Gold Standard for the Global Goals

METHODOLOGY

GS4GG PAA M400-16

SDG 13

SUPPLEMENTARY INFORMATION

PRODUCTION AND APPLICATION FOR THE REMOVAL OF CARBON VIA BIOCHAR (PARC)

Publication Date: 02/11/2026

Version: 1.0

Next Planned Update: 02/11/2029

SUMMARY

This Supplementary Information is a public document. It records how the design decisions of the PARC methodology were made, derives every adopted value from cited evidence, and states where the evidence is thin. It contains no normative rules; the methodology text governs.

PARC quantifies carbon dioxide removals from the production of biochar and its placement in a durable sink: soil, an engineered mineral material, or a sealed anoxic vault.

The methodology offers three compliance tracks set the monitoring burden to the scale of the production unit, and with a common quantification engine that every track runs through. The methodology credits only the fraction of the biochar carbon expected to remain in the sink after 200 years, at a one-sided 95 per cent lower confidence bound on the decay evidence. It deducts every emission the activity causes, including the methane that open kilns can release, the embodied emissions of the production unit, and the soil carbon and nutrients forgone when field residue is removed. It admits an activity only where the carbon stored is at least five times the emissions of producing it. It closes with an uncertainty deduction, a reversal-risk deduction settled by buffer deposit or cancellation, and the downward ambition adjustment of the host country. Where the methodology provides a default, the default sits at the tenth percentile of the published evidence or beyond, and a measured route is open to any developer who can do better.

A calculation tool accompanies the methodology. It runs eight hypothetical scenarios across the three tracks, the three sinks and the main feedstock modules over ten annual monitoring periods, and shows where the carbon of each tonne of biochar goes.

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1.| Section 1: Context

1.1.| Biochar and the case for methodology

Biochar is the solid carbon that remains when biomass is heated above about 450^0C with little or no oxygen. Most of the carbon in the original biomass would have returned to the atmosphere within a few years through decay or burning. In biochar it is converted to condensed aromatic structures that soil organisms cannot easily break down, and a large fraction persists for centuries. The practice is old, the chemistry is well characterised, and the technology spans a wider range of scales than any other engineered removal: a conical steel kiln that a farmer group can afford sits at one end, a continuous plant processing hundreds of tonnes a day at the other.

A crediting framework for this activity should address three things at once. It has to credit the persistence of the carbon and only that, net of every emission the activity causes. It has to set its monitoring burden to the scale of the producer, so that the smallholder network is included and the industrial plant is verified to the standard its data allow. And it has to resist the two ways a biochar claim can go wrong: methane that escapes an open kiln, and biochar that is diverted to fuel after it has been credited. PARC is built around these three requirements.

1.2.| What is credited

The methodology credits the fraction of the biochar carbon expected to remain in a sink after 200 years, net of the activity's emissions. It does not credit the emissions avoided by not burning or not decaying the biomass, nor any soil-health or yield benefit. Those effects are real and may be described, but a removal credit is a claim that carbon was taken from the atmosphere and kept there, and the methodology confines itself to that claim.

The claim is made on the organic carbon in the biochar, measured or defaulted, multiplied by a permanence factor that depends on the stability of the biochar and the temperature of the soil it enters. For engineered materials and anoxic vaults, which isolate the carbon from biological oxidation, a fixed factor applies. The carbon placed in the sink is the gross removal; everything after that is a deduction.

1.3.| Design in outline

Six choices define the methodology.

a.| First, three compliance tracks assign an activity by the input capacity of its production units: below one tonne of dry biomass per day (Track 1), one to fifteen tonnes (Track 2), and above fifteen tonnes (Track 3). Track 1 allows conservative standardised defaults, composite sampling and a fixed cancellation in place of a monitored buffer. Track 2 requires direct weighing and admits a thermal proxy for methane. Track 3 requires continuous emissions monitoring and batch-specific analysis. An activity may move to a higher-rigour track during a crediting period, never to a lower one.

b.| Second, the crediting baseline is zero. No fate of residue biomass forms durable carbon, so there is no baseline removal to deduct. The zero is made a condition of eligibility: feedstock whose carbon would have persisted for ten years or more is excluded rather than credited against a positive baseline.

c.| Third, the permanence factor is a one-sided 95 per cent lower confidence bound on a decay model fitted to the published incubation evidence, tabulated by soil temperature and by the hydrogen-to-organic-carbon ratio of the biochar. It is derived in Annex A and reproducible from the coefficients in Annex C.

d.| Fourth, every emission the activity causes is deducted, with methane from production treated as the one source that may never be omitted on materiality grounds. Field residue carries a deduction for the soil carbon and nutrients it would have returned, conditioned on what would otherwise have happened to it.

e.| Fifth, an efficiency check admits a monitoring period only where the carbon stored in the biochar placed is at least five times the activity emissions of producing and placing it.

f.| Sixth, the issuance chain closes with an uncertainty deduction set to the track, a reversal-risk deduction or buffer contribution set to the sink, and the downward adjustment published for the host country.

1.4.| Eligibility conditions

Section 3 of the methodology sets conditions on the product, the process and the sink.

a.| **On the product:** The molar hydrogen-to-organic-carbon ratio of the biochar shall be at most 0.5, because the ratio is the best single indicator of the

aromatic condensation that confers persistence and the 200-year decay model is calibrated only up to that value. Under Track 1 the limit is 0.4, because the ratio is not measured per batch and the default must cover the whole network. Biochar with a ratio between 0.5 and 0.7 is creditable only where inertinite petrography demonstrates the durable fraction directly, because above 0.5 the decay model no longer applies.

b.| **On the process**: A minimum carbonisation temperature of 450 °C applies, below which the product is torrefied biomass rather than biochar. No fossil fuel may sustain the reaction in any track, and none may be used at any stage under Track 1. No mineral additive counts in the credited mass.

c.| **On the sink**: Every credited batch requires proof of placement. The net carbon efficiency ratio, the carbon stored in the biochar placed divided by the activity emissions of the period, shall be at least 5, so that the production footprint is at most a fifth of the removal.

d.| **Two exclusions**: Activated carbon and metallurgical coke are carbon-rich solids made by the same chemistry, but they are made to be consumed, in filtration and in furnaces, and their carbon returns to the atmosphere within years. A facility making both biochar and such products credits only the biochar and carries the full upstream and processing emissions of the ineligible product as well, because allocating emissions between products by mass or value would understate the footprint of the credited one.

1.5.| Safeguards

The safeguards of Section 3.4 of the methodology address four risks specific to biochar.

a.| **Soil contamination:** Biochar applied to soil meets the heavy-metal and polycyclic-aromatic-hydrocarbon limits of recognised biochar quality standards, with dioxin and PCB testing where the production temperature or the feedstock makes their formation possible. Contaminated biochar is routed to non-soil sinks rather than discarded. Biochar from biosolids, manure, digestate or municipal waste goes to soil only where an accredited laboratory has shown its per- and polyfluoroalkyl substances to be below the host-country limit for soil amendments; the 600^0C pathogen-destruction condition does not establish that these substances are destroyed, and the methodology does not claim that it does.

b.| **Agronomic harm**: Application is capped at 50 tonnes of dry biochar per hectare per application, because higher rates can raise soil pH and immobilise nitrogen. Certified remediation sites are exempt where a qualified professional verifies that the elevated rate safely immobilises the contaminants.

c.| **Worker and community health**: Open kilns are operated outdoors, and the training of Annex 2 covers smoke, dust and burns.

d.| **Diversion**: Biochar has fuel value. The proof-of-placement, sentinel-inspection and aggregator-liability provisions exist to keep it in the sink; Section 8.6 of this document explains them.

1.6.| Scale, de-bundling and start date

Track 1 is capped at 60,000 tonnes of carbon dioxide equivalent per year for each standalone activity or VPA. Two or more activities under common beneficial ownership or operational control are assessed together as one activity for the cap where they share an aggregation hub or production site, lie within one kilometre of each other, or started within two years of each other. The criteria follow the de-bundling requirements. Distinct beneficial owners who each control their own units and biochar are not grouped merely because they share an aggregator, a training provider or a programme. Disclosure of ownership, control and neighbouring activities is required at validation, at inclusion and at every verification; a withheld disclosure is treated as if the activities had been grouped from the start.

The start date of the crediting period is the start of operations or, at most, two years before design certification. The activity start date follows the Gold Standard rule update on the start date of engineered-removal activities, under which an activity may be submitted for preliminary review within three years of its start.

2.| Section 2: Baseline setting

2.1.| Choosing the baseline approach

Paragraph 36 of the Article 6.4 Rules, Modalities and Procedures permits three baseline approaches: best available technologies, an ambitious benchmark, and existing actual or historical emissions adjusted downwards. The first two presuppose a baseline practice of durable carbon storage that can be benchmarked. No such practice exists for residue biomass. The methodology therefore applies the third approach, under Section 8.4 of the Gold Standard baseline standard, and the existing practice it describes is one in which no durable removal occurs.

2.2.| Zero baseline as a condition

A crediting baseline describes what would have happened to the removal in the absence of the activity. For biochar the answer is that no durable removal would have happened. Residue left in the field, piled, composted or burned returns its carbon to the atmosphere within a few years; none of these fates forms pyrogenic carbon. The methodology sets the unadjusted baseline removal at zero for every feedstock module (Equation 1).

The zero is a condition, not only an assumption. Annex 8 of the methodology requires each feedstock to pass a decay test: its realistic alternative fate must return the carbon to the atmosphere within ten years. Feedstock that would have persisted, such as standing biomass, large woody debris and durable wood products, is excluded rather than credited against a positive baseline. This is why the methodology provides no method for quantifying a positive baseline removal: any feedstock for which one would be needed is ineligible. Section 3.1 of this document sets out the decay classes.

2.3.| Downward adjustment

Every Gold Standard methodology lowers its baseline for uncertainty and for host-country ambition. Because the baseline removal is exactly zero, it has no uncertainty to adjust; all measurement uncertainty attaches to the activity side and is handled there (Section 7 of this document). The ambition adjustment cannot lower a zero baseline either, so it is applied instead as a deduction from net removals at issuance (Equation 28), at the rate the Gold Standard downward adjustment tool publishes for the host country and period. The effect is identical to raising the baseline above zero by that share of the removal, and the deduction is the host country's contribution.

2.4.| Business-as-usual screen

The baseline standard also requires a comparison with a conservative business-as-usual case. For biochar the only business-as-usual removal that could exist is one required by law: a jurisdiction that mandated the conversion of residue into biochar and its application to soil. The methodology provides for the case (Equations 3 and 4). Where such a mandate exists and is enforced, the activity is not additional and is ineligible. Where it exists but is partly enforced, the mandated volume, scaled by an enforcement factor, is deducted as the crediting baseline. Where it exists but is systematically disregarded, a developer outside a high-income country may show that non-compliance exceeds half of the regulated population and proceed; in a high-income country every legal requirement is treated as enforced and this route is not available. Laws that ban open burning or regulate residue disposal do not bear on the removal baseline, because they govern the fate of the biomass, not the formation of durable carbon, and the methodology credits no avoided emission from that fate.

3.| Section 3: Feedstock, surplus and leakage

3.1.| Decay test and the residue decay classes

Annex 8 of the methodology makes the zero baseline a condition of eligibility: a feedstock whose realistic alternative fate would retain its carbon for ten years or more is ineligible. The ten-year horizon is chosen because it separates the residue classes cleanly. Fine herbaceous residue, such as straw, stover, husk, leaves and fine prunings, decays in the field or in a pile within two to three years under any climate. Coarse processing residue, such as bagasse, shells and fibre, decays within five. Small-diameter woody debris decays within ten years in warm or humid climates but may persist longer in cold or dry ones, and so requires a climate-specific demonstration. Large-diameter woody debris and logs commonly persist beyond ten years and are presumptively durable. Table 30 of the methodology assigns each class accordingly. The diameter that separates small from large woody debris is 10 cm, which is also the thinning limit for wildfire feedstock under Module F4.

