products.
However, certified Facilities are allowed to make use of a share of their biochar output in such applications, although this share will not result in CORCs, and is expected to meet the WBC quality threshold indicated here (in the absence of local regulation).</td><td>WBC Premium</td></tr>
<tr><td>R2</td><td>Retail to individuals</td><td>Consumer products (e.g. face masks, toothpaste, …)</td><td>Mixed in product</td><td>Cascading</td><td>No, but allowed use</td><td>WBC Premium</td></tr>
<tr><td>R3</td><td>Retail to individuals</td><td>Gardening products sold in store or directly to individuals, in pure form or mixed form (typically in small packaging units)</td><td>Pure or Mixed in product</td><td>Final or Cascading</td><td>No, but allowed use</td><td colspan="2">This type of use is not eligible for CORCs because of high risks of reversals and traceability challenges relating to the cascading use in the context of retail to individuals.

Note that during Public Consultation, Puro.earth received feedback that this category should be made eligible for CORCs under conditions to be determined. Several suggestions were made and discussed with Puro's Advisory Board; however, none of the options addressed the risks in a satisfactory manner. It was therefore decided to maintain this use as allowed but not resulting in CORCs, for the time being. This said, both Puro.earth and its Advisory Board recognise the value of this product category. Hence, Puro.earth remains open to discussion with stakeholders to design new rules, which could be incorporated in a future minor revision.</td><td>WBC Agro</td></tr>
<tr><td>R4</td><td>Retail to individuals</td><td>Landscaping products, in pure or mixed form, sold in larger volumes via landscaping companies (who also do the application at the individual's location, e.g. private property)</td><td>Pure or Mixed in product (to be specified)</td><td>Final</td><td>Yes, under conditions</td><td>- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable
- Cascade risks: not applicable
- Intermediaries risks: as per rule 3.6.8

- In-soil exposure to fire (soil context): deemed not a threat to biochar carbon, see section 4.</td><td>Unlike other situations of retail to individuals, here traceability of the biochar use is facilitated by the relatively large amounts of biochar used for such products and by the landscaping company doing the works and using the biochar.
Evidence from the landscaping company that biochar use has taken place, for a given client, including a description of the works conducted showing biochar has been mixed into soil.</td><td>WBC Agro</td></tr>
</table>

IMF1	Industrial Materials or Fuels	Filter media for water, wastewater or air	Pure (in most cases)	Cascading	Yes, under conditions	- Diversion risks: proof of use as per rule 3.6.5 or rule 3.6.6, as applicable - Cascade risks: applicable (rule 3.6.7) - Intermediaries risks: as per rule 3.6.8 - In-soil exposure to fire (soil context): deemed not a threat to biochar carbon, see section 4.	Biochar use as a filter media is an extremely diverse category of use. In many situations, biochar-based filters can be exposed to re-activation processes that affect its carbon content, or be sent to incineration as final treatment. Those situations are not eligible for CORCs, but are an allowed use. In rare cases, biochar-based filters are used in soil environments and their end-of-life can be demonstrated to be preserving the carbon stored. Examples include: biochar used as part of below-ground small-scale water treatment, or biochar used as nutrient-catching material in an agricultural context. Those uses may be eligible for CORCs provided that sufficient information on the cascade is available.	WBC Premium
IMF2	Industrial Materials or Fuels	Component for paints, plastics, composite, batteries, and other short-lived materials	Mixed in product	Cascading	No, but allowed use	At the moment, this type of use is not eligible for CORCs because there is a high risk of reversal in the material cascade due to disposal in waste incinerators and traceability challenges. However, certified Facilities are allowed to make use of a share of their biochar output in such applications, although this share will not result in CORCs, and is expected to meet the WBC quality threshold indicated here (in the absence of local regulation).		WBC Material
IMF3	Industrial Materials or Fuels	Fuel for energy production or reductant in industrial processes (e.g. steel)	Pure	Final	No, but allowed use	This type of use is not eligible for CORCs because the carbon storage is not preserved. Even if residual amounts of carbon remain in the end-product or ash, these are not sufficient to ensure net-negativity of the removal activity. However, certified Facilities are allowed to make use of a share of their char output in such applications, although this share will not result in CORCs. This share of char is expected to meet the quality threshold required by such industrial users bilaterally agreed between supplier and user.		Industry specific standards or bilaterally agreed quality
GEO1	Passive deposits	Injected in non-accessible underground formations, not accessible (e.g. biochar slurries injected in underground formations)	Pure (or mixed with water)	Final	Yes, under conditions	- Diversion risks: proof of use as per rule 3.6.5 - Cascade risks: not applicable - Intermediaries risks: as per rule 3.6.8	This use is eligible for CORCs only if it is also authorised by competent authorities. The local competent authorities must define the environmental quality of the biochar and require environmental monitoring of the injection site. Unauthorised injection of biochar (or biochar slurries) in environments are not eligible and not allowed.	Quality threshold defined by local competent authority, or at minimum WBC Material

GEO2	Passive deposits	Stored in accessible underground formations, without mixing (e.g. below ground mines, reversible storage in big-bags)	Pure	Final	No, but allowed use	Due to biochar not being mixed, there is risk that the storage site may be excavated in the future. Non-accessibility of the burial site over several centuries is challenging to guarantee. Extensive monitoring would also be required and guaranteed over time, which is not in the scope of this methodology. If a CO_2 Removal Supplier engages in such activities, they must be duly authorized by competent authorities.		Quality threshold defined by local competent authority
GEO3	Passive deposits	Below-ground burial, e.g. in pits and trenches, unused wells, abandoned mine tunnels	Pure or Mixed in product (to be specified)	Final	Yes, under conditions	- Diversion risks: proof of use as per rule 3.6.5 - Cascade risks: not applicable - Intermediaries risks: as per rule 3.6.8	This use is eligible for CORCs only if biochar has been mixed with other mineral constituents or the local soil, to a level ensuring no reversibility of the application and rendering any future excavation of the biochar for oxidative uses not realistically possible. For certain applications, an authorisation from competent authorities may be required, following adequate engineering studies, such as in the case of mine filling.	WBC Agro

Environmental quality of biochar

3.6.9. Any biochar leaving the Production Facility to be used must have been demonstrated to pose no significant environmental harm, via one of the following options:

a. Compliance with biochar- and application- specific regulation existing in the jurisdiction where biochar is used.
b. Compliance with the thresholds values, testing frequencies and analytical methods defined in rules 3.6.10 to 3.6.12, which are applicable in the absence of biochar- and application-specific regulation in the jurisdiction of use.
c. Demonstrated acceptability of a deviation from the threshold values referred to in option a or option b (see rule 3.6.13).

> **EXAMPLE:** In the United States, USDA regulations establish limits on the maximum allowable concentrations of heavy metals in biochar when used as a soil amendment. These regulations do not require measurements of polycyclic aromatic hydrocarbons (PAHs), unless there is a risk for contamination.Hence, USDA regulation here takes precedence over the Puro methodology, for biochar use as soil amendment in the United States.

Environmental quality threshold

3.6.10. In the absence of biochar- and application- specific regulation existing in the jurisdiction of use (see rule 3.6.9), the CO_2 Removal Supplier must conduct laboratory analyses of its biochar, for all the substances mentioned in Table 3.3 that are applicable for the biochar's intended use as per Table 3.2.

These threshold values are reproduced with permission from the voluntary World Biochar Certificate (WBC) guidelines, version 1.1[15]. The latest version of the WBC threshold values always apply.

Disclaimer: Compliance with the values presented in Table 3.3 does not imply certification under the European Biochar Certificate (EBC) or World Biochar Certificate (WBC) schemes. Use of the EBC or WBC names, logos, or references to certification is only permitted with formal approval and certification from Carbon Standards International (CSI). CO_2 Removal Suppliers must refrain from making claims of compliance or certification unless explicitly certified by CSI.

Table 3.3. Threshold values reproduced from the WBC Guidelines for a Sustainable Production of Biochar, for three categories of biochar quality. For valid analytic methods to measure each substance, please refer to rule 3.6.12.

Substance	WBC-Material	WBC-Agro	WBC-Premium
PAHs *(values in mg / kg DM)*			
16 EPA PAH	Declaration	Declaration	6

[15] WBC (2023): World Biochar Certificate – Guidelines for a Sustainable Production of Biochar and its Certification.' Carbon Standards International, Frick, Switzerland, version 1.1 from 20th December 2024

<table>
<tr><th>Substance</th><th>WBC-Material</th><th>WBC-Agro</th><th>WBC-Premium</th></tr>
<tr><td>8 EFSA PAH</td><td>4</td><td>1</td><td>1</td></tr>
<tr><td colspan="4">Heavy metals (values in mg / kg DM)</td></tr>
<tr><td>Pb</td><td rowspan="8">Declaration (no limit values for certification)</td><td>300</td><td>120</td></tr>
<tr><td>Cd</td><td>5</td><td>1.5</td></tr>
<tr><td>Cu</td><td>200</td><td>140</td></tr>
<tr><td>Ni</td><td>100</td><td>50</td></tr>
<tr><td>Hg</td><td>2</td><td>1</td></tr>
<tr><td>Zn</td><td>1000</td><td>420</td></tr>
<tr><td>Cr</td><td>200</td><td>100</td></tr>
<tr><td>As</td><td>20</td><td>13</td></tr>
<tr><td colspan="4">PCDD, PCDF, PCB (*Once per pyrolysis unit for the first production batch)</td></tr>
<tr><td>PCB</td><td colspan="3">0.2 mg / kg DM</td></tr>
<tr><td>PCDD, PCDF</td><td colspan="3">20 ng /kg DM</td></tr>
</table>

Frequency of laboratory analyses for biochar environmental quality

3.6.11. In the absence of biochar- and application- specific regulation existing in the jurisdiction of use (see rule 3.6.9), for each biochar type produced (see rule 3.5.33), the CO_2 Removal Supplier must conduct laboratory analyses of the *biochar environmental quality* at the following minimum frequencies:

a. For **heavy metals**: at least once per 12-month period, on a representative sample (see rule 3.5.34). Since heavy metal content is primarily feedstock dependent, variability related to production conditions is not expected to significantly affect values.

b. For **PAHs**: same applicable frequency as for determination of biochar persistence properties, as PAHs content can be affected by production conditions (see rule 3.5.34).

c. For **other organic contaminants** (PCDD, PCDF, PCB): one time during the crediting period, for the first batch produced of each biochar type, and to be renewed at each crediting period.

Analytical methods of laboratory analyses for biochar environmental quality

3.6.12. In the absence of biochar- and application- specific regulation existing in the jurisdiction of use (see rule 3.6.9), the analytical methods used for laboratory analyses of the *biochar environmental quality* must be in line with the analytical methods listed in the Annex I of the World Biochar Certificate, be demonstrated to be equivalent to these (see also rule 6.1.6, for demonstration of equivalence), or be state-accepted methods in the jurisdiction of use. The analyses must be performed in laboratories that comply with international testing standards (e.g. ASTM, ISO, AS, D). Laboratories shall be accredited by relevant national authorities, where such accreditation schemes exist. In countries without an established accreditation body for such testing, the laboratory must demonstrate adherence to international standards and provide evidence of quality assurance protocols.

Environmental quality deviation mechanism

3.6.13. In the event that the biochar environmental properties deviate from the applicable threshold values identified in rule 3.6.10 or from the local jurisdiction as per rule 3.6.9, the biochar might still be eligible for CORC if:

a. A deviation can be motivated in writing based on the local context.
b. This deviation motivation is approved or recognised by competent authorities.
c. The biochar has been labelled accordingly, and
d. It can be shown that the user has been informed in writing of this deviation.

Known acceptable deviations include: i) the use of biochar for remediation of contaminated soil, ii) the use of biochar in research activities that study the effects of potentially toxic elements in biochar, or iii) the use of biochar in soils with pre-existing high levels of potentially toxic elements that are safely managed (local context). The absence of measurement of the biochar environmental properties is not an acceptable deviation.

Biochar from hazardous biomass

3.6.14. Biochar produced from biomass feedstock that contains any **high-risk micropollutants** (as identified in rule 3.4.22) must not be mixed with other types of biochar. Further, use of such biochar is only allowed in non-agronomic applications (e.g. soil remediation, landfill cover, mine reclamation) provided that: i) laboratory analyses of the biochar have been conducted, including results for the substances of concern that were present in the biomass, ii) a risk analysis is made to determine whether the planned application is environmentally safe, and iii) the planned application is authorised by the local authorities, after review of the risk analysis.

Sound agronomic use of biochar

3.6.15. Whenever biochar is used for direct application onto agricultural or forest land, the CO_2 Removal Supplier must demonstrate that the application is performed in a manner that is not expected to result in negative effects for land productivity (primarily, due to over-application of biochar at rates that could be detrimental to soil equilibriums).
This can for instance be achieved by i) collecting information on the user's biochar experience (e.g. as part of an attestation of use), ii) distribution of information on recommended use of the biochar and its safe handling (e.g. as part of the biochar delivery, specifying also the added value of biochar in terms of nutrient values or liming equivalence), or iii) conducting trainings for users (typically performed in the context of small-holder farmers, to whom biochar may be distributed for free).
In case of suspicion that the biochar application is not performed with a reasonable agronomic purpose, the third-party auditor is allowed to request visit of a selection of application sites and if necessary deem the associated biochar batches ineligible for CORCs.

REMARK ON BIOCHAR AGRONOMIC USE:

Biochar producers should actively support end-users in achieving safe and beneficial agronomic applications. This is particularly relevant for farmers with no prior experience using biochar and in smallholder farming contexts, where tailored guidance can enhance biochar's effectiveness. Producers are encouraged to provide training, technical assistance, and recommendations that consider local soil conditions and agricultural practices to optimize biochar use.

Monitoring the agronomic effects of biochar is also encouraged, as it can provide valuable insights into soil health, crop productivity, and sustainability benefits. In some cases, such monitoring efforts may contribute to third-party certification of Sustainable Development Goal (SDG) attributes.

3.7. Requirements for positive sustainable development goals impacts

The Puro Standard **General Rules** and the **SDG Assessment Requirements**[16] define the requirements related to describing and evidencing expected positive impacts on Sustainable Development Goals (SDGs)[17] across all methodologies. The Puro SDG Assessment Requirements includes a list of project-level indicators, SDG Attributes, for demonstration of positive impacts on SDGs. Additional SDG Attributes can be proposed by external actors via a procedure described in those requirements. Certification of SDG Attributes requires collection of project-specific data and third-party verifications. Certification of SDG Attributes is optional and comes with additional certification fees.

In the context of biochar, SDG Attributes include e.g. improved agricultural productivity (in relation to SDG 2.4), increased production of renewable energy (in relation to SDG 7.2), or improved treatment of municipal or assimilated waste streams (in relation to SDG 11.6).

3.7.1. If the CO_2 Removal Supplier decides to not apply for additional certification of SDG Attributes, the CO_2 Removal Supplier must nevertheless provide in the Project Description a qualitative description of expected positive impacts on SDGs. This description shall be project-specific, based on the actual operations (e.g. type of biomass feedstock used, production technology, and actual biochar applications).

3.7.2. If the CO_2 Removal Supplier decides to apply for certification of SDG Attributes, the CO_2 Removal Supplier must:

a. for the Facility Audit, prepare an SDG Report based on the template provided, in which the selected SDG Attributes are described. The SDG Report must include a plan of how the requirements for each selected SDG Attribute will be demonstrated throughout the course of the crediting period. The plans described in the SDG Report must also be reflected in the Monitoring Plan (e.g. in an appendix specific for SDG Attributes).

[16] Available in the Puro Standard documents library.

[17] Resolution adopted by the General Assembly on Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development, G.A. Res 78/206, U.N. Doc. A/RES/71/313 (Jul. 6, 2017).

b. for the Facility Audit, provide in the Project Description a description of expected positive impacts on SDGs based on the selected SDG Attributes and their associated monitoring plan, and any outcome already available.
c. provide for the Facility Audit or subsequent Output Audits, i.e. whenever available, the data required to demonstrate the achieved positive impact on SDGs. This information will be verified by the appointed auditor, and if successful, result in SDG Attributes associated for the applicable CORCs (see details in the SDG Assessment Requirements).

> **REMARK:** A CO_2 Removal Supplier may decide to pursue certification of SDG Attributes at any time throughout the crediting period, even if it was not declared at the time of the Facility Audit.

3.8. Requirements for prevention of double counting

Non-double counting principles

3.8.1. The CO_2 Removal Supplier shall ensure that the CO_2 removal is not double-counted in a manner which would infringe the Puro Standard General Rules. In particular, section 3.5 of the General Rules entail that:

a. The CO_2 Removal Supplier shall evidence that it has the sole right to claim CORCs from the biochar activity, and that other parties involved in the supply chain have no such right. This can be evidenced by contracts, attestations, or invoices exhibiting the relation between the involved parties.
b. The CO_2 Removal Supplier or any party involved in the supply chain shall not associate any CO_2 removal claim (whether a marketing, branding, or footprint claim) to any other products or services delivered by the CO_2 Removal Supplier or involved party (including other types of environmental products, such as soil carbon or renewable energy certificates, EU RED III biofuel carbon footprints, environmental product declarations (EPDs) or similar schemes), unless the issued CORCs have been explicitly retired for this purpose.
c. The CO_2 Removal Supplier or any party involved in the supply chain may still report their direct emissions and removals in other sectoral GHG inventories (e.g. mandatory national reporting for UNFCCC, or voluntary corporate reporting), making adequate disclosures regarding the issuance of CORCs to their reporting organizations. Such emissions and removals reporting, whether mandatory or voluntary, must be declared to the Issuing Body, continuously over the crediting period.

Double counting prevention in labeling of biochar products

3.8.2. Whenever biochar products or biochar-containing products, that are prepared and shipped by the CO_2 Removal Supplier to a user, are **labeled**, this labeling must contain non-double counting prevention information, such as a direct mention of the CO_2 removal being already reported under the Puro Standard.

Double counting prevention in transaction of biochar products

3.8.3. Whenever biochar products or biochar-containing products, that are prepared and shipped by the CO_2 Removal Supplier to a user, are **transacted** with a next user (whether sold, given for free, or otherwise transferred), the transaction must be recorded in writing. The transaction document (e.g. attestation of transfer, invoice) must include:

a) A direct statement that the CO_2 removal associated with the biochar has already been reported under the Puro Standard,
b) A clear reference to the applicable rules for the user regarding non-double counting and end-use requirements, and
c) A requirement to pass on this information to any subsequent user if the recipient is not the final user. This applies e.g. to wholesalers who do not necessarily qualify as eligible end-users (see section 3.6).

If a contract between the parties explicitly defines the applicable rules, the transaction document may instead include a concise summary and reminder of those contractual terms..

Double counting prevention in online marketing of biochar products

3.8.4. Whenever biochar products or biochar-containing products are **advertised or marketed** on the website of the CO_2 Removal Supplier or the websites of its associated sales partners, such online content must include a direct mention of the CO_2 removal being already reported under the Puro Standard.

Alignment with Host Country commitments and plans

3.8.5. The CO_2 Removal Supplier shall evaluate whether the biochar activity (including all its effects on climate change, beyond just carbon removal covered by this methodology) falls within the Nationally Determined Contributions (NDCs) commitments, or other net-zero plans of the host country[18] relevant to Article 6 of the Paris Agreement[19]. The evaluation shall be disclosed to the Issuing Body prior to the Facility Audit, and subsequently updated at each Output Audit.

3.8.6. If the biochar activity falls within the aforementioned commitments or plans of the host country, the CO_2 Removal Supplier shall request authorization of use for trading CORCs within the Article 6 of the Paris Agreement from the corresponding designated authority. To this end, the CO_2 Removal Supplier shall follow the Puro Standard Article 6 Procedures[20] to ensure proper reporting of the issuance, transfer, and retirement of CORCs, and to avoid double counting between national emission balances and other international mitigation purposes such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) or other entities operating in the voluntary carbon market.

[18] The host country is defined as the country under whose jurisdiction the CO_2 Removal project operates and issues mitigation outcomes (i.e. CORCs). In other words, the host country is the country of location of the Production Facility, as defined in the Puro General Rules.

[19] Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Addendum. Part two: Action taken by the Conference of the Parties at its twenty-first session (a.k.a the Paris agreement). https://unfccc.int/documents/9097

[20] Puro Standard Article 6 Procedures is available in Puro Standard Document Library

4. Reversal, environmental and social risks

4.1. Overview

Definition of risks

In this methodology, **risk** refers to the potential for negative consequences resulting from identifiable events or situations whose likelihood and impact can be reasonably estimated. Risk is typically assessed as a function of the likelihood of occurrence and the severity of its adverse effects. Effective risk management involves identifying, assessing, and implementing measures to avoid or mitigate these potential consequences.

Categories of risks and layered approach to addressing them

Risks addressed by the Puro Standard fall within two broad categories, namely: **reversal** risks, and **socio-environmental** risks. The Puro Standard follows a layered approach for addressing risks. First, the Puro General Rules have a set of requirements that apply to all CO_2 Removal Suppliers and their Production Facilities, independently from the removal pathway considered. Second, this methodology identifies risks specific to biochar carbon removal, and associated eligibility rules are defined to ensure that all Production Facilities adequately tackles those common pathway-specific risks. Finally, any potential remaining risks that are specific to the local context of a Production Facility also have to be identified and addressed by the CO_2 Removal Supplier, whenever material and severe.

Importance of design phase and monitoring plan

Identification of risks normally takes place during the design phase of a project, and is further guided by questionnaires and materials provided by Puro.earth during audit preparation. Whenever risks are identified during the design phase, a CO_2 Removal Supplier can either redesign its activity to avoid the risks altogether or design its activity to minimize the risks and include adequate monitoring of the risks in its monitoring plan. Hence, the design phase and the development of a robust monitoring plan are key steps in addressing risks and ensuring compliance with the Puro Standard.

Purpose of this section

The purpose of this section is two-fold: provide background information on the relevant risks to consider for biochar carbon removal activities, and specify the rules that ensure risks are adequately addressed. The rest of the section is organised in two sub-section, one for storage permanence and reversal risks (section 4.2) and one for socio-environmental risks (section 4.3).

4.2. Storage permanence and risk of reversal

Definition of reversal risk and related notions

In the Puro Standard, the term **reversals** refers to an event that cancels, entirely or in part, the effects of an already issued CORC (for further details, see the Puro Standard General Rules). Reversal events may arise from natural processes, anthropogenic interference, or a combination of both. Methodologies in the Puro Standard must consider and evaluate the materiality of the reversal risks associated with the removal pathway.

Note that reversals are different from expected re-emissions that are known and deducted from a CORC prior to issuance (C_{loss}, see section 6.2). Reversals (i.e. post-issuance) are also different from risks of unintended re-emissions of carbon prior to the issuance of a CORC (see examples below and Table 4.1).

It is worth reminding that biochar CORCs under this methodology are issued with a durability of **several centuries (CORC 200+)**. Expected re-emissions (C_{loss}, see section 6.2) as well as the analysis of reversal risks cover the same period of several centuries.

Unintended re-emissions and reversal risks in biochar supply-chains

For biochar carbon removal activities, risks of re-emission of stored carbon in biochar can materialise at various points of the supply-chain, both prior to and after the issuance of a CORC.

- *Once biochar has been produced and is on its way to being used, biochar is exposed to important risks*. For instance, biochar in storage at a warehouse can be destroyed due to an accidental fire. Likewise, biochar can be diverted from its intended carbon-preserving application towards oxidative uses, whether intentionally or not, in particular for biochar in pure form.
- *Once biochar has been used in an eligible carbon-preserving application, the risks of unintended re-emissions of the carbon stored are much lower and in most cases immaterial.* The remaining risks that should be evaluated relate to biochar that is used in **cascade**, i.e. in multiple subsequent applications where the last step can potentially be an incineration or oxidative step. Evaluation of those cascading use risks is often **application-specific** (e.g. the nature of the cascading-related risks are different for biochar used in the construction sector and biochar used in animal husbandry) and sometimes **context-specific** (e.g. it can be common to send animal manure to incineration in certain project areas but not in others).
- *Once biochar has reached a final use, most commonly in a soil or soil-like environment, re-emission risks mainly relate to natural processes or land management practices that involve fire.* For those risks, a methodology-level assessment is conducted. In rare cases, application specific rules may be needed (e.g. biochar used as cover material in landfills, when such landfills are subject to fires or future landfill mining prospects).

