GL-MC-004 – Calculation Methodology — Quantification of Conserved Carbon Stock (CO_2eT) by *Ex-Post Stock*

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1. Introduction

1.1 Objective

To define the unique procedures for calculating and reporting CO_2eT (Co_2 Equivalent Stock Maintained) for LULUCF preserved forest projects under Greenline Carbonsat, using official remote sensing and standardized conversions. **GL-MC-004** does not address additionality, permanence, or leakage; these elements are not included in the formula and are used as governance inputs as per **GL-MS-002** .

1.2 Scope of application

a) REDD conservation projects that adopt **GL-M-001** as their parent methodology.
b) Unit of analysis: validated polygon of the project; result determined by cycle/vintage and consolidated in the record.
c) Eligible sources: NASA/ESA approved series/products; field inventories are not accepted for calculation (for comparative use only).

1.3 Normative references

Regulatory basis: CCPs (ICVCM), ICROA Code of Best Practice, CORSIA, ISO 14064-2.
Technical reference: IPCC 2006/2019 (conversions and principles for aboveground biomass).
Methodological integrations: GL-M-001 (core), GL-MC-004 (calculation/reporting), Leakage Annex of GL-MC-004 (class→gate), GL-MS-012 (data/QA/QC), GL-MS-011 (national requirements/Art. 6). *(We only maintain the annotation; the adherence maps are in an informative annex.)*

Normative note on external equivalence: GL **-MC-004** adheres to the principles of the IPCC (2006/2019), ISO 14064-2, ICVCM Core Carbon Principles and ICROA Code of Best Practice.

Compliance with this methodology does not imply automatic eligibility for voluntary market programs. Compatibility or acceptance in these programs depends on specific accreditation with each initiative.

1.4 Integration and cross-references

- **GL-M-001:** requires ex-post quantification by stock with NASA/ESA data and mandates the use of GL-MC-004 for bases, stratification, and formulas; also defines publication/serialization in the registry. Direct cross-reference.
- **GL-MS-002:** additionality, permanence (β/fR/fP) and leakage function as a decision gate (Emit/Condition/Retain) and do not adjust CO_2eT. Direct remission.
- **Leakage Appendix (GL-MC-004):** diagnosis and Green/Yellow/Red classification feed into Appendix III of GL-MS-002 (record with URI/hash and decision). Direct remission.
- **Data quality/QA-QC:** apply GL-MS-012 before consolidating CO_2eT (technical exclusions, versions, hashes). Direct cross-referencing.

1.5 Principles applicable to calculation

a) Ex-post for inventory: emissions based on CO_2eT validated in the cycle; no counterfactual baseline.
b) Technical conservatism: addressing technical uncertainties and exclusions before consolidation (e.g., cloud/shadow/faults).
c) Without multipliers/buffers in the formula: risks and permanence are governance factors, not the mathematics of CO_2eT.
d) Traceability and uniqueness: result per polygon/cycle with ID/version/hash, publication of metadata/aggregates and prevention of double counting.

2. Boundaries, units of analysis and identification of polygons

2.1 Scope

Define, in GIS, the project boundaries and valid polygons (preserved forest) based on official remote sensing data; field inventories are not accepted for CO_2eT calculation. The layers, versions, and eligibility criteria of the NASA/ESA sources must be documented at this stage.

2.2 Spatial boundaries (SSR)

Define, in GIS, the project boundaries and valid polygons (preserved forest) based on official remote sensing data; field inventories are not accepted for CO_2eT calculation. The layers, versions, and eligibility criteria of the NASA/ESA sources must be documented at this stage.

2.3 Unit of analysis and eligibility conditions

a) Unit of analysis: validated polygon of the project. The CO_2eT calculation is determined by polygon and by cycle (vintage) and then consolidated for issuance/registration.

b) Legal and land tenure eligibility (referring to **GL-MS-007**): each polygon is only included in the calculation if the legal status/ownership/licenses are verified according to **GL-MS-007** (KYC/KYB, AML/ABC, ownership of carbon rights). This verification is a prerequisite for the cycle and is part of the decision gate defined in **GL-MS-002** .

2.4 Time window and cycle (vintage)

Each result is linked to the verified annual cycle (vintage) and published in the project cycle package, following the MRV/registration flow defined in **GL-M-001** .

2.5 Identification and serialization

Every polygon/cycle must be identified by a unique ID with a minimum structure: [Project]–[Polygon]–[Vintage]–[Series]–[Hash], ensuring uniqueness and traceability in the **Greenline Carbonsat registry** .

2.6 Overlapping rules and spatial consistency

a) Overlapping polygons within the same project/cycle is prohibited.
b) If there is an intersection with third-party areas, adjust the boundaries before calculation to avoid double counting, while maintaining the decision path (maps/versions).
c) Uniqueness in registration is mandatory.

2.7 Masks, layering and pre-processing

Apply masks (e.g., cloud/shadow/water), stratification by forest typology, and other pre-processing procedures before AGB→C→CO_2e conversion. Rules and parameters must be aligned with the bases defined in this methodology.

2.8 Required metadata (per polygon/cycle)

Record in the technical dossier and in the verification/registration package: data source/version (NASA/ESA), observation period, pre-processing procedures, internal file URI, integrity hash, and calculation report version.

2.9 Publication and linking to the registry

The result per polygon/cycle (CO_2eT) is linked to the Carbonsat record with digital identification and published according to the transparency rules of the parent methodology (metadata and aggregates).

Cross-references to avoid redundancy:

- MRV Flow, publication and deadlines → **GL-M-001** .
- Data/QA-QC (technical exclusions and versioning) → **GL-MS-012** .
- Legal compliance (KYC/KYB, AML/ABC, ownership/licenses) → **GL-MS-007** (precondition).

3. Data sources and eligibility criteria

3.1 Versioned positive list

CO_2eT quantification must exclusively use official remote sensing products listed and versioned by Greenline Carbonsat in **GL-GR-010** (Data Reference Guide).

Examples (to be completed according to the current GL-GR-010):

- NASA GEDI — [accepted version]; use: proxies/structures for aboveground biomass.
- ESA Sentinel-1/2/3 — [accepted versions]; use: coverage, stratification, change detection.
- USGS Landsat 8/9 — [collection/accepted version]; use: historical series and integrity.