3.2.| Surplus test

A residue is surplus only if diverting it to the activity displaces no existing use. Annex 8 tests this in three steps. The existing-use screen asks whether the feedstock is used for fuel, fodder, bedding, composting, mulching or any material purpose; a positive market price is taken as evidence that it is. The supply-shed headroom test asks whether the activity's demand, together with all other registered demand in the shed, exceeds the verifiable surplus. A feedstock that fails is excluded, or carries the market-leakage deduction of Section 10.5 of the methodology. The test is repeated at each renewal, because residue markets change.

3.3.| Residue retention floor

Removing crop residue from a field removes the organic matter that protects the soil surface, feeds soil organic carbon and returns nutrients. Annex 8 sets a default floor of 70 per cent of the residue, by dry mass, to be retained on the field, so that at most 30 per cent may be removed. Blanco-Canqui and Lal (2009), reviewing the field evidence on residue removal, find that removal rates above about 25 to 30 per cent reduce soil organic carbon and increase erosion in most cropping systems, and that higher rates are tolerable only on flat, fine-textured, high-residue land. The 30 per cent limit is set at the lower end of that range.

Above the default floor the methodology does not tabulate retention rates by slope and soil texture. The field evidence supports the direction of the adjustment but not a set of rates that could be applied without site knowledge. On land with a slope above 8 per cent, on sandy or coarse-textured soils, or where the national soil authority classifies the field as erosion-prone, the default floor does not apply: the retention rate is set by a site-specific agronomic assessment, from the national extension recommendation for the crop and soil or by a qualified agronomist, and is at least 70 per cent in every case.

3.4.| Ecological leakage and the alternative fate

Residue removed from a field within the retention floor still carries nutrients off the field and forgoes the soil carbon it would have formed. Section 10.6 of the methodology deducts both: the emissions of replacing the exported nitrogen, phosphorus and potassium with synthetic fertiliser, and the foregone soil organic carbon. The deduction is calculated with Equation 23a of the methodology: the dry mass of residue removed, multiplied by its nutrient contents and the replacement factors, plus the foregone-soil-carbon factor, with each component switched on or off by the alternative fate. Track 3 activities measure the nutrient content of the residue they export; Track 1 and Track 2 activities apply the default contents of Table 31a. The factors are set out in Tables 31 and 31a of the methodology and derived in Annex B of this document.

The deduction is conditioned on the alternative fate of the residue determined under Annex 8, because the components exist only where the counterfactual would have delivered them. Where the residue would have been retained on or incorporated into the field, the foregone-soil-carbon component and the nitrogen, phosphorus and potassium components all apply. Where it would have been burned on the field, the carbon and the nitrogen would have been lost to the atmosphere in any case, and only the phosphorus and potassium components apply. Where it would have been removed from the field and dumped, piled or burned elsewhere, nothing would have been returned to the soil, and no ecological-leakage deduction applies. The fate is evidenced and verified under Annex 8.

Where the biochar is returned to the same field, the phosphorus and potassium components are waived in proportion to the mass returned, because these nutrients are retained in biochar. The nitrogen component is retained in full, because nitrogen is largely volatilised in pyrolysis. The foregone-carbon component is retained, because the carbon in the biochar is credited as the removal and cannot also be counted as replacing soil carbon.

The foregone-soil-carbon factor is charged once per tonne of residue removed, as a foregone stock. It is not charged annually: the residue removed in one year would have formed its stable soil carbon once, and a further year of removal is a further tonne, charged in that year.

Two consequences follow, and the calculation tool shows both. A field-residue activity whose residue would have stayed in the soil is net-negative at any plausible carbon content: the foregone soil carbon and the nitrogen replacement exceed the removal. That is the methodology's position: removing residue that would have fed the soil is not a removal. A field-residue activity whose residue would have been burned in the field, which is the common fate of stover and straw in many regions, credits normally.

3.5.| Market leakage

Where a feedstock fails the surplus test because it has an existing use, Section 10.5 of the methodology deducts the emissions of the resource that replaces it. The default factors in Table 12 of the methodology are derived in Annex B from the energy content of the biomass displaced and the emission factor of the fuel that replaces it, using the net calorific values and emission factors of the 2006 IPCC Guidelines.

Two results follow. A tonne of woody biomass that was burning in a boiler or kiln and is replaced by coal or by wood from a non-renewable source carries a leakage deduction of 1.75 tonnes of carbon dioxide equivalent, which exceeds the gross removal from the biochar that tonne would make. Biomass with an industrial fuel use therefore cannot be diverted to biochar at a net removal, and the surplus test, not the deduction, is the operative safeguard. Household cooking fuel replaced by liquefied petroleum gas carries a much smaller deduction, because a traditional biomass stove delivers a small fraction of the fuel's energy as useful heat and the gas that replaces that heat is correspondingly little. No default is provided for fodder, bedding or mulch: the replacement product and its footprint vary too widely for a single factor, and an activity using such a feedstock quantifies the replacement by the site-specific route.

3.6.| Feedstock-storage methane

Wet biomass stored in piles before processing heats, decays and can emit methane from anaerobic pockets. Section 9.3 of the methodology requires this emission to be quantified where it occurs and provides a default rate of 0.13 per cent of the stored carbon per month as methane, applied to each month of storage beyond

the first. The emission is zero where storage is one month or less, feedstock moisture is 30 per cent or less, the material is coarse woody matter above 10 cm, the feedstock is pelletised, or storage conditions are unchanged from the counterfactual.

The default is the product of two measured quantities: the rate at which a wet pile loses carbon, and the share of that carbon which leaves as methane rather than carbon dioxide. The most complete field measurements on wet plant-residue piles are the two willow-chip heap trials of Whittaker et al. (2016a): a heap on hard standing lost 21 per cent of its dry matter in 97 days, about 6.5 per cent per month, and a heap on grassland lost 18 per cent over 210 days, about 2.6 per cent per month. In the same heaps the carbon dioxide to methane ratio at the methane peak was 40 to 1 by volume, which puts methane at about 2.4 per cent of the carbon emitted at the moment of highest methane production; carbon dioxide readings at that time were off scale, so the true share is lower. The authors note that the heap environment is not favourable to methanogens, against the 3 to 2 ratio of anaerobic digestion. The wider literature collated by Whittaker et al. (2016b) places generic wood-chip losses at 1 to 2 per cent per month, forest-residue heaps at 0.6 to 2.1 per cent, and the hypothesised methane conversion of Wihersaari (2005) at 1.5 per cent of carbon over the first two months of storage.

Applying the 2.4 per cent methane share to the most active heap gives 0.16 per cent of the stored carbon per month; applying it to the longer-stored heap gives 0.06 per cent. The default of 0.13 per cent sits in the upper half of this range. It is applied from the second month because the methane peak in the measured heaps occurred at seven to eight weeks, and the exemptions correspond to the conditions under which the measured heaps did not form anaerobic pockets. Over a three-month storage the default amounts to 0.26 per cent of the stored carbon as methane, or about 0.7 per cent of the stored carbon as a carbon-dioxide-equivalent deduction at a global warming potential of 28.

The measurements behind the rate are on chipped wood and herbaceous plant residue. They do not describe manure, digestate or sewage-sludge piles, in which methane generation is governed by the manure-management conversion factors of the IPCC Guidelines and can be an order of magnitude higher per tonne of carbon. The methodology therefore requires Module F6 feedstock stored wet before pyrolysis to be quantified under the activity-specific route with the IPCC methane conversion factor for the storage system, in place of the default.

3.7.| Land-use reference date

Annex 1 of the methodology excludes biomass from land converted from forest or from another natural ecosystem after 31 December 2020. The date is that of Regulation (EU) 2023/1115 on deforestation-free products. The methodology adopts it so that feedstock eligible under the methodology is eligible under the regulation, and so that developers and verifiers can use the satellite baselines and traceability systems already built for it.

4.| Section 4: Removal quantification

4.1.| Quantities credited

Equation 5 of the methodology credits, for each batch, the wet mass of biochar placed, converted to dry mass, multiplied by its organic carbon content, by the permanence factor, by one less the application loss, and by the stoichiometric ratio of carbon dioxide to carbon, with the uncertainty deduction of the track applied to the sum. Each term has a measured route and, under Track 1, a default. This section explains the permanence factor and the defaults; Section 7 explains the uncertainty deduction.

4.2.| Permanence factor

The permanence factor is the fraction of the organic carbon in a biochar that is expected to remain in the soil 200 years after application. It depends on two things: how reactive the biochar is, measured by its molar hydrogen-to-organic-carbon ratio, and how warm the soil is, measured by the mean annual soil temperature at the application site. A lower ratio means more aromatic, more stable carbon. Warmer soil means faster decay.

The factor is a one-sided 95 per cent lower confidence bound on the fitted relationship. The credited fraction is set so that there is at most a 5 per cent chance that the true mean fraction is lower. The deduction from the central estimate is the methodology's margin against the uncertainty of extrapolating laboratory incubations to 200 years.

The methodology provides three methods. Method 1 is the 200-year soil decay model, which applies to Module A1 and supplies Table 24 of Annex 6. Method 2 is the inertinite route, which applies where a 1,000-year claim is made or where the ratio lies between 0.5 and 0.7. Method 3 is the fixed factor for engineered materials and anoxic storage.

4.3.| Method 1 in outline

Method 1 is derived in full in Annex A and reproducible from the coefficients in Annex C. In outline: 65 incubation observations from 11 studies in the harmonised dataset of Azzi et al. (2024) are each fitted with the power-law decay model of Zimmerman (2010), which credits no permanently inert pool; each fitted curve is corrected from its incubation temperature to the site soil temperature with the temperature response of Woolf et al. (2021); the corrected 200-year fraction is regressed on the hydrogen-to-organic-carbon ratio at each site temperature from 7

to 40 °C, with observations that mineralise completely treated as censored; the coefficients are smoothed across temperature; and the variance is estimated with a cluster-robust estimator, because observations from one study are not independent. The credited factor at each tabulated ratio and temperature is the fitted mean less 1.645 standard errors.

Four properties of Table 24 follow from the derivation are set as the factor falls as the ratio rises and as the soil warms, at every cell. The table applies over ratios from 0.20 to 0.50; biochar below 0.20 is credited at the 0.20 column, which is conservative because permanence rises as the ratio falls. Rows above 32^0C lie beyond the incubation evidence and are marked as such. The reference cell for the Track 1 default route, 25^0C and a ratio of 0.40, gives 0.754.

4.4.| 4Method 2: the inertinite route

Method 2 credits the fraction of biochar carbon that has the structural characteristics of inertinite, the maceral group in coal that persists over geological time. Sanei et al. (2024) showed that biochar carbon with a mean random reflectance of 2 per cent or more has these characteristics, and that the fraction of a biochar passing this benchmark can be measured by petrography under oil immersion following ISO 7404-5 or ASTM D2798. Sanei et al. (2025) refined the method so that only the recalcitrant carbon is counted: the thermally reactive fraction, determined by thermogravimetric analysis, is excluded before the reflectance fraction is applied.

The methodology credits this fraction conservatively (Equation 8). Both the inertinite fraction and the non-reactive carbon fraction are taken at their mean less one sample standard deviation across at least three replicate samples of at least 500 reflectance measurements, and the product is capped at 0.95. Because inertinite is insensitive to soil temperature, no temperature correction applies. Method 2 is available to Tracks 2 and 3. It is the only route for biochar with a ratio between 0.5 and 0.7, because the Method 1 relationship is not calibrated above 0.5, and for any 1,000-year claim.

4.5.| Method 3: engineered materials and anoxic storage

Biochar encapsulated in an inert mineral, cementitious or bituminous matrix (Module A2), or sealed in a dedicated anoxic earth vault (Module A3), is isolated from the biological oxidation that drives decay in soil. Both modules apply a fixed factor of 0.95.

The value of 0.95 is the ceiling applied to the carbon itself under Methods 1 and 2. No pathway in the methodology credits more than 95 per cent of the organic carbon, because some loss of the labile fraction is expected in every environment and a factor of 1.00 would assert zero loss over the durability period. A single ceiling keeps the three methods consistent: encapsulation or anoxic burial removes the temperature-dependent decay of Method 1 but does not remove the physical limit. No 1,000-year claim is available under Module A2; the evidence base for the end-of-life fate of built materials over that period does not yet support one. Where a soil sink is available, the methodology prefers it over Module A3, because the agronomic value of the biochar is realised there; the vault is for biochar that cannot go to soil.

