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Contact:
Ecosystem Restoration Standard
25 Rue de Frémicourt
75015 Paris, FRANCE
info@ers.org

METHODOLOGY

Quantification Methodology for Terrestrial Forest Restoration

SUMMARY

This document details the methodological approach for quantifying GHG emission removals from terrestrial forest restoration activities. To guarantee conservative calculations and minimise the risk of perverse incentives, ERS is the entity responsible for performing these calculations, not the Developer. VVBs are responsible for auditing these calculations as part of the Validation and Verification audits. For details on how calculations impact units & issuance, please refer to [ERS Programme](#).



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NORMATIVE REFERENCE


This document must be read in conjunction with:

- [ERS Programme](#);
- [MOO1](#);
- [Reference Ecosystem Guidelines](#);
- [Zonation Guidelines](#);
- [Leakage Mitigation Template](#);
- [Additionality Sheet](#).

READING NOTES

- Colour code:
 - Every element underlined in gold refers to an ERS template, guidelines or supporting document.
 - Every element underlined in black italic refers to another section of the Standard.
 - Every element underlined in green refers to a link external to ERS.
- Definitions can be found in the [Glossary](#).
- Reading indications:

 These sections offer complementary insights into the Methodology, offering more in-depth information on future improvements or details on specific topics to facilitate comprehension.

 These sections provide examples to illustrate technical requirements of the Methodology.



Boundaries

PROJECT BOUNDARIES

The physical boundaries relevant to this methodology are the Restoration Sites, the Reference Site, and Leakage Areas, as defined in the Glossary. The physical boundaries delimit all the carbon pools, emission sinks, and emission sources considered in this quantification methodology.

EMISSION SINKS & SOURCES

1. List of Emission Sinks

Carbon pools included as emission sinks in the quantification methodology are listed below. Carbon pools are considered emission sinks if the Project absorbs GHG emissions from the atmosphere. Definitions for each carbon pool can be found in the Glossary.

Carbon Pool	Type	Inclusion	Justification
Woody biomass	Aboveground	Yes	Significant carbon pool
	Belowground	Yes	Significant carbon pool
Non-woody biomass	Aboveground	Yes	Significant carbon pool
	Belowground	Yes	Significant carbon pool



Soil organic carbon (SOC)	No	Measurement uncertainties, conservative to exclude
Soil inorganic carbon (SIC)	No	Measurement uncertainties, conservative to exclude
Dead wood	No	Conservative to exclude
Litter	No	Conservative to exclude
Harvested wood products	No	Out of scope for this methodology

2. List of Emission Sources

Carbon pools included as emission sources in the quantification methodology are listed below. Carbon pools are considered emission sources in the event of reversals or leakage. Definitions for each carbon pool can be found in the Glossary.

Carbon Pools	Type	Leakage	Reversal	Justification
Woody biomass	Aboveground	Yes	Yes	Significant carbon pool
	Belowground	Yes	Yes	Significant carbon pool
Non-woody biomass	Aboveground	Yes	Yes	Significant carbon pool
	Belowground	Yes	Yes	Significant carbon pool



Soil organic carbon (SOC)	No	No	Measurement uncertainties & out of scope for this methodology (soil inversion >25 cm not allowed)
Soil inorganic carbon (SIC)	No	No	Measurement uncertainties
Dead wood	No	N/A	Measurement uncertainties
Litter	No	N/A	Measurement uncertainties
Harvested Wood Products	No	N/A	Out of scope for this methodology (commercial harvesting not allowed)

Other emission sources that have been excluded from the quantification methodology, and the rationale for exclusion are listed below.

Emission sources	Justification
Burning of biomass	Out of scope for this methodology (not allowed)
Emissions from nitrogen fertilisers	Out of scope for this methodology (not allowed)
Burning of fossil fuels	<i>De minimis</i>

 Note that the only GHG covered in the scope of this methodology is carbon dioxide.




Carbon Stock *Quantification*

INITIAL CARBON STOCK

This step is used to estimate the initial baseline of the Restoration Site.

1. Land Cover Assessment

A land cover assessment is performed upon receipt of the Project shapefile. This assessment is performed to distinguish woody from non-woody areas within the Restoration Site.

 Remote sensing models quantifying AGB are solely trained on woody biomass and should not be used to estimate non-woody biomass. In order to assess GHG sequestration accurately, ERS separates woody from non-woody areas and uses different datasets to estimate them.