Note: *Field inventories can only be cited as comparative/validation material and are not included in the CO_2eT calculation .*

3.2 Version update policy

- Prospective replacement: new versions replace previous ones only for future cycles (they do not retroactively apply).
- Change control: each version change must record the reason, expected impact, and cutoff date in the cycle's dossier.
- Traceability: every source used must have a registered internal URI, official version, and hash (see 3.3).

3.3 Required metadata by source and by polygon/cycle.

In the technical dossier and the VVB/registration package, please include at least the following:

- Official source (e.g., NASA/ESA/USGS); product; version; date/period of acquisition;
- Processing parameters (product level, filters, relevant thresholds);
- Internal URI (Greenline Carbonsat repository); integrity hash; calculation report version;
- Technical manager and processing date.

3.4 Minimum required pre-processing (checklist)

Apply before any conversion AGB→C→CO_2e:

- Masks: cloud, shadow, water/non-forest surface;
- Stratification: applicable forest typologies and LULUCF classes;
- Spatial consistency: geometric alignment of the datasets;
- Temporal integrity: coherence of the observation period per polygon/cycle;
- Quality tests: SNR/QA flags for the product, percentage of useful coverage, artifact verification.

3.5 Operational criteria for data eligibility

A dataset is eligible if it cumulatively meets the following criteria:

- Official status & auditability (recognized agencies and public documentation);
- Minimum quality (parameters defined in GL-GR-010, e.g., maximum cloud percentage, resolution, time interval per biome);
- Replicability (clear procedures, archived scripts or parameters);
- Consistency with the cycle (dates compatible with vintage and defined windows).

3.6 Inconsistencies, technical exclusions and CAPA

- When there are material flaws/gaps/uncertainties, the applicant must apply for technical exclusion or reprocessing before consolidating the CO_2eT.
- Open CAPA (Correction/Prevention) documenting the root cause, correction applied, and prevention for future cycles.
- Mandatory cross-referencing: QA/QC criteria, uncertainty thresholds, and evidence formats follow **GL-MS-012.**

3.7 Responsibilities

- Proponent: select eligible sources, apply pre-processing, register metadata and evidence.
- VVB: verify adherence to the positive list, versions, and quality/traceability criteria.
- Greenline Carbonsat: validate data package conformity, approve accepted versions in **GL-GR-010** , and register the dataset used in the cycle.

Legend of Abbreviations:

- *AGB — Above-Ground Biomass*
- *CAPA — Corrective and Preventive Action*
- *CO_2eT — Stock of carbon dioxide equivalent conserved (tons)*
- *ESA — European Space Agency*
- *GEDI — Global Ecosystem Dynamics Investigation (NASA)*
- *GLI — Greenline Institute*
- *GL-GR-010 — Greenline Carbonsat Data Reference Guide*
- *Hash — Cryptographic signature for file integrity (e.g., SHA-256)*
- *LULUCF — Land Use, Land-Use Change and Forestry*
- *NASA — National Aeronautics and Space Administration*
- *SNR — Signal-to-Noise Ratio*
- *URI — Uniform Resource Identifier (digital resource identifier)*
- *USGS — United States Geological Survey*
- *VVB — Validation and Verification Body (independent verification entity)*

4. Stratification, masks and pre-processing

4.1 Stratification of forest areas

The applicant must stratify the valid areas into LULUCF forest typologies (e.g., dense forest, open forest, secondary forest), using official remote sensing series (NASA/ESA/USGS) and **GL-GR-010 parameters** .

- The stratification should be documented with auditable maps and shapefiles.
- Each stratum must be linked to a unique polygon (ID/vintage).
- Changes in stratification between cycles must be technically justified and recorded in metadata with URI and hash.

4.2 Mandatory mask application

Before the calculation, the applicant must apply masks of:

a) Clouds and shadows — using native source algorithms (e.g., Sentinel/Landsat QA flags).
b) Water and non-forest surfaces — exclusion via spectral classification.
c) Ineligible areas — overlaps with untitled or legally invalid areas (check **GL-MS-007**).

4.3 Data preprocessing

The data must undergo minimal pre-processing steps, including:

- Geometric correction (coherence of projections and alignment between series).
- Radiometric correction (when applicable).
- Temporal consistency (use of images from the same observation period per cycle).
- Technical exclusion of inconsistent pixels (as per **GL-MS-012 QA/QC**).

4.4 Documentation and metadata

For each stratification, masking, and preprocessing step, the applicant must document:

- Input data (source, version, URI, hash).
- Procedures applied (algorithms, parameters, software).
- Intermediate results (stratified maps, shapefiles, reports).
- Technical manager and execution date.
- 4.5 Verification and validation
- Proponent: performs the stratification, applies masks, and generates the technical documentation.
- VVB: reviews the consistency of stratifications, the application of masks, and the traceability of steps.
- Greenline Carbonsat: validates the methodological conformity of the data package and confirms its publication in the corresponding registration cycle.

Legend of Abbreviations:

- *GL-GR-010 — Greenline Carbonsat Data Reference Guide*
- *GL-MS-007 — Legal Compliance for Carbon Projects*
- *GL-MS-012 — QA/QC and data criteria*
- *ID — Unique identifier of the polygon/cycle*
- *LULUCF — Land Use, Land-Use Change and Forestry*
- *QA/QC — Quality Assurance / Quality Control*
- *URI — Uniform Resource Identifier*
- *VVB — Validation and Verification Body*

5. Conversions and formulas (AGB → C → CO_2e)

5.1 Pipeline overview

This chapter defines how to calculate CO_2eT (Conserved Equivalent CO_2 Stock) from ex-post stock, using only aboveground biomass (AGB) obtained by remote sensing. The calculation is done per eligible pixel/cell, aggregated to the polygon and cycle (vintage).

Note: *risks (permanence), additionality, and leakage are not factored into the CO_2eT calculations; they influence emission decisions under other standards.*

5.2 Mandatory entries (per cycle)

a) Raster/Grade AGB (units: Mg/ha or t/ha) for valid areas (post-masks and stratification).
b) Eligibility map (binary) applied previously (Sections 2–4).
c) Area per pixel (ha) consistent with the reference system.
d) Parameters and factors (Section 5.3; Tables in Appendix A – Factors and Equations).
e) Metadata: source/version, observation period, URI, hash, technical manager.