Risks addressed by end-use eligibility rules

In light of the above, the point of creation of biochar CORC has been defined, in section 2.3, as the step in the supply-chain where biochar *has been used* in a manner that ensures durable carbon storage, and that it can be demonstrated. Further, section 3.6 specifies the evidence of end-use that is required, for various biochar applications, ensuring diversion is no longer possible for reported CORCs and that selected cascading uses are demonstrated to have low risks of reversals. Together, the point of creation and the end-use eligibility rules, ensure that the most material risks of unintended re-emissions and reversals along the supply-chain are addressed and minimized prior to CORC issuance. An overview of the risks is presented in Table 4.1.

Reversal risks in final recipient

To evaluate risks of reversals once biochar has reached a final use, the methodology distinguishes between different environmental compartments, namely agricultural land, forest land, and other material uses.

Case of agricultural and forest land

Once biochar has been applied and incorporated in agricultural or forest soils, a common concern is that biochar can be exposed to natural or anthropogenic fires that could pose a threat to the carbon stored in biochar.

This concern has to be analyzed in the context of the global pyrogenic carbon cycle. Biochar as well as fire-derived charcoals are subject to modification in the environment, and fire is one possible remineralisation pathway among other biotic and abiotic processes (Bird et al., 2015). However, biochar and charcoals are also mobile in the environment, and their disappearance from soil surface and topsoil is also explained by illuviation and other soil processes (Bird et al., 2015), resulting in biochar's incorporation in deeper soil layers, where its carbon is better protected from fire events as well as other degradation processes. For fire-derived char, estimates of remineralisation by subsequent fire is deemed fairly low, compared to other pyrogenic disappearance processes (Belcher et al., 2018) (Bird et al., 2015). Research also highlights that biochar made from engineered thermochemical conversion has different properties than fire-derived chars, and is generally more recalcitrant to forest fires (Santín et al., 2017). Finally, unlike fire-derived chars that are formed on the surface and only slowly incorporated in soil by natural processes, biochar use in forest application and agriculture is required to be incorporated to soil or mixed with other constituents (see rules in section 3.6), which enhances protection to possible future fire events.

Additional contextual elements play a role in the evaluation of fire risks. On agricultural land, natural fires are relatively rare events with lower intensities than in forests in most climatic regions. Man-made fires for agricultural purposes, e.g. slash and burn, are also not common practice in many regions. However, in regions where slash and burn is still common, the intensity and duration of these types of fires is not expected to pose a risk to biochar that was well incorporated in the soil. It can also be noted that the introduction of a biochar practice in areas where burning of agricultural residues is common, is often related to initiatives of collecting field residues to put an end to residue burning, addressing air pollution. On forest land, as of today, biochar application is not widespread. However, an emerging biochar system is the production of biochar directly from accumulated forest fuel, as a strategy to reduce forest fire risks in the first place (Adhikari et al., 2024) (Puettmann et al., 2020), and where biochar is usually incorporated on-site with the native soil. Another emerging forest application is the use of biochar as part of planting mix in tree sapling production, for forest regeneration and replanting.

For this combination of reasons, fires on forest or agricultural land are deemed not a material reversal risk for this methodology.

Case of construction materials

For biochar that is used in long-lived (i.e. several decades) construction materials, like concrete or bricks, the end-of-life of the product has the potential of being a situation of reversal. This depends on the nature of the recycling or treatment technology used. A certain level of uncertainty exists here due to the fact that the end-of-life of the product is bound to happen in a relatively distant future after CORCs have been issued. However, the currently available recycling, downcycling and disposal technologies for such long-lived construction materials do not seem to pose a threat to biochar carbon. The most likely outcome for biochar incorporated in concrete and similar materials is that it will be landfilled at the destruction of the building, downcycled as a backfill material, or recycled as secondary aggregate, ultimately reaching a soil-like environment. *Hence, no reversal risks are considered for biochar used in long-lived construction materials, beyond the rules stated in* section 3.6.

Case of biochar burial

For biochar that is buried in below-ground pits, used as a backfill material of holes, wells, or similar structures, there is an anthropogenic risk that over the next centuries an interest will emerge to excavate the previously stored biochar. This risk is particularly relevant if biochar has been buried in a form that makes it easily extractable. To mitigate this risk, whether intentional or not, the methodology requires (section 3.6, e.g. application category GEO3) that biochar is mixed with other mineral soil constituents to an extent that makes it realistically impractical to excavate in the future the stored quantities. *Hence, no reversal risks are considered for biochar buried in below-ground pits and similar structures, provided it has been adequately mixed, as specified in* section 3.6.

Table 4.1 Overview of expected re-emissions (included in CORC calculation), unintended re-emissions prior to CORC issuance, and post-issuance reversal risks, and rules or sections tackling those risks.

Risk	Description	Classification	Addressed via
Degradation in soil environment	Biotic and abiotic processes that lead to the slow decomposition of biochar carbon, in particular its most labile components.	Expected re-emission, included in CORC calculation	Section 6.2
Use is non-carbon preserving application	Biochar is used in ways that do not ensure long-term carbon storage (e.g., used as fuel, discarded as waste, or processed into short-lived products). *This is allowed under certain circumstances, but shall not be reported as CORCs.*	Re-emission risk, addressed prior to issuance	Section 3.6 Rules 3.6.5; 3.6.6; 3.6.8; Table 3.2
Combustion during storage or transport	Biochar is destroyed due to accidental fires, whether during storage or transport to users. *This is addressed by requiring various levels of evidence to be made available to prove that the use has actually taken place, and thereby that no accidents have taken place along the distribution chain.*	Re-emission risk, addressed prior to issuance	Section 3.6 Rules 3.6.5; 3.6.6; 3.6.8; Table 3.2
Diversion from the reported application	Biochar is reported or declared to be used in an application that preserves its carbon storage, but is in fact diverted towards an ineligible use, intentionally or not. *This is addressed by requiring various levels of evidence to be made available to prove that the use has actually taken place.*	Re-emission risk, addressed prior to issuance	Section 3.6 Rules 3.6.5; 3.6.6; 3.6.8; Table 3.2
Cascading uses with uncertain fate	Biochar is used in cascading applications where its final fate is difficult to predict, potentially leading to partial or complete oxidation (e.g. biochar filters with re-activation steps, animal manure enriched with biochar sent for energy recovery). *This is addressed by requiring various*	Reversal risk, addressed prior to issuance, with application and	Section 3.6 Rules 3.6.7; 3.6.8 Table 3.2

Risk	Description	Classification	Addressed via
	levels of evidence to be made available to prove that the cascade has low risks of reversal.	context specific rules	
Anthropogenic disturbance of buried biochar	For biochar that has been buried below-ground or used to backfill certain types of structures, there is a risk of future excavation and potential misuse, whether intentional or not. *This is addressed by requiring mixing of biochar in a manner that makes its extraction and use in oxidative application not realistically possible.*	Reversal risk, addressed prior to issuance, with application specific rules	Section 3.6 Table 3.2
Forest & agricultural fires	For biochar that ultimately reaches a soil, whether on forest land or agricultural land, anthropogenic and natural fires can pose a risk to biochar carbon storage. *Based on current understanding and the eligibility rules requiring biochar mixing (as opposed to biochar surface application), this risk is deemed not material.*	Reversal risk, deemed not material after mixing	Section 4.2 Section 3.6 Table 3.2

Absence of default deduction for reversal risks

4.2.1. Given the rules imposed by the methodology for biochar management throughout the supply-chain and the current knowledge on biochar potential reversal pathways, it is considered that the risk of reversal, as defined in the Puro Standard General Rules, is not relevant enough to necessitate a default percentage deduction from the Output volume of all Production Facilities.

Deviations from the risk evaluation made in the methodology

4.2.2. If a Production Facility encounters reversal risks that are not sufficiently covered by the provisions in section 4.2 or the eligibility rules in section 3.6, and these situations represent deviations from the methodology's original risk assessment, the CO_2 Removal Supplier must report them to Puro.earth. Such reports will enable Puro.earth to address these cases through appropriate rule clarifications. This requirement applies specifically to unforeseen risks that fall outside the methodology's anticipated risk framework.

Liability in the event of reversals materializing

4.2.3. If a reversal event occurs due to the failure of the CO_2 Removal Supplier to meet its obligations, the CO_2 Removal Supplier is liable for compensation. In accordance with Puro Standard General Rules, upon detection of a reversal event, the CO_2 Removal Supplier must without delay:

i) Prevent further reversal from occurring.

ii) Notify the Issuing Body of the Reversal event within five (5) days of detection.

iii) Determine the failure that caused the Reversal event.

iv) Calculate the Reversal quantity (in tCO_2e).

4.3. Environmental and social risks

Socio-environmental risks are addressed following a layered approach, based on Puro's General Rules and Standard documents, pathway specific eligibility rules in the methodology, and project-specific identification of risks supported by the screening questionnaires provided by Puro.earth. The purpose is to ensure that all activities around biochar production and use are conducted in an environmentally safe and socially responsible manner. At a higher level, this includes compliance with national and international regulations, respect for human rights, labor rights, and gender equality, as well as the protection of indigenous peoples' rights. At the removal pathway level, this includes managing socio-environmental risks arising from biomass sourcing (e.g. safe stockpiling, sustainable sourcing), biochar production (e.g. emission of air pollutants, management of chemical waste), and biochar use (e.g. low contamination, safe stockpiling and distribution), as well as during project design and establishment (e.g. site selection, stakeholder participation). Importantly, adequate management of socio-environmental risks also requires transparent data collection and regularly updated monitoring plans (section 9.4), alongside open communication and collaboration between the CO_2 Removal Supplier, regulatory authorities, and relevant stakeholders

Abiding by local statutory and Puro requirements

4.3.1. The CO_2 Removal Supplier must have in place, maintain, and abide by environmental and social safeguards to the extent required by any applicable local statutory requirements, this methodology, the Puro Standard General Rules, and the Puro Stakeholder Engagement Requirements.

Provision of statutory documentation

4.3.2. The CO_2 Removal Supplier must provide any permits (e.g. construction permit, environmental permit), licenses, environmental and social impact assessments (EIA), or other similar documents meant for the evaluation of social and environmental impacts, that are required by any applicable local statutory requirements.

> **EIA Regulation for Biochar Facilities:** In most jurisdictions, large-scale industrial projects, including biochar production facilities, may be subject to Environmental Impact Assessment (EIA) regulation to evaluate and address their potential social and environmental effects. The need for an EIA is typically determined by local regulations based on project size, environmental risks, and location. If an EIA is required by law, compliance is mandatory for certification under this methodology. If regulation does not require an EIA, conducting an EIA is encouraged by Puro.earth as a best practice but is not a strict prerequisite.

Initial stakeholder engagement

4.3.3. The CO_2 Removal Supplier must conduct stakeholder engagement procedures in line with the Puro Stakeholder Engagement Requirements. The CO_2 Removal Supplier must then provide a Stakeholder Engagement Report[21] alongside relevant supporting evidence, detailing the stakeholders identified, the consultation activities conducted, the outcome of these consultations, the amendments made to the project in response to these consultations, and the plans on how dialogue with stakeholders will continue over the course of the crediting period. Upon successful Facility Audit, this report must be made public in the Puro Registry; however, supporting evidence is not required to be made public as they may contain private information of individuals who contributed to consultations.

Continuous stakeholder engagement

[21] Available in the Puro Standard document library: Document library | Website (puro.earth)

4.3.4. The CO_2 Removal Supplier must maintain ongoing stakeholder engagement throughout the crediting period. This continuous engagement must be described in the Monitoring Plan. This includes implementing a public policy to allow stakeholders to submit continuous feedback and address potential grievances. The Supplier must maintain a record of all stakeholder feedback, track follow-up actions, and report their status and resolution in the corresponding Output Report until adequately addressed.

Environmental and social safeguard questionnaire

4.3.5. To further support the evaluation of environmental and social risks, the CO_2 Removal Supplier must answer the latest version of the Puro Environmental and Social Safeguards Questionnaire[22] and make available to the appointed auditor any pieces of evidence required in this questionnaire. The information provided must be specific to the Production Facility and reflected in its Monitoring Plan as necessary (section 9.4). Upon successful Facility Audit, the questionnaire must be made public in the Puro Registry; however, supporting pieces of evidence used during verification are not required to be made public.

Identification of context-specific risks

4.3.6. During the design phase of the Production Facility, with the support of the Puro Environmental and Social Safeguards Questionnaire, the CO_2 Removal Supplier shall:

i) identify whether the Production Facility may pose risks that are specific to the local context, but not necessarily specific to biochar systems,

ii) ensure that those risks are adequately tackled during the design phase, and

iii) adequate provisions are included in the Monitoring Plan (section 9.4).

> **Example of context-specific risk:** A CO_2 Removal Supplier has identified a site for the construction of a biochar production facility. However, the site has high soil moisture, which may pose structural and safety risks for the planned warehouses and buildings. Recognizing this challenge early in the design phase, the CO_2 Removal Supplier has engaged a construction expert to develop suitable building plans. Once the facility is operational, the supplier will need to monitor soil subsidence regularly to ensure its safety. While this is a context-specific risk unrelated to biochar technologies, it must still be carefully considered and addressed whenever relevant.

Record keeping and reporting of incidents and grievances

4.3.7. The CO_2 Removal Supplier shall keep records and promptly report to the Issuing Body any event potentially having had material negative environmental or social impacts (or claims thereof) occurred during the monitoring period, including but not limited to any incidents occurring on-site (e.g. accidental release of chemicals or pollutants, improper waste disposal), or any legal actions and/or other written complaints filed by affected parties, and how these events are being addressed. Failure to report and address such material events can lead to suspension of the Production Facility by the Issuing Body.

Risks specific to biochar supply-chains tackled in the methodology

[22] Available in the Puro Standard document library: https://puro.earth/document-library?tab=templates_and_guidelines

Risks associated with biochar supply-chains are well known and the eligibility rules have been designed to explicitly address the most significant risks. Table 4.2 provides a summary of those key socio-environmental risks and indicates where each is addressed within the methodology.

Table 4.2. Overview of most significant socio-environmental risks associated with biochar activities and rules or sections addressing those risks. Green: biomass sourcing phase. Orange: biochar production phase. White: biochar use phase. Blue: all phases.

Socio-environmental risk	Description	Addressed in
Inadequate biomass sourcing	Sourcing of biomass can have negative environmental and social effects if done inadequately, leading to e.g. deforestation, biodiversity loss, land degradation, impacts on local water resources, or even land use changes.	Rules 3.4.1 to 3.4.8, rule 3.4.26 Puro Biomass Sourcing criteria
Biomass handling and stockpiling (odours, particles, fire)	Large-scale biomass stockpiling and handling is associated with health and safety risks, as they can emit odours, organic compounds, or in inadequate conditions lead to fires and explosions.	Rules 3.4.9 to 3.4.12, rule 3.4.26
Hazardous biomass, impurities and micropollutants	Some biomass sources may contain contaminants or impurities such as heavy metals, pesticides, plastics, metal or glass. Pressure-treated wood often contains heavy metals (e.g. As, Cr, Cu), while painted or varnished wood may contain lead, formaldehyde, and other volatile organic compounds (VOCs). Processing such materials can result in hazardous byproducts, air pollution, and toxic biochar that may pose risks to human health and ecosystems.	Rules 3.4.13 to 3.4.26
Air emissions during biomass carbonization	If not properly controlled, the thermal conversion of biomass can release air pollutants (e.g., VOCs, PAHs, NOx, PM), fugitive emissions, affecting air quality and climate mitigation goals.	Rules 3.5.3, 3.5.4, 3.5.8 to 3.5.22
Co-products management	Depending on the technology selected, biochar production generates co-products such as bio-oil, syngas, and tar, which must be managed properly. Improper handling of these byproducts can lead to spills, toxic emissions, or wasted resources that could otherwise be valorized.	Rules 3.5.6 to 3.5.8
Residue and waste management	Solid or liquid residues from the process, such as ashes, cleaning tars, but also biochar that doesn't meet quality standards, need to be disposed of or repurposed safely to avoid pollution. Some residues may contain hazardous compounds. Water used in cooling or gas scrubbing may also require treatment before discharge. If chemicals are used during biochar production, they must be handled, stored, and disposed of safely to prevent environmental contamination and occupational hazards.	Rule 3.5.5, rule 3.5.7, rule 3.5.12. rule 3.5.28, rule 3.5.30

Socio-environmental risk	**Description**	**Addressed in**
Explosion or fire at factory	Biomass carbonization involves high temperatures and flammable gases. Without adequate safety measures, there is a risk of explosions, fires, and worker injury due to gas leaks, static electricity, or dust accumulation. Biochar can also lead to dust formation or self-ignite under certain storage conditions.	Rules 3.5.12 to 3.5.16. Rules 3.5.23 to 3.5.25
Other occupational hazards	Workers in biochar facilities may be exposed to high heat, hazardous gases, dust, and moving machinery. Proper ventilation, personal protective equipment (PPE), and safety training are essential to minimize health risks.	Rules 3.5.25 to 3.5.27 GR 6.4.1.1.iv
Biochar environmental quality	Low-quality or improperly produced biochar may contain PTEs, which may end in the leaching of contaminants, harming soils and ecosystems.	Rule 3.5.39. Rules 3.6.3, 3.6.9 to 3.6.14
Biochar over-application and improper handling by users	Over-application of biochar can be detrimental to soil agronomic properties (e.g. high pH affecting nutrient availability) and improper handling of biochar by farmers can cause occupational and health hazards (e.g. exposure to fine particles). Instructions on safe use of biochar and biochar-containing products ought to be made available.	Table 3.2 Rule 3.6.15
Infrastructure-related risks	Developing or expanding biomass supply chains and construction of biochar production facilities can cause environmental disturbances, land-use conflicts, and social disruption, especially in ecologically sensitive or populated areas (e.g., new transportation routes, storage facilities, or processing plants). During construction, but also operations, noise, dust and other nuisance factors can occur.	Rule 3.1.5, rule 3.4.26, rule 3.5.30, rule 3.5.39, rule 3.6.3 GR 6.4.1.1.vii Section 8 Puro Biomass Sourcing criteria

5. Quantification of net CO_2 removal

5.1. General principles

In general, a CORC represents the durable net removal of 1 tonne of CO_2e from the atmosphere. In the context of biochar, this removal is achieved by ensuring its use in applications that enable long-term carbon storage.

The general principle of the CORC calculation is that the CO_2 Removal Supplier first determines the gross amount (in metric tonnes) of CO_2-eq stored as biochar (C_{stored}) over a given monitoring period. Various deductions are then made, such as any potential CO_2-eq losses from storage (C_{loss}), project emissions ($E_{project}$), the effect of the unmitigated negative ecological, market and activity-shifting leakage ($E_{leakage}$) and baseline carbon removal ($C_{baseline}$), if applicable. The resulting net amount of CO_2-eq sequestered is credited as CORCs (figure 5.1). Any form of avoided emissions relative to the baseline scenario are never included in the calculations.

$$\underbrace{\text{CORCs}} = \underbrace{C_{\text{stored}}} - \underbrace{C_{\text{baseline}}} - \underbrace{C_{\text{loss}}} - \underbrace{E_{\text{project}}} - \underbrace{E_{\text{indirect}}}$$

	CORCs	C_{stored}	$C_{baseline}$	C_{loss}	$E_{project}$	$E_{indirect}$
Description	Net amount of CO_2-eq removed by the biochar activity during the reporting period.	Gross amount of carbon stored in the utilized biochar, in CO_2-eq	Total amount of CO_2-eq which would have been stored in the absence of the removal activity, if any.	Total GHG re-emissions during the storage period due to e.g. biochar decomposition.	Total life cycle emissions arising from the whole supply chain of the biochar activity.	Total indirect GHG emissions resulting from unmitigated negative impacts associated with the biochar activity.

Figure 5.1: Equation for the calculation of the amount of CORCs supplied by the biochar production activity over a given monitoring period.

Each component of the CORC equation is defined in the following subsection (5.2). Detailed rules on the quantification of each component are presented in sections 6, 7, and 8. For each component, the rules define whenever applicable other equations with measurement variables and constants to use. Moreover, this measurement model and its components are the basis of the monitoring system described in section 9. Finally, this measurement model also provides the framework for the estimation of the uncertainty of the net carbon dioxide removal.

It should be noted that although the CORC equation is presented as a total over the monitoring period, many of the intermediary calculations are in fact performed and reported at the level of individual biochar batches produced and used, thereby capturing differences between types of biochar and other sources of variability. For ease of readability, equations in this methodology use an implicit notation where sums over batches and biomass types are shown.

5.2. Overall equation

5.2.1. The overall number of CORCs (i.e. the total net amount of CO_2 removed) during a Monitoring Period shall be calculated as follows (see also figure 5.1 for an illustration):

$$CORCs = C_{stored} - C_{baseline} - C_{loss} - E_{project} - E_{leakage} \qquad \text{(Equation 5.1)}$$

Variable	Description	Unit
$CORCs$	Net amount of CO_2 equivalents removed by the removal activity.	tCO_2e
C_{stored}	Gross amount of eligible CO_2e stored in biochar at the time of the measurement. Further requirements on the calculation of this term are given in section 6.1.	tCO_2e
$C_{baseline}$	Total amount of CO_2e which would have been stored (naturally or man-made) in the selected baseline scenario, in the absence of the removal activity. Further requirements on the calculation of this term are given in section 6.3.	tCO_2e
C_{loss}	Total amount of CO_2e which is re-emitted back to the atmosphere in the form of e.g. CO_2, CH_4 or N_2O, and can no longer be considered durably stored. Further requirements on the calculation of this term are given in section 6.2.	tCO_2e
$E_{project}$	Total amount of CO_2e that is emitted along the supply chain of the removal activity. Further requirements on the calculation of this term are given in section 7.	tCO_2e
$E_{leakage}$	The amount of CO_2e that is emitted indirectly due to unmitigated negative ecological, market, and activity-shifting leakage resulting from the removal activity. Further requirements on the calculation of this term are given in section 8.	tCO_2e

5.2.2. The length of a Monitoring Period must comply with the Puro General Rules and the cadence of the Output Audits.

5.3. Requirements for robust quantification of net carbon removal

5.3.1. The CO_2 Removal Supplier shall follow robust and auditable monitoring, measurement and reporting practices for the data needed for the calculation of CORCs resulting from the removal activity, in accordance with section 9 (monitoring), section 10 (measurement), and section 11 (reporting).

5.3.2. The CO_2 Removal Supplier shall quantify the combined uncertainty from the components included in the equation 5.1, in accordance with the relevant parts of the ISO/IEC Guide 98-3[23] as further described in section 10.

5.3.3. The CO_2 Removal Supplier shall have in place, maintain, and utilize an information system to keep records of any events and monitoring affecting the amount of CORCs resulting from the removal activity. These records must include the necessary time stamped, quantitative information such that their effect on the Output volume of the monitoring period can be quantified. The information system and its records must be available to the Auditor, for the Production Facility Audit and Output Audits.

[23] ISO/IEC Guide 98-3:2008 Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement.

6. Determination of stored carbon (C_{stored}), baseline removal ($C_{baseline}$) and carbon storage losses (C_{loss})

This section defines how the components stored carbon (C_{stored}), baseline carbon removal ($C_{baseline}$) and carbon storage losses (C_{loss}) must be determined for calculation of CORCs.