- 1.1. **Woody/Non-woody mask.** The Project shapefile is transferred to an AGB Provider to obtain a woody/non-woody biomass mask, a raster format map that distinguishes the location and size of woody areas within the Project Area. For precise information on the AGB Provider, refer to *Appendix 1*.
- 1.2. **Non-woody areas classification.** An analysis is performed to distinguish the different primary classes of the remaining non-woody areas (water, shrubs, grasses, bare soil, crops and buildings). The latest version of the ten metre ESA WorldCover model¹ is used to classify non-woody areas into specific land cover types (grasslands, shrublands, croplands, bare soils, built-up, and snow). This model

¹ At the time of publication, the 2021 v200 version. Zanaga, D., Van De Kerchove, R., Daems, D., De Keersmaecker, W., Brockmann, C., Kirches, G., Wevers, J., Cartus, O., et al. (2022). 'ESA WorldCover 10 m 2021 v200'. Available at: [URL](#) (Accessed 03/11/2023).



harnesses data from Sentinel-1 and Sentinel-2 satellites and employs machine-learning techniques to generate maps with a resolution of 10 metres.

2. Biomass Quantification of Woody and Non-Woody Areas

Separate approaches are then used to estimate AGB for Woody and Non-Woody land cover classes.

2.1. Above Ground Biomass.

2.1.1. **Woody areas.** The AGB Provider generates a Woody AGB map that estimates the AGB at the pixel level in raster format for woody areas. This is referred to as AGB_{rest}^w .

2.1.2. **Non-Woody areas.** Based on the information provided in the non-woody areas classification (1.2) various methods are employed to calculate non-woody AGB. Non-woody AGB is referred to as AGB_{rest}^{n-w} .

2.1.2.1. For shrubland a default ratio of 0.1 is used for conversion of forest biomass to shrubland biomass according to the AR-TOOL14².

2.1.2.2. For grasslands a default value for each climate zone is selected, according to the IPCC, as demonstrated in *Appendix 2*.

2.1.2.3. For bare soils and croplands, the AGB is estimated at 0.

2.1.2.4. Non-reforestable zones (infrastructure and water bodies) are excluded from the AGB quantification.

² UNFCCC. (2013). 'AR-TOOL14 A/R Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities Version 04.1'. Available at: [URL](#) (Accessed 25/01/2023)



2.2. Below Ground Biomass.

2.2.1. **Woody areas.** The woody BGB is estimated to be a proportion of its AGB as dictated by the root-to-shoot ratio (RS). The relationship between BGB and AGB is represented by the equation (1):

$$(1) \text{BGB}_{\text{rest}}^{\text{w}} = \text{AGB}_{\text{rest}}^{\text{w}} \times \text{RS}^{\text{w}}$$

Where:

- $\text{BGB}_{\text{rest}}^{\text{w}}$ = Woody BGB at the Restoration Site; tDM.
- $\text{AGB}_{\text{rest}}^{\text{w}}$ = Woody AGB at the Restoration Site; tDM.
- RS^{w} = Root-to-shoot ratio of woody biomass. A default value of 0.25 is adopted³; dimensionless.

2.2.2. **Non-woody areas.** For non-woody terrains, the estimation of BGB follows the same equation as for woody areas, guided by the IPCC's root-to-shoot ratio (RS)⁴, tailored to the specific climate zone. This approach ensures that the BGB estimation is reflective of the ecological and climatic characteristics of the region.

³ UNFCCC. (2013). 'AR-TOOL14 A/R Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities Version 04.1'. Available at: [URL](#) (Accessed 25/01/2023)

⁴ Eggleston, H S, Buendia, L, Miwa, K, Ngara, T, and Tanabe, K. (2006) 'IPCC Guidelines for National Greenhouse Gas Inventories. Japan.' Volume 4, Chapter 6, Table 6.4, p 6.27. Available at: [URL](#) (Accessed 03/11/2023).



Non-woody BGB is calculated using equation (2):

$$(2) \text{BGB}_{\text{rest}}^{\text{n-w}} = \text{AGB}_{\text{rest}}^{\text{n-w}} \times \text{RS}^{\text{n-w}}$$

Where:

- $\text{BGB}_{\text{rest}}^{\text{n-w}}$ = Non-woody BGB at the Restoration Site; tDM.
- $\text{AGB}_{\text{rest}}^{\text{n-w}}$ = Non-woody AGB at the Restoration Site; tDM.
- $\text{RS}^{\text{n-w}}$ = Root-to-shoot ratio of non-woody biomass. A default value is obtained from the IPCC for each climate zone or from AR-TOOL14; dimensionless.