5.3 Parameters and factors (defined in Annex A)

- CF — carbon fraction in aboveground biomass (adopt value/tier as per Annex A).
- $\rho CO_2/C$ — stoichiometric factor 44/12 ($C \rightarrow CO_2$).
- a_px — area (ha) of each pixel/cell in the adopted cartographic system.
- AGB_px — aboveground biomass per hectare in the pixel (Mg/ha).
- M — eligibility mask (1 = valid; 0 = invalid).
- S — forest stratum (when there are specific parameters per stratum).

Notes:

• Only aboveground biomass (AGB) is used. Roots, litter, soil, and dead wood are not included in the calculation.

• The CF (Center of Formation) may vary by biome/stratum as per Annex A; in the absence of a specific factor, apply the conservative standard established in the Annex.

• ***Annex A*** *– Factors and Equations (normative): contains the CF table by biome/stratum, examples of units and conversions, and consistency validations (quick checks) for auditing.*

5.4 Calculation by pixel/cell (micro level)

For each eligible pixel i in polygon P:

1. Apply a scientific model based on the interaction between electromagnetic radiation and the biophysical properties of vegetation.
2. Consider that the radiation reflected by vegetation presents spectral signatures associated with photosynthetic activity, water content, cellular structure, pigments and biochemical composition, temperature, and surface energy.
3. Combining spectral indices validated in the scientific literature, organized into ten functional groups that represent complementary dimensions of vegetation — greenness, pigmentation, moisture, structure, biomass, and physiological stress.
4. Use only data from public and verifiable sources (NASA, ESA, USGS and related agencies), ensuring traceability, auditability and transparency.

Steps in the methodological process

5. Perform preprocessing of the input data:
   a) Atmospheric and radiometric correction of remote sensing products;
   b) Application of cloud, shadow and water masks (QA60, SCL and QA composites);
   c) Resampling and spatial normalization between sensors; d) Intersensory reflectance equalization (*cross-calibration*).

6. Perform the calculation of the spectral indices:
   a) To compute multispectral and hyperspectral indices derived from approved sensors; b) To functionally group the indices into ten thematic categories; c) To normalize and statistically standardize the values (*z-score* method).

7. Proceed with the integration of structural data:
   a) Interpolate observed biomass *footprints ;* b) Cross-reference spectral variables through regression and

supervised learning; c) Generate regional models calibrated by biome and forest typology.

8. Perform the modeling and validation:
   a) Train the GLVCI (Greenline Vegetation Carbon Index) model with real biomass plots (t/ha);
b) Perform cross-validation (*k-fold*) and stratified spatial sampling;
c) Obtain an average correlation $R^2 \geq 0.90$ between observed and estimated biomass;
d) Control for standard error by vegetation cover class.

9. Perform the final conversion and integration:
a) Convert biomass to carbon using a coefficient of 0.47 (IPCC 2006);
b) Convert carbon to CO_2 equivalent using a factor of 3.667;
   c) Integrate the results spatially and temporally to determine the conserved stock and the annual increment (tCO_2e/ha/year);
   d) Issue a georeferenced and verifiable report with full traceability of metadata.

10. To guarantee governance, traceability, and technical confidentiality of the model, recognizing that the algorithms, weights, and internal parameters constitute the intellectual property of Greenline Carbonsat, protected by confidentiality and access controls.

11. Please note that the Greenline Carbonsat calculation model and methodology were audited and validated by Bureau Veritas through the "Greenline 2024 Validation Statement," which attests to the technical credibility, traceability of processes, and scientific conformity of the carbon calculation methodology, ensuring the integrity and transparency of the results presented.

    Source: Bureau Veritas, *Greenline 2024 Validation Statement (ENG)* . Available at: https://www.bureauveritas.com.br/sites/g/files/zypfnx206/files/media/document/Declara%C3%A7%C3%A3o%20de%20Valida%C3%A7%C3%A3o%20Green%20Line%202024%20ENG.pdf

5.5 Polygon and cycle aggregation (meso level)

For a polygon P in the cycle t:

1. Define polygon P as the geospatial reference unit, resulting from the sum of the eligible pixels that make up the project's area of interest.
2. Consider that each pixel has an individual reading associated with the orbital time and the availability of passes by the sensors used.
3. Perform periodic spectral readings according to the orbital calendar of each satellite, with an average update every 4 (four) days, ensuring temporal continuity and traceability of each observation.
4. After obtaining the spectral readings and intermediate results, sum the values of all pixels in polygon P for the cycle t.
5. Divide the sum by the total number of valid observations within the monitoring cycle to obtain the weighted average of the readings and results.
6. Apply consistency corrections and eliminate outliers identified in the QA/QC process, according to GL-MS-012 criteria.
7. Generate the aggregate value of $CO_2eT_(P,t)$, representing the average carbon stock conserved in polygon P during cycle t.
8. Record the result with three decimal places and consolidate the metadata with the complete identification of the cycle (project–polygon–vintage–hash).
9. Maintain a record of the original readings, intermediate averages, and applied filters, ensuring the reproducibility of the calculations and full traceability of the history.

5.6 Consolidation of the cycle's results (macro level)

1. Consolidate the calculations for all polygons in the project.
2. Apply final QA/QC (integrity checks, total reconciliation, metadata consistency).
3. Generate the Cycle Calculation Report with: data version, parameters, cutoff date, and hash.
4. Serialize the result (Project–Polygon–Vintage–Series–Hash) and publish metadata in the record.

5.7 Precision, rounding, and decimal places

- Pixel level: maintain ≥ 3 decimal places (tCO_2e).
- Aggregation by polygon: maintain ≥ 2 decimal places.
- Disclosure/recording: round the total per polygon/cycle to whole tCO_2e (bank rounding rule; document in the report).
- Never round before adding sums.

5.8 Uncertainty treatment (before the final number)

- Material uncertainty (e.g., low quality, large percentage of exclusion due to cloud/shadow) should be remedied with reprocessing or technical exclusion before consolidating the calculations.
- If unresolved material uncertainty persists, the outcome will be "conditional" within the cycle package (governance gate outside this methodology).
- Quantification does not apply multipliers or discounts for uncertainty; the treatment is pre-account (**GL-MS-012**).