6.1. Biochar carbon storage (C_{stored})

6.1.1. The gross amount of carbon stored in biochar must be calculated, at the biochar batch level, as follows:

$$C_{stored} = Q_{biochar} \times C_{org} \times \frac{44}{12} \qquad \text{(Equation 6.1)}$$

Variable	Description	Unit
C_{stored}	Gross amount of carbon stored in eligible biochar, expressed as CO_2e.	tCO_2e
$Q_{biochar}$	Total dry mass of eligible biochar, expressed free of impurities.	tonnes
C_{org}	Organic carbon content of the biochar, expressed on a dry basis, and free of impurities.	%
$\frac{44}{12}$	Mass conversion factor from elemental carbon to a corresponding amount of carbon dioxide, calculated as the ratio between the molar masses of carbon dioxide and carbon.	Unitless

6.1.2. The total dry mass of eligible biochar ($Q_{biochar}$) must be determined, at the biochar production batch level (see rule 5.3.39), following the monitoring plan of the Production Facility, in accordance with rule 6.1.3 regarding the determination of moisture, and rules 3.4.6 and 3.4.14 - 3.4.17 regarding biomass feedstock type and management of impurities. The notion of eligible biochar also includes the fact that the biomass batches used for production biochar must be demonstrated to be eligible as per the rules in section 3.4.

6.1.3. The approach used to determine the total dry mass of eligible biochar ($Q_{biochar}$) must follow at least one of the general options listed below:

a. **On-site measurement of total wet mass, combined with on-site moisture measurement**:
The total wet mass is measured by scale for every batch (e.g. big bags, truckloads). Moisture measurements are made on-site using drying ovens or using other types of devices (calibrated moisture meters). Sample taken for moisture measurement are representative of the batches

produced and of the time of measurement of the total wet mass (e.g. after/before quenching), following a procedure to be detailed in the Facility's monitoring plan.

b. **On-site measurement of total wet mass, combined with off-site laboratory moisture measurement**: The total wet mass is measured by scale for every batch (e.g. big bags, truckloads). Moisture measurements are made by a third-party laboratory, using drying ovens. Sample taken for moisture measurement shall be representative of the batches produced and of the time of measurement of the total wet mass (e.g. after/before quenching), following a procedure to be detailed in the Facility's monitoring plan. Samples are sent to the third-party in a manner that does not affect moisture, e.g. using sealed bags.

c. **On-site continuous measurement of total dry mass, in reactor, at temperature ensuring no moisture adsorption on biochar or with built-in moisture sensor**: The total dry mass of biochar is measured continuously via a calibrated scale built in the production equipment (e.g. conveyor system, cooling screw). Measurements are performed under conditions that ensure that biochar remains dry (sufficiently high temperature, closed system) or with a built-in moisture sensor.

d. **On-site measurement of biochar bulk volume, combined with measurement of dry bulk density**: The bulk volume of biochar is determined on-site for every batch. Moisture and bulk density measurements are made by a third-party laboratory, enabling calculation of the dry bulk density. Moisture is determined by oven drying, and bulk density is determined in triplicate on a non-grounded (as received) sample. Sample taken for analyses shall be representative of the batches produced and of the time of measurement of the bulk volume (e.g. after/before quenching/crushing), following a procedure to be detailed in the Facility's monitoring plan. Samples are sent to the third-party in a manner that does not affect particle size.

For other potential approaches, approval from the Issuing Body prior to the Facility Audit must be obtained.

6.1.4. Analytical methods that must be used in biochar dry mass calculations, as applicable in rule 6.1.3, are:

a. For moisture measurements using drying oven, any of the following:
   - ISO 589:2008 (*Hard coal — Determination of total moisture*)
   - DIN 51718 (*Determining the moisture content of solid fuels*)
   - ASTM D1762-84 (*Standard Test Method for Chemical Analysis of Wood Charcoal*)
   - Other analytical methods, using drying ovens, equivalent to one of the above, with attestation of equivalence from the laboratory or a documented experimental protocol, and with approval of the Issuing Body

b. For bulk density (as received sample), conducted in a third-party laboratory, any of the following:
   - ISO 17828 (*Solid biofuels — Determination of bulk density*)
   - Other analytical methods equivalent to one of the above, with attestation of equivalence from the laboratory and with approval of the Issuing Body

c. For other approaches allowed by rule 6.1.3, such as the use of in-line moisture sensors and other hand-held moisture meters, the devices shall have a minimum accuracy threshold of at least 2% and be calibrated as per its specification.

6.1.5. Determination of biochar moisture or bulk density, as applicable for the selected approach, must be done at least at the same frequency as for determination of biochar properties (see rule 3.5.35), and separately for each type of biochar (see rule 3.5.33).

6.1.6. The organic carbon content (C_{org}) of the eligible biochar must be determined following the monitoring plan of the Production Facility, at the applicable frequency (see rule 3.5.35), and separately for each type of biochar (see rule 3.5.33), via laboratory analyses. The selected laboratory must comply with internationally recognized testing standards and be accredited by relevant national authorities, where such accreditation schemes exist. In countries without an established accreditation body for such testing, the laboratory must demonstrate adherence to international standards and provide evidence of quality assurance protocols. The analytical methods to be used shall be according to one of the options below, as applicable:

a. **Default option**: the organic carbon content (C_{org}) of the biochar is determined by difference between the total carbon content (C_{tot}) and the inorganic carbon content (C_{inorg}):

$$C_{org} = C_{tot} - C_{inorg} \qquad \text{(Equation 6.2)}$$

where, the total carbon content (C_{tot}) is determined by one of the following analytical methods:

- ISO 16948:2015 (*Solid biofuels — Determination of total content of carbon, hydrogen and nitrogen*)
- ISO 29541:2025 (*Coal and coke — Determination of total carbon, hydrogen and nitrogen — Instrumental method*)
- DIN 51732:2014 (*Testing of solid mineral fuels - Determination of total carbon, hydrogen and nitrogen - Instrumental methods*)
- ASTM E870-82 (Standard Test Methods for Analysis of Wood Fuels), itself referring to ASTM E777-23.
- ASTM D5373 (Standard Test Methods for Determination of Carbon, Hydrogen and Nitrogen in Analysis Samples of Coal and Carbon in Analysis Samples of Coal and Coke)
- Other analytical methods, using a dry combustion-elemental analyzer, equivalent to one of the above, with attestation of equivalence from the laboratory, a documented experimental protocol, and with approval of the Issuing Body.

where, the inorganic carbon content (C_{inorg}) is determined by one of the following analytical methods:

- DIN 51726 (*Testing of solid fuels - Determination of the carbonate carbon dioxide content*)
- ISO 925 (*Solid mineral fuels — Determination of carbonate carbon content — Gravimetric method*)

- ASTM D4373-21(*Standard Test Method for Rapid Determination of Carbonate Content of Soils*)
- Other analytical methods, equivalent to one of the above, with attestation of equivalence from the laboratory, documented experimental protocol, and with approval of the Issuing Body.

and where, the sub-samples used for determination of C_{tot} and C_{inorg} are derived from the same sample sent to the laboratory.

Variable	Description	Unit
C_{org}	Organic carbon content of the biochar produced, calculated.	%
C_{tot}	Total carbon content of the biochar produced, measured from the dry weight.	%
C_{inorg}	Inorganic carbon share of the biochar produced, measured from the dry weight.	%

b. **Low-inorganic carbon option**: the organic carbon content (C_{org}) of the biochar is determined by difference between the total carbon content (C_{tot}) and the inorganic carbon content (C_{inorg}), as in option a, with the following differences:

- C_{inorg} is set to a default value of 0.005 kg C per kg dry biochar

This option is only applicable if:

- The analysed biochar is made from wood biomass
- The CO_2 Removal has already reported laboratory results for this type of biochar, following option a, showing that C_{inorg} is consistently below 0.5% (dry basis) for at least 2 such analyses from different biochar production batches.

> **REMARK:** In certain regions, the availability of laboratories able to quantify C_{inorg} has been limited. For wood biochars, there is sufficient evidence to suggest that C_{inorg} is usually low and less variable. For other types of feedstocks, and in particular agricultural residues, food residues, and sludges, such simplification is not yet possible, but might be considered in the future.

6.2. Carbon storage losses (C_{loss})

The definition for carbon storage losses applies to re-emission pathways known or assumed *a priori*, and which therefore need to be deducted in the CORC calculations, *prior to issuance*. Previously unknown or unanticipated re-emissions *after issuance of CORCs* are termed reversals and are accounted for via a procedure described in the Puro Standard General Rules[24].

[24] Available in the Puro Standard document library.

In the case of biochar, carbon storage losses include expected re-emissions of biochar carbon due to decomposition of its most labile components over several centuries, when exposed to environmental factors in soil or similar environments. The quantification of carbon storage losses hence assumes that biochar has been used in an eligible application as per section 3.6 which addresses various other risks of diversion and reversal.

This section presents applied knowledge on biochar persistence, equations for calculation of biochar persistence alongside a model description, and optional procedures for complementary characterisation of biochar persistence properties.

Biochar persistence research: two main approaches

Research on biochar persistence has spanned over several decades (Glaser et al., 2001) (Spokas, 2010) (Harvey et al., 2012), and has been the foundation for biochar to emerge as a climate change mitigation tool. Early research highlighted that the chemical properties of biochar, being made of highly condensed aromatic structures, are the primary factor for its persistence in soil environments, contrasting with structures found in conventional organic matter and litter (Glaser et al., 2001). Research then took a quantitative turn by conducting biochar decomposition experiments, primarily in laboratory conditions but also in field conditions. These studies attempted to unveil how measured decomposition rates vary with time, biochar properties and production conditions, and environmental parameters. Reviews of those individual studies combined with modelling led to the emergence of the first biochar persistence models (Spokas, 2010) (Budai et al., 2013), improved and re-worked over time (Woolf et al., 2021) (Rodrigues et al., 2023) (Azzi et al., 2024). This ensemble of models derived from decomposition data is here referred to as **decay-based models** and have been used in the VCM to date and recommended by the IPCC (IPCC, 2019). More recently, in relation with a strong policy interest for biochar, biochar's physico-chemical properties has been put forward as an argument for its persistence over geological time scale, with particular attention to random reflectance and maceral content or morphotype analyses, as determined by optical microscopy methods (Petersen et al., 2023) (Drobniak et al., 2024) (Sanei et al., 2024), and other indicators of high degree of aromaticity such as hydrogen pyrolysis (Howell et al., 2022). Those approaches, although not always associated with usable nor established quantification equations, are here referred to as **composition-based models** or **random reflectance based models**. It is worth noting that research efforts are ongoing to integrate decay-based modelling and composition-based modelling, and that Puro.earth continues to support such initiatives.

Biochar persistence models for the voluntary carbon market

Development of a biochar persistence model depends on how the model will be used and interpreted (Azzi et al., 2024). Puro.earth operates in the voluntary carbon market where **scientific integrity**, **conservativeness** and **project-specificity** are critical aspects. Further, as projects seeking certification evolve in competitive markets, analytical methods required to be used in quantification should also be **reliable**, reasonably **affordable** and **available** globally. Options given to projects via rules must also strive to be **pragmatic** and ensure **fairness** across the actors in the market. Those criteria played an important role in how Puro.earth decided to incorporate in this methodology the recent scientific advances on biochar persistence. It is noted that those criteria are specific to the voluntary carbon market, and are different from the ones applicable to e.g. national greenhouse gas inventory reporting to the UNFCCC (where a national representative average is typically the objective).

Puro.earth quantification approach of biochar persistence

Since 2022, Puro.earth has been using a conservative decay-based model derived from Woolf et al. 2021, resulting in CORC100+. This model extrapolated biochar persistence in soil to 100 years, using multi-pool exponential decay. Persistence was correlated to the biochar H/C_{org} ratio and the annual average soil temperature in the region of use - two project-specific parameters - using a linear regression but without incorporation of uncertainties. This persistence model is now perceived as overly conservative, and not reflecting the recent advances in biochar persistence.

In this edition of the methodology, Puro.earth is introducing a revised decay-based model, building on Woolf et al. 2021 and recent advances in decay-based models (Azzi et al., 2024) (Li et al., 2024) (Sanei et al., 2025) and specific considerations for the VCM. This revised decay-based model has the following key features:

- *Biochar persistence in soil is extrapolated over 200 years by the decay model.* From 200 years onwards, biochar natural movements deeper in the soil profile are assumed to then ensure its protection from further decay, guaranteeing storage over several centuries (i.e. CORC200+).
- *Biochar decay is represented by a power model, instead of multi-pool exponential decay*. Power models for biochar decay were introduced back in 2010 (Zimmerman, 2010) but were until recently deemed not conservative enough for use in the VCM. Re-analysis of the data available (Azzi et al., 2024) (Li et al., 2024) however suggests they are better suited than exponential decay models to represent decay of a range of feedstocks, from biomass to biochars.
- *Biochar persistence remains correlated to the project-specific biochar H/C_{org} ratio and the annual average soil temperature in the region of use*, using a linear regression and updated dataset processed as in (Azzi et al., 2024). This regression is performed solely over the relevant domain for biochar (*H/C_{org}* between 0 and 0.7).
- *This model now also incorporates an 80% confidence interval,* increasing the conservativeness of the model, as CORC calculation includes the lower boundary of this confidence interval[25].
- *Soil temperature adjustment remains unchanged relative to Woolf et al 2021*. It is noted that soil temperature effects remain an area of uncertainty, where some suggest that soil temperature effects are only relevant for the most labile biochar components, while others suggest that it is an important factor capturing at least some degree of environmental variability.

The model briefly presented above was developed by Puro.earth and is made available in a reproducible and open-source format[26]. The resulting model parameterization incorporates recent advances in decay-based models and new conservativeness measures, to meet the expectation of

[25] The coverage probability of a confidence interval reflects the likelihood that the constructed interval contains the true value. Applying a discount based on an 80% confidence interval at the methodology level means that in fewer than 10% of cases, the quantification approach would result in an overestimation of carbon removal. It is important to note that this applies at the program level—across all certified projects—rather than to individual projects.

[26] The model is built upon the open-source library for analysis of biochar decomposition date (Azzi et al. 2024) available on GitHub (https://github.com/SLU-biochar/biocharStability) and a notebook is released by Puro.earth demonstrating how to reproduce the persistence model used in this methodology, also available on GitHub: https://github.com/puro-earth/PuroBiocharPersistenceEdition2025

the VCM. Overall, with this biochar persistence model, biochar durability claims are extended to several centuries (CORC200+), in a conservative manner, with a project-specific parameterization, relying on existing and affordable characterisation methods. Numerically, the differences with the previously used model are deemed minor, and this is due to a combination of changes (primarily, increased time horizon, changed decay extrapolation, confidence threshold inclusion). This persistence model is required to be used by all projects, ensuring comparability of biochar removal claims and fairness among the ecosystem of Puro-certified biochar suppliers.

Future perspectives encouraged

In addition to the incubation-based model, Puro.earth aspires to support the development of composition-based models and scientific advances towards integration of both approaches. Since this requires collection of new data, Puro.earth invites suppliers to contribute to this effort by reporting additional characterisation of their biochars (see rules 6.2.5 and 6.2.6). However, Puro.earth cannot require these additional characterisation because they are not yet sufficiently standardized, global availability and affordability is limited, and the scientific consensus around interpretation of these approaches remains to be consolidated with on-going and further research.

Decay-based persistence model

6.2.1. The gross amount of carbon loss from biochar must be calculated, at the biochar batch level, as follows:

$$C_{loss} = C_{stored} \times (100 - PF) \qquad \text{(Equation 6.3)}$$

Variable	Description	Unit
C_{loss}	Gross amount of carbon loss from eligible biochar, expressed as CO_2.	tCO_2e
C_{stored}	Gross amount of carbon stored in eligible biochar, expressed as CO_2.	tCO_2e
PF	Persistence fraction of biochar carbon over several centuries.	%

6.2.2. The persistence fraction PF (%) of biochar carbon over several centuries is determined as per the following equation:

$$PF = M - a \times H/C_{org} \qquad \text{(Equation 6.4)}$$

where, H/C_{org} is the hydrogen to organic carbon molar ratio of the biochar considered, and M and a are regression parameters varying with the soil temperature in the region of use. Values for the parameters M and a are provided in Table 6.1.

Table 6.1. Regression parameters

T_s (°C)	7	8	9	10	11	12	13	14	15	16	17
M	96,59	95,98	95,36	94,73	94,10	93,50	92,92	92,38	91,87	91,40	90,96
a	11,28	13,44	15,66	17,92	20,15	22,31	24,38	26,33	28,16	29,84	31,39

T_s (°C)	18	19	20	21	22	23	24	25	26	27	28
M	90,57	90,20	89,87	89,57	89,29	89,03	88,79	88,57	88,37	88,18	87,99
a	32,81	34,11	35,29	36,36	37,35	38,26	39,09	39,87	40,59	41,27	41,91

T_s (°C)	29	30	31	32	33	34	35	36	37	38	39	40
M	87,82	87,66	87,50	87,34	87,19	87,04	86,90	86,75	86,61	86,47	86,33	86,19
a	42,52	43,10	43,67	44,21	44,74	45,26	45,77	46,27	46,77	47,27	47,76	48,25

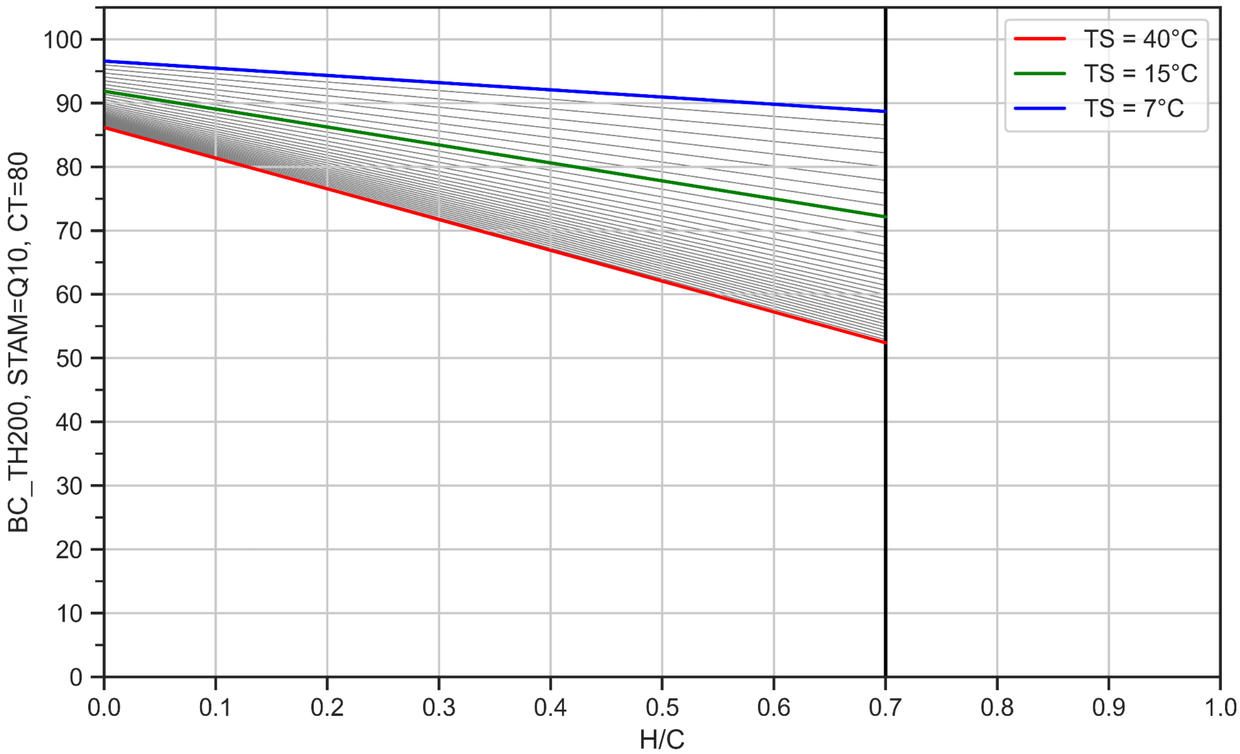

Figure 6.1. Biochar persistence fraction for a time horizon of 200 years (BC_TH200) for a range of H/C_{org} values and soil temperatures (TS), based on the model developed by Puro.earth. STAM = Soil temperature adjustment method. CT = Confidence threshold.

6.2.3. The hydrogen to organic carbon molar ratio of the biochar organic must be determined following the monitoring plan of the Production Facility, at the applicable frequency (see rule 3.5.35), and separately for each type of biochar (see rule 3.5.33), via laboratory analyses, using the following equation:

$$H/C_{org} = m_H / m_{C_{org}} \times 12.0 \qquad \text{(Equation 6.5)}$$

where $m_{C_{org}}$ is the organic carbon mass content, determined as per rule 6.1.6 and m_H is the total hydrogen mass content of the biochar, measured jointly with C_{tot} (see also rule 6.1.6, for list of analytical methods). Note that analytical methods used to determine C_{tot} normally also yield H.

6.2.4. The selection of a soil temperature for the calculation of the persistence fraction in rule 6.2.2 must be performed using the dataset prepared and provided by Puro.earth, derived from (Lembrechts et al., 2022) (specifically, the layer representing annual mean temperature at a soil depth of 5 to 15 cm, SBIO1_Annual_Mean_Temperature_5_15cm). The selection of a soil temperature must be based on the region of first use of the biochar product, for both soil and non-soil applications**.** The dataset provides averages by sub-national administrative regions. The minimum soil temperature is conservatively set to 7°C, due to uncertainties in soil temperature effects in regions with periods of frozen soil conditions. Temperature data are rounded to the closest upper integer value.

REMARK: Persistence in non-soil applications

Biochar used in non-soil applications may degrade more slowly than when applied to soils, for the time it is embedded in material. However, end-of-life scenarios may, at least partially, expose the biochar-containing material to soil-like environments. In the absence of peer-reviewed methods to estimate persistence in such products, the Puro Standard applies a conservative approach. The same methodology used for estimating decomposition in soils is extended to non-soil applications. Puro.earth may consider different approaches for non-soil applications as they emerge in the future. See further detail in section 4.2 on reversal risks for non-soil applications, and other application-specific considerations in section 3.6.

Towards composition-based persistence models

Although the H/C_{org} ratio is a simple analytical method to characterise the degree of carbonisation and aromaticity of a biochar sample, it is also a bulk method that provides an average, potentially hiding heterogeneity within the sample. Other analytical methods, often more complex and costly, have been used in research to gain further insights in the degree of carbonisation of biochar (e.g. measurement of the portion of non-aromatic carbon and degree of aromatic condensation by nuclear magnetic resonance (Singh et al., 2012), measurement of molecular markers of benzene poly-carboxylic acids (BPCA) (Glaser et al., 1998) (Glaser et al., 2021), measurement of aromatic clusters by hydrogen pyrolysis (Ascough et al., 2009) (McBeath et al., 2015) (Howell et al., 2022), or extended slow heating® (Petersen et al., 2023). However, one such method has recently gained attention for use in persistence estimation, namely random reflectance, maceral analyses, and morphotype analyses[27], as determined by optical microscopy (Petersen et al., 2023) (Mastalerz et al., 2023) (Sanei et al., 2024) (Drobniak et al., 2024) (Mastalerz et al. 2025).