The factor is conditional on the physical-integrity safeguards of Section 12 of the methodology. If a vault cap is breached and not repaired within 30 days, Module A3 reverts to the Method 1 value at the site temperature and the difference is treated as a reversal.

4.6.| Track 1 default soil temperature

Track 1 activities may apply a default mean annual soil temperature of 25^0 C without site measurement. The value is set above the global mean cropland soil temperature so that a Track 1 activity with no site data is placed on a conservative point of the permanence curve. At 25^0C the Track 1 factor at a ratio of 0.40 is 0.754; at a temperate 15^0C it would be 0.798.

The quantity is the annual mean at 0 to 30 cm depth, integrated across seasons and across day and night. In active agricultural settings the topsoil is cooled by crop-canopy shading and by evaporation from rainfall and irrigation, so the sub-surface annual mean is lower than surface temperatures suggest. A sustained 30^0C at 30 cm depth occurs almost only in hyper-arid, unvegetated land where crop residues are not produced. A Track 1 activity that evidences a lower site temperature from a recognised gridded dataset may use the corresponding row of Table 24.

4.7.| Organic carbon defaults

The organic carbon content of biochar depends mainly on the feedstock and the production temperature. Woody and nut-shell feedstocks give carbon-rich biochar; herbaceous feedstock gives less; rice husk, manure and biosolids give ash-rich biochar in which the carbon is diluted by silica or mineral matter. The 2019 Refinement to the IPCC Guidelines compiles organic carbon content by feedstock class for pyrolysis, as a mean with a 95 per cent confidence limit. Annex B

reproduces the values and derives the tenth percentile of each, treating the limit as symmetric and normal. The defaults of Table 21 of the methodology are the tenth percentiles rounded down to the nearest 0.05: 0.55 for woody biomass and for nut shells, 0.45 for herbaceous residue, 0.35 for rice husk, and 0.25 for manure and biosolids.

The IPCC distributions span all pyrolysis temperatures, including low-temperature char that the methodology excludes under its 450^0C minimum and its ratio limit. The defaults are therefore somewhat lower than the typical value for compliant Track 1 biochar, which is the intended direction. Mixed feedstock takes the default of its lowest-carbon component unless the blend composition is documented to within 10 per cent by dry mass, in which case the dry-mass-weighted mean applies.

4.8.| Biochar yield

The yield default converts weighed biochar output to the dry biomass input where the input cannot be weighed, for the purpose of quantifying leakage (Equation 6). A lower yield gives a larger back-calculated input and a larger leakage deduction, so the conservative direction is downward. The route is open to processing residues and to Modules F3 and F4. It is not open to field residue: the ecological-leakage deduction is charged per tonne of residue removed, and at a yield set low enough to be conservative that deduction, charged on a back-calculated mass, would exceed the removal it is netted against. Field residue is therefore weighed at the collection point, on the same hanging scale the activity already uses for biochar, and leakage is charged on the weighed mass.

Field measurements of flame-curtain kilns on woody and shrub feedstock give a yield of 22 ± 5 per cent on a dry-weight basis across 17 runs, with a range of 13 to 32 per cent (Cornelissen et al., 2016). The tenth percentile is 15.6 per cent, and the default for every Track 1 class is set at 0.15, on the basis that herbaceous feedstock does not yield more char than woody feedstock at the same temperature. Annex B gives the class table with the ceilings.

The yield ceiling is a plausibility check, not a credit limit. Where both biochar output and dry feedstock input are recorded and the implied yield exceeds the ceiling for the declared class, the batch is quarantined and excluded until the discrepancy is reconciled. The ceilings are set at the upper bound of reported yields for compliant-temperature char, so that the check triggers only on physically implausible balances.

4.9.| Biochar moisture

Biochar is weighed wet and credited dry. Track 1 activities measure moisture with a calibrated handheld meter on the charcoal setting at the time of weighing. Where a reading is unavailable, a default deduction of 0.15 may be applied to air- or snuff-quenched biochar, that is, biochar quenched with soil or by smothering, which leaves it near air-dry. No default is provided for water-quenched biochar: its moisture content varies with the quench volume and the time since quenching, commonly from 30 per cent to above 50 per cent, and a single default cannot be set conservatively without making the credited mass unreasonably small. Water-quenched biochar is therefore measured.

4.10.| Application loss

A fixed deduction accounts for biochar lost as dust, by wind or by spillage between weighing and placement in the sink. The deductions of Table 9 of the methodology, 5 per cent for mechanised surface spreading, 2 per cent for precision manual placement and 1 per cent for delivery to an encapsulation plant or a vault, are conservative assumptions rather than measured values. They represent untracked mass excluded for conservativeness, not reversals. Where the credited mass is weighed at the point of placement, or at intake to the plant or the vault under chain of custody, there is no untracked interval and no deduction applies.

4.11.| Composite sampling and the ash proxy

Track 1 and Track 2 activities may combine sub-samples from several batches into a single master sample for laboratory analysis. A master sample represents at most 50 tonnes under Track 1 or 100 tonnes under Track 2, or one calendar month, whichever is reached first. These limits bound the quantity of biochar that a single analytical result can credit, so that an unrepresentative sample cannot propagate across a large volume. Compositing is permitted only within one organic-carbon class, because a master sample drawn across classes would credit the lower-carbon fraction at the higher-carbon result.

Where a Track 1 aggregator has established a site-specific regression between ash content and organic carbon from at least ten paired laboratory analyses, with a coefficient of determination of at least 0.90, ash content measured on site by muffle furnace may be used to derive organic carbon for routine batches, with every fiftieth sample sent to the laboratory to re-validate the curve. The derived organic carbon is applied at the one-sided lower confidence bound of the

regression, not at the fitted value, so that the uncertainty of a ten-point calibration is carried into the credit.

5.| Section 5: Activity emissions

5.1.| Why methane is the critical source

Pyrolysis produces a gas stream rich in carbon monoxide, hydrogen, methane and tars. In an engineered reactor this stream is combusted to supply process heat, and the methane in it is destroyed. In an open or semi-open kiln, part of the stream can escape unburned. At the emission factors measured for poorly operated kilns, methane alone can cancel a large share of the removal. The methodology therefore treats methane as the one source that may never be omitted on materiality grounds.

5.2.| Kiln classes and the Track 1 position

Track 1 admits manual and semi-manual production units with a biomass input below one tonne per day: flame-curtain kilns, including the Kon-Tiki form, and top-lit updraft gasifiers. Traditional earth-mound kilns and charcoal clamps are prohibited in all tracks. Track 2 admits mechanised retorts and containerised continuous units with a secondary combustion chamber. Track 3 requires continuous emissions monitoring.

The flame-curtain kiln is a conical or trough-shaped open vessel in which biomass is added in layers. Each new layer ignites on top of the glowing char below, and the flame it produces burns across the kiln mouth. The pyrolysis gases rising from the char bed pass through this flame curtain and are oxidised there. The design has no stack, so its emissions cannot be measured by stack sampling; they have been measured in the field by hood and tracer methods.

The measured evidence, summarised in Annex B, shows that the methane emission of a flame-curtain kiln is governed by feedstock moisture. Dry feedstock gives methane below the detection limit of field instruments. Wet feedstock cools the flame curtain, the pyrolysis gases pass through unoxidised, and methane rises by an order of magnitude. The methodology therefore admits the flame-curtain kiln under Track 1 on the condition that feedstock moisture is controlled, and places its safeguard in three provisions: a feedstock moisture limit measured per batch and taught as a required training element; a restriction of the default factor to the feedstock classes on which it was measured; and the periodic third-party corroboration testing of Section 3.2 of the methodology. The flame-curtain kiln is the production unit available to the smallholder cooperatives that Track 1 exists to include, and the field evidence supports its use under these conditions.

5.3.| Track 1 methane factors and the moisture classes

Table 22 of the methodology sets the Track 1 methane factors by kiln technology and feedstock moisture class. The factors are set at or above the highest value measured in the corresponding class, so that the credited emission is not understated for any feedstock within the class. For woody, grass and cob feedstock at or below 15 per cent moisture, methane is below the quantification limit of about 5 grams per kilogram of biochar in every measurement across two research groups, and the factor is set at that limit, 0.0055 tonnes per tonne. In the band above 15 and up to 24 per cent the highest measured value is 20 grams per kilogram, and the factor is 0.020. Above 24 per cent moisture the same feedstock emits 28 to 40 grams per kilogram, six to eight times the dry value, and the batch is not creditable; feedstock is dried to 24 per cent or less before charging.

The factors apply only to the feedstock classes for which they were measured: woody biomass, grasses and herbaceous stems of ordinary density, maize cobs, and twigs and leaves. Fine or dense residues with restricted airflow, such as husks, pomace, nut-shell fines and sludges, emit far more even when dry. They are not covered by the measurements and may not use the default. Nor is a default provided for top-lit updraft gasifiers: the only published methane value for such a unit comes from a single laboratory cookstove test, and one value from one unit cannot set a factor for a class. Biochar from these feedstocks, or from such a unit, is creditable under Track 1 only with an activity-specific factor.

The moisture limit is enforced per batch. Feedstock moisture is measured with a calibrated handheld meter at charging, recorded against the batch, and the batch takes the factor for its class. Drying to the dry class is the expected practice and is the subject of the Annex 2 training.

The semi-moist factor has a consequence that the calculation tool makes visible. At 0.020 tonnes of methane per tonne of biochar, the deduction is 0.56 tonnes of carbon dioxide equivalent per tonne, against a stored carbon of 1.65 to 2.0 tonnes for the Track 1 classes. A monitoring period run mainly on semi-moist feedstock cannot pass the efficiency check of Section 11.4 of the methodology. The ratio is assessed over the period across all batches, so an activity may include semi-moist batches; it cannot run on them.

5.4.| Activity-specific methane factor

Section 9.4 of the methodology allows a Track 1 activity to establish its own methane factor for a kiln type and feedstock class in place of the default, or where

no default exists. The route is open to any developer at its own cost and carries six conditions, so that a measured factor cannot be set lower than the evidence supports or applied beyond what was measured. The factor is the mean plus one standard deviation of the measured batches, and is never lower than the default for the moisture class, or 5 grams per kilogram where there is no default. Measurement is made by an independent party, by a published field method for open kilns, on at least ten batches drawn from at least three production units, with feedstock moisture recorded for every batch. The factor applies only to the kiln type, feedstock class and moisture class measured. It is corroborated annually by a further measurement set: a higher result replaces it from the next monitoring period, a lower result does not replace it until two consecutive annual sets agree. The measurement report and data are submitted with the monitoring report and verified. Where the activity changes kiln design, feedstock source or drying practice, the factor lapses and the default applies until it is re-established.

5.5.| Track 2 thermal proxy and excursion penalty

A Track 2 unit with a secondary combustion chamber or thermal oxidiser destroys methane by holding the pyrolysis gas at high temperature for long enough. The methodology treats continuous verification of a chamber temperature of at least 850^{0}C and a residence time of at least two seconds as evidence of destruction, and deems methane slip zero while both conditions hold. These are the conditions at which methane destruction efficiency in a well-mixed oxidiser exceeds 99 per cent; they are the standard design basis for thermal oxidisers on process off-gas.

For any period in which the chamber temperature falls below 850^{0}C, the proxy fails and a penalty of 0.15 tonnes of methane per tonne of biochar applies to all biochar produced in that period (Equation 16). The value represents the stoichiometric case of raw pyrolysis gas vented without oxidation. It is deliberately severe, so that operators maintain the chamber rather than tolerate excursions.

5.6.| Black carbon

Open-flame carbonisation emits particulate matter, part of which is black carbon, a short-lived climate forcer that warms by absorbing sunlight. The methodology does not deduct an emission for it, for three reasons. The net climate effect of the particulate emitted by a kiln is of uncertain sign: black carbon is co-emitted with organic carbon aerosol, which scatters sunlight and cools, and the ratio of the two depends on the combustion conditions of each batch. No measured default exists: a factor would require the particulate mass per tonne of biochar, the black-carbon fraction of that mass, and a global warming potential for black carbon. And black

carbon is not a greenhouse gas under the inventory framework in which the methodology operates and carries no agreed 100-year warming potential. For the same reason the methodology credits no avoided black carbon from the open burning that biochar production may displace; the exclusion is applied on both sides. Particulate matter remains a health matter and is addressed as one, through the outdoor-operation and training requirements.