2.2.3. The aggregated biomass (AGB and BGB) is also provided by the IPCC and is outlined in [Appendix 2](#).

3. Total Biomass of the Restoration Site

The aggregated biomass is composed of the above and below ground biomass of the woody and non-woody components in the Restoration Site. To quantify this, equations (3), (4) and (5) are used:

$$(3) \text{B}_{\text{rest}}^{\text{w}} = \text{AGB}_{\text{rest}}^{\text{w}} + \text{BGB}_{\text{rest}}^{\text{w}}$$

Where:

- $\text{B}_{\text{rest}}^{\text{w}}$ = Total woody biomass at the Restoration Site; tDM.
- $\text{AGB}_{\text{rest}}^{\text{w}}$ = Woody AGB at the Restoration Site; tDM.
- $\text{BGB}_{\text{rest}}^{\text{w}}$ = Woody BGB at the Restoration Site; tDM.



$$(4) \mathbf{B}_{rest}^{n-w} = \mathbf{AGB}_{rest}^{n-w} + \mathbf{BGB}_{rest}^{n-w}$$

Where:

- \mathbf{B}_{rest}^{n-w} = Total non-woody biomass at the Restoration Site; tDM.
- $\mathbf{AGB}_{rest}^{n-w}$ = Non-woody AGB at the Restoration Site; tDM.
- $\mathbf{BGB}_{rest}^{n-w}$ = Non-woody BGB at the Restoration Site; tDM.

$$(5) \mathbf{B}_{rest} = \mathbf{B}_{rest}^w + \mathbf{B}_{rest}^{n-w}$$

Where:

- \mathbf{B}_{rest} = Total biomass at the Restoration Site; tDM.
- \mathbf{B}_{rest}^w = Total woody biomass at the Restoration Site; tDM.
- \mathbf{B}_{rest}^{n-w} = Total non-woody biomass at the Restoration Site; tDM.

4. Biomass Conversion to CO2 Equivalents

Biomass in the Restoration Site is converted into CO2 equivalents (CO2e) to determine its total CO2 sequestration.



The AR-TOOL14 A/R Methodological tool's equations⁵ are used to translate biomass into carbon content and subsequently into CO₂e. This ensures a consistent and standardised measurement aligned with global carbon reporting metrics.

The relation between carbon stock and tree biomass can be established with equation (6).

$$(6) \mathbf{C}_{rest} = \frac{44}{12} \times \mathbf{CF} \times \mathbf{B}_{rest}$$

Where:

- \mathbf{C}_{rest} = Carbon stock in the Restoration Area; tCO₂e.
- $\frac{44}{12}$ = Represents the molecular weight ratio of CO₂ to Carbon, which is $\frac{44}{12}$; dimensionless.
- \mathbf{CF} = Carbon fraction of tree biomass; tC:tDM⁻¹.
A default value of 0.47 is adopted⁶.
- \mathbf{B}_{rest} = Total biomass at the Restoration Site; tDM.

This initial baseline is determined by the carbon stock (\mathbf{C}_{rest}) and is expressed in tonnes of CO₂e.

FINAL CARBON STOCK

This step estimates the carbon stock of the Reference Site.

1. Selection of a Reference Ecosystem

- 1.1. ERS requests the selection and adoption of a Reference Ecosystem and geographical coordinates of a physical Reference Site.

⁵ UNFCCC. (2013). 'AR-TOOL14 A/R Methodological tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities Version 04.1'. Available at: [URL](#) (Accessed 25/01/2023)

⁶ Eggleston, H S, Buendia, L, Miwa, K, Ngara, T, and Tanabe, K. (2006) 'IPCC Guidelines for National Greenhouse Gas Inventories. Japan.' Volume 4, Chapter 4, Table 4.3, p 4.48. Available at: [URL](#) (Accessed 03/11/2023).



- 1.2. The Project's Reference Ecosystem is used to inform the restoration objectives.
- 1.3. The Reference Site is used to quantify the carbon sequestration potential of the Project.