Random reflectance measurements, maceral analyses, and morphotype analyses, are used in petrography to characterise different forms of organic carbon present in coals, but also rocks and sediments. These different forms of organic carbon are referred to as macerals, which themselves are classified in maceral groups (International Committee for Coal and Organic Petrology (ICCP) 1993). In petrography, macerals and maceral groups provide information on the botanical origin of the organic

[27] Morphotype refers to the shapes observed under optical microscopy in a sample. These include solids, networks, and spheres, which are further classified based on pore shape and wall thickness. Morphotypes offer an additional way to describe the petrographic composition of a biochar sample, alongside maceral analyses.

carbon and the transformation processes it was exposed to. Higher random reflectance values are associated with greater thermal maturity and higher degrees of aromaticity. There are three maceral groups in coal petrography, namely: vitrinite, liptinite, and inertinite (International Committee for Coal and Organic Petrology (ICCP) 1993, Taylor et al. 1998, International Committee for Coal and Organic Petrology (ICCP) 2001, Sýkorová et al. 2005, Pickel et al. 2017)[28]. The inertinite group includes subcomponents such as fusinite, semi-fusinite, funginite and secretinite (among others). When applied to biochar, organic carbon structures in biochar are said to resemble inertinite, mainly its subcomponent fusinite as well as less carbonized fractions sometimes described as "semi-inertinite" (Sanei et al. 2024, Mastalerz et al. 2025´). Note that semi-inertinite is not considered an established term, but is built on an analogy with semi-fusinite, defined as "a maceral of the inertinite maceral group that shows intermediate reflectance and structure between humotelinite/vitrinite and fusinite in the same coal or sedimentary rock" (International Committee for Coal and Organic Petrology (ICCP) 2001).

In terms of analytical methods for measurement of random reflectance, the method is described by ISO 7404 (Methods for the petrographic analysis of coals) and its 5 parts, where Part II (Methods of preparing coal samples), Part III (Method of determining maceral group composition) and Part V (Method of determining microscopically the reflectance of vitrinite) are most relevant to biochar applications. It should be noted that results of random reflectance measurements depend on the quality of sample preparation, the calibration of the apparatus, and manual data point selection and interpretation (although automated methods are in development). Sample preparation, calibration procedures, and analysis procedures specific for biochar samples do not yet exist, and might need to be developed according to experts. More specifically, distinction may need to be made between biochars made from plant-based materials, resembling coal for which ISO 7404 seems best suited, and biochars made from sludges, resembling dispersed matter for which the ASTM D7708-14 may be better suited. Further, reflectance threshold values used to classify macerals are not absolute and can depend on the nature of the sample itself (i.e. the random reflectance threshold value that distinguishes between fusinite and semi-fusinite can vary from one sample to another), and be associated with different physical interpretations (e.g. in two samples, where a grain is measured to have a reflectance of 2.4%, interpretations can differ: in one sample, the grain can be interpreted as being partially carbonized, while in another sample the grain can be interpreted as fully carbonized, due to morphological differences seen in the photomicrographs). These threshold values and interpretation for biochar are not yet well established nor documented in standards, but efforts have started to compile such information (Drobniak et al., 2024). Inter-laboratory standardization work for biochar random reflectance measurements is also on-going but the outcome of this initiative is not yet available.

Recent works (Sanei et al., 2024, Mastalerz et al. 2025) argue that any share of biochar that is classified as inertinite with a random reflectance above 2% (noting that the threshold value can be discussed) has a condensed aromaticity such that no biotic or abiotic process in soils can realistically

[28] Note that the concept of maceral groups (vitrinite, liptinite, inertinite) is not directly applicable to the microscopic study of biochar because maceral groups are defined by their relative reflectance and must all occur in the same sample in order to be determined.

decompose or oxidise this carbon over millennia (i.e. 100% persistence). While a consensus around this remains to be established, those arguments also implicitly disregard the carbon storage value of other macerals with random reflectance values below 2%, and in particular semi-fusinite macerals, which is likely inaccurate and could create non-desirable incentives in biochar production systems. In fact, the only published field data (Chiaramonti et al., 2024) on petrographic composition of biochar after 15 years in field did not yield statistically significant results, but likely inferred that inertinite and semi-inertinite fractions (as defined by the authors) had similar behaviors in soil, although the data reported does not enable to conclude on the extent of the alteration, if any. Other suggestions have been made to assign to each maceral present in a biochar a given persistence fraction (e.g. 100% for inertinite, 75% for semi-inertinite, 0% for other macerals), but the choice of these persistence fractions remains largely arbitrary.

Based on the above context, Puro.earth highlights the importance of not only measuring one maceral (inertinite) but rather the complete petrographic composition, following volumetric analyses rather than average analysis (volumetric requires more measurement points than average). Transparency is also of utmost importance regarding the analytical method used, any deviations from ISO7404 or ASTM D7708-14, and threshold values used for classification of macerals or other classifications of the degree of carbonization (e.g. based on high and low reflectance populations within a sample). This context informs the rules below.

6.2.5. On a voluntary basis, the CO_2 Removal Supplier can report, at the applicable frequency (see rule 3.5.35), and separately for each type of biochar (see rule 3.5.33), via laboratory analyses, the results from volumetric random reflectance measurements, subject to the following:

- The analysis must follow ISO 7404 (*Methods for the petrographic analysis of coals*) for plant-based biochars or ASTM D7708-14 for sludge-based biochars, but is allowed to make the necessary deviations to adjust the method to biochar samples. Those deviations, in particular when it comes to sample preparation and apparatus calibration, must be documented in writing and provided as part of the results.
- The threshold values of random reflectance used in classification and interpretation of the petrographic components of biochar must be disclosed as part of the results, and briefly motivated.
- The raw data from the volumetric random reflectance measurements must be provided as a data file, enabling plotting of the distributions and re-calculation of petrographic component shares. Note that volumetric analysis, also known as point counting, typically requires a higher number of measurements compared to average random reflectance analysis[29]. While the latter generally involves between 300 and 500 measurements, volumetric analysis demands a more extensive dataset following a standardized grid.
- A set of high resolution pictures of the polished surface from which measurements were made must be provided as part of the results. The resolution must be sufficient to enable processing of such images for future automated validation methods. Such files are estimated to represent about 1 gigabyte of data per sample (greyscale).

[29]The number of pores, mineral content and grain density of the sample are factors determining the actual number of points which need to be measured.

6.2.6. Any reported random reflectance measurements will be part of the documents submitted to the auditor for verification, although those measurements do not affect CORC calculation at the moment.

> **REMARK:** The rules 6.2.5 and 6.2.6, although optional and not affecting CORC calculations, can be useful for certain stakeholders (CORC buyers, rating agencies, buyers) that would like to obtain such data after third-party verification, and possibly, for retroactive actions from the Issuing Body, if the biochar persistence calculation rules were to change in a future update of the methodology. The photomicrographs obtained can also be used by the CO_2 Removal Supplier to better understand sources of variability in its operations, e.g. by understanding whether heat transfer throughout the biomass is uniform enough to ensure complete carbonization.

6.3. Baseline removal ($C_{baseline}$)

Baseline removal refers to carbon that would have been stored (naturally or man-made) in the selected baseline scenario, in the absence of the removal activity. This baseline removal must be deducted in CORC calculations. Types of baseline scenarios relevant for biochar activities are defined in section 3.2, distinguishing between New Facility, Retrofit Facility, and Charcoal Repurpose. Depending on the baseline scenario, but also the alternative fate of the biomass, it is possible that baseline removals are not null. This section defines rules on how to identify such situations and how to quantify $C_{baseline}$. Note that this section is also related to other sections on indirect emissions (section 8) and sustainable biomass sourcing rules (section 3.4).

Baseline removal from Retrofit Facilities, in the form of char or high carbon ash

6.3.1. For Production Facilities classified as **Retrofit Facility** (see rule 3.2.2.b), the CO_2 Removal Supplier must reliably characterize the amount of carbon stored in the baseline, i.e. prior to retrofit of the facility, according to the following:

a. Estimate the amounts of chars produced per year, distinguishing between different forms of chars (see rule 3.5.2), in relation to the amounts of biomass processed, over the last 5 years or shorter if the facility was in operation for less than 5 years.

b. Determine what has been the fate of the produced char, e.g. disposal in landfills or ponds, and assess the reversal risks in those situations. Claims that char was exposed to significant risks of reversal or actually destroyed must be supported by evidence.

c. Characterise the persistence properties of the chars produced (see rule 3.5.35), with at least 3 analyses, taken from different months of operations prior to retrofit, to determine whether the char historically produced had an H/C_{org} ratio below 0.7.

6.3.2. For Production Facilities classified as **Retrofit Facility** (see rule rule 3.2.2.b), in the event that the data provided as per rule 6.3.1 shows that the chars produced prior to retrofit were not exposed to reversal risks and had eligible persistence properties, then the term $C_{baseline}$ must be calculated as follow for each monitoring period:

$$C_{baseline} = Q_{biomass} \times C_{char,\, retrofit} \qquad \text{(Equation 6.6)}$$

where, $Q_{biomass}$ is the amount of biomass processed during the monitoring period (in dry metric tonnes), and $C_{char,\,retrofit}$ is the amount of baseline carbon removal per amount of biomass processed, expressed in tonne CO_2 per dry metric tonne of biomass processed. The term $C_{char,\,retrofit}$ is calculated based on the data provided for rule 6.3.1, prior to the Facility Audit and then re-used throughout the crediting period, as follow:

$$C_{char,\,retrofit} = Q_{char} \times C_{char,\,org} \times PF_{char} / Q_{biomass,\,baseline} \times 44/12 \qquad \text{(Equation 6.7)}$$

where, Q_{char} is the amount of char produced in the baseline (dry metric tonnes), $C_{char,\,org}$ is the organic carbon content of this char (%, dry basis), PF_{char} is the persistence fraction of this char (%, calculated as per section 6.1), and $Q_{biomass,\,baseline}$ is the amount of biomass processed in the baseline (dry metric tonnes). This calculation shall yield an representative average for the 5 years of data and the different forms of chars produced in the baseline. In the event that the calculation of the term $C_{char,\,retrofit}$ is not possible or cannot be shown to be conservative, the retrofit activity may be deemed ineligible.

Baseline removal from Charcoal Repurpose, in the form of charcoal

6.3.3. For Production Facilities classified as **Charcoal Repurpose** (see rule 3.2.2.c), the CO_2 Removal Supplier must reliably characterize the amount of carbon stored in the baseline, i.e. prior to diversion of charcoal products or co-products (e.g. fines) from their historical use or fate.

a. Estimate the amounts of charcoal and co-products produced per year, in relation to the amounts of biomass processed, over the last 5 years or shorter if the facility was in operation for less than 5 years.

b. Determine what has been the historical use or fate of charcoal and co-products, assess the reversal risks in those situations, and identify which fractions of charcoal are meant to be diverted. Claims that charcoal and co-products were exposed to significant risks of reversal or actually destroyed must be supported by evidence.

c. Characterise the persistence properties of the charcoal and co-products produced that are intended to be diverted from their historical fate, with at least 3 analyses taken from different months of operations prior to repurposing, and determine whether those fractions had an H/C_{org} ratio below 0.7.

6.3.4. For Production Facilities classified as **Charcoal Repurpose** (see rule 3.2.2.c), in the event that the data provided as per rule 6.3.3 shows that the charcoal products to be diverted were not exposed to reversal risks and had eligible persistence properties, then the term $C_{baseline}$ must be calculated as follow for each monitoring period:

$$C_{baseline} = Q_{biomass} \times C_{char,\,repurpose} \qquad \text{(Equation 6.8)}$$

where, $Q_{biomass}$ is the amount of biomass processed during the monitoring period (in dry metric tonnes), and $C_{char,\,repurpose}$ is the amount of baseline carbon removal per amount of biomass processed, expressed in tonne CO_2 per dry metric tonne of biomass processed. The term

$C_{char,\,repurpose}$ is calculated based on the data provided for rule 6.3.3, prior to the Facility Audit and then re-used throughout the crediting period, as follow:

$$C_{char,\,repurpose} = Q_{diverted} \times C_{char,\,org} \times PF_{char} \,/\, Q_{biomass,\,baseline} \times 44/12 \qquad \text{(Equation 6.9)}$$

where, $Q_{diverted}$ is the amount of charcoal products that contributed to carbon storage in the baseline (dry metric tonnes), $C_{diverted,\,org}$ is the organic carbon content of this charcoal (%, dry basis), $PF_{diverted}$ is the persistence fraction of this charcoal (%, calculated as per section 6.1), and $Q_{biomass,\,baseline}$ is the amount of biomass processed in the baseline (dry metric tonnes). This calculation shall yield an representative average for the 5 years of data and the different forms of chars produced in the baseline. In the event that the calculation of the term $C_{char,\,repurpose}$ is not possible or cannot be shown to be conservative, the retrofit activity may be deemed ineligible.

6.3.5. In the event of deviations from the standard cases illustrated above (6.3.1 to 6.3.4), the CO_2 Removal Supplier may suggest to the Issuing Body an alternative method to calculate $C_{baseline}$. The Issuing Body shall consider the alternative method and issue a rule clarification if acceptable for use in quantification.

7. Determination of project emissions ($E_{project}$)

This section specifies how project emissions ($E_{project}$) shall be determined, based on the life cycle of supply-chain activities.

7.1. General life cycle assessment requirements

LCA goal and scope alignment

7.1.1. The CO_2 Removal Supplier shall calculate the whole life cycle project emissions of the carbon removal activity for every monitoring period, via a life cycle assessment (LCA) model that follows the scope defined in this section of this methodology, and following the general principles defined in ISO-14040/44 and the ISO-14064 series. Note however that methodology rules take precedence over these standards.

LCA Model

7.1.2. The LCA Model for the biochar activity shall be developed in a digital tool that enables complete and transparent verification of the calculations, from input activity data to selection of emission factors. The digital tool can either be:

a. A spreadsheet LCA model, required to be built using the template provided by Puro.earth
b. A non-spreadsheet tool (e.g. dMRV platforms) provided that at least the same level of transparency and verifiability is achieved by the tool as enabled by the Puro.earth LCA spreadsheet model, and that data and model structure can be inspected and extracted by a third party.

LCA Model description

7.1.3. An LCA Model Description must be provided, alongside the LCA Model, to explain how the LCA Model was developed and demonstrate its representativeness for the Production Facility. This document must outline each emission source, detailing what it represents, the relevant activity data, how it is monitored, and the emission factors chosen, along with justifications for their appropriateness. Additionally, it must specify any assumptions or omissions made in the inventory and explains the calculation of key parameters, such as allocation factors. The document must also be aligned with the Monitoring Plan. This LCA Model Description is meant to support third-party auditors in their verifications as well as be the basis for public disclosure of the LCA modelling approach as part of the Project Description.

LCA Model validation at Facility Audit

7.1.4. The LCA Model and its Description must be validated during the Production Facility Audit by the third-party auditor.

Changes to LCA Model during crediting period

7.1.5. The LCA Model and its Description may be updated by the CO_2 Removal Supplier during the course of the crediting period to reflect changes that have occurred within the operations of the Production Facility (e.g. calculation of emissions for several types of biochar applications, while initially only one type of biochar application was envisioned). Any such change must be declared and reported at the next Output Audit, during which the updated LCA Model and its Description shall be re-validated by the third-party auditor.

> **REMARK:** An LCA Model Description is a term defined by Puro.earth and differs from a traditional LCA Report under ISO-14040/44. A standard LCA Report includes an introduction, goal and scope definition, inventory modelling, results, sensitivity analysis, and interpretation. However, this format is not suited to the Puro Standard, as its key elements are either covered in other project documents (e.g., Project Description, CORC Report Summary) or not relevant for the CORC issuance process (e.g. an LCA Report contains static results and figures while CORC issuance requires updated data for each period). Puro.earth opts for a concise LCA Model Description, ensuring efficiency for CO_2 Removal Suppliers and Auditors while avoiding redundancy.

Use of the LCA Model for reporting of project emissions

7.1.6. The CO_2 Removal Supplier must update the LCA model with operational activity data at every monitoring period, where relevant. The resulting updated project emissions must be used for reporting and verification of CORCs during the Output Audit.

Supporting evidence for reporting of project emissions

7.1.7. The CO_2 Removal Supplier must provide the supporting evidence to the operational activity data that was used in the calculation, to enable verification of the third-party auditor during the Output Audit. Supporting evidence can be in various forms e.g. records of activity, energy meter readings, utility bills, sensor data. Whenever assumptions are made, these shall be conservative and supported by some form of evidence. Part of this evidence may be required to be submitted to Puro for review, while other evidence may be sufficient to have available for the audit. The evidence required to be submitted to Puro is specified elsewhere, in Puro's operative documents, but typically includes: biomass records, biochar records, energy use, material use (as specified mostly in eligibility requirements, see section 3). In any case, all supporting data must be available to the auditor upon request.

Separation of operational emissions and foreground embodied emissions

7.1.8. The LCA model shall be based on separate life cycle inventories (LCI) of operational and foreground embodied emissions according to the rules in this methodology. In practice, all operational emissions are calculated and reported for each monitoring period (see section 7.3), while foreground embodied emissions are determined at the first Facility Audit and then amortized over time (see section 7.4).

Climate metric

7.1.9. The LCA shall calculate the climate change impact of the activity, characterized using 100-year global warming potentials (GWP_{100}) for greenhouse gases, ideally derived from the IPCC Sixth Assessment Report. Other environmental impact categories may be included but are not required.

> **REMARK:** Many public LCA data sources for emission factors, as well as literature data, have not yet been updated to reflect the changes of GWP_{100} from the latest IPCC Assessment Report. Those changes are however deemed minor, and CO_2 Removal Suppliers should strive to use the most up-to-date emission factors available.

Type of emission factors

7.1.10. The emission factors used in the LCA shall comply with the following elements:

a. include at least the contribution of major greenhouse gases (fossil CO_2, biogenic non-renewable CO_2, CH_4, N_2O).
b. include a full-scope of emissions (i.e., including upstream and downstream emissions, or so-called supply chain emissions, as opposed to emission factors used for greenhouse gas inventory purposes). Note that it is common to use multiple emission factors to represent the full-scope of an activity, e.g. one factor for direct emissions and one or several factors for upstream and downstream emissions.
c. do not include any recycling or substitutions terms (i.e. diminishing the impact of the activity)
d. be geographically appropriate to the location of the activity:

Further, the CO_2 Removal Supplier may use emission factors from publicly available or commercial databases, or developed by peer-reviewed studies complying with the above elements.

Use of renewable energy certificates and similar instruments

7.1.11. The CO2 Removal Supplier may purchase and use Guarantees of Origin (GOO), Renewable Energy Certificates (REC), or other similar certificates of energy attributes to claim lower GHG emission intensity for its direct energy consumption and use them to calculate the corresponding project emissions. The certificates shall follow all of these conditions:

a. The purchased certificates originate from the same physical grid or network as where they are consumed (i.e. same spatial resolution).
b. The purchased certificates have been issued within the same calendar year as when they are consumed (i.e. same temporal resolution).
c. The purchased certificates specify the energy source or mix of sources, so that a carbon footprint can be calculated and used in the LCA (i.e. non-zero value).
d. The purchased certificates specify when the production capacity of the energy source or mix of sources was commissioned, and that information is then disclosed by the CO2 Removal Supplier as part of the Output Audit. The information on the year of commissioning of the energy asset is an indicator of the additionality of the renewable energy production, allowing to distinguish between already existing assets and more recently built assets.
e. The amount of purchased certificates matches with the amounts of low-carbon energy declared in the LCA calculations.
f. The CO_2 Removal Supplier provides evidence of purchased certificates at each Output Audit, or alternatively reverts to using market average emission factors if certificates are no longer purchased.

Disaggregated results for auditing

7.1.12. For transparency, interpretability and auditing purposes (i.e., verification of claims), the climate change impact calculated in the LCA shall be presented in a disaggregated way exhibiting the contributions of the different emission sources for each unit process described in figure 7.1 and table 7.1.

Aggregated results for public disclosure

7.1.13. Public disclosure of LCA results in the Puro Registry (i.e. the verified LCA results after each Output Audit) may be aggregated to a level sufficient to protect sensitive information or licensed LCA data, as agreed with the Issuing Body. However, the aggregation shall at least disclose the level 1 and level 2 contributions, as well as certain level 3 contributions (e.g. direct land use change emissions) as further defined in table 7.1 in the summary section of this chapter.

Handling of valuable by-products

7.1.14. If co-products *with a meaningful use outside the process boundaries* are generated during the activity, an allocation of the relevant life cycle stages between the co-products may be applied. The allocation shall follow the rules in section 7.5 for different unit processes, and for allocation situations not covered in the methodology, resort to the general approach defined in EN 15804+A2 or ISO 14044:2006.

Modeling of secondary resources

7.1.15. If waste, recycled or post-consumer secondary resources are used as input to the activity (e.g., recycled steel or plastic), it is permissible and recommended to apply the cut-off system model approach[30] for waste, recycled and post-consumer secondary products in the LCA. Specifically, the environmental burdens from disposal of such resources shall be excluded from the system boundary, but the supply, transformation and handling of the secondary resources must be included from the start of the end-of-waste point[31].

Cooperation between operators for LCA

7.1.16. The CO_2 Removal Supplier shall coordinate data collection and LCA modeling with any external operators[32] to the level necessary to ensure compliance with this methodology and the Puro Standard requirements.

7.2. Scope of project emissions

Functional unit

7.2.1. The **functional unit** of the LCA shall be the production and use of biochar during the monitoring period. Note that due to potential for stocks of unused biochars across monitoring periods, the functional unit can technically refer to two different quantities of biochar: biochar produced and biochar used during the monitoring period.

[30] Description of the cut-off system model is available on the website of the ecoinvent life cycle database. This approach can also be described as a "polluter-pay" approach, as the emissions from waste treatment are attributed to the previous life cycle.

[31] This aligns with the European Commission 2023 targeted revision of the Waste Framework Directive and the proposal to include end-of-waste criteria. Accessed on 15 May 2025: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en#end-of-waste-criteria

[32] Data required for performing the LCA of a biochar activity originates from multiple parties, and most importantly from biomass providers, the biochar producer, biochar resellers and users.

> **REMARK:** The attribution of project emissions to the corresponding batches of biochar produced and used is managed seamlessly with the templates and tools provided by Puro.earth, to calculate the correct amount of CORCs for a given monitoring period. The system used is flexible for multiple types of projects, from single LCA calculation over an entire monitoring period to individual biochar batch tracking and associated LCA calculations.

System boundary

7.2.2. The **system boundary is set cradle-to-grave** and shall include operational and embodied life cycle emissions (i.e., upstream and downstream activities), and calculated using equation 7.1 as follows:

$$E_{project} = E_{ops} + E_{emb} \tag{7.1}$$

Where:

Variable	Description	Unit
$E_{project}$	Lifecycle emissions associated with the operation of the project during the monitoring period and the amortized portion of the lifecycle's embodied emissions.	tCO_2e
E_{ops}	Lifecycle emissions of materials and energy used associated with the operation of the project during the monitoring period.	tCO_2e
E_{emb}	Sum of lifecycle emissions associated with production, use, and disposal of infrastructure and equipment assets and direct land use changes.	tCO_2e

7.2.3. The **system boundary** of the carbon removal activity shall be defined across these dimensions:

a. Technical
b. Spatial or geographical
c. Temporal

7.2.4. The **technical dimension** of the system is organized into three main unit processes as described below and represented in Figure 7.1 and summarised in Table 7.1:

a. **Biomass sourcing** refers to all activities required for production, transport, and processing of the biomass feedstock until it reaches the Production Facility. *This process ends with biomass supplied to the Production Facility.*
b. **Biochar production** refers to all activities required for converting the biomass into biochar, including any on-site handling and processing of biomass and biochar. *This process ends with biochar at the gate of the Production Facility, ready to be used or shipped for use.*
c. **Biochar end-use** refers to all activities required for ensuring the biochar is used in an eligible application that preserves its carbon stored, including primarily transportation and incorporation into a soil or a product. *This process ends with biochar securely stored in an eligible application*.

7.2.5. The LCA model must include a project-specific process-flow diagram that details each of the unit processes shown in figure 7.1 for the purpose of defining the scope and completeness of life cycle inventories (see also rule 7.2.4).