5.7.| Pre-processing energy

A Track 1 or Track 2 activity sourcing feedstock from a small processing hub, rated at or below 15 tonnes a day, may apply a default pre-processing emission factor of 0.082 tonnes of carbon dioxide equivalent per dry tonne of feedstock in place of metered energy data. The factor is the product of a conservative size-reduction electricity demand and a conservative electricity emission factor: 0.050 megawatt-hours per tonne, at 1.3 tonnes of carbon dioxide per megawatt-hour, grossed up by 25 per cent for transmission and distribution, gives 0.081, rounded up to 0.082 because it is an emission.

The size-reduction demand of 50 kilowatt-hours per dry tonne is twice the highest specific energy measured for hammer-milling wood chips, which rises from about 1.4 kilowatt-hours per tonne at a 25 mm screen to about 25 at a 3 mm screen (Naimi et al., 2016); the margin covers two-stage grinding and screening. The electricity factor and the gross-up are the conservative defaults of the methodology tool for electricity emission quantification. Thermal drying is excluded from the default: drying by solar or ambient means, or by recovered carbonisation heat, contributes no emission, and fossil-fired drying is metered and added.

5.8.| Embodied emissions

Tracks 1 and 2 apply a standardised embodied-emission deduction of 0.02 and 0.05 tonnes of carbon dioxide equivalent per tonne of dry biochar respectively, covering the steel and materials of the production unit amortised over the first crediting period (Equation 21). Track 3 facilities, and any Track 1 or 2 activity that selects to, determine embodied emissions from a cradle-to-gate inventory of the production unit amortised over the first crediting period (Equation 22).

The defaults bound the embodied emissions of the production unit per tonne of dry biochar, taking the smallest unit at the lowest utilisation admitted under each track. For Track 1, a one-cubic-metre steel flame-curtain cone of about 80 kilograms, at 1.91 tonnes of carbon dioxide per tonne of steel (worldsteel, 2023), carries 0.15 tonnes of carbon dioxide equivalent. At 130 kilograms of feedstock per

run, a 22 per cent yield (about 29 kilograms of biochar per run) and 100 runs a year over five years, the unit produces about 14 tonnes of biochar, giving 0.011 tonnes per tonne; the default is set at 0.02. A two-cubic-metre cone producing 500 kilograms per run gives under 0.003. For Track 2, a mechanised unit of one tonne of dry biomass input per day, with about five tonnes of steel and five cubic metres of concrete at 0.35 tonnes of carbon dioxide per cubic metre, carries about 11 tonnes; at 0.2 tonnes of biochar a day over 250 days a year for five years, 250 tonnes in all, that is 0.045 per tonne, and the default is set at 0.05. Larger units give lower values. Electronic and ancillary equipment is below the materiality threshold. An activity whose unit is heavier or less utilised than these bounding cases applies the inventory route.

6.| Section 6: Additionality

6.1.| Regulatory surplus and lock-in

An activity is regulatorily surplus if no law requires it. The relevant question for biochar is whether any legal requirement mandates the conversion of biomass into a stabilised carbon product and its durable application. Laws on residue burning are assessed for compliance but do not affect surplus, for the reason given in Section 2.4. In high-income countries legal requirements are deemed enforced; elsewhere a requirement may be treated as unenforced only on authoritative evidence of non-enforcement. The assessment is repeated at each renewal.

Lock-in is assessed with the Gold Standard lock-in tool. Track 1 activities are micro-scale and follow the tool's Track A: they complete the first two steps and are deemed to carry no lock-in risk where policy alignment is demonstrated. Tracks 2 and 3 follow Track B, with the operational lifetime of the unit taken from the tool's defaults or from the technical-lifetime tool, and the net carbon efficiency ratio serving as the tool's performance benchmark. Biochar production cannot bind a host country into high-emitting infrastructure: fossil fuel may not sustain the reaction, the surplus test prevents the activity from creating a demand for residue, and production units have lives of ten to twenty years.

6.2.| Additionality pathways

Section 6.4 of the methodology offers three pathways, assigned by track and scale. Small and micro-scale activities under Tracks 1 and 2 may use the positive list, a barrier analysis or an investment analysis. Large-scale Track 2 and all Track 3 activities must use investment analysis, because an industrial facility has a business case that can be examined and should be.

The positive list deems two categories additional without further analysis. The first is small or micro-scale Track 1 or Track 2 production in a least-developed country or small island developing State, where durable-carbon biochar has negligible commercial deployment and the barriers of capital, awareness and demand are strongest. The second is a small or micro-scale activity whose sole feedstock is invasive-species biomass under Module F3, where the removal is a restoration cost that no market pays for, provided no government programme already funds it. Neither category is open to a large-scale activity.

Barrier analysis is permitted only for small-scale activities, and only in combination with the common-practice analysis, because the barriers it recognises, no access to finance without collateral, no local capacity to operate kilns safely, no residue

supply chain, are the barriers of smallholder networks, and they are to be evidenced. The barriers are limited to the financial, institutional and information types; the developer shows that at least one alternative, including continuing the current practice, does not face them; and the evidence is applied conservatively so that the effect of a barrier is very unlikely to be overstated.

Investment analysis follows the Article 6.4 investment-analysis tool as applied under the Gold Standard additionality standard: a benchmark or comparison analysis including all revenues, biochar sales, energy, co-products, gate fees and subsidies among them, with carbon revenue shown to be decisive and the sensitivity analysis the tool requires.

6.3.| Common practice and the 15 per cent threshold

The common-practice test asks whether the activity is already usual in its market. The methodology fixes the three elements of the test, the area, the comparable activities and the threshold, so that developers apply one consistent test under the Gold Standard common-practice tool.

a.| **Area**: Biochar production is bound to its feedstock: residues are bulky and low in value, and the distance over which they can be collected economically is a few tens of kilometres. A national share would combine many separate local markets and conceal saturation in any one of them. The area is therefore the feedstock collection area for each feedstock type, which is the market the activity competes in, and a separate assessment is made for each collection area and feedstock type, and repeated when either changes materially.

b.| **Comparable activities and measure**: Comparable activities are those producing biochar for durable storage without carbon finance. Charcoal for fuel, activated carbon and torrefied biomass are distinct products made for consumption and are excluded, as are activities that already receive carbon finance. The share is measured on the installed base: the number of comparable production units in operation in the collection area, divided by the total number of units converting the same feedstock type, including the proposed activity. Production units are long-lived and the number in operation can be established from registries, permits and surveys.

c.| **Threshold**: The activity is common practice if the measured share is 15 per cent or more. A single threshold applies in every host country. The technology-maturity gradings that the common-practice tool provides for

emission-reduction technologies do not transfer to a removal activity whose product has no established market of its own, and a differentiated threshold would rest on a classification the methodology cannot support with evidence for each region. Fifteen per cent is low enough that an activity is excluded well before biochar production becomes usual in its collection area, and it is the same figure whether the activity is in a least-developed country or elsewhere. Global biochar production was about 521,000 tonnes in 2025 against roughly 3.7 billion tonnes of dry crop residue produced each year from six major crops alone (International Biochar Initiative, 2026; Bentsen et al., 2014), so in practice the measured share will be far below the threshold in almost every collection area; the test exists to catch the exceptions.

6.4.| Ongoing financial need at renewal

A crediting period of five years may be renewed twice, to fifteen years in total. Activities using invasive-species or purpose-grown feedstock may renew once, to ten years, so that an invasive stand or a plantation is not maintained for carbon revenue. At each renewal the developer shows that carbon revenue is still needed. For a distributed activity that need is the cost of aggregation, monitoring, hardware replacement and benefit sharing, which biochar sales to smallholders do not cover. For an industrial facility it is an updated investment analysis on actual costs and revenues. An activity whose biochar sales alone have met the benchmark over the preceding period is no longer additional and is not renewed. Long-term offtake agreements signed during an earlier period are evidence of a carbon-dependent structure and do not retroactively void additionality.

7.| Section 7: Net quantification, uncertainty and conservativeness

7.1.| Issuance chain

Net removals for a monitoring period are the activity removals less the crediting baseline, the activity emissions, the leakage and any deficit carried from the previous period (Equation 25). Where the deductions exceed the removals, nothing is issued and the negative balance is carried forward. Where the efficiency check fails, nothing is issued and the positive balance is banked until the activity's efficiency improves. From the net removals the reversal-risk deduction or buffer contribution and the downward adjustment are taken, and the remainder is issued (Equations 27 to 29). Under Track 1, issuance is capped at 60,000 tonnes a year per activity or programme component; removals above the cap can be claimed only after transition to a higher track.

7.2.| Efficiency check

The net carbon efficiency ratio is the carbon stored in the biochar placed in the sink during the period, before the permanence, application-loss and uncertainty adjustments, divided by the activity emissions of the period before the uncertainty adjustment (Equation 26). Leakage is excluded. The ratio shall be at least 5.

The ratio is defined on gross stored carbon rather than on the adjusted removal, because it is a test of the production process, not of the sink. A ratio defined on the permanence-adjusted, loss-adjusted and uncertainty-adjusted removal would fall with soil temperature and with the conservativeness of the track's deductions, and a well-run facility in a warm climate would fail it for reasons unrelated to its efficiency. Defined on gross carbon, the ratio asks one question: is the carbon placed at least five times the carbon-dioxide equivalent emitted to place it? The threshold of 5 means the production footprint is at most a fifth of the carbon stored. The ratio is assessed for the period as a whole, across all batches.

7.3.| Three approaches to uncertainty

Track 1 relies on standardised defaults. Each default that raises the credited removal is set at the tenth percentile of its published distribution, and each that raises a deduction at the ninetieth or above. A separate uncertainty deduction of 5 per cent is applied to removals and to activity emissions, because the one quantity Track 1 measures rather than defaults, the weighed biochar mass and its moisture,

is measured on hanging or spring scales and handheld meters whose precision no default covers.

Track 2 measures mass and moisture directly but uses a thermal proxy for methane and composite sampling for carbon content. A fixed 5 per cent deduction on removals and on activity emissions stands in for the variance of those simplified methods. A Track 2 activity that measures a parameter to the precision Track 3 requires, platform-scale weighing of biochar and biomass or laboratory organic carbon on batch samples, may elect at design certification, per parameter, to apply the calculated route to it instead; the selection is not reversible within the crediting period, and the fixed deductions continue to apply to the thermal proxy and to composite sampling.

Track 3 measures everything and propagates the measurement and sampling uncertainty of each parameter at a 95 per cent confidence level (Equations 31 to 34). Only the excess over an allowed precision threshold, 1 per cent for removals and 5 per cent for activity emissions, is deducted, so that a precise facility carries no deduction at all. Invoiced utility parameters are taken to have no measurement uncertainty. Published emission factors from authoritative sources are applied at face value: they are selected conservatively, and their intrinsic uncertainty is not separately propagated.

Leakage carries no uncertainty deduction where the default factors are used, because the defaults are themselves set at conservative bounds, and a 15 per cent uplift under Tracks 2 and 3 where a site-specific value is used.

7.4.| Conservativeness ledger

Table 7.1 lists every deduction in the order it is applied to a Track 1 tonne of biochar, from weighed mass to issued credit. Each addresses a distinct risk. The permanence factor addresses the physics of decay; the uncertainty deduction addresses measurement precision; the risk deduction addresses reversal events after issuance; the downward adjustment addresses host-country ambition. Each is set at its own conservative bound.

Table 7.1 Conservativeness ledger for a Track 1 tonne of biochar.

Deduction	Value (Track 1)	Direction	Applied to	Basis and the risk it addresses
Moisture	measured, or 0.15 default for soil-quenched biochar	credit down	weighed mass	Converts wet mass to dry. Default only where the char is near air-dry (Section 4.9).