5.9 Scripts, reproducibility and soundtracks

- Store scripts/notebooks, parameters, library versions, URIs, and input and output hashes.
- Link all files to the Carbonsat-ID of the cycle.
- Greenline Carbonsat validates the methodological compliance of the data package and the calculation procedure before the cycle is published.

5.10 Minimum chapter outputs (per polygon/cycle)

- Table of parameters actually used (CF, 44/12, pixel area, etc.)
- Calculation report (PDF/spreadsheet) with formulas, versions, URI, and hash.
- Post-mask AGB raster and polygon shape (versions and hashes)
- Consolidation file with calculations and serialization keys.

Legend of Abbreviations:

- *AGB — Above-Ground Biomass*
- *CF — Carbon Fraction (carbon fraction of biomass)*
- *CO_2eT — Store of carbon dioxide equivalent conserved (t)*
- *GL-GR-010 — Greenline Carbonsat Data Reference Guide*
- *Hash — Cryptographic signature for integrity (e.g., SHA-256)*
- *LULUCF — Land Use, Land-Use Change and Forestry*
- *URI — Uniform Resource Identifier*
- *VVB — Validation and Verification Body*

Appendix A – Factors and Equations (normative): contains the CF table by biome/stratum, examples of units and conversions, and consistency validations (quick checks) for auditing.

6. Technical Confidence Factor (TCF)

6.1 Objective

Establish the technical confidence index for the calculation of CO_2eT by polygon and by cycle, consolidating data quality and processing metrics under **GL-MC-004** . The FTC expresses, on a scale of 0–1 (or 0–100%), the degree of reliability of the result without altering the CO_2eT formula.

6.2 Scope

This applies to all projects/cycles submitted using this methodology. The FTC is mandatory and must accompany the CO_2eT result in the cycle package and in the Public Summary.

6.3 Nature and effect

FTC is not included in the CO_2eT calculation (Section 5).

- Results ≥ FTC_min are eligible for the normal issuance flow.
- Results < FTC_min are marked as "conditional" and subject to the decision gate foreseen in **GL-MS-002** , along with other governance inputs (e.g., leakage).
- The FTC_min is normative and defined in Annex F; it may be adjusted prospectively (future cycles) according to technical criteria.

6.4 Normative Note — FTC_min (Greenline Carbonsat standard)

The applicable minimum FTC is 0.65. Results ≥ 0.80 are accepted without conditions; 0.65 ≤ FTC < 0.80 must be conditioned (with corrective measures or remediation); FTC < 0.65 are retained until review and reprocessing. These thresholds are harmonized with the Emission Gate (GL-MS-002) and QA/QC (GL-MS-012), and should only be reviewed prospectively for future cycles (Annex F).

6.5 FTC Inputs

The FTC consolidates, at a minimum, the following dimensions (with weights defined in Annex F):

a) Useful data coverage in the polygon/cycle (% of area effectively analyzed after masking).
b) Technical exclusions (cloud/shadow/artifacts) and appropriate treatment (reprocessing or disposal).
c) Temporal consistency (coherent windows by biome and by cycle).
d) Spatial consistency (geometric alignment/reprojection, absence of distortions).
e) Compliance with versions approved in **GL-GR-010** (data/products and their respective versions).
f) Documentary QA/QC trail (evidence of checks and reconciliations required in **GL-MS-012**).

6.6 Calculation and evidence

The FTC is calculated according to Annex F, based on scores (0–1) per component and weights (adding up to 1.00).

- FTC = Σ (weight_k × score_k).
- Each component must have verifiable evidence (URIs, versions, hashes, reports, scripts, QA flag printouts) attached to the cycle dossier.
- 6.6 Publication and verification
- Publication: disclose FTC (%) in the Public Summary of the cycle (metadata), along with main sources/versions and cutoff date.
- Verification (VVB): check FTC calculation, evidence, and compliance with Annex F and GL-MS-012.
- Methodological validation: Greenline Carbonsat validates the data package, method, and calculation (including the FTC) before publishing the cycle in the registry.
- Update: FTC weight/threshold/formula adjustments should be prospective, with cutoff date, attachment version, and hash archived.

Legend of Abbreviations:

- *COVER — Corrective and Preventive Action*
- *CO_2eT — Store of carbon dioxide equivalent conserved*
- *FTC — Technical Confidence Factor*
- *Hash — Cryptographic signature of integrity (e.g., SHA-256)*
- *VVB — Validation and Verification Body*

7. Handling uncertainty and technical exclusions (pre-consolidation)

7.1 Objective

Define when and how to address material uncertainties and apply technical exclusions before consolidating CO_2eT by polygon/cycle, while adhering to the principle of not using multipliers/discounts in the formula. The result only follows consolidation after documented cleanup.

7.2 Treatment triggers

Treatment should be initiated when the following occurs, either in isolation or cumulatively:

a) Insufficient useful post-mask coverage (e.g., cloud/shadow/water) in the polygon/cycle;
b) Temporal inconsistency (windows not compatible with the cycle/biome period);
c) Spatial/geometric inconsistency (misalignment between datasets/polygon);
d) Unapproved versions (not on the positive list/GL-GR-010) or incomplete metadata;
e) Preprocessing artifacts/errors detected in QA/QC;
f) FTC (Section 6) indicating confidence below internal targets (even if ≥ FTC_min).

7.3 Sanitation options (in order of preference)

1. Reprocess with correct parameters/versions (same official source);
2. Replace dataset with equivalent approved version (**GL-GR-010**), recording the cutoff date;
3. Temporally interpolate within the cycle window (when permitted **by GL-GR-010**);
4. Technically exclude unrecoverable pixels/cells/sectors, provided that:
    - (i) the cause documented; (ii) the excluded area quantified; (iii) traceability maintained;
    - Never extrapolate or assign values to fill gaps.

7.4 Objective criteria for technical exclusion

Exclusion is mandatory when:

- QA flags from the source indicate unacceptable quality;
- Useful coverage < minimum threshold defined for the biome (**GL-GR-010**);
- The geometric alignment does not reach the maximum permissible error;
- The time window does not meet the cycle requirements, and no reprocessing is possible.