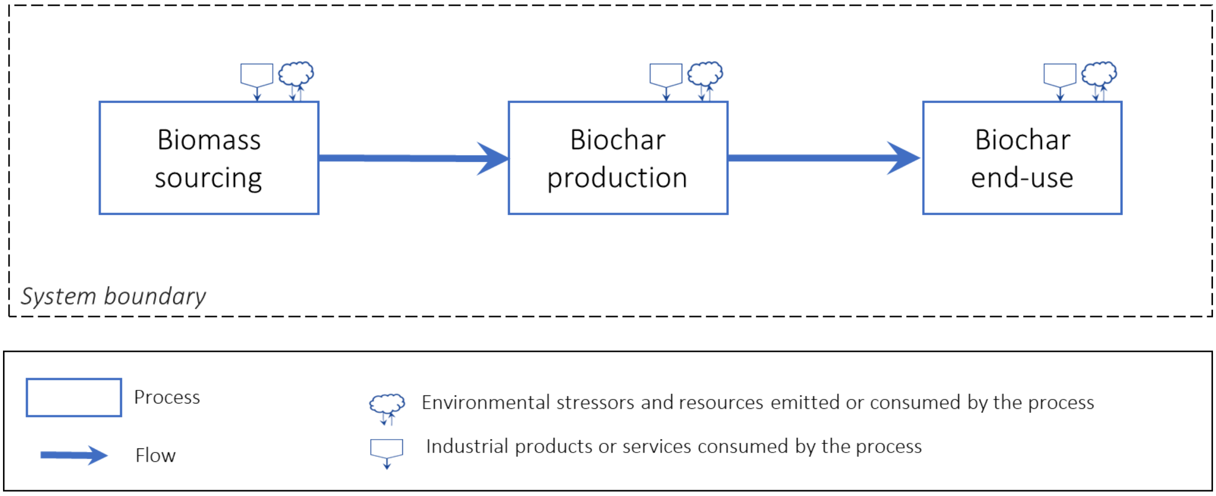

Figure 7.1. Life cycle assessment (LCA) system boundary of a biochar activity.

Spatial boundary

7.2.6. The **spatial dimension** of the LCA shall be defined in the LCA Model Description and applied to the selection of spatially-relevant emission factors and activity data. This includes the areas covered by the three unit processes, from biomass sourcing to biochar use.

Time boundaries

7.2.7. The **temporal dimensions** of the LCA shall be made explicit in the LCA Model and LCA Model Description, in relation to the Monitoring Period, and the specifics of each inventory (operational and embodied):

a. For **operational** emissions: the monitoring period serves as the temporal unit for calculating operational emissions. Therefore, the CO_2 Removal Supplier shall ensure that all operational emissions that occur during a monitoring period have been calculated and reported in one or several LCA calculations with explicit time boundaries.

b. For **embodied** emissions: the CO_2 Removal Supplier shall disclose in the LCA Model Description both technical design lifetimes, as well as any useful lifetimes of the Production Facility infrastructure, because the useful lifetimes may be shorter than technical design lifetimes.

7.3. Quantification of operational emissions

Operational emissions include the greenhouse gas emissions associated with the energy used to operate facilities, machinery, or other types of equipment as well as the material inputs (e.g., biomass, water, chemicals, packaging), waste treatment, and transportation (e.g., biomass sourcing or biochar delivery) necessary for the carbon removal activity.

7.3.1. The CO_2 Removal Supplier shall develop an operational LCI, accounting for the **operational emissions** of the three main unit processes described in rule 7.2.4.

7.3.2. The emissions from the activities covered in the operational LCI shall be measured and reported during the monitoring period following equation 7.2, and be possible to link to the amounts of biochar produced and used during the monitoring period.

$$E_{ops} = E_{biomass} + E_{production} + E_{use} \tag{7.2}$$

Where:

Variable	Description	Unit
$E_{biomass}$	Operational lifecycle emissions associated with biomass sourcing incurred during the monitoring period.	tCO_2e
$E_{production}$	Operational lifecycle emissions associated with biochar incurred during the monitoring period.	tCO_2e
E_{use}	Operational lifecycle emissions associated with biochar end-use sourcing incurred during the monitoring period.	tCO_2e

For the process of **Biomass Sourcing ($E_{biomass}$)**, the following rules apply in **quantification of operational emissions** based on the supply and pre-processing of eligible biomass feedstock as follows:

7.3.3. The CO_2 Removal Supplier shall account for the emissions arising from all activities involved in biomass cultivation and harvesting whenever the biomass feedstock is considered as originating from dedicated cultivation for biochar production. This applies in particular to category I (Agricultural crops that are neither food nor feed crop, cultivated on agricultural land) and certain feedstocks in category O (Cultivated or harvested water-based plants or algae, and associated derivatives) referred to in rule 3.4.5. Cultivation and harvesting emissions must include: use of fuel in machinery, production of fertilizers, emissions from soils following fertilizer use, use of fuel for irrigation, supply of irrigation water.

7.3.4. The CO_2 Removal Supplier shall consider eligible agricultural residues and other non-agricultural biomass feedstocks that are not the result of dedicated cultivation for biochar production as burden free from the emissions of the cultivation and/or production.

7.3.5. For all biomass feedstocks, the CO_2 Removal Supplier shall account for the **supply** (e.g., collection, transport and hub operations) of eligible biomass feedstocks from their first gathering point (including sourcing area) or collecting point to the gate of the biochar production facility.[33] .

7.3.6. For all biomass feedstocks, the CO_2 Removal Supplier shall account for the emissions associated with **pre-processing** of eligible biomass to a state that may be used for the production of biochar. For example, this may include biomass processing anywhere along the supply chain, such as chipping or drying.

[33] The CO_2 Removal Supplier may refer to the ISO 14083:2023 and/or use the GLEC Framework v3.1 to estimate GHG emissions associated with transport and logistics.

7.3.7. The CO_2 Removal Supplier may utilize national or regional average emission factors from peer-reviewed databases and literature, for biomass pre-processing and supply, when not in direct control of the supply-chain, as long as the reported sourced volume is supported by records of purchase. Such average emissions factors shall be cradle-to-gate and include all relevant upstream and downstream emissions.

7.3.8. The CO_2 Removal Supplier may use transport distances reported by the transporter, or if unavailable, may estimate the practical route between start and end points of the transport activity (i.e., shortest feasible distance[34]) using route planning software, if applicable. Calculation of transport-related emissions shall include, whenever applicable, emissions from unladen backhaul transport (empty return trips). This can be achieved in different manners, such as:

a. Using emission factors (g CO2e/t-km) that already include an estimate of empty returns and loading rates (e.g. certain *ecoinvent* emission factors); or
b. Using emission factors (g CO2e/t-km) that do not include estimates of empty returns, but multiply the transport distance by 1.5. This captures approximately the lower fuel consumption of the empty return trip; or
c. Using a combination of emission factors, typically one for laden and one for unladen transport, e.g. following the GLEC Framework v3.1, or GHG Protocol[35] Category 4 Fuel-based method, accounting for unladen backhaul.

For the stage **Biochar Production ($E_{production}$)**, the following rules apply in **quantification of operational emissions** from the conversion of biomass feedstock:

7.3.9. Biomass **conversion into biochar** shall include, as applicable:

a. Energy inputs, e.g., start-up or ancillary fuel usage for the carbonization process, other energy use for biomass handling and biochar processing at the facility.
b. Material inputs, such as consumables used for flue gas treatment systems (e.g., chemicals, bag filters, water), sealing of machinery, and lubricant oil.
c. Disposal of waste streams (e.g., ash disposal, disposal of other consumables from flue gas treatment systems, wastewater, discarded co-products).
d. Direct greenhouse gas emissions from the biomass conversion process (e.g., CH_4, N_2O at the stack). See section 3.5 for rules on their determination.
e. Direct methane emissions from biomass storage at the facility. See section 3.4 for rules on their determination.
f. Direct emissions of fossil CO_2 from the biomass conversion process, when the biomass contains impurities or chemicals of fossil origin (e.g. plastic impurities in garden waste, fossil-derived chemicals in sewage sludge). See section 3.4 for rules on their determination.
g. Emissions associated with the maintenance of the biochar production facility (e.g. replacement of spare parts and reparation works).

[34] GLEC Framework v3.1.
[35] GHG Protocol (2013) Technical Guidance for Calculating Scope 3 Emissions. Accessed on 16th May 2025: Scope 3 Calculation Guidance | GHG Protocol

7.3.10. The CO_2 Removal Supplier shall keep records of maintenance, improvements, and repair works performed on the infrastructure, to enable inventory calculations.

7.3.11. In case the conversion process (i.e., pyrolysis) results in other valuable co-products, the CO_2 Removal Supplier shall quantify them and may allocate process emissions based on rule 7.5.1 and 7.5.2.

7.3.12. In case of mobile biochar facilities, the CO_2 Removal Supplier shall also include emissions from the relocation of the Production Facility from its previous point of operation to its operating site as it relates to the Monitoring Period. Also, any additional emissions associated with the preparation of the working site for the current operations shall be accounted for.

For the stage **Biochar use (E_{use})**, the following rules apply in the **quantification of operational emissions**:

7.3.13. In case of direct soil application, the CO_2 Removal Supplier shall account for the emissions associated with the packaging, transport, and incorporation of biochar to the soil.

7.3.14. In case of non-direct soil applications, the CO_2 Removal Supplier shall account for the emissions associated with packaging, transport, and incorporation of the biochar into another product or series of products, until the biochar-containing products meet the conditions of rule 3.6.6.

7.3.15. The CO_2 Removal Supplier shall account for all consumable materials, and treatment of any waste arising during the transportation of biochar from the production facility to the eligible use.

7.4. Quantification of embodied emissions

Embodied emissions (E_{emb}) represent the carbon emitted in the fabrication, construction, and demolition of infrastructure and/or equipment assets (E_{infra}), and in direct land-use conversion (E_{dLUC}) associated with the production facility and supporting infrastructure (when applicable).

7.4.1. The CO_2 Removal Supplier shall develop an embodied LCI, accounting for the **embodied emissions** of the foreground infrastructure of the Production Facility and the associated direct land use change emissions, if applicable. The LCI is subject to the cut-off criteria defined in section 7.6.

7.4.2. These embodied emissions shall be estimated subject to the accounting requirements found in rule 7.4.3 and rule 7.4.4, and using equation 7.3:

$$E_{emb} = E_{infra} + E_{dLUC} \tag{7.3}$$

where:

Variable	Description	Unit
E_{emb}	Sum of lifecycle emissions associated with infrastructure and equipment assets and direct land use changes.	tCO_2e
E_{infra}	Lifecycle emissions associated with infrastructure and equipment assets.	tCO_2e
E_{dLUC}	Lifecycle emissions associated with direct land use changes.	tCO_2e

7.4.3. **Embodied emissions shall account for the life cycle emissions of infrastructure and/or equipment (E_{infra})** as follows:

a. The calculation of embodied emissions shall be cradle-to-grave, including all steps from material extraction to waste disposal, and may follow as general guidance: EN 15804+A2[36], EN 15978[37], or ISO 21930:2017.[38]

b. Alternatively, recent monetary emission factors (e.g., kg CO_2e per USD spent) may be used as a proxy for estimating embodied emissions based on capital expenditure (CAPEX), provided that such factors are available in the countries where the facilities are built, or from other countries as proxy, if deemed sufficiently conservative. This approach may be based on an economic input-output life-cycle assessment (EIO-LCA).

c. The embodied emissions of operational pre-existing facilities shall not be accounted for in the project's embodied emissions. However, additional embodied emissions associated with the retrofit of the facility shall be accounted for.

d. In the event of an ownership change of an asset (rule 3.2.4, e.g. a mobile reactor changing ownership for a New Facility), the embodied emissions from the initial manufacturing shall be accounted to the pro-rata of its remaining lifetime. However, additional embodied emissions associated with the transportation, installation, or upgrading of the asset shall be accounted for in full.

7.4.4. **Embodied emissions shall account for direct land-use (dLUC) conversion** if land use has been changed for the construction of the Production Facility or any supporting infrastructure necessary for the operation of the carbon removal activity. To this end, the following rules shall apply:

a. dLUC emissions shall be considered and included in the embodied LCI when the construction of the Production Facility and its supporting infrastructure entails land conversion.

b. dLUC shall be assessed relative to the land area remaining in its historical state prior to the carbon removal project (new built or retrofit).

c. dLUC shall include any loss of aboveground and belowground biogenic carbon stocks, relative to the historical state of the land. dLUC shall also include any greenhouse emissions arising during the land conversion such as emissions associated with land clearing by fire as these may include significant amounts of methane (CH_4) and dinitrogen monoxide (N_2O).

d. These emissions shall be quantified using either the default values for land conversion available in the IPCC Guidelines for National Greenhouse Gas Inventories[39] (IPCC, 2006) (IPCC, 2019) (Tier 1), or country-specific values (Tier 2), or data specific to the project (Tier 3).

e. The calculation shall be performed using the equations 7.4 and 7.5 below:

$$E_{dLUC} = 44/12 \; * \; (CS_B - CS_P) \; * A + \; E_{conversion} \tag{7.4}$$

[36] EN 15804:2012+A2:2020 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.

[37] EN 15978:2012 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

[38] ISO 21930:2017 Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services.

[39] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).

where the carbon stock per unit area is defined as:

$$CS_X = C_{VEG_X} + C_{DOM_X} + SOC_X \quad (7.5)$$

Where:

Variable	Description	Unit
E_{dLUC}	Absolute direct land use change associated with the construction of infrastructure.	tCO_2e
CS_B	Carbon stock per unit area associated with the baseline land use.	tC ha^{-1}
CS_P	Carbon stock per unit area associated with the project land use.	tC ha^{-1}
A	Area of land converted.	ha
$E_{conversion}$	Greenhouse gas emissions associated with the land use conversion activities, e.g. fuel usage for clearing the land, direct emissions from fire.	tCO_2e
CS_X	Carbon stock per unit area with the project or baseline land use, where subscript X indicates the type of land use.	tC ha^{-1}
C_{VEG_X}	Above and below ground living biomass carbon stock.	tC ha^{-1}
C_{DOM_X}	Dead organic matter or litter biomass carbon stock.	tC ha^{-1}
SOC_X	Soil organic carbon stock.	tC ha^{-1}

The variables C_{VEG_X}, C_{DOM_X}, and SOC_X should be determined using the equations presented in volume 4 of the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) (IPCC, 2019)[40] and the EU Commission decision on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC[41] (see also subrule d).

7.4.5. Embodied emissions shall be amortized[42] evenly over a period of time in line with its first crediting period (see rule 2.2.2), or the lifetime assumption of the Production Facility, whichever is shorter. Alternatively, the CO_2 Removal Supplier may decide to amortize all embodied emissions earlier, e.g. upfront during the first monitoring period, if requested by a third party (e.g. investor or buyer). In any case, if the project is terminated prior to complete amortization of

[40] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds).

[41] 2010/335/: Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (notified under document C(2010) 3751).

[42] In this document, amortization is an equivalent concept to the “linear discounting approach” presented in the GHG Protocol (2011) Product Life Cycle Standard (Appendix B) and GHGP (2022) Land Sector and Removals Guidance, Part 1: Accounting and Reporting Requirements and Guidance. (Draft for pilot testing and review).

its attributable embodied emissions, the remaining unamortized embodied emissions are considered a liability and the CO_2 Removal Supplier shall settle the outstanding embodied emissions by retiring CO_2 Removal Certificates (CORC) of similar permanence.

> **REMARK ON BACKGROUND INFRASTRUCTURE EMISSIONS:** The rules in section 7.4 apply specifically to *foreground* infrastructure emissions, not *background* infrastructure emissions. Foreground infrastructure includes facilities built by the operator, such as biochar production equipment and factory buildings. In contrast, background infrastructure refers to elements like the infrastructure required for electricity generation used in the process. Since background infrastructure emissions are already accounted for in the LCA emission factors—along with their own assumptions e.g. on lifetime and maintenance requirements—CO_2 Removal Suppliers do not need to modify or verify these assumptions. Background emission factors can be applied as provided.

7.5. Emissions allocation to co-products

The biochar activity allows for the creation of valuable co-products within its supply chain. The following rules apply when these valuable co-products are identified and how to proceed with the allocation of lifecycle emissions to the biochar supply chain and the co-products for the determination of project emissions ($E_{project}$) and quantification of CORCs.

7.5.1. In the event that co-products with a meaningful use outside the biochar supply chain process boundaries are generated during the activity as shown in Figure 7.2, an allocation of the accumulated emissions until that point may be applied between the co-products. The allocation procedure is possible to use only if the meaningful use of the co-products can be demonstrated with evidence, and the properties of the co-products required for calculation of allocation factors have been determined.

7.5.2. The following allocation rules are defined for different stages in the biochar supply chain:.

a. **For the biomass sourcing process**, it is possible that the biomass cultivation or its subsequent processing yields multiple co-products. Unless tackled by other rules in section 7.3, the allocation rule may follow the general approach defined in EN 15804+A2 or ISO 14044:2006, as most relevant to the project context. In practice, economic allocation may be preferred over dry mass allocation, when the mass-based prices between the different biomass co-products differ by more than 25%.

b. **For the biochar production process**, whenever an allocation is performed, it is required to use an energy content allocation between the biochar and its co-products. This energy content allocation shall be based on the lower heating value (LHV) in the general case. In the case of power generation, another energy content allocation rule can be suggested by the CO_2 Removal Supplier, as relevant to the project context. Waste treatment services, potentially delivered by the activity, are not allowed to be included in the allocation (conservative measure). Likewise, mass-based allocation between co-products is not allowed, and hence, non-energy co-products (e.g. wood vinegar) cannot be attributed any supply-chain emissions.

c. **For the biochar use process**, it is common that biochar is used in different applications, some being eligible for CORCs and others not eligible for CORCs. In that case, the relevant emissions must be allocated between the biochar streams based on their dry mass.

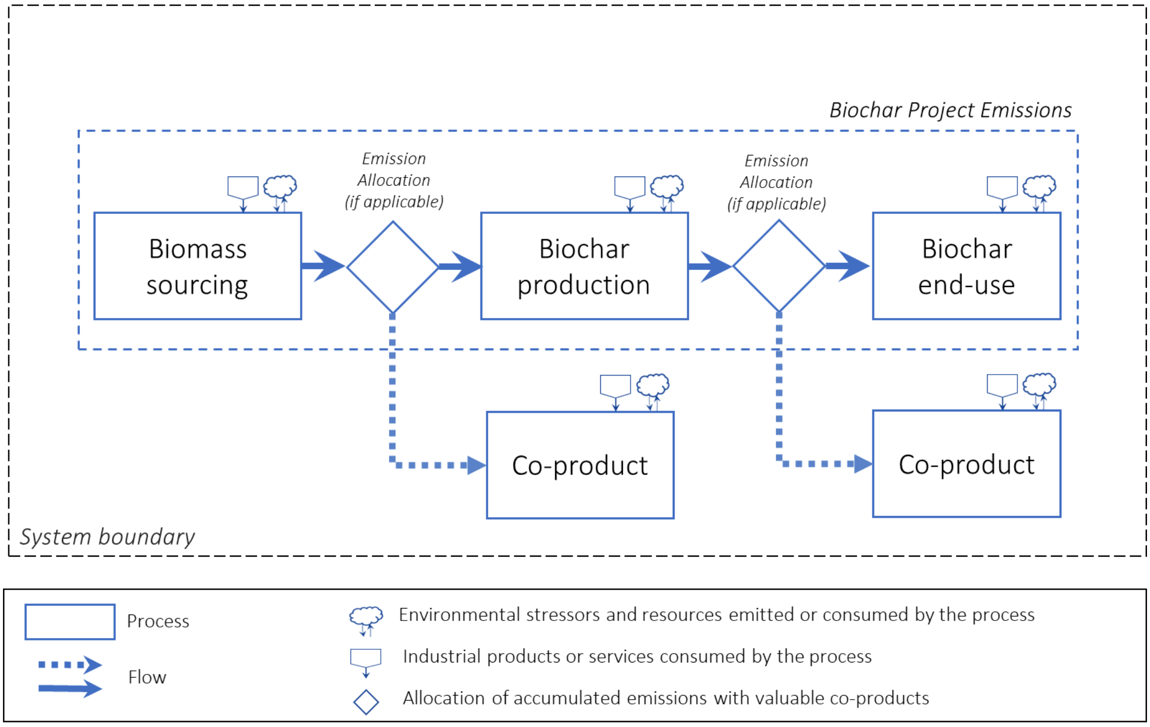

Figure 7.2. Emission allocation options at different stages of the biochar supply chain.

7.6. LCI cut-off criteria

In order to simplify the development of the LCA model and the data collection process during operations, it is possible to leave out individual activities or emission sources that have an overall negligible impact on CORC quantification, following the cut-off criteria defined in this section. Cut-off criteria is here synonymous with materiality threshold. Note also that cut-off criteria cannot be applied to all emissions sources, as certain sources are explicitly required to be reported regardless of their magnitude (see section 3).

7.6.1. To identify which individual activities or emission sources can be left out from an inventory model (operational or embodied), the CO_2 Removal Supplier shall first endeavor to develop a life cycle inventory that lists all possible individual activities or emission sources for each unit process (see rule 7.2.5) and type of emissions sources (e.g. energy use, material use, waste treatment, direct emissions). Supported by initial data and preliminary calculations for normal operations, the CO_2 Removal Supplier may demonstrate that certain individual activities or emission sources are expected to be negligible.

7.6.2. For the individual activities or emission sources that are deemed negligible, the CO_2 Removal Supplier may decide to exclude them from the inventory, and thereby neglect their contribution to project emissions. This decision must be made explicitly and be documented in the LCA Model Description, and can be challenged by the third-party auditors during Facility Audit or

Output Audits alike. For example, the auditor may compare the LCI data with similar processes or available emissions databases to determine the plausibility of completeness of the proposed inventory.

7.6.3. The following elements are considered to be not relevant for the purposes of LCA modeling, and therefore do not need to be included in the LCA Model:

a. Site selection and feasibility studies, non-recurring R&D activities.
b. Staff transport (e.g., business travel and employee commuting)
c. Non-production related products, which include office furniture and supplies, IT support, and janitorial and cleaning services.
d. Monitoring activities.

7.7. Summary

7.7.1. The CO_2 Removal Supplier shall collect and organize the elements and processes that contribute to generate the overall project emissions ($E_{project}$, including both embodied and operational emissions) according to the levels of information described in table 7.1 using Puro supporting templates and tools.

7.7.2. The LCA model shall be provided in a disaggregated manner and aligned with table 7.1, exhibiting the contributions of each main stage (level 1) and substage (level 2). Each sub-stage can be further divided into contributions (level 3) relevant for each project type. If a contribution is deemed not relevant or equal to 0, an explicit motivation shall be provided in accordance with the LCI cut-off criteria (see section 7.6).

7.7.3. The CO_2 Removal Supplier shall publicly disclose the results of the LCA calculation as part of the Output Audit in the Puro Registry, at least the contributions marked with an asterisk (*) in table 7.1.

Table 7.1. Levels of contribution to the LCA calculations of the unit processes, and identification of which contributions must be made public in the Puro Registry as part of Output Audit data (marked with an asterisk, *).

Main stages Level 1 contributions	Sub-stages Level 2 contributions	Further sub-stages Level 3 contributions	Comment
$E_{biomass}$	*Operational emissions of biomass production, supply, processing, (if applicable) and transport to the production site	Production Processing Supply	Third-level contributions may be split in sub-stages as relevant for each supply-chain.
$E_{production}$	*Operational emissions of biochar production	Energy use (heat, electricity, fuel) Material use Transport Waste treatment	Third-level contributions may be split in sub-stages as relevant for each supply-chain.

Main stages Level 1 contributions	**Sub-stages Level 2 contributions**	**Further sub-stages Level 3 contributions**	**Comment**
		Stack emissions	
	*Embodied emissions of biochar production assets	Construction and disposal of infrastructure and equipment *Direct land use change (dLUC)	Those emissions are verified at the Facility Audit, and then amortized evenly over the first crediting period.
E_{use}	*Operational emissions of biochar use, including transportation from facility to site of use and use-related activities	Energy use (heat, electricity, fuel) Material use Waste treatment	Third-level contributions may be split in sub-stages as relevant for each supply-chain.