Organic carbon	0.55 / 0.45 / 0.35 / 0.25 by class	credit down	dry mass	Tenth percentile of the IPCC (2019a) distribution by feedstock (Section 4.7). Risk: carbon content below the class average.
Permanence factor	0.754 at 25 °C and a ratio of 0.40	credit down	organic carbon	One-sided 95 per cent lower bound on the 200-year decay model at the default site temperature (Annex A). Risk: decay faster than the central estimate.
Application loss	0.02 or 0.05; zero where weighed at placement	credit down	stable carbon	Conservative assumption for dust and spillage before placement (Section 4.10). Risk: credited mass not reaching the sink.
Removal uncertainty	5 per cent	credit down	gross removal	Precision of field scales and handheld meters. Risk: over-reading of the one measured input.
Methane	0.0055 or 0.020 t CH_4/t by moisture class	deduction up	dry biochar	At or above the highest value measured in the class (Section 5.3). Risk: methane slip understated.
Emission uncertainty	5 per cent	deduction up	activity emissions	Section 9.7 of the methodology.
Embodied emissions	0.02 t CO_2e/t, first crediting period	deduction up	dry biochar	Bounding steel cone at low utilisation (Section 5.8).
Ecological leakage (Module F1)	F_{SOC} 0.19 per t residue; EF_N 12.1 per t N; P and K factors	deduction up	weighed residue	By alternative fate (Section 3.4). Risk: off-field effects of residue removal.
Reversal risk	10 per cent	credit down	net removal	Cancelled at issuance for distributed sinks that cannot be monitored (Section 8). Risk: post-issuance loss.
Downward adjustment	as published in the Gold Standard tool	credit down	net removal	Host-country ambition share. Not a conservativeness layer; a policy deduction.

7.5.| Why the layers do not overlap

Three of the layers act on the same physical quantity, the organic carbon in the biochar, and the question is whether together they deduct more than the

uncertainty justifies. They do not, because each answers a different question. The organic-carbon default answers: how much carbon is in this biochar, given that it was not analysed? The permanence factor answers: how much of that carbon is still in the soil after 200 years? The removal-uncertainty deduction answers: how accurately was the mass weighed? Each would be needed even if the other two were known exactly.

The compound effect is nonetheless larger than any single layer. Taking the organic-carbon and permanence defaults together with the 5 per cent deduction, the credited stable carbon per dry tonne of woody Track 1 biochar is 0.55 × 0.754 × 0.95 = 0.394 tonnes of carbon. Sampling the two underlying distributions jointly, about 96 per cent of real batches would hold more stable carbon than this. The credited quantity therefore sits near the fourth percentile of the joint distribution, not the tenth. Thus an activity that analyses its biochar is credited at its own lower 95 per cent bound, not at the class default. The calculation tool shows the difference: the same network issues 1.10 tonnes of carbon dioxide equivalent per tonne of biochar on the all-default route and 1.74 with laboratory carbon, measured moisture and an evidenced site temperature.

8.| Section 8: Reversal risk and the buffer

8.1.| Reversal

The permanence factor already accounts for the slow oxidation of biochar in soil over 200 years. That expected decay is not a reversal. A reversal is a loss in excess of it caused by an event: severe wildfire reaching incorporated char, excavation of char for fuel, demolition of an encapsulating structure, or breach of a vault cap. The methodology distinguishes avoidable reversals, within the developer's control and compensated by the developer, from unavoidable ones, from natural catastrophe or third-party acts, which are covered from the buffer.

8.2.| One deduction, two settlement routes

The methodology applies a single reversal-risk deduction at issuance (Equation 27), at a rate set for the sink. What differs between sinks is how the deduction is settled, and that follows from whether a reversal could ever be detected. Large contiguous application areas and engineered vaults can be monitored: by satellite for burn scars and land-use change, by inspection for cap integrity. For these sinks the deduction is deposited in the Gold Standard compliance buffer, drawn only on a verified unavoidable reversal, and otherwise retained. Thousands of smallholder fields, and biochar dispersed through concrete and asphalt, cannot be monitored individually over a century, so a deposit for them could never be drawn. For these sinks the deduction is cancelled at issuance, backed by the aggregator's liability for avoidable reversals and by sample-based sentinel inspection to detect systemic diversion. The two routes settle the same deduction; neither is an additional charge on the other.

This design follows the engineered removals and A6.4 standard for removal and non-permanence standards, which require every removal activity to carry a reversal-risk rating that covers avoidable and unavoidable reversals and to forward a proportionate share of issued units to a buffer (Article 6.4 Supervisory Body, 2024, paras 38 to 39 and 55; 2025, paras 6, 12 and 31). Those standards place biochar and construction materials within scope and do not exempt engineered storage. The rates below are set by this methodology from the evidence described in Section 8.3.

8.3.| The rates

Table 8.1 gives the rates and their basis. The rate is a reserve against events, not against decay, which the permanence factor already carries. The Track 1 soil rate of 10 per cent covers the one reversal that matters on dispersed plots, diversion of

biochar to fuel, together with surface loss, on sinks where neither can be observed and where a cancelled volume has no replenishment route; it is held at the base rate for open soil without site-specific assessment, plus the diversion margin that such plots carry. For soil sinks under Tracks 2 and 3 the Annex 7 tool starts from a base of 7.5 per cent for incorporated biochar on monitored land, adds the site-specific hazards of Table 27 (fire exposure, charcoal price above production cost, a lease shorter than the crediting period without a right of renewal, no covenant on the deed, surface application without incorporation) and subtracts the verified mitigations of Table 28 (deep incorporation, irrigation, denaturing, freehold ownership, insurance), floored at 2.5 per cent. The floor is the value the Gold Standard reversal-risk tool for geological storage applies where the calculated rating falls below it (Gold Standard, 2025, Tool 4, para 7.2.2): no sink is credited without a reserve against events the ex-ante factors cannot foresee. Module A3 vaults take that floor as their default, because a sealed anoxic vault under a legal covenant is the biochar sink closest to geological storage. Module A2 is held at 3 per cent: encapsulation removes the oxidation and diversion pathways, and the 0.95 permanence factor already carries the structural uncertainty, but there is no demolition-cycle evidence either way and accidental building fire is an unavoidable reversal under the non-permanence standard (Article 6.4 Supervisory Body, 2025, para 45).

The additions and mitigations are weighted so that a well-run commercial site computes close to the base risk and a poorly sited one above it. Deep incorporation carries the largest mitigation because surface runoff is the only physical loss pathway for soil biochar that has been quantified: on a field of under 2 per cent slope, 20 to 53 per cent of surface-applied black carbon left by runoff within two years of tillage (Major et al., 2010), and black carbon is preferentially eroded on steep cultivated slopes (Rumpel et al., 2006). Incorporation below 20 cm removes that pathway. Most of what is lost by erosion is relocated rather than oxidised, which is why the base rate is below the land-use default and why a reversal is quantified by the damage factors of Section 8.4 rather than assumed total. The denaturing discount offsets only the diversion addition, because mixing biochar with manure removes the fuel value and nothing else; where diversion is not triggered, denaturing confers no discount, so that a mitigation cannot reduce the reserve below the residual risk actually present. The tenure addition applies only to a lease without a right of renewal, because a renewable lease on land the activity continues to farm carries no more reversal risk than freehold; the earlier weighting made leased land, which is the ordinary case for a mechanised operator, an aggravating factor in itself.

Table 8.1 Reversal-risk rates (Tables 13, 14 and 25 to 29 of the methodology).

Sink	Rate	Settlement	Basis
Module A1, Track 1	10 per cent, fixed	cancelled at issuance	Open-soil base risk plus the diversion margin of dispersed, unmonitorable plots; no replenishment route (Table 25).
Module A1, Track 2, smallholder plots that cannot be monitored individually	10 per cent, fixed (the Track 1 rate)	cancelled at issuance	The same unmonitorable dispersion as Track 1 soil; the Sentinel Site protocol applies (Section 11.5 and Table 14).
Module A1, Tracks 2 and 3	Annex 7 assessment, base 7.5 per cent, floor 2.5 per cent	buffer deposit	Mandatory site-specific assessment: base 7.5 per cent for incorporated biochar on monitored land, with the additions and mitigations of Tables 27 and 28; an addition whose criterion cannot be evidenced applies.
Module A2 (Tracks 2 and 3)	3 per cent, fixed	cancelled at issuance	Residual end-of-life risk of demolition and accidental building fire, applied in place of a century-long asset registry.
Module A3 (Tracks 2 and 3), subterranean or above-ground	2.5 per cent	buffer deposit	Sealed, denatured, anoxic vault under covenant; residual risk is containment failure; the geological-storage floor.
Floor, all sinks	2.5 per cent	either	No sink is credited without a reserve against events the ex-ante factors cannot foresee.

Worked outcomes of the Annex 7 tool, on the mechanised scenario of Section 10: a freehold, irrigated, deeply incorporated and insured site computes below the floor and takes 2.5 per cent; a leased site without a covenant in a moderate fire zone, with deep incorporation and insurance, computes 7 per cent; a site in a high fire zone where charcoal sells above the cost of biochar, on a non-renewable lease with no covenant and no mitigation, computes 19 per cent. The assessment is mandatory for these sinks: a fixed default would act as a ceiling, because a site assessed above it would take the default and the additions would never apply to the sites they were written for.

8.4.| Damage factors

When a reversal is confirmed, Equation 30 quantifies the loss as the credited stable carbon in the affected area multiplied by a damage factor for the event. Surface-applied biochar in a severe fire loses half its carbon to oxidation; incorporated biochar below 10 cm is insulated from peak heat and loses a tenth. Diversion to fuel and excavation from a vault are total losses. A vault cap breached and not repaired within 30 days loses the anoxic protection and reverts to the Method 1 soil-decay value at the site temperature; the damage factor is the difference. The wildfire factors are conservative assumptions for a high-severity event; they are not measured values, and they apply only to the credited stable fraction.

8.5.| Beyond the crediting period

Active monitoring runs for the crediting period, to a maximum of fifteen years. The 200-year claim is not secured by observation after that. It is secured ex ante: by the permanence factor, which already credits only the carbon expected to survive 200 years; by the buffer or fixed cancellation, which reserves against events; by the legal covenant on a vault, which runs for the full credited duration; and, for Track 1, by the agronomic value of biochar to the farmer, which removes the incentive to excavate it. Biochar is not a standing stock that can be felled or ploughed out; once incorporated it has no fuel value and no recovery route. Cessation of monitoring during the crediting period, where monitoring is feasible, is treated as an avoidable reversal.

8.6.| Social permanence

The avoidable reversal that matters for distributed activities is diversion of biochar to cooking fuel. The methodology guards against it in three ways. Every credited batch requires geo-tagged proof of incorporation into the sink; biochar that is sold or stockpiled without it is not credited. A sample of sentinel sites is inspected annually, sized to a 90/10 confidence and precision level; if 5 per cent or more of the sampled sites show diversion, the aggregator is liable across the stratum, crediting is suspended, and the fixed cancellation rate is permanently doubled until remedial training is proven. And the training of Annex 2 is built around the economic case that incorporated biochar is worth more to the farmer in yield and carbon payment than as charcoal.

9.| Section 9: Adopted default values and their basis

Every fixed value the methodology uses is listed here with its adopted value and its basis. Three kinds of basis are distinguished: a value derived from published evidence at a stated percentile or bound; a value set by the methodology as a rule, where the quantity is a policy choice rather than a measured one; and a value taken from a Gold Standard requirement or tool. A value of the second kind is not to be mistaken for a measurement. Values determined by maintained external tools are applied from those tools and are not fixed in the methodology.

Table 9.1 Adopted default values and their basis.