7.5 CAPA Record (Correction and Prevention)

For each case handled, issue a cover sheet containing:

- Root cause analysis, corrective action (reprocessing/replacement/deletion), and preventive action.
- Tables showing the percentage of area affected, expected impacts on the FTC, and references (URI/hash);
- Technical manager, dates, and internal verification.

7.6 Treatment discharge and referral

- If resolved: proceed to consolidation (Section 8).
- If material uncertainties remain: the polygon/cycle continues to be "conditioned" for governance decision (GL-MS-002).
- The FTC is recalculated after cleanup; if < FTC_min, it qualifies as conditional (Section 6).

7.7 Minimum documents and evidence

- QA/QC report with printouts/flags, useful coverage metrics, and exclusion maps;
- Updated preprocessing log (parameters, versions, scripts, software);
- URIs and hashes of inputs, intermediates, and post-processing outputs;
- Cover signed by the technical manager and checked by Greenline Carbonsat.

7.8 Roles and responsibilities

- Proponent: perform remediation, issue CAPA, update metadata, and redo the FTC;
- VVB: verify that the criteria in this section were applied before consolidation;
- Greenline Carbonsat: validate methodological compliance of the post-treatment data package and authorize advancement to Section 8.
- GLI: not applicable (only acts on co-benefits/ **GL-MS-003**).

Legend of Abbreviations:

- *COVER — Corrective and Preventive Action*
- *CO_2eT — Store of CO_2 equivalent conserved*
- *FTC / FTC_min — Technical Confidence Factor / Minimum Normative Threshold*
- *GL-GR-010 — Greenline Carbonsat Data Reference Guide*
- *GLI — Greenline Institute*
- *QA/QC — Quality Assurance / Quality Control*
- *URI / Hash — Resource identifier / integrity signature*
- *VVB — Validation and Verification Body*

8. Consolidation by cycle and numerical outputs

8.1 Objective

To define how to consolidate the CO_2eT result by polygon and by cycle (vintage), standardizing identification keys, rounding rules, reconciliation, and serialization of the outputs that feed the Greenline Carbonsat registry.

8.2 Entries for consolidation (post-Section 7)

- Result of the calculation by polygon P in cycle t (after sanitation/QA-QC).
- FTC recalculated and in effect (Section 6).
- Minimum consolidated metadata (sources/versions, period, parameters).
- CAPA logs (if any) and evidence of technical exclusions.

8.3 Keys and data structure (by polygon/cycle)

Each record must contain, at a minimum:

- Project-ID; Polygon-ID; Vintage; Series (incremental);
- CO_2eT (t) — final numerical value of the polygon in the cycle;
- FTC (%) — cycle value (for the polygon);
- Leakage class (result of the leakage appendix of this methodology);
- URIs of the artifacts (raster/shape/report); corresponding hashes;
- Version stamp (methodology/annexes/GL-GR-010) and cut-off date.

8.4 Rounding and presentation rules

- Polygon level: store with two decimal places; display in the record in whole tons (bank rounding).
- Project level (sum of polygons): display in whole tons.
- Never round off before totals and reconciliations.

8.5 Reconciliation and consistency

Before closing the loop:

a) Sum of polygons = total project (maximum difference after rounding ≤ 0.5 t per polygon).
b) Cross-checking versions (data, parameters, scripts) versus declared metadata.
c) Temporal coherence (all dates within the cycle period) and spatial coherence (non-overlapping polygons).
d) FTC: confirm whether or not it meets the FTC_min (register status as "eligible" or "conditional").

8.6 Serialization and integrity

- Output sequential series by polygon/vintage: [Project]-[Polygon]-[Vintage]-[Series].
- Link hash to Calculation Report and key artifacts (rasters/shapes).
- Any reprocessing generates a new series, maintaining the history (previous series remain archived, not replaced).

8.7 Numerical outputs and required files

- Consolidation file (table) with one record per polygon/cycle and fields from 8.3.
- Cycle Calculation Report (PDF/spreadsheet) with formulas, parameters, sources/versions, cutoff date, and hash.
- Post-masked AGB rasters and polygon/stratum shapes (with URIs and hashes).
- FTC spreadsheet/report (components, weights, final score).
- Summary of the Leakage (classification by polygon/cycle and minimal evidence).

8.8 Cycle completion (ready for VVB and registration)

Consolidation is considered complete when:

1. All polygons in the cycle have the Calculation Result, FTC, and leakage class;
2. Reconciliations from 8.5 are OK;
3. Artifacts and metadata have a URI and a hash;
4. The series and the version are consistent;
5. The dossier meets the minimum content requirements (Section 9) and will proceed to VVB and methodological validation by Greenline Carbonsat.

8.9 Responsibilities

- Proponent: compile the consolidation table, apply rounding rules, check reconciliations, and generate the series.
- VVB: Verify the integrity of outputs, reconciliations, and adherence to the rules in this section.
- Greenline Carbonsat: Validate the method, data, and compliance of the consolidation for publication authorization of the cycle.
- GLI: not applicable (only works on co-benefits).

Legend of Abbreviations:

- *COVER — Corrective and Preventive Action*
- *CO_2eT — Store of CO_2 equivalent conserved*
- *FTC / FTC_min — Technical Confidence Factor / Minimum Normative Threshold*
- *Hash — Cryptographic signature of integrity*
- *ID — Unique identifier*
- *URI — Uniform Resource Identifier*
- *VVB — Validation and Verification Body*
- *Vintage — Reference cycle/year of emission*

9. Verification Package (VVB)

The Verification Package is consumed directly by the **GL-MS-002** (issuance decision) and **GL-MS-005** (independent verification) modules. All artifacts delivered to VVB must maintain hash and version integrity as per **GL-GR-010.**

9.1 Objective

Define the minimum dossier that allows for independent verification (VVB) of the CO_2eT calculation and methodological validation by Greenline Carbonsat before publication of the cycle in the registry.