8. Determination of leakage ($E_{leakage}$)

As defined in the Puro Standard General Rules, leakage refers to indirect or secondary effects, associated with a removal activity and depending on the selected baseline. Leakage effects may lead to an increase or decrease in greenhouse gas emissions or removals outside of the system boundaries of the activity. For CORC quantification, only the increase in GHG emissions or decreases in carbon stocks are quantified, and the removal activity is penalized if leakage effects are not avoided or mitigated. Net positive effects are not included in the quantification of CORCs.

This section defines what leakage sources are relevant to consider for different types of biochar carbon removal activities, following the three-step approach defined in the Puro Standard General Rules:

1. Identify and characterize leakage sources (see section 8.1)
2. Avoid or mitigate leakage sources (see section 8.2)
3. Quantify unmitigated leakage sources (see section 8.3)

8.1. Identification and characterisation of leakage sources

As defined in the Puro Standard General Rules, methodologies in the Puro Standard shall first identify and present the potential sources of leakage that are relevant to consider for the CO_2 Removal pathways included in the scope of the Methodology. Further, the rules categorizes sources of leakage in two groups, whose definition is reminded here:

- **Ecological leakage:** a project can change the greenhouse gas fluxes mediated by ecosystem-level changes in surrounding areas outside of the project boundaries, specially with hydrologically connected land areas. *This is also referred to as potential negative effects to nearby land and ecosystem.*
- **Market and activity-shifting leakage**: a project may compete for resources and services, shifting the supply-demand equilibrium. This change affects prices and availability of goods or services, which may indirectly increase or decrease emissions elsewhere (market effect). Furthermore, a project may also displace activities outside of the project's boundaries, or change the likelihood of activities to occur elsewhere (activity shifting). These two notions are grouped together as they are often interrelated and sometimes necessary to assess jointly.

Scoping of leakage sources for biochar

As with any infrastructure project, biochar projects might have negative effects on nearby land and ecosystems, e.g. due to land drainage for construction purposes, or deforestation to enable construction works. In this context, nearby land and ecosystems refers to the physical areas directly surrounding the project area but excluding the actual project area itself[43]. Biomass production and sourcing may also be associated with similar effects, e.g. due to land drainage to enable the use of heavy machinery for harvesting, or deforestation following construction of roads used for transporting

[43] Land use change emissions directly affecting the project area are part of project emissions and quantified in section 7.

the biomass. *Such effects on nearby land and ecosystems represent a potential source of ecological leakage for biochar projects.*

Biochar projects rely on resources available in limited amounts—namely biomass and land—and their deployment may affect existing uses of these resources. For instance, biochar production may occur at the expense of other bio-based applications such as bioenergy or biomaterials, particularly in cases of retrofitted facilities or diversion of charcoal from existing supply chains. Likewise, new facilities may disrupt existing uses of biomass and land, in particular bioenergy and nutrient recycling. *Such effects on the land sector, bioenergy markets and biomaterial markets represent a potential source of market and activity shifting leakage for biochar projects.*

Leakage assessment procedure

8.1.1. The CO2 Removal Supplier shall assess all potential sources of leakage identified in this methodology for the biochar activity type and selected baseline scenario (see section 3.2). Each leakage source must be either avoided or mitigated according to the rules in section 8.2, or quantified according to the rules in section 8.3. Furthermore, the CO_2 Removal Supplier shall account for any unmitigated leakage in the quantification of CORCs according to the rules in section 5.2 (General equation).

Leakage sources applicable to all baselines

8.1.2. For all types of biochar activities and baseline scenario, the following leakage sources are identified and must be addressed by the CO_2 Removal Supplier:

a. Ecological leakage relating to negative effects, either via land drainage or land cover change, on the nearby land and ecosystems, *surrounding the areas where facilities are built or extended.*

b. Ecological leakage relating to negative effects, either via land drainage or land cover change, on the nearby land and ecosystems, *surrounding the areas where biomass is sourced from*.

c. Market and activity shifting leakage in the agriculture, forestry and other land use (AFOLU) sector*, relating to the use of biomass feedstock or the use of land*.

Leakage sources specific to New Built

8.1.3. For biochar activities under the **New Built** baseline, the following additional leakage sources are also identified and must be addressed by the CO_2 Removal Supplier:

a. Market and activity shifting leakage in the material and energy sector, *relating to the use of biomass feedstocks or land that were already utilized for other productive purposes* (feedstock diversion).

Leakage sources specific to Retrofit Facility

8.1.4. For biochar activities under the **Retrofit Facility** baseline, the following additional leakage sources are also identified and must be addressed by the CO2 Removal Supplier:

a. Market and activity shifting leakage in the material and energy sector, *relating to reduced bioenergy or biomaterial output due to retrofitting of the facility.*

Leakage sources specific to Charcoal Repurpose

8.1.5. For biochar activities under the **Charcoal Repurpose** baseline, the following additional leakage sources are also identified and must be addressed by the CO_2 Removal Supplier:

a. Market and activity shifting leakage in the material and energy sector, relating to diversion of charcoal or related products (e.g. charcoal fines, activated carbon) from their existing use (product diversion).

Deviations from identified leakage sources

8.1.6. In case the specifics of the removal activity proposed by the CO_2 Removal Supplier do not fully align with the situations described in this methodology (e.g. atypical pathways, mixed baseline), the CO_2 Removal Supplier shall re-assess potential sources of leakage in cooperation with the Issuing Body, who will in turn issue a rule clarification statement. For instance, this might apply to projects where a facility is retrofitted to both expand its biomass processing capacity, adding new biochar production reactors and retrofitting existing ones (see rule 3.2.5), or other unforeseen situations.

8.2. Avoidance or mitigation of leakage sources

The mitigation of a particular leakage source refers to the process of demonstrating that it has no significant effect for the Production Facility being assessed. In this methodology, leakage mitigation relies on a combination of system-level measures and supplier-level measures. In other words, the CO_2 Removal Supplier may demonstrate that an identified source of leakage has no significant effect for its Production Facility by demonstrating that certain features apply in the project area (*system-level*) in combination with, whenever relevant, other measures directly implemented by the supplier (*supply-level*). If this can be demonstrated following the rules defined below, the emissions from the corresponding leakage source can be set to zero in the CORC quantification. If specified in the rules below, demonstrating the mitigation of a leakage source can be conditioning the eligibility of the Production Facility.

Mitigation of ecological leakage from facility construction or extension

8.2.1. The procedure detailed in **subrules a-e** shall be applied to mitigate ecological leakage relating to negative effects on the nearby land and ecosystems surrounding the areas where facilities are built or extended:

a. The CO2 Removal Supplier shall assess this leakage source during the design phase of the project. For facilities that have been designed or built prior to the publication date of this methodology, a retrospective assessment shall be performed.
b. In the assessment of this leakage source, the CO2 Removal Supplier shall at least:
    i. Define the areas of surrounding land and ecosystems potentially affected (e.g. spatial extent, locations, soil types, hydrology, land cover, cultural and biodiversity values).
    ii. Determine whether or not the planned construction works will affect the local hydrology.
    iii. Determine whether or not the planned construction works will affect the land cover.
    iv. Conclude whether the nearby land and ecosystems will suffer from loss of carbon stocks or from emissions of other greenhouse gases.
c. If the assessment concludes that nearby land and ecosystems would not be negatively affected, then this leakage source is considered mitigated and can be set to zero in the quantification of CORCs. Otherwise, the project shall perform an ex-ante quantification of the

loss of carbon stocks and emission of greenhouse gases, which shall then be included in the CORC quantification as per rules 8.3.1 and 8.3.2. The ex-ante quantification shall be based on either methods derived from the IPCC Guidelines for National Greenhouse Gas Inventories (as in rule 7.4.4), or site-specific quantification approaches.

d. In case the assessment concludes that nearby land and ecosystems would be negatively affected, but that quantification is not possible, the project is not eligible in its current design. However, construction plans or locations may be changed for the project to become eligible.
e. In case the assessment concludes that nearby land and ecosystems would not be negatively affected, but later events and/or grievances demonstrate otherwise, penalties shall apply retrospectively, following the Puro Standard General Rules for reversals.

> **REMARK:** In practice, ecological leakage related to negative effects on nearby land and ecosystems surrounding the areas where facilities are built or extended can typically be identified during the project design phase. This may be done through a brief standalone assessment, where the CO_2 Removal Supplier gathers primary evidence (e.g. satellite imagery of the surroundings, construction plans, and related engineering studies) to demonstrate that no ecological leakage will occur nor has occurred due to construction. If the Facility is also required by the host jurisdiction to carry out an Environmental Impact Assessment (EIA) or similar environmental studies, the CO_2 Removal Supplier may integrate the ecological leakage assessment into those statutory processes for efficiency. For clarity, Rule 8.2.1 does not require an EIA to be conducted.

Mitigation of ecological leakage from biomass sourcing

It is considered that the Puro Biomass Sourcing Criteria are sufficient to ensure that the sourcing of the biomass will not significantly affect the local hydrology nor the land cover of nearby lands and ecosystems surrounding the areas of sourcing.

8.2.2. Mitigation of ecological leakage relating to negative effects on the nearby land and ecosystems surrounding the areas where biomass is sourced from is achieved if the biomass used is demonstrated to be eligible as per the Puro Biomass Sourcing Criteria. This leakage source can be set to zero in the quantification.

Mitigation of market and activity shifting leakage in the land sector

In theory, any use of biomass can have repercussions on the land sector, but the level of risk varies significantly depending on the type of biomass and the production system it originates from. The objective of this rule is to prevent indirect land use change (iLUC), particularly in high-risk scenarios where increased demand for biomass could indirectly contribute to deforestation or the conversion of high-carbon-stock lands. This mitigation rule is therefore an additional safeguard layered on top of the Puro Biomass Sourcing Criteria, which primarily address direct sustainability impacts. To achieve this, the rule below distinguishes between biomass origins. If the feedstock does not originate from agricultural or forest land (e.g. industrial or post-consumer waste), the risk of land-sector leakage is minimal, and no further mitigation is required. If the feedstock does come from agricultural or forest land, further differentiation is made based on whether the biomass is the primary driver of land use and whether the feedstock is associated with high iLUC risk. In each case, the rule defines specific eligibility and mitigation conditions to ensure that land sector impacts are adequately addressed.

8.2.3. For all biochar projects regardless of the baseline, the procedure detailed in **subrules a-d** shall be applied to mitigate market and activity shifting leakage in the agriculture, forestry and other land use (AFOLU) sector, relating to the use of land or biomass:

a. If the biomass feedstock used for biochar production is a post-consumer or industrial waste stream (feedstock categories B-F defined in rule 3.4.5), effects on the land sector are deemed minimal, and this leakage source is considered not relevant.

b. If the biomass feedstock used for biochar production otherwise originates from **agricultural or forest land**, is **not a feedstock associated with high iLUC risk** (see sub-rule 8.2.3.d) and is **not the primary driver of land use**: this leakage source is considered mitigated provided that the biomass used is demonstrated to be eligible as per the Puro Biomass Sourcing Criteria.

   Examples of such situations include:

   - Forest residues or sawmill residues originating from forest land, where the primary driver of land use is timber for material use.
   - Wheat straw sourced from agricultural land, where the primary driver of land use is food production.
   - Rice hull sourced from the processing of rice, cultivated on agricultural land, where the primary driver of land use is food production

c. If the biomass feedstock used for biochar production otherwise originates from **agricultural or forest land** (including plantations), is **not a feedstock associated with high iLUC risk** (see sub-rule 8.2.3.d) but **is the primary driver of land use**: this leakage source is considered mitigated provided that the biomass used is demonstrated to be eligible as per the Puro Biomass Sourcing Criteria, and that one of the following conditions is met:

   i. The feedstock is produced on agricultural land as an intermediary or cover crop.

   ii. The feedstock is produced on marginal land, degraded or contaminated land, not suited for food or feed production.

   If none of the conditions above can be demonstrated, then the feedstock is considered not eligible. This rule primarily excludes the use of land for dedicated production of biomass when this land could have been used for food or feed production.

d. If the biomass feedstock used for biochar production otherwise originates from **agricultural or forest land** (including plantations) and **is a feedstock associated with high iLUC risk**, the feedstock is considered eligible only if the CO_2 Removal Supplier can demonstrate that both:

   i. The Puro Biomass Sourcing Criteria, applicable to the feedstock, are met.

   ii. The feedstock is certified by a third-party as being associated with low iLUC risks, under a voluntary certification scheme such as the International Sustainability and Carbon Certification ISCC-EU program, or similar regulations or schemes approved by the Issuing Body.

Further, albeit the above points being demonstrated, the leakage source shall not be considered mitigated or avoided. The CO_2 Removal Supplier shall also quantify and account for this leakage source in accordance with rule 8.3.4.

In this methodology, a feedstock associated with high iLUC risks (regardless of whether the feedstock is the primary product or a co-product of the cultivation activity) is defined as a feedstock for which a significant expansion of the production area into land with high-carbon stock is observed.[footnote: This definition is adopted from the Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)]. In this methodology, high iLUC-risk feedstocks currently include:

- Biomass from palm tree plantations.
- Biomass from soybean cultivation

Mitigation of market and activity shifting leakage in the material and energy sector, from biomass feedstock diversion

Biochar production can divert biomass from other important uses, such as nutrient cycling or energy generation. The following rule ensures that such diversions do not cause unintended negative impacts by setting conditions under which leakage can be considered mitigated. For nutrient-rich feedstocks (e.g. manures), mitigation focuses on maintaining nutrient recycling unless environmental benefits (e.g. nutrient pollution control) justify diversion. For bioenergy-relevant feedstocks, mitigation requires either efficient energy recovery from co-products or reasonable evidence that the biomass was not previously used for energy.

8.2.4. For biochar activities under the **New Built** baseline, the procedure detailed in sub-rules a and b shall be applied to mitigate *market and activity shifting leakage in the material and energy sector, relating to the use of land or biomass that were already utilized for other productive purposes*:

a. If the biomass feedstock used for biochar production is **a nutrient-rich feedstock** (e.g. animal manure, human manure, sewage sludge) from which nutrients were previously recovered (e.g. via direct land application, composting or anaerobic digestion), the leakage source is deemed mitigated, and thereby set to zero in the quantification of CORCs, if one of the following conditions can be demonstrated by the CO_2 Removal Supplier:
    i. Biochar produced from this feedstock is used in soil applications, regardless of whether in agriculture, forestry, landscaping, or urban areas. In other words, biochar from nutrient-rich feedstock cannot be used in construction materials, disposed of in landfills, or buried in a non-productive manner.
    ii. The project area suffers from an over-supply of nutrients that has demonstrated negative effects on water resources; and justifies the carbonization of the feedstock as an environmental remediation measure. Here, biochar produced from this feedstock can be used in any type of applications.

If the above condition cannot be demonstrated, leakage remains unmitigated and must be quantified according to rule 8.3.3.

b. If the biomass feedstock used for biochar production is also used for bioenergy in the project area (e.g. via combustion for heat or power generation), the leakage source is deemed mitigated, and thereby set to zero in the quantification of CORCs, if one of the following conditions can be demonstrated by the CO_2 Removal Supplier:
   i. The Production Facility delivers bioenergy for external uses (i.e. beyond internal use for supporting carbonization or drying the biomass feedstock)
   ii. The biomass was not being used for bioenergy prior to sourcing, but instead left to decay.

   If the above condition cannot be demonstrated, leakage remains unmitigated and must be quantified according to rule 8.3.3.

Mitigation of market and activity shifting leakage in the material and energy sector, from retrofitting of a bioenergy facility

8.2.5. For biochar activities under the **Retrofit Facility** baseline, the CO_2 Removal Supplier shall apply the following procedure to assess and mitigate leakage risks due to reduced bioenergy or biomaterial outputs:

a. If the retrofit **does not lead to any decrease** in bioenergy or biomaterial outputs, leakage is considered not to occur and is set to zero. This shall be demonstrated through a simplified mass and energy balance (pre- and post-retrofit), including descriptions of any energy efficiency measures or increased biomass throughput (subject to sustainable sourcing) that explain maintained or increased output levels.

b. If a decrease in output is identified, leakage is considered mitigated and set to zero if one or more of the following conditions apply:
   i. The CO_2 Removal Supplier can demonstrate that Facility is located in a region where:
      1. For reduced *electricity output* to the grid, the electricity grid has an average proportion of renewable electricity (excluding nuclear power) exceeding 90% in the previous calendar year, or has an emission intensity of electricity is lower than 18.0 gCO2e/MJ (64.8 gCO2e/kWh) as determined by national statistics, or is subject to a cap-and-trade mechanism deemed effective by the Issuing Body.
      2. For reduced *thermal energy output* to a network, the thermal energy network is over 90% renewable, or subject to a cap-and-trade mechanism deemed effective by the Issuing Body.
      3. For reduced *thermal energy output* to specific users (i.e. not part of a network), the CO2 Removal Supplier can demonstrate that previous users of the thermal energy have deployed or are planning to deploy other low-carbon means of meeting their energy demand (e.g. via energy efficiency measures or deployment of new energy systems)
   ii. The CO_2 Removal Supplier can demonstrate that the demand for the reduced bioenergy or biomaterial output is structurally declining in the region

If none of the above conditions are met, the resulting leakage shall be quantified in accordance with rule 8.3.3.

Mitigation of market and activity shifting leakage in the material and energy sector, from diversion of charcoal and related products

8.2.6. For biochar activities under the **Charcoal Repurpose** baseline, the CO_2 Removal Supplier shall apply the following procedure to assess and mitigate leakage risks, from diversion of charcoal and related products:

a. If no decrease occurs in the volume of charcoal or related products previously sold or used for other purposes, then leakage is considered not to occur and is set to zero. This shall be demonstrated through a mass balance of inputs and outputs before and after project implementation, as performed for rule 6.3.3 (regarding baseline carbon storage). A maintained or increased output level may result from:
   i. Improved process efficiency, or
   ii. Increased production capacity, provided that all biomass processed at the facility (not just the portion dedicated to biochar) is sustainably sourced as per the Biomass Sourcing Criteria.
   iii. Valorisation of charcoal fractions that were previously discarded (however, subject to carbon baseline storage rules 6.3.3 and 6.3.4).

b. If a decrease in charcoal or related product output is identified, leakage is considered mitigated and set to zero if one or more of the following conditions can be demonstrated:
   i. The production of use of charcoal or related products is restricted in the host country by regulation
   ii. The demand for charcoal or related products in the host country is demonstrably declining, supported by market data

If none of the above conditions are met, the resulting leakage shall be quantified in accordance with rule 8.3.3.

Suggestion of other leakage mitigation options

8.2.7. The CO_2 Removal Supplier may suggest to the Issuing Body additional options for mitigating leakage. Such proposals must be submitted prior to Facility Audit and be supported by a clear justification. The Issuing Body shall assess the proposal and, if deemed acceptable, issue a rule clarification confirming that the relevant leakage source may be considered mitigated for the purpose of CORC quantification.

8.3. Quantification of unmitigated leakage sources

Overall unmitigated leakage equation

8.3.1. The total greenhouse gas emissions due to unmitigated negative ecological, market, and activity-shifting leakage resulting from the biochar activity shall be calculated as follows:

$$E_{leakage} = L_{ECO} + L_{MA} \quad (8.1)$$

where:

Variable	Description	Unit
$E_{leakage}$	Total GHG emissions due to unmitigated negative leakage resulting from the biochar activity.	tCO_2e
L_{ECO}	Total GHG emissions due to unmitigated negative ecological leakage resulting from the biochar activity.	tCO_2e
L_{MA}	Total GHG emissions due to unmitigated market and activity-shifting leakage resulting from the biochar activity.	tCO_2e

Quantification of ecological leakage from facility construction or extension

8.3.2. The CO_2 Removal Supplier shall quantify and amortize any unmitigated ecological leakage relating to negative effects on the nearby land and ecosystems surrounding the areas where facilities are built or extended, in accordance with the following sub-rules:

a. An ex-ante quantification of unmitigated leakage associated with the construction or extension of the Production Facility has been made, following the procedure and methods outlined in rule 8.2.1. This quantification results in absolute impact from ecological leakage, noted AEL (in tCO2e), for the Production Facility.
b. The absolute impact AEL must be added to the term L_{ECO} following a time-based amortization procedure as for embodied project emissions in rule 7.4.5.

Quantification of market and activity shifting leakage relating to bioenergy or biomaterial markets (e.g. bioenergy, biomaterials, nutrients, charcoal-related products)

8.3.3. The CO2 Removal Supplier shall quantify any unmitigated market and activity shifting leakage relating to bioenergy or biomaterial markets (as triggered by either rule 8.2.4, 8.2.5 or 8.2.6), as follows:

$$L_{MA} = max(0,\ \sum_{i} \Delta P_{i} \times EF_{i}) \qquad (8.2)$$

where:

Variable	Description	Unit
L_{MA}	Total GHG emissions due to unmitigated market and activity-shifting leakage resulting from the biochar activity.	tCO_2e
ΔP_{i}	Net change in product i between project and baseline situations affected by a leakage situation	as applicable
EF_{i}	Emission factor representative of the service delivered by the output i.	tCO_2e per unit of product i
i	Summation index over the relevant products affected by a leakage situation (e.g. power, heat, liquid fuel, charcoal, biocoke, nutrients)	unitless

a. By definition, the term L_{MA} is a number higher or equal to zero, and cannot be negative.

b. For the product i, the term ΔP_i is positive in case of a net loss of product or service, and negative in case of a net gain (sign convention). Within this leakage category, the CO_2 Removal Supplier may consider both gains and losses to calculate a net leakage effect.

c. The emission factors EF_i are defined as positive numbers, updated annually, which shall be determined based on the type of product of service as follows:

   i. For **electricity output**, EF_i is the average emission factor of the grid (as defined by the bidding zone or national boundaries) to which the facility is connected.

   ii. For **thermal energy** (heat or steam), EF_i is the average emission factor of the network to which the facility is connected or the most likely non-constrained substitute off-network thermal energy source available in the area where the facility is located.

   iii. For **nutrients** (N, P, K), EF_i is the average emission factor of replacing a unit of the corresponding nutrient.

   iv. For **diverted charcoal and related products**, EF_i is the emission factor from the most likely non-constrained substitute material available in the area where the facility is located.

   v. For **gas** or **liquid fuel**, EF_i is the most likely non-constrained substitute fuel source available in the area where the facility is located.

Quantification of market and activity shifting leakage in the land sector

8.3.4. The CO_2 Removal Supplier shall quantify any unmitigated market and activity shifting leakage in the agriculture, forestry and other land use (AFOLU) sector, relating to the use of biomass feedstock or the use of land as follows:

a. The CO_2 Removal Supplier shall utilize the iLUC factors listed in table 8.1 to calculate, for each monitoring period, an additional contribution to the market and activity shifting leakage (L_{MA}) due to land sector leakage (see rule 8.2.3). This additional contribution, denoted $iLUC$, shall be calculated as follows.

$$iLUC = \sum_f (Q_f \times LHV_f \times iLUC_f \times AF_f) \qquad (8.3)$$

where:

Variable	Description	Unit
$iLUC$	Indirect land use change contribution to be added to market and activity shifting leakage, for the monitoring period.	tCO_2e
Q_f	Quantity of the biomass feedstock f with high risk of indirect land use change processed during the monitoring period	dry metric tonnes
LHV_f	Lower heating value of the biomass feedstock f, expressed in GJ per dry tonne.	GJ per dry metric tonnes

Variable	Description	Unit
$iLUC_f$	Indirect land use change factor for biomass feedstock f	kg CO_2e per MJ
AF	Attribution factor of the iLUC emissions to the CORC, varying between 0 and 100%, and set to 100% in the normal case.	unitless
f	Summation index (an element in the set of biomass feedstocks subject to this rule)	unitless

b. The value of the attribution factor AF is defined as 100% in the general case, meaning that the iLUC emissions are conservatively attributed in full to the biochar carbon removal activity.

c. The value of the attribution factor AF can be lowered only if the CO_2 Removal Supplier can demonstrate that both of the following conditions apply:

   i. The climate footprints of products made from the primary biomass (e.g. biofuel made from palm oil) already incorporate in part or in full the iLUC emissions

   ii. The climate footprints of those products are reported as part of an governmental or intergovernmental regulatory scheme (e.g. EU RED II / III).