Value	Adopted	Status	Basis and section
Minimum carbonisation temperature	450 °C	Rule	Boundary between torrefaction and pyrolysis; SI 1.4
Molar H:Corg eligibility limit	0.5; 0.4 under Track 1; 0.5 to 0.7 by Method 2 only	Evidence	Calibration range of the decay model; SI 1.4, Annex A
Net carbon efficiency ratio	at least 5 per monitoring period, on gross stored carbon	Rule	SI 7.2
Track 1 issuance cap	60,000 tCO_2e per year per activity or VPA	Rule	SI 1.6
De-bundling criteria	common ownership or control with shared hub or site, 1 km, or two-year window	Rule	SI 1.6
Track capacity limits	below 1; 1 to 15; above 15 t dry input per day per unit	Rule	SI 1.3
Soil application cap	50 t dry per hectare per application	Evidence	Agronomic limit on pH and nitrogen immobilisation; SI 1.5
Land-use reference date	31 December 2020	Rule	Regulation (EU) 2023/1115; SI 3.7
Decay-test horizon	10 years	Rule	Separates the residue classes; SI 3.1
Woody-debris diameter limit	10 cm	Rule	SI 3.1
Residue retention floor	70 per cent by dry mass; site-specific above	Evidence	Blanco-Canqui and Lal (2009); SI 3.3
Nitrogen replacement factor	12.1 tCO_2e per t N	Evidence	Above the global mean of Menegat et al. (2022); Annex B

Phosphorus replacement factor	1.5 tCO_2e per t P_2O_5	Evidence	Above European Commission (2015) and Brentrup et al. (2018); Annex B
Potassium replacement factor	0.6 tCO_2e per t K_2O	Evidence	European Commission (2015), rounded up; Annex B
Foregone soil organic carbon	0.19 tCO_2e per t dry residue, once	Evidence	Residue carbon 45 per cent, humification 11.5 per cent; Annex B
Market leakage, fuel replacement	1.75 woody; 1.30 herbaceous; 0.27 and 0.20 cooking	Evidence	Net calorific value × emission factor, IPCC (2006); Annex B
Market leakage, fodder, bedding, mulch	no default; site-specific	Rule	SI 3.5
Baseline removal	0	Evidence	No durable carbon forms in any residue fate; SI 2.2
Enforcement factor	1.0 / 0.5 / 0	Rule	SI 2.4
Common-practice threshold	15 per cent, all host countries	Rule	SI 6.3
Permanence factor, Method 1	Table 24; 0.754 at 25 °C and a ratio of 0.40	Evidence	One-sided 95 per cent lower bound, 65 observations; Annex A
H:Corg domain of Table 24	0.20 to 0.50; below 0.20 credited at 0.20	Evidence	Monotonicity of the lower bound; Annex A
Temperature domain	7 °C floor; above 32 °C flagged as extrapolated	Evidence	Incubation range 12 to 32 °C; Annex A
Track 1 default soil temperature	25 °C; lower where evidenced	Rule	SI 4.6
Permanence factor, Method 2	mean less one SD of inertinite × non-reactive fraction; cap 0.95	Evidence	Sanei et al. (2024, 2025); SI 4.4
Permanence factor, Method 3	0.95 for Modules A2 and A3	Rule	SI 4.5
Organic carbon defaults	0.55 / 0.55 / 0.45 / 0.35; manure and biosolids 0.25 informative only (Track 3 measures)	Evidence	Tenth percentile of IPCC (2019a); SI 4.7, Annex B
Yield default	0.15, all Track 1 classes; not for Module F1	Evidence	Tenth percentile of Cornelissen et al. (2016); SI 4.8

Yield ceilings	0.32 / 0.42 / 0.38 / 0.50	Evidence	Upper bound of reported yields; Annex B
Biochar moisture default	0.15, air- or snuff-quenched only	Rule	SI 4.9
Application loss	5 / 2 / 1 per cent; zero where weighed at placement	Rule	SI 4.10
Composite sample limit	50 t Track 1; 100 t Track 2; or one month	Rule	SI 4.11
Ash-proxy calibration	at least 10 pairs, R^2 at least 0.90, lower bound applied	Rule	SI 4.11
Uncertainty deduction, Tracks 1 and 2	5 per cent on removals and on activity emissions; Track 2 may elect the calculated route per parameter	Rule	SI 7.3
Uncertainty, Track 3	excess over 1 per cent (removals) and 5 per cent (emissions) at 95 per cent confidence	Rule	SI 7.3
Leakage uncertainty	0 with defaults; 15 per cent with site-specific factors	Rule	SI 7.3
Methane, Track 1 flame-curtain kiln	0.0055 (≤ 15 per cent); 0.020 (above 15 to 24 per cent); above 24 per cent not creditable	Evidence	Cornelissen et al. (2024); Lotz et al. (2026); SI 5.3, Annex B
Methane, gasifier and non-default feedstocks	no default; activity-specific factor	Rule	SI 5.4
Activity-specific methane floor	class default, or 5 g per kg	Rule	SI 5.4
Track 2 thermal proxy	850 °C and 2 s; excursion penalty 0.15 t CH_4 per t	Evidence	Oxidiser design basis; SI 5.5
Black carbon	not deducted	Rule	SI 5.6
Feedstock-storage methane	0.13 per cent of stored carbon per month beyond the first; Module F6 by the IPCC conversion factor	Evidence	Whittaker et al. (2016a, 2016b); SI 3.6
Pre-processing default	0.082 tCO_2e per dry tonne of feedstock	Evidence	50 kWh/t × 1.3 tCO_2/MWh × 1.25; SI 5.7
Embodied emissions	0.02 Track 1; 0.05 Track 2; inventory route for Track 3	Evidence	Bounding-unit derivation; SI 5.8
Materiality	below 2 per cent per source, at most 5 per cent in total; methane never omitted	Gold Standard	SI 5.1
Reversal risk	10 per cent fixed, Track 1	Rule	SI 8.3

	soil; computed from a 7.5 per cent base with a 2.5 per cent floor, Tracks 2 and 3 soil; 3 per cent Module A2; 2.5 per cent Module A3		
Damage factors	0.5 surface fire; 0.1 incorporated fire; 1.0 diversion or excavation; vault breach by formula	Rule	SI 8.4
Sentinel inspection	annual sample at 90/10; 5 per cent diversion triggers liability and doubles the rate	Rule	SI 8.6
Downward adjustment factor	country default	Determined by the maintained tool	MT400-05; SI 2.3
Radiocarbon sampling	1 per 1,000 t or monthly; six-month baseline; quarterly at the 95 per cent lower limit	Rule	Annex 4 of the methodology
Crediting period	5 years, renewable twice; Modules F3 and F5 renewable once	Gold Standard	SI 6.4

10.| Section 10: Worked scenarios and the calculation tool

10.1.| Scenarios exercise

The published calculation tool carries eight hypothetical scenarios. Together they exercise the whole methodology across the three tracks, the three sinks and five of the six feedstock modules, over ten annual monitoring periods each. Their inputs are plausible values chosen to show how the provisions work; they are not data from any activity, and the tool says so on every sheet.

Scenario 1 runs a Track 1 kiln network clearing an invasive shrub on the all-default route. Scenario 1M runs the same network with the measurements Track 1 permits: laboratory carbon and ratio on composite samples, metered moisture, an evidenced site temperature and a measured methane factor, which the methodology floors at the class default. Scenarios 2 and 2M run a Track 2 cooperative on nut shells with the thermal proxy and the Annex 7 risk tool, the second weighing at placement and electing the calculated uncertainty route. Scenario 3 runs a Track 3 industrial plant on sawmill residues with continuous methane measurement, calculated uncertainty and inventory-based embodied emissions. Scenario 4 runs a Track 1 network on maize stover, with the residue weighed, the retention floor applied and the ecological leakage conditioned on a burned-in-field fate. Scenario 5 delivers biochar to a concrete batch plant under Module A2. Scenario 6 pyrolyses sewage sludge under Track 3 and places the biochar in an anoxic vault under Module A3, with storage methane on the activity-specific route.

Table 10.1 Results of the worked scenarios over ten monitoring periods.

Scenario	Track and modules	Carbon applied	Permanence factor	Risk rate	Issued, tCO_2e per t dry biochar	Issued as a share of stored carbon
1 Distributed, default route	T1, F3, A1	0.55 default	0.754	10 per cent	1.10	55 per cent
1M Distributed, measured	T1, F3, A1	0.76 measured	0.820	10 per cent	1.74	62 per cent
2 Mechanised, soil	T2, F2, A1	0.74 measured	0.807	6.5 per cent	1.67	62 per cent
2M Calculated route	T2, F2, A1	0.74 measured	0.807	6.5 per	1.82	67 per cent

				cent		
3 Industrial, soil	T3, F2, A1	0.80 measured	0.820	3.5 per cent	2.04	70 per cent
4 Field residue	T1, F1, A1	0.62 measured	0.785	10 per cent	1.30	57 per cent
5 Concrete	T2, F2, A2	0.80 measured	0.95	3 per cent	2.40	82 per cent
6 Biosolids, vault	T3, F6, A3	0.34 measured	0.95	2.5 per cent	0.91	73 per cent

Four results are to be read from the table. The all-default Track 1 route issues about 55 per cent of the carbon placed; measurement raises the same network to 62 per cent and the per-tonne yield by more than half, which is the incentive to test that the defaults are meant to create. The engineered-material sink issues the largest share, because the fixed permanence factor removes the temperature-dependent decay and the delivery is weighed at intake. The biosolids case issues the least per tonne, because biosolids char is a third carbon by mass; it is nonetheless positive. And in every scenario the permanence factor is the largest single deduction, followed by the activity emissions, of which methane is the largest component under Track 1, and the reversal-risk rate.

10.2.| What the tool shows when the inputs change

Three provisions produce negative or withheld results that a developer will find by changing the inputs, and the tool is built so that they are found. A monitoring period run mainly on semi-moist feedstock under Track 1 fails the efficiency check, because the semi-moist methane factor alone costs a third of the stored carbon (Section 5.3). The small-hub pre-processing default applied to a feedstock of low carbon content and low yield can fail the check on its own (Section 5.7). And a field-residue activity whose residue would have been retained in the soil is net-negative under the ecological-leakage deduction (Section 3.4). None of these is an error of the tool; each is the methodology applied.

10.3.| Conventions applied in the tool

Values are carried exactly through each chain and rounded for display. Embodied-emission defaults apply to the biochar produced in the first crediting period only. The efficiency check is applied per period; where it fails, the positive balance is banked to the next period, and a negative balance is carried as a deficit. Emission

factors for fuel, electricity and freight, and the downward adjustment factor, are values published in the Gold Standard and Article 6.4 tools for the host country and year. The tool recomputes its own defaults and re-derives Equations 5, 9 and 26 to 29 on a checks sheet.

11.| Section 11: Scope boundaries and limitations

11.1.| Scope boundaries

The methodology's boundaries are stated so that readers know what it covers and what it does not. It credits the durable fraction of biochar carbon and nothing else: no avoided emission from the counterfactual fate of the biomass, no soil-carbon or yield effect, no avoided black carbon. Purpose-grown and organic-waste feedstocks are admitted only under Track 3, because the land-use and contamination risks they carry can be controlled and documented only by an industrial facility. The 1,000-year claim is available only through inertinite petrography and only for soil and vault sinks. Biochar in combustible matrices, in asphalt wearing courses and in landfills is excluded as a sink. The default values are adopted defaults; activity-specific evidence may replace most of them where the methodology so provides, and the measured route is always open at the developer's cost.

11.2.| Limitations of the evidence

a.| **Permanence:** The decay model is fitted to 65 incubation series from 11 studies, with a median length of 510 days and none longer than five years, and extrapolated to 200 years. Forty-three per cent of the observations lie above the eligibility limit of the ratio, so the relationship over the creditable range is anchored substantially on biochar that the methodology does not credit. The one-sided 95 per cent lower bound, the domain limits and the temperature flag are the response to these limits; they do not remove them. Field studies of comparable length do not yet exist in sufficient number to replace the incubation evidence.

b.| **Methane**: The Track 1 factors rest on two field campaigns on flame-curtain kilns, covering four feedstock classes in the dry regime. Nothing is known at the same standard about other open-kiln designs, about fine or dense residues, or about the top-lit updraft gasifier. The methodology provides no default for these and routes them through activity-specific measurement.

c.| **Feedstock storage**: The storage-methane rate rests on two willow-chip heaps and the wood-storage literature. It is not evidence for manure or sludge piles, which the methodology routes to the IPCC conversion factors.

d.| **Ecological leakage**: The foregone-soil-carbon factor rests on a humification coefficient that varies with climate and soil; the single value is a central estimate applied as a one-off stock. The fertiliser factors are European and global means applied worldwide.

e.| **Reversal rates and damage factors**: The fixed cancellation rate and the wildfire damage factors are conservative assumptions, not measured frequencies. No dataset of biochar reversal events exists on which they could be estimated.

f.| **Yield and carbon content**: The Track 1 yield default rests on 17 field runs on woody and shrub feedstock; no field yield data for pure herbaceous residue were found. The organic-carbon defaults rest on the IPCC compilation, which spans all pyrolysis temperatures and is therefore somewhat lower than compliant Track 1 biochar would show.

g.| **Embodied emissions**: The Track 1 and Track 2 defaults are bounding calculations on a representative unit, an activity whose unit is heavier or less utilised than the bounding case applies the inventory route.