9.2 Dossier composition (by project/cycle)

1. **Cycle Calculation Report**
   - Description of the applied pipeline (Sections 2–8) and effective formulas/parameterizations.
   - Tables by polygon: Project–Polygon–Vintage–Series–CO_2eT–FTC–Leakage–Hash.
   - Cut-off date and rounding rules.
2. **Versioned inputs and intermediates**
   - Post-mask AGB rasters; polygon/layer shapes.
   - Positive list of sources/versions (according to GL-GR-010), with URI and hash.
   - Preprocessing logs (stratification, masks, geometric/temporal alignments).
3. **QA/QC (GL-MS-012)**
   - Complete checklist; useful coverage metrics and technical exclusions;
   - Evidence of temporal/spatial consistency;
   - CAPA (when applicable), with cause, correction and prevention.
4. **FTC — Technical Confidence Factor (Section 6 / Annex F)**
   - Spreadsheet/calculation code, components/weights, FTC (%) and comparison with FTC_min.
5. **Leakage — GL-MC-004 Leakage Attachment**
   - Diagnosis, analysis boundaries and classification (Green/Yellow/Red), with minimum evidence.
6. **Legal land tenure eligibility (GL-MS-007)**
   - Summary by polygon of ownership/license evidence (excluding sensitive documents), with internal references.
7. **Reproducibility**
   - Scripts/notebooks, library parameters and versions; execution instructions; input/output URIs/hashes.

9.3 VVB acceptance criteria

- Consistency between inputs → processing → outputs;
- Adherence to Sections 2–8, **GL-MS-012** (QA/QC) and **GL-GR-010** (sources/versions);
- FTC calculated and ≥ FTC_min (or conditional if < FTC_min);
- Leakage attachment completed (class defined);
- Complete serialization and traceability (IDs, series, URIs/hashes).

9.4 Flow and roles

- Proponent: compiles the dossier, ensures traceability and consistency.
- VVB: verifies methodological conformity and reproducibility.
- Greenline Carbonsat: validates the data package, methods, and applicability of the methodology and authorizes the publication of the cycle in the registry.

9.5 Evidence and format

- Accepted formats: PDF (reports), CSV/Parquet (tables), GeoTIFF/COG (rasters), GeoPackage/GeoJSON (vectors).
- All evidence must have a URI and hash; scripts/notebooks must open and run with declared versions.
- Confidential items (e.g., legal documents) are referenced but not attached to the public dossier.

Legend of Abbreviations:

- *AGB — Above-Ground Biomass*
- *COVER — Corrective and Preventive Action*
- *CO_2eT — Store of CO_2 equivalent conserved*
- *FTC / FTC_min — Technical Confidence Factor / Minimum Threshold*
- *GL-GR-010 — Greenline Carbonsat Data Reference Guide*
- *GL-MS-007 — Legal compliance for carbon projects*
- *GL-MS-012 — Data/QA/QC*
- *Hash — Cryptographic signature of integrity*
- *ID / Series — Unique identifier / sequential cycle number*
- *URI — Uniform Resource Identifier*
- *VVB — Validation and Verification Body*

10.Metadata, Versioning and Traceability

10.1 Objective

Standardize which metadata accompanies the CO_2eT calculation and how to ensure the uniqueness, integrity, and traceability of the cycle artifacts (data, scripts, reports), ensuring reproducibility and preventing double counting.

10.2 Required keys and identifiers

For each polygon/cycle, record at least:

- Project-ID • Polygon-ID • Vintage (year/cycle) • Series (incremental).
- Cycle Carbonsat-ID (record).
- Methodology: GL-MC-004 version (e.g., v3.0).
- Current annexes: Annex F (FTC) version; Annex Leakage version.
- GL-GR-010 (Data Guide) version applied.
- Polygon status in the cycle: *eligible* / *conditional* (as per Sections 6–7).

*The keys must remain identical between **GL-MS-002** , **GL-MS-005** , and **GL-GR-010** , forming the universal identifier [Project–Polygon–Vintage–Series–Hash]. Version discrepancies must be recorded in the changelog for the cycle.*

10.3 Minimum technical metadata (per artifact)

For each raster, vector, table, report, script:

- Title/Type (e.g., Raster AGB, Shape Polygons, Consolidation Table, Calculation Report).
- Source/Product/Version (e.g., NASA GEDI vX; Sentinel-2 L2A vY; Landsat CZO).
- Observation period (acquisition dates).
- Relevant processing parameters (masks, thresholds, projection, resolutions).
- Internal URI (official repository) and integrity hash (SHA-256).
- Technical lead, date/time of creation, and software/libraries (including versions).

- Note: QA/QC metadata (checks and CAPA) follows **GL-MS-012** and must be linked by URI/hash.

10.4 Versioning rules (prospective)

- Series Immutability: Once published, a polygon/cycle series is not altered. Any reprocessing generates a new series (maintaining history).
- Source/method updates: changes to **GL-GR-010** , Appendix F (FTC), Appendix Leakage, or parameter settings only apply to future cycles (documented cutoff date).
- Change tracking: every update should record what changed, why, cutoff date, expected impact, URIs, and hashes.

10.5 Logs and audit trail

- Changelog for the cycle: a chronological list (timestamp) of relevant events (data import, pre-processing, executions, reprocessing, CAPA emissions).
- Reproducible execution: versioned scripts/notebooks; environment file (requirements/lockfile) with library versions.
- Cross-linking: each result points to input(s) and intermediates via URI/hash; each artifact lists outputs that depend on it.

10.6 Integrity and security

- SHA-256 hash for all normative artifacts.
- Storage in an institutional repository with backup and access control (read-only for published versions).
- Automatic integrity checks before cycle publication.

10.7 Publishing and mirroring

- The Greenline Carbonsat registry publishes metadata and aggregates (minimum fields: 10.2 + CO_2eT, FTC (%), leakage class).
- Complete artifacts remain in the official repository; the registry mirrors the URIs and hashes (without duplicating files).

10.8 Responsibilities

- Proponent: maintain complete metadata, generate hashes, update changelog, and ensure end-to-end traceability.
- VVB: Audit metadata consistency and coherence between artifacts, hashes, and series.
- Greenline Carbonsat: validate the package's methodological compliance (metadata/versions/logs) and authorize publication in the registry.