Refer to the [Reference Ecosystem Guidelines](#) for more information.

2. Carbon Stock at Reference Site

- 2.1. Upon submission of the Reference Site's shapefile, the AGB provider generates:
 - 2.1.1. **A woody/non-woody biomass mask** in raster format, showing the distinction between woody and non-woody areas at the Reference Site.
 - 2.1.2. **A woody AGB map** that estimates the AGB at the pixel level in raster format.
- 2.2. Woody BGB is estimated using AGB values from step 2.1.2, following equation (7):

$$(7) \text{BGB}_{\text{ref}}^{\text{W}} = \text{AGB}_{\text{ref}}^{\text{W}} \times \text{RS}^{\text{W}}$$

Where:

- $\text{BGB}_{\text{ref}}^{\text{W}}$ = Woody BGB in the Reference site; tDM.
- $\text{AGB}_{\text{ref}}^{\text{W}}$ = Woody AGB in the Reference site; tDM.
- RS^{W} = Root-to-shoot ratio, a default value of 0.25 is adopted; dimensionless.



2.3. The total biomass of the Reference Site is calculated using equation (8):

$$(8) \mathbf{B}_{\text{ref}} = \mathbf{AGB}_{\text{ref}}^w + \mathbf{BGB}_{\text{ref}}^w$$

Where:

- \mathbf{B}_{ref} = Total woody biomass at the Reference Site; tDM.
- $\mathbf{AGB}_{\text{ref}}^w$ = Woody AGB in the Reference Site; tDM.
- $\mathbf{BGB}_{\text{ref}}^w$ = Woody BGB in the Reference Site; tDM.

2.4. The conversion to CO₂e is obtained using formula (9):

$$(9) \mathbf{C}_{\text{ref}} = \frac{44}{12} \times \text{CF} \times \mathbf{B}_{\text{ref}}$$

Where:

- \mathbf{C}_{ref} = Carbon stock on the Reference Site; tCO₂e.
- $\frac{44}{12}$ = Represents the molecular weight ratio of CO₂ to Carbon, which is $\frac{44}{12}$; dimensionless.
- CF = Carbon fraction of tree biomass; tC·tDM⁻¹.
A default value of 0.47 is used.
- \mathbf{B}_{ref} = Total woody biomass at the Reference Site; tDM.

2.5. The average carbon sequestration in the Reference Site is calculated as an estimate of the carbon sequestration by size (in hectares). This process enables the utilisation of this data for further processing in the calculation of the carbon sequestration potential of the Project. To



calculate the average carbon sequestration per hectare in the Reference Site, equation (10) is followed:


$$(10) \overline{C}_{ref} = C_{ref} / A_{ref}$$

Where:

- \overline{C}_{ref} = Mean carbon stock on the Reference Site, represents the mean CO₂ sequestered; tCO₂e·ha⁻¹.
- C_{ref} = Carbon stock on the Reference Site; tCO₂e.
- A_{ref} = Area of the Reference Site; ha.

CARBON SEQUESTRATION POTENTIAL

Using the initial and final carbon stocks, this step estimates the carbon sequestration potential of the Restoration Sites.

 In this methodology, ERS assumes that Restoration Sites will achieve levels of carbon sequestration similar to the Reference Site by the end of the crediting period.

1. Carbon Sequestration Potential of Restoration Sites

- 1.1. The carbon sequestration potential is defined as the GHG emission removal capacity of the Project.
- 1.2. The initial baseline and the mean carbon stock of the Reference Site are evaluated to determine the Project's GHG emission removal capacity.



- 1.3. The carbon sequestration potential of a terrestrial forest restoration Project is determined by calculating the difference between the projected carbon sequestration of the Restoration Site and the current carbon sequestration in the Restoration Site. This is represented by equation (11):

$$(11) C_{\text{potential}} = (A_{\text{project}} \times \overline{C}_{\text{ref}}) - C_{\text{rest}}$$

Where:

- $C_{\text{potential}}$ = Represents the Project's carbon sequestration potential; tCO₂e.
- A_{project} = Represent the size of the Restoration Site; ha.
- $\overline{C}_{\text{ref}}$ = Mean carbon stock on the Reference Site, represents the mean CO₂ sequestered; tCO₂e·ha⁻¹.
- C_{rest} = Represents the initial carbon stock of the Restoration Sites; tCO₂e.