   In cases where both of the above conditions are demonstrated by the CO_2 Removal Supplier, the value of the attribution factor AF shall be equal to the percentage share of iLUC emissions that have not been attributed to the co-products (thus not double-counting the iLUC emissions).

Table 8.3. iLUC factors for different crop types.

Crop type	iLUC factor[44] (kgCO_2e MJ^{-1})
Cereals and other starch-rich crops	0.012
Sugar crops	0.013
Oil crops	0.055

[44] The iLUC factors are derived from the EU RED II, Annex VIII, and are expressed per MJ of biomass feedstock on a dry lower heating value basis.

9. Monitoring Requirements

Monitoring, measuring, and reporting the performance of carbon removal activity is essential to ensure compliance with the methodology throughout the crediting period. The CO_2 Removal Supplier is responsible for meeting these requirements through a facility-specific monitoring plan. Third-party verification involves reviewing evidence resulting from the execution of the monitoring plan and corroborating the supplier's calculations and claims. Depending on the requirements, evidence may include data records, permits, or other official documents demonstrating compliance. Based on the outcome of the auditor verifications, consigned in an Audit Report, the Issuing Body can then issue CORCs in accordance with the General Rules.

9.1. Scope of Monitoring

9.1.1. The CO_2 Removal Supplier shall monitor the performance of the carbon removal activity by collecting and archiving all relevant information necessary to:

a. Ensure the activity conforms with the eligibility requirements defined in this Methodology and the Puro General Rules.

b. Monitor environmental and social impacts to support Sustainable Development Goals and safeguard against environmental and social risks.

c. Estimate the carbon sequestration and GHG emissions to ensure net negativity within the project's boundary.

d. Verify the permanence of the sequestered carbon and alert of any reversal events.

It is important to note that these goals can be achieved through several routes, and multiple monitoring techniques can often be utilized for the same parameter. Figure 9.1 illustrates the scope of monitoring.

9.1.2. The CO_2 Removal Supplier shall consider site-specific needs and select appropriate monitoring methods that enable the effective measurement and verification across the entire biochar life cycle — from biomass sourcing to end-use. The selected methods must ensure accurate tracking of key parameters, plus meet the resolution and certainty levels required by applicable local regulations and this methodology.

Figure 9.1: Monitoring scope

9.2. Monitoring Plan

9.2.1. The CO_2 Removal Supplier shall design and implement a Monitoring Plan to assess the performance of the Production Facility according to the purpose described under section 9.1.

9.2.2. The CO_2 Removal Supplier shall submit the Monitoring Plan for validation during the Production Facility Audit, as described in the Puro Standard General Rules, and is required to be made available in the Public Registry, either in full or in a redacted form for confidentiality, once the Facility Audit is successfully completed.

9.2.3. The Monitoring Plan shall describe the procedures by which the CO_2 Removal Supplier will collect data and evidence. In accordance with ISO 14064-2:2019 and Puro Standard requirements, the Monitoring Plan shall therefore include the following:

a. Purpose of monitoring.
b. Project boundaries and monitoring system diagram.
c. Description of the monitoring practices based on their purpose (e.g., compliance, GHG measurement, risk assessment, etc.).
d. Monitoring frequency.
e. Monitoring roles and responsibilities of the project personnel.
f. Data collection plan, including a list of parameters and their attributes and data sources.
g. Uncertainty assessment and measurement procedures.
h. Data quality control (QC) plan.

i. Information management system for record-keeping and data sharing.
j. Threshold values for environmental and social safeguards and follow-up procedures for responsible parties involved in the carbon removal activity.

9.2.4. The Monitoring Plan shall include one or several diagrams clearly identifying all points of monitoring and measurement.

9.2.5. The Monitoring Plan shall cover all the project stages and different purposes of monitoring, and the elements to be monitored shall be identified by the CO_2 Removal Supplier during the project design phase, based on the requirements of the methodology and other statutory requirements. More precisely, during the design phase, identification of monitoring elements for environmental and social impacts shall be performed alongside the procedures described in section 4.3, in particular stakeholder engagement processes and the environmental and social safeguard questionnaire. Table 9.1 provides an overview of the sections in the methodology that identify monitoring elements, here classified by project stage and monitoring purpose. Note there may overlap and redundancy (i.e. one monitoring element may contribute to various objectives).

Table 9.1: Main sections in the methodology that identify monitoring elements, classified by project stages and monitoring purpose.

Monitoring Purpose	Biomass sourcing	Biochar production	Biochar use
Eligibility compliance	Section 3.4, Section 8	Section 3.5	Section 3.6, Section 3.8
CORC quantification	Section 3.4, Sections 5 to 8	Section 3.5, Sections 5 to 8	Section 3.6, Sections 5 to 8
Environmental and social impacts	Section 3.4, Section 4.3, Section 8, (Section 3.7)	Section 3.4, Section 4.3, (Section 3.7)	Section 3.6, Section 4.3, (Section 3.7)
Permanence and reversals			Section 3.6, Section 4.2

9.2.6. Unless otherwise specified, all monitoring shall be based on activity data specific to the removal activity.

9.2.7. The monitoring plan shall be periodically evaluated and updated to ensure the monitoring practices remain appropriate and effective.

a. The evaluation shall include a reassessment of the site-specific monitoring requirements and risks.
b. Updates to the monitoring plan might be necessary due to:
    i. Changes to the Production Facility that affect the activities being monitored.
    ii. Changes to the Puro normative framework (e.g., Puro Biomass Sourcing Criteria) that require an update in the monitoring activities.
    iii. Corrective actions requested from the auditor.

c. If changes are made, the updated Monitoring Plan must be submitted to the Issuing Body at the next Output Audit, during which it will be re-validated by the auditor.

9.2.8. The Monitoring Plan shall describe how the CO_2 Removal Supplier plans to respond to any significant irregularities in the project performance (i.e., contingency monitoring), including the case of reversal events. Examples of irregularities in project performance are: i) reception of hazardous biomass although not licensed to receive such feedstock, ii) production equipment broke down or requires preventive maintenance, or iii) natural catastrophe damaged the facility.

9.2.9. The performance of the parameters and items identified in the Monitoring Plan shall be reported for each monitoring period and submitted with the Output Report for verification by the third-party auditor in accordance with the Reporting requirements (section 11) of this document.

9.3. Monitoring Frequency and Record Keeping

9.3.1. The following definitions apply to the description of monitoring frequency:

a. Monthly monitoring is defined as at least once per calendar month.
b. Quarterly monitoring is defined as at least four times per calendar year (once every three months).
c. Semi-annual monitoring is defined as at least twice per calendar year (once every six months).
d. Annual monitoring is defined as at least once per calendar year.

9.3.2. Periodical monitoring is defined as monitoring at predetermined, regular temporal intervals decided by the CO_2 Removal Supplier based on site-specific needs and any applicable regulations. The monitoring frequency and rationale shall be explained in the monitoring plan.

9.3.3. Monitoring activities with a predefined cadence (e.g., quarterly monitoring) shall be evenly distributed throughout the monitoring period (e.g., once every three months for quarterly monitoring). The CO_2 Removal Supplier may reasonably adjust the monitoring schedule for reasons of necessity or practicality. Still, such adjustment shall not result in undue or disproportionate monitoring activity delays.

9.3.4. The CO_2 Removal Supplier shall have in place, maintain, and utilize an information system to keep records of all monitoring activities associated with the carbon removal activity. In addition:

a. These records shall include information on the parameter or process monitored (i.e. what was monitored and how), as well as the results of any measurements performed.
b. The information shall be time-stamped and quantitative, where applicable.
c. These records shall be available to the Auditor for the Production Facility Audit and Output Audits.
d. These records shall be kept for at least two years after the end of the crediting period or the last issuance of CORCs for this project activity, whatever occurs later.

10. Measuring Requirements

10.1. Uncertainty Assessment of the Carbon Removal Activity

A Puro-approved Methodology is designed to minimise the uncertainty (i.e., bias) associated with conceptualisation and modelling the carbon removal activity. As improvements in knowledge become available, this Methodology will be updated. Nonetheless, The CO_2 Removal Supplier plays an important role in minimizing the uncertainty associated with the performance of carbon removal activity. This section aims at assisting in reducing and quantifying the measurement uncertainty of the activity.

10.1.1. The estimate of net carbon removal resulting from implementing Puro-approved methodologies using the corresponding CORC calculation equation shall be *accurate* and *precise*.

> **REMARK:**
>
> **Precision** refers to the degree to which repeated measurements of the same variable produce consistent results. A higher precision indicates lower random error.
>
> **Accuracy** refers to how closely the average of repeated measurements or predictions corresponds to the actual value of a variable. Accuracy implies the absence of systematic error or bias. This translates into the need for proper calibration of measuring equipment, the use of representative data, to name a few.
>
> Note that precision is independent of accuracy, meaning that measurements can be precise without necessarily being accurate. For example, results can be inaccurate but precise, as illustrated in Figure 10.1(a).

Accuracy and precision depend on understanding the uncertainty associated with the processes and data inputs involved in quantifying GHG emissions and the resulting net carbon removal from implementing the carbon removal activity. Figure 10.1 illustrates the definitions of accuracy and precision

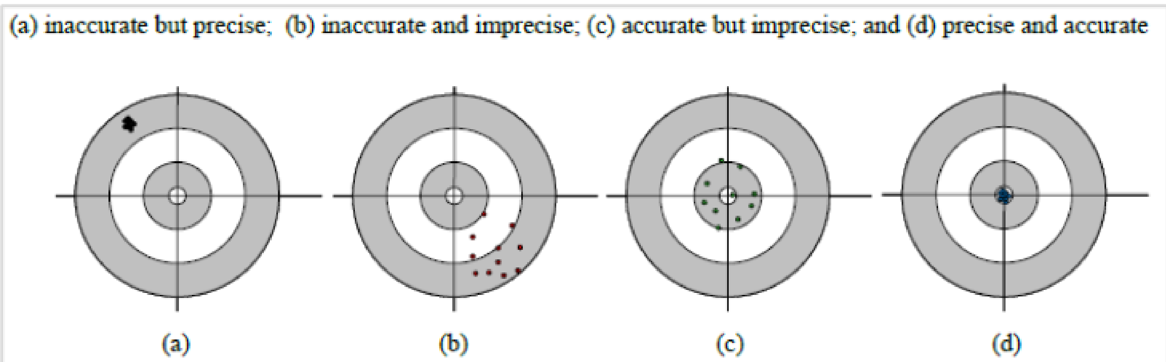

Figure 10.1: Illustration of accuracy and precision (IPCC 2019)

10.1.2. The CO_2 Removal Supplier shall, similarly, measure accurately and precisely other parameters required by the Methodology for purposes other than GHG inventory accounting indicators as necessary. This may include indicators of toxicity levels or SDG impacts.

10.1.3. The CO_2 Removal Supplier shall perform an uncertainty assessment of the implementation of the carbon removal activity to:

a. Identify the possible causes of uncertainty.
b. Establish actions to reduce that uncertainty through the design of the Production Facility (or project) and improve the accuracy and precision of the net carbon removal calculation.

10.1.4. The process of producing an uncertainty assessment follows the steps in the decision tree (see Figure 10.2) and the steps described in section 10.3.

10.1.5. For the purposes of this methodology, two types of uncertainty are defined as follows:

a. **Bias or systematic errors** may arise from conceptual errors or an incomplete understanding of the processes involved in the CORC equation (measuring model) and its main components. Also, this may be encountered in the completeness and representativeness of the data (e.g., geographical, temporal, etc.). This type of uncertainty impacts the accuracy of the net carbon removal estimation.
b. **Random errors** may arise based on the system's inherent variability, measurement errors, and uncertainty obtained from expert judgment. This type of uncertainty can be estimated following the requirements set in section 10.3, and it impacts the precision of the net carbon removal estimation.

10.1.6. The CO_2 Removal Supplier shall define the actions to be taken to reduce the causes of uncertainty in implementing the carbon removal activity in the Quality Control procedures for each parameter included in data collection (see rule 10.5.3.c).

10.1.7. The CO_2 Removal Supplier may refer to the IPCC Guidelines for National Greenhouse Gas Inventories and General Guidance and Reporting for information on treating uncertainty (IPCC 2006, 2019). Table 10.1 summarizes the broad causes of uncertainty and lists the mitigation actions under the responsibility of the CO_2 Removal Supplier.

10.1.8. The CO_2 Removal Supplier shall endeavour to identify and address all possible causes of uncertainty in the performance of the carbon removal activities.

Table 10.1. Causes of Uncertainty (after IPCC 2006, 2019).

Cause of uncertainty	Type	Mitigation actions
Lack of data	Bias	Quality Control: expert judgement
Lack of representativeness of data	Bias	Quality Control: Pedigree matrix approach[45]
	Random errors	Quality Control: Sampling
Statistical random sampling errors	Random errors	Quality Control: Sampling
Measurement error	Bias	Quality Control: Calibration
	Random errors	Quality Control: Sampling
Misreporting	Bias	Quality Control
Data gaps	Bias and random errors	Quality Control: Statistics, experts

[45] GHG Protocol Quantitative Uncertainty Guidance.

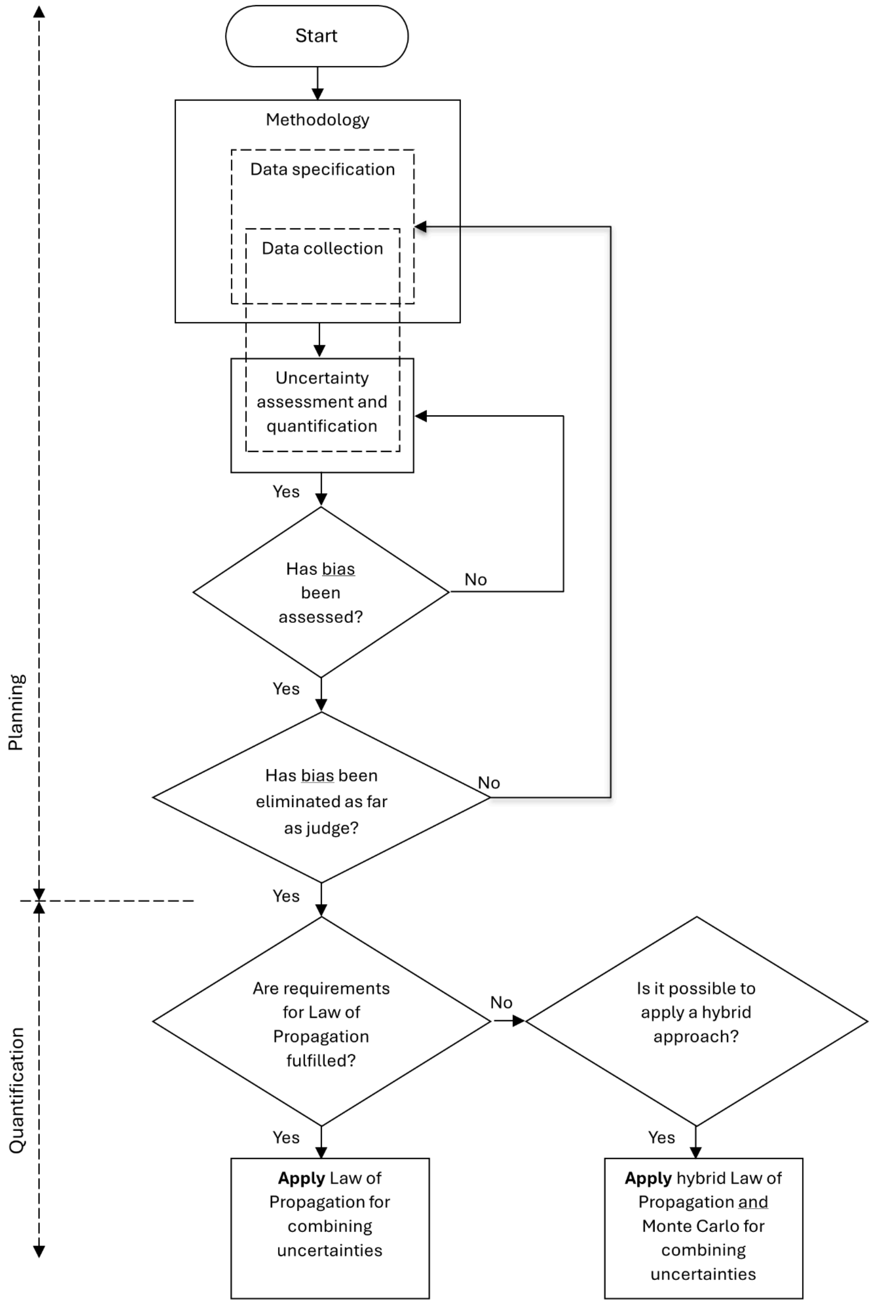

Figure 10.2: Uncertainty assessment steps and decision tree, adapted from Figure 3.1.A in IPCC (2019).

10.2. Data Collection

10.2.1. The CO_2 Removal Supplier shall define the attributes of all the parameters described in the Monitoring Plan in accordance with table 10.2.

Table 10.2. List of required parameter attributes.

Field name	Description
ID	A unique identifier of the parameter.
Parameter	The name of the parameter.
Unit	The measurement unit of the parameter.
Value	The value of the parameter.
Equation	Reference to the equation where this parameter contributes to.
Description	A brief text describing what the parameter is about, and how it is used in calculations.
Source of data	Classify the data sourced as measured (m), estimated (e), or calculated (c) based on the definitions described in rule 10.2.2.
Monitoring frequency	The frequency of monitoring of the parameter.
QC procedures	A brief text describing how the data is obtained, via what measurements, and why the value selected is conservative considering possible error or uncertainty.
Measurement uncertainty (%)	An estimation of the ***random error*** component associated with the measurement is estimated as percentage uncertainty in the parameter.
Data archive process	How is the data archived?
Time of data archive	For how long will the data be archived?
Comments	Free text comments

10.2.2. For the calculation of the net carbon removal and associated uncertainty of measurement, the sources of data and information on the carbon removal activity are:

a. **Measured.** This applies to measurements obtained via tools designed explicitly for this purpose.
b. **Estimated**. Quantified estimates based on expert judgement or based on surveys or other peer-reviewed studies. This applies to emission factors (EF) and average activity data (AD).
c. **Calculated**. Data that results from calculations based on the measured and/or estimated inputs using equations or models.

10.2.3. The International System of Units (SI) are the preferred units of measurement. Nonetheless, other unit measurement systems (e.g., the British imperial system and the United States customary system) may be used, provided the reported values are in their SI equivalent.

10.2.4. The data collection procedures shall specify the measurement and calibration methods used to collect the data in accordance with the Quality Control procedures described in this document (see section 10.5).

10.2.5. The CO_2 Removal Supplier shall develop a process for keeping a record of the data collected and submitted with the Output Report, and describe it with the data attributes (see table 10.2).

10.3. Estimation of Measurement Uncertainty

Knowledge of measurement uncertainty implies increased confidence in a result's validity (EURACHEM/CITAC Guide CG 4). In the context of this methodology, the object of estimating measurement uncertainty is the net carbon dioxide removal based on the elements that contribute to the CORC calculation equation.

10.3.1. The CO_2 Removal Supplier shall estimate the combined percentage uncertainty of the net carbon dioxide removal activity results from combining the standard uncertainty of all the parameters identified in the measurement model, the CORC equation (equation 5.1), and all its components, expanding it to cover a confidence interval of approximately 95% or two standard deviations from the mean.

10.3.2. The CO_2 Removal Supplier should refer to the ISO/IEC Guide 98 series or the EURACHEM-CITAC Guide CG 4 for guidance on the estimation of measurement uncertainty.

10.3.3. The estimation of uncertainty shall start by determining the contributions to measurement of uncertainty from the parameters in the lowest level of the data hierarchy summarized in table 10.3 and use relevant Puro Standard guidelines and templates.

Table 10.3: Hierarchy of parameters contributing to uncertainty.

Level 0 component	Level 1 contributor	Level 2 contributor	Level 3 contributor	Level 4 or more
C_{stored}	$Q_{biochar}$			
	C_{org}	C_{total}		
		C_{inorg}		
$C_{baseline}$	Facility classification	$Q_{diverted}$ or $Q_{biomass}$		
		$C_{char,retrofit}$ or $C_{char,repurpose}$	Q_{char} or $Q_{biomass}$	
			$C_{char,org}$	
			PF_{char}	
C_{loss}	Permanence Factor	H/C_{org}		
		Soil temp	M	
			a	
$E_{project}$	Operation emissions	$E_{biomass}$	Emission factor (EF_i) Activity data (AD_i) Allocation factor (AF_i)	
		$E_{production}$		
		E_{use}		
	Embodied emissions	E_{infra}	WBLCA*	
		E_{dLUC}	CS	C_{veg}
				C_{DOM}

Level 0 component	Level 1 contributor	Level 2 contributor	Level 3 contributor	Level 4 or more
				SOC
			A	
			$E_{conversion}$	
$E_{leakage}$	Ecological			
	Market and activity shifting			

Note (*): A whole building life cycle assessment (WBLCA) for infrastructure emissions requires an extensive life cycle inventory. The CO_2 Removal Supplier should request or provide an estimated uncertainty for the whole infrastructure model.

10.3.4. The CO_2 Removal Supplier shall follow these steps to proceed with the estimation of combined percentage uncertainty of the net carbon removal:

a. The CO_2 Removal Supplier shall identify the sources of uncertainty (see rule 10.2.2) of the parameters described in table 10.3, which aims at covering the complete measuring model.

b. The CO_2 Removal Supplier shall define the uncertainty of parameters based on the source data, measured or estimated;

   i. The uncertainty of parameters with calculated source data shall follow the step

   ii. Potential sources of data uncertainty may include:

      1. Evaluation of the dispersion of repeated measurements.
      2. Previous measurement data.
      3. Expert knowledge or judgement.
      4. Manufacturer's specifications.
      5. Data provided in calibration and other certificates.
      6. Uncertainties assigned to reference data taken from peer-reviewed publications.

c. The CO_2 Removal Supplier shall start combining the percentage uncertainty of the lowest parameters in the data hierarchy described in Table 10.3 to estimate the combined uncertainty of the next highest dependent parameter in the hierarchy.

d. The estimation of combined uncertainty shall use one of the two principal methods for propagating measurement uncertainty, which are:

   i. The **law of propagation** of uncertainty. This approach is described in greater detail in subrule 10.3.4.e.

   ii. The **propagation of distributions using Monte Carlo simulations**. This approach is not covered in this document. For further details, refer to ISO/IEC Guide 98-3:2008/Suppl. 1.

e. The application of the law of propagation of uncertainty depends on the format of the parameter´s uncertainty, and may be combined using any of the following methods:

   i. In case the parameter uncertainty is defined as standard deviation of a measured parameter, it shall be converted into "standard uncertainty" before combining it. For a detailed description, refer to EURACHEM-CITAC Guide CG 4 (2012), section 8.2.

ii. In case the single parameter uncertainty is unknown, it is possible to estimate the uncertainty using the GHG Protocol guidance for "Quantitative Inventory Uncertainty"[46] This involves using the pedigree matrix approach based on qualitative indicators to compute the parameter's geometric standard deviation and propagating its uncertainty using a Taylor series expansion.

iii. In case the uncertainty values are presented as a percentage uncertainty, it may be combine according to IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006, 2019).

f. If applicable, the CO_2 Removal Supplier should take steps to improve the quantification of the inventory of GHG emissions and carbon removal based on the experience obtained from the previous steps with the aim of reducing the parameter uncertainty. This step should be designed in accordance with the Quality Control plan (section 10.5).