11.3.| Items for the next review

Three items are recorded for the first scheduled review of the methodology. The semi-moist methane class is compatible with the efficiency check only in combination with dry batches; a measured factor for semi-moist feedstock, if the evidence base grows, would allow the class to stand on its own. Field data on flame-curtain yields for herbaceous residue, and on methane from gasifier units, would allow defaults where the methodology now requires measurement. And field studies of biochar persistence beyond five years, as they are published, should be added to the permanence dataset and Table 24 re-derived.

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Annex A: Derivation of the Method 1 permanence factor

A.1 Dataset

The derivation uses the harmonised biochar decomposition dataset of Azzi et al. (2024), available from the public repository SLU-biochar/biocharStability under a CC BY-SA 4.0 licence. The dataset compiles carbon-remaining time series from soil incubation studies, with the properties of each biochar.

An observation is included where its decay series has enough points to constrain a fit, runs for at least one year, converges under the decay model of A.2, and reports the molar hydrogen-to-organic-carbon ratio of the biochar. Where the ratio is not reported directly it is bridged from the reported elemental composition; 11 of the included observations are bridged in this way.

The included set is 65 observations from 11 studies. Incubation temperatures run from 12 to 32^{0}C with a median of 22^{0}C. Series lengths run from 365 to 1,829 days with a median of 510 days. The largest study contributes 18 observations. The ratio runs from 0.22 to 0.68 with a mean of 0.50; 28 of the 65 observations are above the 0.50 eligibility limit. The data are therefore centred on the upper boundary of the creditable range, and this shapes both the uncertainty treatment (A.6) and the domain limits (A.8).

Table A.1 Studies contributing to the included set.

Study	Observations	Study	Observations	Study	Observations
Zimmerman (2010)	18	Fang et al. (2014)	10	Fang et al. (2019)	8
Singh et al. (2012)	7	Aubertin et al. (2021)	6	Wu et al. (2016)	5
Herath et al. (2015)	4	Liu et al. (2020)	2	Santos et al. (2021)	2
Ventura et al. (2019)	2	Major et al. (2010)	1	Total	65

A.2 Decay model

Each observation is fitted with the power-law decomposition model of Zimmerman (2010). Under this model the rate of carbon loss declines continuously with time and no fraction is assumed to be permanently inert. The carbon remaining at time t, in days, is

$C(t) = c_0 - c_0 \cdot e\text{^}b / (m + 1) \cdot t\text{^}(m + 1)$

where c_0 is the initial carbon and b and m are the fitted rate and shape parameters. The power-law form is used rather than a multi-pool exponential model because it does not credit a stable pool that the incubation data cannot demonstrate. The 200-year horizon is 73,000 days. The decay series of the study contributing 18 observations are reconstructed in the dataset from the fitted parameters it reports.

A.3 Correction to site soil temperature

Each fitted curve is corrected from the temperature at which it was incubated, Ts, to the mean annual soil temperature of the application site, Ttarget, using the temperature-dependent Q_{10} relationship of Woolf et al. (2021):

$Q_{10}(T_1, T_2) = 1.1 + 63.1579 \cdot (e^{(-0.19 \cdot T_1)} - e^{(-0.19 \cdot T_2)}) / (T_2 - T_1)$

$f_T = \exp[\ \ln Q_{10}(Ts, Ttarget) \cdot (Ttarget - Ts) / 10\ ]$

The factor f_T scales the mineralisation rate. Re-integrating the decay model with the scaled rate gives the temperature-corrected fraction remaining at 200 years. Site temperatures are floored at 7 °C, the lower limit of the calibration data; the correction is not extrapolated below it.

A.4 Estimation

At each target temperature from 7 to 40 °C, the corrected 200-year fraction is regressed on the molar ratio:

$F_{200}(x) = M - a \cdot x$, with x the molar H:Corg

For some observations the temperature-corrected projection falls at or below zero: the biochar is projected to mineralise completely within 200 years. The number of such observations rises with temperature, from 1 at 7 °C to 5 at 25 °C and 6 at 40 °C. These observations are treated as left-censored at zero and the parameters M, a and the residual scale σ are estimated jointly by maximum likelihood (Tobit regression). For an uncensored observation the likelihood is the normal density of its value; for a censored observation it is the probability that the latent value lies at or below zero.

Censored estimation is used because the alternatives bias the result. Recording a fully mineralised sample as exactly zero invents a value that was not observed. Discarding it is worse, because the censored samples are the high-ratio ones, and removing them deletes the evidence that reactive biochar does not persist. Censored estimation uses the information that the sample mineralised fully without assigning it a value.

A.5 Smoothing across temperature

The regressions at successive target temperatures are not independent: each re-projects the same 65 observations through a smooth temperature correction. The underlying temperature response is therefore smooth, and any roughness in the fitted coefficients is an artefact of individual observations crossing the censoring threshold at particular temperatures. Each coefficient, and each component of the variance matrix of A.6, is fitted as a quadratic in ln(T). The coefficients are given in Annex C. The smoothed a(T) and σ(T) are monotonic across the applicable range. M(T) turns over at about 20 °C, but the credited factor remains monotonically decreasing in temperature at every applicable ratio because the growth in a(T) dominates; this has been verified cell by cell in Table 24.

A.6 Uncertainty

Observations from the same study share feedstock, production conditions, soil, incubation protocol and laboratory. They are not independent draws, and treating them as independent would understate the uncertainty of the fitted relationship. The variance of the fitted coefficients is therefore estimated with the cluster-robust (sandwich) estimator, clustering by study:

$V = H^{-1} \cdot (\Sigma_g s_g s_g^T) \cdot H^{-1} \cdot \kappa$

H is the observed information, s_g the summed score for study g, and $\kappa = [G/(G - 1)]\cdot[(N - 1)/(N - k)]$ the small-sample correction with G = 11 studies, N = 65 observations and k = 3 parameters. The standard error of the fitted mean at ratio x is

$SE(x) = \sqrt{(v_{11} + x^2 \cdot v_{22} + 2x \cdot v_{12})}$

The variance components are smoothed in ln(T) as in A.5. The resulting matrix is positive-definite at every tabulated temperature. The standard error is narrowest near the centre of the data, at ratios of about 0.35 to 0.45, and widens towards both ends of the creditable range.

A.7 The credited factor

The credited permanence factor is the one-sided 95 per cent lower confidence bound on the fitted mean, evaluated at each tabulated ratio and temperature:

$F_{perm}(T, x) = [M(T) - a(T) \cdot x - 1.645 \cdot SE(x, T)] / 100$

The bound is evaluated exactly at each ratio. It is a curved band, not a straight line, because the standard error varies with the ratio; a straight-line approximation would overstate the factor at the edges of the range.

A.8 Domain of application

a.| **Molar ratio**: Table 24 applies over ratios from 0.20 to 0.50. The lowest ratio in the dataset is 0.22, so there are no observations below about 0.20 and the fitted relationship is unconstrained there. Biochar above 0.50 is not credited under Method 1 and is directed to Method 2. Biochar below 0.20 remains eligible and is credited at the 0.20 column: permanence rises as the ratio falls, so flooring the input is conservative, and it mirrors the treatment of soil temperature below 7^0C. The lower limit is set for a second reason as well. Below about 0.19 the standard error widens faster than the fitted mean rises, and the credited factor would begin to increase with the ratio, so that a more reactive biochar would be credited more than a less reactive one. Restricting the domain to 0.20 and above removes this, and Table 24 is monotonically decreasing in the ratio at every temperature.

b.| **Temperature:** Factors are tabulated from 7 to 40^0C, but the observations were incubated between 12 and 32^0C. Values above 32^0C are extrapolation beyond the evidence base and are marked as such. Their use requires activity-specific justification or recourse to Method 2.

A.9 Limitations

The 200-year horizon is 73,000 days, while the median observation series runs 510 days. The projection is an extrapolation of about two orders of magnitude beyond the observed window, and the fitted tail parameter is correspondingly weakly constrained. Only seven observations, all from one study, extend beyond 1,000 days. The lower confidence bound of A.7 is the mechanism by which this uncertainty enters the credited factor.

The cluster-robust variance is estimated over 11 clusters, which is a small number for a sandwich estimator; the small-sample correction is applied for this reason. Forty-three per cent of the observations lie above the eligibility limit, so the fitted relationship over the creditable range is informed substantially by biochar that Method 1 does not credit.

The maximum-likelihood coefficients are fitted outside the background workbook, because an iterative optimisation cannot be expressed as a spreadsheet formula. The workbook recomputes the log-likelihood at the adopted coefficients and at

values perturbed by one per cent on each parameter, and shows that every perturbation gives a lower likelihood, so the fit can be confirmed as a maximum without re-running the optimisation.

A.10 Table 24

Table 24 of the methodology is reproduced below. Column headings are the molar ratio. Values are the fraction of biochar organic carbon credited as remaining after 200 years. Biochar below a ratio of 0.20 is credited at the 0.20 column. Rows above 32^0C are beyond the temperature range of the data.

Table A.2 Credited 200-year permanence factors, one-sided 95 per cent lower confidence bound. The reference cell for the Track 1 default route is 25 °C and a ratio of 0.40, giving 0.754.

Soil temperature, °C	0.20	0.25	0.30	0.35	0.40	0.45	0.50	Note
7	0.907	0.901	0.894	0.888	0.881	0.873	0.865	
8	0.894	0.891	0.885	0.876	0.864	0.850	0.833	
9	0.885	0.882	0.876	0.866	0.851	0.831	0.808	
10	0.877	0.875	0.869	0.857	0.839	0.815	0.787	
11	0.870	0.869	0.862	0.849	0.829	0.802	0.770	
12	0.865	0.863	0.856	0.842	0.820	0.790	0.756	
13	0.859	0.858	0.851	0.836	0.812	0.780	0.744	
14	0.855	0.853	0.845	0.830	0.804	0.771	0.733	
15	0.850	0.848	0.841	0.824	0.798	0.763	0.724	
16	0.846	0.844	0.836	0.819	0.792	0.756	0.715	
17	0.842	0.840	0.832	0.814	0.786	0.750	0.708	
18	0.839	0.836	0.828	0.810	0.781	0.744	0.701	
19	0.835	0.833	0.824	0.806	0.777	0.739	0.695	
20	0.832	0.829	0.820	0.802	0.772	0.734	0.689	
21	0.829	0.826	0.817	0.798	0.768	0.729	0.684	
22	0.826	0.823	0.814	0.795	0.764	0.725	0.679	
23	0.823	0.820	0.810	0.791	0.761	0.721	0.675	
24	0.820	0.817	0.807	0.788	0.757	0.717	0.671	
25	0.818	0.814	0.804	0.785	0.754	0.714	0.668	
26	0.815	0.812	0.802	0.782	0.751	0.711	0.664	
27	0.813	0.809	0.799	0.779	0.748	0.708	0.661	
28	0.810	0.806	0.796	0.777	0.746	0.705	0.658	
29	0.808	0.804	0.794	0.774	0.743	0.703	0.656	
30	0.806	0.802	0.791	0.772	0.741	0.700	0.653	
31	0.804	0.799	0.789	0.769	0.738	0.698	0.651	
32	0.801	0.797	0.787	0.767	0.736	0.696	0.649	
33	0.799	0.795	0.785	0.765	0.734	0.694	0.647	beyond data
34	0.797	0.793	0.782	0.763	0.732	0.692	0.645	beyond data

35	0.795	0.791	0.780	0.761	0.730	0.690	0.644	beyond data
36	0.793	0.789	0.778	0.759	0.728	0.688	0.642	beyond data
37	0.792	0.787	0.776	0.757	0.726	0.687	0.640	beyond data
38	0.790	0.785	0.774	0.755	0.725	0.685	0.639	beyond data
39	0.788	0.783	0.773	0.753	0.723	0.684	0.638	beyond data
40	0.786	0.781	0.771	0.751	0.721	0.682	0.637	beyond data

13.| Annex B: Evidence tables

B.1 Methane emissions measured for flame-curtain kilns

Table B.1 Methane emission factors measured for flame-curtain kilns.