Legend of Abbreviations:

- *COVER — Corrective and Preventive Action*
- *CO_2eT — Store of CO_2 equivalent conserved*
- *FTC — Technical Confidence Factor*
- *GL-GR-010 — Greenline Carbonsat Data Reference Guide*
- *Hash (SHA-256) — Cryptographic integrity signature*
- *ID / Series — Unique identifier / sequential cycle number*
- *URI — Uniform Resource Identifier*
- *VVB — Validation and Verification Body*
- *Vintage — Reference cycle/year of emission*

11.Publication and Transparency

11.1 Objective

To define the scope of public disclosure of the results of GL-MC-004, preserving the operational privacy of the proponents and avoiding over-claims, in line with GL-M-001 (Public Summary on Carbonsat).

11.2 What is public (Public Summary – Carbonsat)

For each cycle, the following will be published:

- Project ID and Polygon ID (anonymized according to Carbonsat policy).
- Vintage and Series (incremental).
- Consolidated CO_2eT by polygon (tCO_2e, rounded to integers).
- FTC (%) of the polygon/cycle.
- Leakage class (Green/Yellow/Red).
- Main versions: methodology (**GL-MC-004**), annexes (FTC/Leakage), **GL-GR-010.**
- Cycle cutoff date and hash of the consolidated report.

11.3 What is not public (confidential)

- Rasters, shapefiles, scripts, and detailed reports remain in an institutional repository, accessible only to the proponent, VVB, and Greenline Carbonsat.
- Legal and land tenure eligibility data — processed by GL-MS-007; only status (eligible / conditional) can be published.
- QA/QC and CAPA documents remain restricted, but with public reference (URI/hash).

11.4 Claims rules and use of results

- The applicant may only use the numbers published on Carbonsat in external communications.
- It is forbidden to infer equivalence with other standards (Verra, GS, ART, Cercarbono) unless there is formal accreditation.
- Commercial claims should refer to the official Carbonsat link with the Public Summary.
- 11.5 Responsibilities
- Proponent: To ensure consistency between what is reported to Carbonsat and what is communicated externally.
- VVB: to attest that the published data faithfully reflects the verified dossier.
- Greenline Carbonsat: publish and maintain an up-to-date Public Summary, ensuring traceability and preventing double counting.

Legend of Abbreviations:

- *COVER — Corrective and Preventive Action*
- *CO_2eT — Store of CO_2 equivalent conserved*
- *FTC — Technical Confidence Factor*
- *GL-GR-010 — Greenline Carbonsat Data Reference Guide*
- *URI — Uniform Resource Identifier*
- *VVB — Validation and Verification Body*

Appendix A — Factors and Equations (normative)

I. Scope

Define the units, factors, and order of operations for converting AGB → C → CO_2e in LULUCF (Low-Level, Low-Level, and Low-Level) forest conservation projects.

II. Regulatory requirements

1. **Units:** AGB in Mg/ha (t/ha); result in tCO_2e.
2. **Carbon fraction (CF):** apply normative value per biome/stratum (Tier 1) as per **Table A.1** of GL-MC-004; if a higher Tier is approved in **GL-GR-010** , apply prospectively.
3. **C→CO_2 conversion:** stoichiometric factor 44/12.
4. **Order of operations:** AGB → C (=AGB×CF) → CO_2e (=C×44/12) → eligibility mask → aggregation by polygon/cycle.
5. **Rounding:** rules from Section 5 and Section 8.

III. Acceptance criteria

- Strict use of the current Table A.1.
- Coherence of units and aggregations.
- Validation that there are no negative AGB values or null values.

IV. Minimum deliverables

- **Table A.1** (CF by biome/stratum, version and cut-off date).
- Consolidated report with references to CF and factor 44/12.

Table A.1 — Carbon fraction (CF) by biome/stratum (normative values) - Example

Biome / Stratum LULUCF	CF (fraction)	Source / Tier	Regulatory observations
Amazon — Dense forest	0.47	IPCC 2006, Vol. 4, T1	Default value until Tier 2 approval.
Cerrado — Wooded savanna	0.47	IPCC 2006, Vol. 4, T1	Conservative standard value
Other biomes (LULUCF)	0.47	IPCC 2006, Vol. 4, T1	Apply default until a specific Tier exists.

Normative note:

1. *All values in Table A.1 are conservative Tier 1 (IPCC 2006, Vol. 4).*
2. *When Tier 2/3 or regional values are approved in GL-GR-010, they prospectively replace the default (0.47).*
3. *Changes to the CF (Cycle Function) do not retroactively apply to previous cycles; they only apply to future cycles, with a record of the cutoff date, URI, and hash.*
4. *All calculations expressed in CO_2e assume* ***a GWP of 100 years*** *(AR5/IPCC). Other greenhouse gases are not accounted for in this methodology, unless updated in the future.*

Appendix B — Stratification and Masks (guideline)

I. Scope

Define stratification classes and mandatory masks to apply before calculation.

II. Regulatory requirements

1. **LULUCF stratification:** adopt minimum classes per biome (e.g., dense forest, open forest, secondary forest).
2. **Required masks:** cloud, shadow, water, and non-forest, obtained from official source flags.
3. **Consistency:** apply to uniform CRS and cycle time window.
4. **Change of stratum:** only with a documented technical justification.

III. Acceptance criteria

- Masks applied to 100% of polygons/cycles.
- Stratification without overlapping classes.
- Record of the versions and dates of each layer.

IV. Minimum deliverables

- List of LULUCF classes and their codes.
- Declaration of applied masks with source/version.

Appendix C — QA/QC (reference to GL-MS-012)

I. Scope

To consolidate the mandatory application of GL-MS-012 as a data quality reference, without duplicating details.

II. Regulatory requirements

1. Apply the procedures of **GL-MS-012 in full** .
2. Issue a CAPA in all cases of material uncertainty (as per Section 7).
3. Complete QA/QC before the final FTC calculation (Section 6).

III. Acceptance criteria

- Documentary evidence that all non-conformities have been addressed.
- Identification of the **GL-MS-012 version** used in the cycle.

IV. Minimum deliverables

- Declaration of conformity with **GL-MS-012** .
- List of CAPAs issued (with IDs and status).

Appendix D — Leakage (Leak Management)

I. Scope

Standardize the leakage result as a governance input, without altering CO_2eT.

II. Regulatory requirements

1. **Analysis boundary:** 10 km ring of influence (standard), adjustable with versioned technical justification.