10.3.5. The CO_2 Removal Supplier shall report the combined percentage uncertainty "U" of the net removal activity in the CORC Report. The recommended reporting form follows:

(Result): (x ± U) (units)
Example: Carbon dioxide removed: 100 ± 0.05% tCO_2e

10.4. Sampling Procedures

These sampling procedures aim to assist the CO_2 Removal Supplier in obtaining a representative sample of e.g. biochar, biomass, or other products necessary to sample for demonstrating compliance with the methodology.

10.4.1. The CO_2 Removal Supplier shall determine the potential biomass feedstocks to sample according to the requirements of the Puro-approved Methodology.

10.4.2. If applicable, the CO_2 Removal Supplier shall prepare a complete sampling plan of the material sources (e.g., biomass feedstock, biochar).

a. The sampling plan may be developed in accordance with ISO 18135:2017 Solid Biofuels—Sampling;
b. Alternatively, the sampling plan may be developed in accordance with EN-12579 "Soil improvers and growing media - Sampling".
c. For biochar sampling, it may follow the representative sampling guidelines provided by the European Biochar Certificate v.10.4, Annex 4[47].
d. In case of bio-oil or other biomaterial, the CO_2 Removal Supplier shall provide evidence of following a relevant standard or guideline.

10.4.3. The sampling plan shall be prepared with a clear objective, such as quantifying carbon content or other relevant parameters.

[46] GHG Protocol Quantitative Uncertainty Guidance.
[47] EBC (2012-2024) 'European Biochar Certificate - Guidelines for a Sustainable Production of Biochar.' Carbon Standards International (CSI), Frick, Switzerland. Version 10.4 from 20th Dec 2024.

10.4.4. In the case of a new feedstock or feedstock supplier, the existing sampling plan shall be checked and updated accordingly, or a new full sampling plan shall be prepared. The new sampling plan shall be incorporated with the corresponding Output Report for verification by the third-party auditor.

10.4.5. A sampling plan may be used to prepare the corresponding sampling certificate. The certificate shall be made available to the third-party auditor.

10.5. Quality Control (QC) System and Procedures

10.5.1. The CO_2 Removal Supplier shall develop a quality control (QC) system that includes procedures to measure and control the GHG inventory's quality to calculate the net carbon removal that will be included in the Output Report. The QC system is designed to:

a. Ensure the data is presented in accordance with the principles described under ISO 14064-2, namely, relevance, completeness, consistency, accuracy, transparency, and conservativeness.
b. Identify and address errors and omissions.
c. Document and archive all inventory material and records in accordance with rule 9.3.4.

10.5.2. Information provided by the CO_2 Removal Supplier shall be verified by a third-party Auditor, who will provide quality assurance (QA) of the carbon removal activity's performance in accordance with the Puro Standard General Rules and the requirements set in this methodology.

10.5.3. The CO_2 Removal Supplier shall provide a quality control (QC) plan to be included in the Monitoring Plan. The plan shall include, at minimum:

a. Identify the parties involved in coordinating the implementation of the quality control procedures.
b. Define the quality control procedures.
c. Ensure availability and access to information on activity data and emission factors, including data quality and measurement uncertainty in accordance with the requirements for data collection (section 10.3).
d. Ensure confidentiality of inventory and source category information when required.
e. Define requirements for archiving information.
f. Define the frequency of QC checks on different parts of the inventory.

10.5.4. The CO_2 Removal Supplier should consider the feedback from the verification of the Output Report to:

a. Improve the estimates of emissions and/or removals.
b. Reassess inventory compilation processes and uncertainty estimates when required.

10.5.5. The QC procedures shall include, at minimum, the calibration of the measuring equipment. To this end,

a. All measurement devices shall be installed, operated, and calibrated according to the manufacturer's specifications or an appropriate industry consensus standard.

b. All measurement devices shall be calibrated to an accuracy of at least 5% (i.e. the calibration error of any measurement device shall not exceed 5%). Calibration records shall be made available for third-party verification.

c. This requirement does not apply to energy (heat, electricity, fuel) billing meters, provided that the energy supplier and the CO_2 Removal Supplier do not have any common owners and are not owned by subsidiaries or affiliates of the same company. The uncertainty level (qualitative approach) differs from the uncertainty level of the measurement approach.

10.5.6. The QC procedures should be specific to the parameters' requirements and summarized in a table for ease of reference (see Table 10.2).

11. Reporting Requirements

11.1. Output Report

11.1.1. The CO_2 Removal Supplier shall prepare and make available an Output Report to provide evidence of the Production Facility performance for the monitoring period covering the scope of monitoring described in section 9.1. The Output Report is a structured compilation of documents and data, based on templates provided by Puro.earth and other free-format documents and data. It can also contain updated documents from the Facility Audit, such as an updated monitoring plan, if changes to operations have taken place and need to be re-validated, as allowed under certain circumstances by the methodology. The Output Report is transmitted by the Issuing Body, after review, to the Auditor and serves as a basis for the performance verifications.

11.1.2. The CO_2 Removal Supplier must, in conformity with the Puro General Rules, submit the Output Report within the allowed timelines, promptly report any delays to the Issuing Body.

11.1.3. In case any non-conformity with the eligibility requirements and the validated design of the Production Facility is detected during a monitoring period, the CO_2 Removal Supplier shall:

a. Notify promptly the Issuing Body after detection of the situation
b. Develop a plan to solve the situation at the earliest possible
c. Demonstrate to the Issuing Body actions have been taken to resolve the situation at the earliest possible
d. Keep records and evidence of the resolution available for the next Output Audit.

11.1.4. Any delays in reporting (rule 11.1.2) or non-conformity situations (rule 11.1.3) may:

a. Impact the verification of the Output of the Production Facility and the corresponding CORC issuance for that period.
b. Require the Issuing Body to suspend the Production Facility in accordance with the Puro Standard General Rules.

11.1.5. The Output Report shall include supporting evidence for each monitoring element described in the Monitoring Plan, including the following:

a. **Production Facility and Supplier Information**: details as presented in the Project Description document, including the crediting period, type of carbon removal activity, and the methodology version followed.
b. **Report Details**: Date of the report and the monitoring period covered.
c. **CORC Report**: a CORC Report with supporting detailed calculations and evidence, based on the template provided by Puro.earth, and including the Public Summary for in the Public Registry. The CORC Report contains the total amount of CORCs the CO_2 Removal Supplier is reporting for verification.
d. **Uncertainty Statement**: describe uncertainties in the quantification, their impact on the CORC Report, and measures taken to minimize misrepresentation.

e. **Stakeholder engagement**: records of ongoing feedback and grievance provided by stakeholders and the state of resolution of any outstanding issues.
f. **Environmental and social impacts**: document any environmental and social impacts that may have occurred during the monitoring period and the corresponding actions taken by the CO_2 Removal Supplier to address the needs of the situation.
g. **Changes to Facility Audit documentation**: updated documents from the Facility Audit, such as an updated monitoring plan, if changes to operations have taken place during the monitoring period.

References

Adhikari, R. K., Falkowski, T. B., & Sloan, J. L. (2024). Identifying optimal locations for biochar production facilities to reduce wildfire risk and bolster rural economies: A New Mexico case study. *Forest Policy and Economics*, *169*, 103313. https://doi.org/10.1016/j.forpol.2024.103313

Ahmed, S. F., Mehejabin, F., Chowdhury, A. A., Almomani, F., Khan, N. A., Badruddin, I. A., & Kamangar, S. (2024). Biochar produced from waste-based feedstocks: Mechanisms, affecting factors, economy, utilization, challenges, and prospects. *GCB Bioenergy*, *16*(8), e13175. https://doi.org/10.1111/gcbb.13175

Allohverdi, T., Mohanty, A. K., Roy, P., & Misra, M. (2021). A Review on Current Status of Biochar Uses in Agriculture. *Molecules*, *26*(18), 5584. https://doi.org/10.3390/molecules26185584

Ascough, P. L., Bird, M. I., Brock, F., Higham, T. F. G., Meredith, W., Snape, C. E., & Vane, C. H. (2009). Hydropyrolysis as a new tool for radiocarbon pre-treatment and the quantification of black carbon. *Quaternary Geochronology*, *4*(2), 140–147. https://doi.org/10.1016/j.quageo.2008.11.001

Azzi, E. S., Karltun, E., & Sundberg, C. (2021). Assessing the diverse environmental effects of biochar systems: An evaluation framework. *Journal of Environmental Management*, *286*, 112154. https://doi.org/10.1016/j.jenvman.2021.112154

Azzi, E. S., Li, H., Cederlund, H., Karltun, E., & Sundberg, C. (2024). Modelling biochar long-term carbon storage in soil with harmonized analysis of decomposition data. *Geoderma*, *441*, 116761. https://doi.org/10.1016/j.geoderma.2023.116761

Azzi, E. S., Sundberg, C., Söderqvist, H., Källgren, T., Cederlund, H., & Li, H. (2023). *Guidelines for estimation of biochar durability: Background report* (Rapport (Institutionen För Energi Och Teknik, SLU)) [Rapport (Institutionen för energi och teknik, SLU)]. Department of Energy and Technology, Swedish University of Agricultural Sciences.

https://doi.org/10.54612/a.lkbuavb9qc

Bartoli, M., Giorcelli, M., Jagdale, P., Rovere, M., & Tagliaferro, A. (2020). A Review of Non-Soil Biochar Applications. *Materials*, *13*(2), 261. https://doi.org/10.3390/ma13020261

Belcher, C. M., New, S. L., Santín, C., Doerr, S. H., Dewhirst, R. A., Grosvenor, M. J., & Hudspith, V. A. (2018). What Can Charcoal Reflectance Tell Us About Energy Release in Wildfires and the Properties of Pyrogenic Carbon? *Frontiers in Earth Science*, *6*, 169. https://doi.org/10.3389/feart.2018.00169

Bird, M. I., Wynn, J. G., Saiz, G., Wurster, C. M., & McBeath, A. (2015). The Pyrogenic Carbon Cycle. *Annual Review of Earth and Planetary Sciences*, *43*(1), 273–298. https://doi.org/10.1146/annurev-earth-060614-105038

Budai, A., Zimmerman, A., Cowie, A., Webber, J. B. W., Singh, B. P., Glaser, B., Masiello, C. A., Andersson, D., Shields, F., Lehmann, J., & Camps-Arbestain, M. (2013). *Biochar Carbon Stability Test Method: An assessment of methods to determine biochar carbon stability.* (pp. 1–10). International Biochar Initiative.

Chiaramonti, D., Lotti, G., Vaccari, F. P., & Sanei, H. (2024). Assessment of long-lived Carbon permanence in agricultural soil: Unearthing 15 years-old biochar from long-term field experiment in vineyard. *Biomass and Bioenergy*, *191*, 107484. https://doi.org/10.1016/j.biombioe.2024.107484

Cowie, A., Azzi, E., Weng, Z. H., & Woolf, D. (2024). Biochar, greenhouse gas accounting, and climate change mitigation. In J. Lehmann & S. Joseph, *Biochar for Environmental Management* (3rd ed., pp. 759–784). Routledge. https://doi.org/10.4324/9781003297673-30

Drobniak, A., Mastalerz, M., Knauth, W., Adarkani, O., Dos Santos, T., De Faria, V., Congo, T., Hackley, P., Hatcherian, J., Hower, J., Petersen, H., Reyes, J., & Sanei, H. (2024). Atlas of Microscopic Images of Biochar: Using Reflected Light Microscopy in Biochar Characterization. *Indiana Journal of Earth Sciences*, *6*. https://doi.org/10.14434/ijes.v6i1.37623

Gabhane, J. W., Bhange, V. P., Patil, P. D., Bankar, S. T., & Kumar, S. (2020). Recent trends in biochar production methods and its application as a soil health conditioner: A review. *SN Applied Sciences*, *2*(7), 1307. https://doi.org/10.1007/s42452-020-3121-5

Glaser, B., & Birk, J. J. (2012). State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). *Geochimica et Cosmochimica Acta*, *82*, 39–51. https://doi.org/10.1016/j.gca.2010.11.029

Glaser, B., Guenther, M., Maennicke, H., & Bromm, T. (2021). Microwave-assisted combustion to produce benzene polycarboxylic acids as molecular markers for biochar identification and quantification. *Biochar*, *3*(4), 407–418. https://doi.org/10.1007/s42773-021-00124-z

Glaser, B., Haumaier, L., Guggenberger, G., & Zech, W. (1998). Black carbon in soils: The use of benzenecarboxylic acids as specific markers. *Organic Geochemistry*, *29*(4), 811–819. https://doi.org/10.1016/S0146-6380(98)00194-6

Glaser, B., Haumaier, L., Guggenberger, G., & Zech, W. (2001). The “Terra Preta” phenomenon: A model for sustainable agriculture in the humid tropics. *Naturwissenschaften*, *88*(1), 37–41. https://doi.org/10.1007/s001140000193

Harvey, O. R., Kuo, L.-J., Zimmerman, A. R., Louchouarn, P., Amonette, J. E., & Herbert, B. E. (2012). An Index-Based Approach to Assessing Recalcitrance and Soil Carbon Sequestration Potential of Engineered Black Carbons (Biochars). *Environmental Science & Technology*, *46*(3), 1415–1421. https://doi.org/10.1021/es2040398

Howell, A., Helmkamp, S., & Belmont, E. (2022). Stable polycyclic aromatic carbon (SPAC) formation in wildfire chars and engineered biochars. *Science of The Total Environment*, *849*, 157610. https://doi.org/10.1016/j.scitotenv.2022.157610

Ibitoye, S. E., Loha, C., Mahamood, R. M., Jen, T.-C., Alam, M., Sarkar, I., Das, P., & Akinlabi, E. T. (2024). An overview of biochar production techniques and application in iron and steel industries. *Bioresources and Bioprocessing*, *11*(1), 65.

https://doi.org/10.1186/s40643-024-00779-z

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change. https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Ippolito, J. A., Cui, L., Kammann, C., Wrage-Mönnig, N., Estavillo, J. M., Fuertes-Mendizabal, T., Cayuela, M. L., Sigua, G., Novak, J., Spokas, K., & Borchard, N. (2020). Feedstock choice, pyrolysis temperature and type influence biochar characteristics: A comprehensive meta-data analysis review. *Biochar*, *2*(4), 421–438. https://doi.org/10.1007/s42773-020-00067-x

Jung, S., Park, Y.-K., & Kwon, E. E. (2019). Strategic use of biochar for CO2 capture and sequestration. *Journal of CO2 Utilization*, *32*, 128–139. https://doi.org/10.1016/j.jcou.2019.04.012

Kwapinski, W., Byrne, C. M. P., Kryachko, E., Wolfram, P., Adley, C., Leahy, J. J., Novotny, E. H., & Hayes, M. H. B. (2010). Biochar from Biomass and Waste. *Waste and Biomass Valorization*, *1*(2), 177–189. https://doi.org/10.1007/s12649-010-9024-8

Lehmann, J. (2007). Bio-energy in the black. *Frontiers in Ecology and the Environment*, *5*(7), 381–387. https://doi.org/10.1890/1540-9295(2007)5[381:BITB]2.0.CO;2

Lehmann, J., Cowie, A., Masiello, C. A., Kammann, C., Woolf, D., Amonette, J. E., Cayuela, M. L., Camps-Arbestain, M., & Whitman, T. (2021). Biochar in climate change mitigation. *Nature Geoscience*, *14*(12), 883–892. https://doi.org/10.1038/s41561-021-00852-8

Lehmann, J., & Joseph, S. (2024). *Biochar for Environmental Management: Science, Technology and Implementation* (3rd ed.). Routledge. https://doi.org/10.4324/9781003297673

Lembrechts, J. J., Van Den Hoogen, J., Aalto, J., Ashcroft, M. B., De Frenne, P., Kemppinen, J., Kopecký, M., Luoto, M., Maclean, I. M. D., Crowther, T. W., Bailey, J. J., Haesen, S., Klinges,

D. H., Niittynen, P., Scheffers, B. R., Van Meerbeek, K., Aartsma, P., Abdalaze, O., Abedi, M., … Lenoir, J. (2022). Global maps of soil temperature. *Global Change Biology*, *28*(9), 3110–3144. https://doi.org/10.1111/gcb.16060

Li, H., Azzi, E. S., Sundberg, C., Karltun, E., & Cederlund, H. (2024). Can inert pool models improve predictions of biochar long-term persistence in soils? *Geoderma*, *452*, 117093. https://doi.org/10.1016/j.geoderma.2024.117093

Li, L., Long, A., Fossum, B., & Kaiser, M. (2023). Effects of pyrolysis temperature and feedstock type on biochar characteristics pertinent to soil carbon and soil health: A meta-analysis. *Soil Use and Management*, *39*(1), 43–52. https://doi.org/10.1111/sum.12848

Liu, C., Oshita, K., Takaoka, M., & Fukutani, S. (2021). Behaviour of Fossil and Biogenic Carbon in Sewage Sludge Treatment Processes and Their Impacts on Greenhouse Gas Emissions. *Chemical Engineering Transactions*, *89*, 97–102. https://doi.org/10.3303/CET2189017

Liu, Y., Lonappan, L., Brar, S. K., & Yang, S. (2018). Impact of biochar amendment in agricultural soils on the sorption, desorption, and degradation of pesticides: A review. *Science of The Total Environment*, *645*, 60–70. https://doi.org/10.1016/j.scitotenv.2018.07.099

Mastalerz, M., Drobniak, A., Briggs, D., & Bradburn, J. (2023). Variations in microscopic properties of biomass char: Implications for biochar characterization. *International Journal of Coal Geology*, *271*, 104235. https://doi.org/10.1016/j.coal.2023.104235

McBeath, A. V., Wurster, C. M., & Bird, M. I. (2015). Influence of feedstock properties and pyrolysis conditions on biochar carbon stability as determined by hydrogen pyrolysis. *Biomass and Bioenergy*, *73*, 155–173. https://doi.org/10.1016/j.biombioe.2014.12.022

Moško, J., Pohořelý, M., Cajthaml, T., Jeremiáš, M., Robles-Aguilar, A. A., Skoblia, S., Beňo, Z., Innemanová, P., Linhartová, L., Michalíková, K., & Meers, E. (2021). Effect of pyrolysis temperature on removal of organic pollutants present in anaerobically stabilized sewage sludge. *Chemosphere*, *265*, 129082. https://doi.org/10.1016/j.chemosphere.2020.129082

Petersen, H. I., Lassen, L., Rudra, A., Nguyen, L. X., Do, P. T. M., & Sanei, H. (2023). Carbon stability and morphotype composition of biochars from feedstocks in the Mekong Delta, Vietnam. *International Journal of Coal Geology*, *271*, 104233. https://doi.org/10.1016/j.coal.2023.104233

Puettmann, M., Sahoo, K., Wilson, K., & Oneil, E. (2020). Life cycle assessment of biochar produced from forest residues using portable systems. *Journal of Cleaner Production*, *250*, 119564. https://doi.org/10.1016/j.jclepro.2019.119564

Rex, P., Mohammed Ismail, K., Meenakshisundaram, N., Barmavatu, P., & Sai Bharadwaj, A. (2023). Agricultural Biomass Waste to Biochar: A Review on Biochar Applications Using Machine Learning Approach and Circular Economy. *ChemEngineering*, *7*(3), 50. https://doi.org/10.3390/chemengineering7030050

Rodrigues, L., Budai, A., Elsgaard, L., Hardy, B., Keel, S. G., Mondini, C., Plaza, C., & Leifeld, J. (2023). The importance of biochar quality and pyrolysis yield for soil carbon sequestration in practice. *European Journal of Soil Science*, *74*(4), e13396. https://doi.org/10.1111/ejss.13396

Rondón-Quintana, H. A., Reyes-Lizcano, F. A., Chaves-Pabón, S. B., Bastidas-Martínez, J. G., & Zafra-Mejía, C. A. (2022). Use of Biochar in Asphalts: Review. *Sustainability*, *14*(8), 4745. https://doi.org/10.3390/su14084745

Ross, J. J., Zitomer, D. H., Miller, T. R., Weirich, C. A., & McNamara, P. J. (2016). Emerging investigators series: Pyrolysis removes common microconstituents triclocarban, triclosan, and nonylphenol from biosolids. *Environ. Sci.: Water Res. Technol.*, *2*(2), 282–289. https://doi.org/10.1039/C5EW00229J

Safarian, S. (2023). To what extent could biochar replace coal and coke in steel industries? *Fuel*, *339*, 127401. https://doi.org/10.1016/j.fuel.2023.127401

Sanei, H., Petersen, H. I., Chiaramonti, D., & Masek, O. (2025). Evaluating the two-pool decay model for biochar carbon permanence. *Biochar*, *7*(1), 9.

https://doi.org/10.1007/s42773-024-00408-0

Sanei, H., Rudra, A., Przyswitt, Z. M. M., Kousted, S., Sindlev, M. B., Zheng, X., Nielsen, S. B., & Petersen, H. I. (2024). Assessing biochar's permanence: An inertinite benchmark. *International Journal of Coal Geology*, *281*, 104409. https://doi.org/10.1016/j.coal.2023.104409

Santín, C., Doerr, S. H., Merino, A., Bucheli, T. D., Bryant, R., Ascough, P., Gao, X., & Masiello, C. A. (2017). Carbon sequestration potential and physicochemical properties differ between wildfire charcoals and slow-pyrolysis biochars. *Scientific Reports*, *7*(1), 11233. https://doi.org/10.1038/s41598-017-10455-2

Singh, B. P., Cowie, A. L., & Smernik, R. J. (2012). Biochar Carbon Stability in a Clayey Soil As a Function of Feedstock and Pyrolysis Temperature. *Environmental Science & Technology*, *46*(21), 11770–11778. https://doi.org/10.1021/es302545b

Spokas, K. A. (2010). Review of the stability of biochar in soils: Predictability of O:C molar ratios. *Carbon Management*, *1*(2), 289–303. https://doi.org/10.4155/cmt.10.32

Sundberg, C., & Azzi, E. (2024). Biochar sustainability. In J. Lehmann & S. Joseph, *Biochar for Environmental Management* (3rd ed., pp. 785–804). Routledge. https://doi.org/10.4324/9781003297673-31

Wang, L., Deng, J., Yang, X., Hou, R., & Hou, D. (2023). Role of biochar toward carbon neutrality. *Carbon Research*, *2*(1), 2. https://doi.org/10.1007/s44246-023-00035-7

Woolf, D., Lehmann, J., Ogle, S., Kishimoto-Mo, A. W., McConkey, B., & Baldock, J. (2021). Greenhouse Gas Inventory Model for Biochar Additions to Soil. *Environmental Science & Technology*, *55*(21), 14795–14805. https://doi.org/10.1021/acs.est.1c02425

Yaashikaa, P. R., Kumar, P. S., Varjani, S., & Saravanan, A. (2020). A critical review on the biochar production techniques, characterization, stability and applications for circular bioeconomy. *Biotechnology Reports*, *28*, e00570. https://doi.org/10.1016/j.btre.2020.e00570

Zhao, L., Cao, X., Mašek, O., & Zimmerman, A. (2013). Heterogeneity of biochar properties as a function of feedstock sources and production temperatures. *Journal of Hazardous Materials*, *256–257*, 1–9. https://doi.org/10.1016/j.jhazmat.2013.04.015

Zimmerman, A. R. (2010). Abiotic and Microbial Oxidation of Laboratory-Produced Black Carbon (Biochar). *Environmental Science & Technology*, *44*(4), 1295–1301. https://doi.org/10.1021/es903140c