Source and feedstock	Moisture	CH_4, g per kg biochar	n	Note
Cornelissen et al. (2024), grass	8.0 ± 1.0 per cent	below 5.5	17	below quantification limit
Cornelissen et al. (2024), grass and twigs	9.6 ± 1.5 per cent	below 5.5	19	below quantification limit
Cornelissen et al. (2024), maize cobs	11.2 ± 2.5 per cent	below 5.5	21	below quantification limit
Cornelissen et al. (2023, 2024), twigs and leaves	14.7 ± 3.4 per cent	below 5.5	25	below quantification limit
Cornelissen et al. (2024), sesame stems	10.0 ± 1.5 per cent	about 17	17	one spike during quenching
Cornelissen et al. (2024), coffee husk	12.1 ± 1.1 per cent	179 (134 to 274)	4	fine, dense husk
Cornelissen et al. (2016, 2024), twigs	25.0 per cent	28.5	190	wet feedstock
Lotz et al. (2026), five feedstocks, dry class	at most 15 per cent	below 5	—	woody average about 5
Lotz et al. (2026), semi-moist class	16 to 24 per cent	up to 20	—	wheat straw highest
Lotz et al. (2026), moist class	at least 25 per cent	30 to 40	—	—

Cornelissen et al. (2024) report medians; “below 5.5” is the quantification limit of the method. The moisture basis is not stated in the sources; the methodology specifies wet basis as read by a handheld meter.

An earlier campaign on the same kiln type supports these findings (Cornelissen et al., 2016). Across 17 runs on woody and shrub feedstock at about 25 per cent moisture, methane averaged 30 grams per kilogram with a standard deviation of 60, the same order as the moist class with the wide spread that wet feedstock produces. Two runs on a blend of rice husk and shrub at 15 per cent moisture reported methane below detection; two runs of a blend cannot set a default for rice husk, which remains outside the Track 1 default classes. The only published methane value for a top-lit updraft unit, 40 grams per kilogram of char, comes from a single laboratory cookstove test (MacCarty et al., 2008).

B.2 Organic carbon content by feedstock class

Table B.2 Organic carbon content of biochar, tonnes of carbon per tonne of dry biochar: IPCC (2019a) compiled values and the derived defaults. The manure and biosolids values are informative: Module F6 is restricted to Track 3, which measures the organic carbon.

Feedstock class (pyrolysis)	IPCC mean	95 per cent limit	Tenth percentile	Table 21 default
Wood	0.77	± 42 per cent	0.56	0.55
Nut shells, pits and stones	0.74	± 39 per cent	0.55	0.55
Herbaceous, excluding rice	0.65	± 45 per cent	0.46	0.45
Rice husk and rice straw	0.49	± 41 per cent	0.36	0.35
Animal manure	0.38	± 49 per cent	0.26	0.25
Biosolids	0.35	± 40 per cent	0.26	0.25

B.3 Yield defaults and ceilings

Table B.3 Yield defaults and mass-balance ceilings, tonnes of dry biochar per tonne of dry feedstock.

Feedstock class	Yield default	Yield ceiling	Basis
Woody biomass	0.15	0.32	Tenth percentile and maximum of Cornelissen et al. (2016)
Nut shells, stones and pits	0.15	0.42	Lower bound of woody; ceiling from the dense-precursor literature
Herbaceous and crop residues, bagasse	0.15	0.38	Lower bound of woody; no separate field data
Rice husk and high-silica husks	0.15	0.50	Lower bound of woody; high ceiling reflects retained silica
Manure and biosolids	Track 3 only	—	Not a Track 1 feedstock

B.4 Ecological-leakage factors

Table B.4 Ecological-leakage factors (Table 31 of the methodology).

Factor	Value	Unit	Basis
Nitrogen replacement	12.1	tCO_2e per t N	Full-chain intensity of synthetic nitrogen: production, transport and field nitrous oxide. The global mean for 2018 is 10.5, with regional means up to about twice that (Menegat et al., 2022). Set above the global mean so that it is conservative for most host countries without adopting the highest regional value.
Phosphorus	1.5	tCO_2e per	Production of phosphate fertiliser. The European

replacement		t P_2O_5	Commission standard value is 1.01 (European Commission, 2015); regional footprints for triple superphosphate correspond to about 1.2 (Brentrup et al., 2018). Set above both.
Potassium replacement	0.6	tCO_2e per t K_2O	Production of potash. The European Commission standard value is 0.58; the footprint of muriate of potash is about 0.25 (Brentrup et al., 2018). Set at the higher, rounded up.
Foregone soil organic carbon	0.19	tCO_2e per t dry residue, once	Residue carbon about 45 per cent of dry mass; humification to stable soil organic carbon about 10 to 15 per cent of residue carbon; 0.45 × 0.115 × 44/12 = 0.19.

The default nutrient contents of Table 31a are set at the upper range of published residue compositions, so that a Track 1 or Track 2 activity that does not measure is charged at least the replacement emissions a measurement would show. Cereal straw and stover carry about 0.5 to 0.8 per cent nitrogen, 0.2 to 0.3 per cent phosphorus as P_2O_5 and 1.0 to 1.5 per cent potassium as K_2O on a dry basis (Smil, 1999; the nitrogen contents of the 2019 Refinement, Volume 4, Chapter 11, Table 11.1A, fall within this range). Legume haulms and sugar-cane trash carry more nitrogen, about 1.2 per cent; woody prunings carry about half the nitrogen and a quarter of the potassium of straw (Smil, 1999).

Table B.4a Default nutrient contents of field residues, tonnes per tonne of dry residue (Table 31a of the methodology).

Residue class	N	P_2O_5	K_2O
Cereal straw and stover	0.008	0.003	0.015
Other herbaceous residues	0.012	0.003	0.015
Woody prunings and orchard residues	0.005	0.001	0.004

B.5 Market-leakage replacement factors

The factor for each prior use is the net calorific value of the biomass multiplied by the emission factor of the replacement fuel and by the ratio of conversion efficiencies, EF_market = NCV_biomass × EF_replacement × (η_biomass / η_replacement), using the net calorific values and emission factors of the 2006 IPCC Guidelines (Volume 2, Tables 1.2 and 2.2): wood and wood waste 15.6 gigajoules per tonne, other primary solid biomass 11.6; non-renewable wood 112 kilograms of carbon dioxide per gigajoule, used as the bound for coal (94.6) and wood; liquefied petroleum gas 63.1. Cooking efficiencies are 15 per cent for a traditional biomass stove and 55 per cent for a gas stove.

Table B.5 Derivation of the market-leakage default factors (Table 12 of the methodology).

Prior use and replacement	NCV, GJ per t dry	EF replacement, tCO_2 per GJ	Efficiency ratio	Factor, tCO_2e per t dry biomass
Boiler or kiln fuel, woody biomass, replaced by coal or non-renewable wood	15.6	0.112	1.0	1.75
Boiler or kiln fuel, herbaceous residue, replaced by coal or non-renewable wood	11.6	0.112	1.0	1.30
Household cooking fuel, woody biomass, replaced by LPG	15.6	0.0631	0.15 / 0.55	0.27
Household cooking fuel, herbaceous residue, replaced by LPG	11.6	0.0631	0.15 / 0.55	0.20

B.6 Feedstock-storage methane

Table B.6 Basis of the feedstock-storage methane rate.

Quantity	Value	Source
Dry-matter loss, willow-chip heap on hard standing	21 per cent in 97 days (about 6.5 per cent per month)	Whittaker et al. (2016a)
Dry-matter loss, willow-chip heap on grassland	18 per cent in 210 days (about 2.6 per cent per month)	Whittaker et al. (2016a)
Carbon dioxide to methane ratio at the methane peak	40 to 1 by volume (methane about 2.4 per cent of emitted carbon)	Whittaker et al. (2016a)
Generic wood chip, forest-residue heaps	1 to 2 per cent; 0.6 to 2.1 per cent per month	Whittaker et al. (2016b), collating the literature
Hypothesised methane conversion, wood residue	1.5 per cent of carbon over the first two months	Wihersaari (2005)
Product, most active heap	6.5 × 2.4 per cent = 0.16 per cent of stored carbon per month	Derived
Product, longer-stored heap	2.6 × 2.4 per cent = 0.06 per cent per month	Derived
Adopted default	0.13 per cent per month beyond the first	Section 9.3 of the methodology

14.| Annex C: Reproduction data

C.1 Smoothed coefficients for Table 24

Each of the five quantities below is a quadratic in L = ln(T), with T the site soil temperature in degrees Celsius: $q(T) = q_0 + q_1 L + q_2 L^2$. M is the fitted carbon remaining at a ratio of zero (per cent), a the slope in the ratio (per cent per unit), and v_{11}, v_{12}, v_{22} the elements of the cluster-robust covariance of (M, a). The credited factor at ratio x is

$$F_perm(T, x) = [M(T) - a(T)\cdot x - 1.645 \cdot \sqrt{(v_{11}(T) + x^2\cdot v_{22}(T) + 2x\cdot v_{12}(T))}] / 100$$

bounded to [0, 1], with x taken as 0.20 for any value below 0.20, and the result capped at 0.95.

Table C.1 Coefficients of the smoothed Tobit fit. Check value: T = 25 °C, x = 0.40 gives 0.754. The residual scale σ(T) has coefficients −26.9412, 31.2095 and −4.3377 and is not needed to evaluate the credited factor.

Quantity	q_0	q_1	q_2
M	64.826366	26.633423	−4.460573
a	−125.335261	99.362193	−13.974058
v_{11}	−688.500055	493.903554	−67.181140
v_{12}	2038.782694	−1456.820483	206.336376
v_{22}	−6046.261876	4331.993091	−620.516151

C.2 Inputs to the worked scenarios

Table C.2 Principal inputs of the calculation-tool scenarios. The full input set, including fuel, electricity, transport and the Annex 7 criteria, is in the tool.

Input	Scenario 1	Scenario 1M	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Wet biochar placed at full output, t per period	1,500	1,500	1,900	21,700	900	1,170	8,400
Moisture	0.15 default	0.10	0.10	0.08	0.15 default	0.06	0.05
Organic carbon	0.55 default	0.76	0.74	0.80	0.62	0.80	0.34
Molar ratio and	default, 0.40	0.28, 0.30	0.30	0.26, 0.30	0.32, 0.35	Method 3	Method 3

column							
Soil temperature, °C	25 default	20	24	20	25 default	—	—
Methane	0.0055 class default	0.004 measured, floored to 0.0055	proxy; 40 to 20 t excursions	measured, 0.0009 t per t	0.0055 class default	proxy; 12 t excursions	measured
Placement and loss	manual, 2 per cent	manual, 2 per cent	mechanised, 5 per cent (2M weighed, 0)	mechanised, 5 per cent	manual, 2 per cent	weighed at intake, 0	weighed at intake, 0
Reversal-risk rate	10 per cent fixed, cancelled	10 per cent fixed, cancelled	Annex 7, 6.5 per cent, buffer	Annex 7, 3.5 per cent, buffer	10 per cent fixed, cancelled	3 per cent fixed, cancelled	2.5 per cent, buffer
Uncertainty on removals	5 per cent	5 per cent	5 per cent (2M: 2.7 per cent calculated)	0.6 per cent calculated	5 per cent	5 per cent	1.3 per cent calculated
Embodied	0.02 per t, periods 1 to 5	0.02 per t	0.05 per t	650 t per period, inventory	0.02 per t	0.05 per t	900 t per period, inventory
Downward adjustment	1.25 per cent, illustrative	same	same	same	same	same	same