2. **Minimum indicators:**

    - Variation in forest cover in the ring (last 36 months).
    - Suppression hotspots on official bases.

3. **Final classification (by polygon/cycle):** Green / Yellow / Red, with target thresholds approved by Greenline Carbonsat.

Class	Objective criterion	Normative effect
🟢 **Green**	**Variation ≤ 0.5% of the forest area of the ring**	**Project remains eligible**
🟡 **Yellow**	**Variation > 0.5% and ≤ 2%**	**Project marked as "conditional" at the gate (GL-MS-002)**
🔴 **Red**	**Variation > 2%**	**Emissions suspended until remediation/mitigation is resolved.**

4. **Note:** Only the final class is published in the Public Summary (Section 11).

III. Acceptance criteria

- Existence of a final class per polygon/cycle.

- Consistency between boundary, window, and indicators used.
- Record of the version of the leakage guideline applied.

IV. Minimum deliverables

- Table showing leakage class by polygon/cycle.
- Reference to the version of Annex D used.

Appendix E — Serialization and Registration

I. Scope

Define the required keys and fields for submission to the Greenline Carbonsat registry.

II. Regulatory requirements

1. **Unique series** by polygon/vintage: [Project]-[Polygon]-[Vintage]-[Series].
2. **Required fields** (per polygon/cycle):
    - Project-ID, Polygon-ID, Vintage, Series;
    - CO_2eT (t), FTC (%), Leakage class;
    - Applicable versions: GL-MC-004, Appendix F (FTC), Appendix D (Leakage), GL-GR-010;
    - URI and hash of the consolidated Calculation Report; cutoff date.
3. **Immutability:** Published series are not altered; reprocessing generates a new series.

III. Acceptance criteria

- All required fields are complete and consistent.
- Valid hash, reconciled with the report.
- Totals per cycle are consistent with Section 8.

IV. Minimum deliverables

- Submission file (CSV/JSON) according to the registration template.
- Report with hashes and URIs of the linked artifacts.

Appendix F — FTC (Technical Confidence Factor): formula, parameters and audit

I. Index structure and weights

FTC is a **weighted average** of technical components. **Weights** may vary by biome/stratum (**GL-GR-010**), provided the sum is **1.00** and the rules below are respected.

Component (k)	**Description**	**Standard weight***
F1 Useful Coverage	Percentage of valid area analyzed after masks (cloud/shadow/water)	0.30
F2 Technical Exclusions	Percentage of area excluded + CAPA treatment (reprocessing/discarding)	0.20
F3 Temporal consistency	Windows/periodicity consistent with biome and cycle.	0.15
F4 Spatial consistency	Geometric consistency between datasets and polygons	0.15
F5 Approved Versions	Adherence to the versions accepted in GL-GR-010	0.10
F6 QA/QC documentation	Required evidence and reconciliations (GL-MS-012)	0.10
Total		**1.00**

** Standard weights are the reference; adjustments by biome/stratum must be approved and versioned in the cycle dossier (prospective).*

** Changes to FTC weights, ranges, or thresholds have a prospective effect, with a version number (vX.Y), hash, effective date, and dossier URI.*

II. Calculation of the score by component

Each component receives a score_k ∈ [0,1] according to target ranges. Example of rules (default):

F1 Useful coverage (% valid area after masks)

- ≥ 90% → 1.00
- 80–<90% → 0.90
- 70–<80% → 0.75
- 60–<70% → 0.60
- < 60% → 0.30

F2 Technical exclusions (% excluded area + CAPA)

- ≤ 5% and CAPA not applicable → 1.00
- 5–10% with CAPA completed → 0.85
- 10–20% with CAPA completed → 0.70
- 20% (even with CAPA) → 0.40

F3 Temporal consistency (windows/periodicity)

- Fully consistent period per polygon/cycle → 1.00
- Small justified asymmetry (≤ 15 days) → 0.85

- Relevant asymmetry justified (> 15 and ≤ 45 days) → 0.70
- Unjustified asymmetry → 0.40

F4 Spatial consistency (geometric coherence)

- No displacement; RMS/ER controlled → 1.00
- Small adjustments with evidence → 0.85
- Relevant adjustments with evidence → 0.70
- Failures without evidence → 0.40

F5 Approved versions (GL-GR-010)

- 100% on accepted versions → 1.00
- ≥ 90% accepted + justified residual → 0.85
- 70–<90% accepted with justification → 0.70
- < 70% accepted → 0.40

F6 Documentary QA/QC (GL-MS-012)

- Complete checklist + evidence/URIs/hashes → 1.00
- Minor gaps filled → 0.85
- Relevant gaps filled → 0.70
- Lack of sanitation → 0.40

III. FTC formula

$$\mathbf{FTC} = \sum_{k=1}^{6} (\text{peso}_k \times \text{score}_k)$$

Report FTC in 0–1 and % (e.g., 0.86 → 86%). Save spreadsheet/code and inputs in the cycle dossier (URIs + hashes).

IV. Normative threshold and governance effect

- FTC_min (default): 0.80 (80%).
- If FTC < FTC_min → conditioned in the cycle packet and forwarded to the gate (GL-MS-002) along with other inputs (e.g., leakage class).
- Programs/clients may require a higher FTC_min (prospective, by contract); register in the dossier.

V. Evidence and audit (minimum)

- F1–F6 metrics documented (tables and screenshots).
- URIs and hashes of rasters, shapes, reports, and scripts.

- CAPA (cause, correction, prevention) logs when applicable.
- Record of the version of this Annex F and the **GL-GR-010** used, with the cut-off date.

VI. F.6 Controlled (prospective) update

Any changes to **weights, ranges, thresholds, or** FTC calculation:

- They must be versioned (Annex F vX.Y), with cut-off date and hash archived.
- They do not revert to previous cycles.
- They will come into effect from the next cycle after approval and publication by Greenline Carbonsat.

Legend of Abbreviations:

- *COVER — Corrective and Preventive Action*
- *FTC_min — Minimum FTC threshold*
- *Hash — Cryptographic signature of integrity*
- *RMS/ER — Root Mean Square / Registration Error (geometric)*
- *URI — Uniform Resource Identifier*