Adjustment Factors

EMISSIONS

1. Initial Leakage Quantification

This section describes how a Project's leakage is estimated **at the beginning of the Project**. To quantify leakage, ERS conservatively assumes that the total carbon stock in the Leakage Areas will be reduced to 0.

1.1. Leakage is quantified for each displaced activity following equation (12):

$$(12) \mathbf{L}_i^d = \mathbf{A}_i \times \mathbf{P}_i \times \mathbf{C}_i$$

Where:

- \mathbf{L}_i^d = Declared GHG emissions from a Leakage Area i ; tCO₂e.
- \mathbf{A}_i = Land-surface of the activity i within the Project Area; ha.
- \mathbf{P}_i = Declared % of displacement of the activity i ; dimensionless.
- \mathbf{C}_i = Mean carbon stock in the Leakage Area where activity i is located; tCO₂e·ha⁻¹.

1.2. Total Leakage is calculated using the following equation (10):

$$(13) \mathbf{L}^d = \sum_{i=1}^n \mathbf{L}_i^d$$



Where:

- L^d = Total declared Leakage; tCO₂e.
- L_i^d = Estimated GHG emissions from a Leakage Area i ; tCO₂e.

2. Leakage Correction

This section describes how the initial leakage is corrected at Verification and how new leakage is estimated throughout the Project's lifetime. To quantify leakage, ERS conservatively assumes that the total carbon stock in the Leakage Areas will be reduced to 0.

$$(14) \Delta L_t^c = \sum_{i=1}^n (\Delta L_{i,t-1}^c - L_{i,t}^m), t \geq 1$$

Where:

- ΔL_t^c = Corrected Leakage at the verification cycle t ; tCO₂e.
- $\Delta L_{i,t-1}^c$ = Corrected Leakage from the Area i at the verification cycle $t-1$, where $\Delta L_{i,t=0}^c = L_i^d$; tCO₂e.
- $L_{i,t}^m$ = Monitored GHG emissions from a Leakage Area i at verification cycle t ; tCO₂e.

3. Quantification of Loss Events

- 3.1. In case of a loss event, the GHG emissions of the Loss Area are quantified.



- 3.2. The carbon stock of the Loss Area is calculated before and after the loss event, following the *Initial Carbon Stock* calculation.
- 3.3. The carbon stock loss is determined following equation (15):

$$(15) \ C_{\text{loss-event}} = C_{\text{post-event}} - C_{\text{pre-event}}$$

Where:

- $C_{\text{loss-event}}$ = Impact of the loss event; tCO₂e.
- $C_{\text{post-event}}$ = Carbon stock in the zone after the loss event; tCO₂e.
- $C_{\text{pre-event}}$ = Carbon stock in the zone before the loss event; tCO₂e.

4. Loss Event Characterisation

- 4.1. Before Verification, ERS calculates the GHG Benefits of the verification cycle, and categorises the loss event(s) of the period as follows:
 - 4.1.1. If $\Delta C_t \geq 0$, then the loss event is considered as underperformance.
 - 4.1.2. If $\Delta C_t < 0$, then the loss event is considered a reversal.

$$(16) \ \Delta C_t = C_t - C_{t-1}$$

Where:

- ΔC_t = Net GHG benefits achieved during the verification cycle t ; tCO₂e.



- C_t = CO₂ sequestration at the end of the verification cycle t ; tCO₂e.
- C_{t-1} = CO₂ sequestration at the end of the previous verification cycle $t-1$; tCO₂e.

DYNAMIC BASELINE

1. Concept

- 1.1. A dynamic baseline evaluation consists of a periodic re-evaluation of the initial baseline scenario to adjust credit issuance.
- 1.2. The Dynamic Baseline process is performed every two years, prior to Verification. This process will lead to the adjustment of credit issuance if necessary, following procedures detailed in the *Units & Issuance* section of the [ERS Programme](#).
- 1.3. To generate a dynamic baseline, control plots that are outside of the Project Area but that share similar ecological and bio-physical characteristics, including levels of degradation, are selected. Shapefiles of control plots for dynamic baseline plots will be published on the ERS Registry.

2. Project Clustering

- 2.1. **Concept.** Once the indicators are selected, the Project Area is stratified utilising the K-means clustering algorithm, a statistical technique that discerns natural patterns within the dataset and supports the identification of optimal clusters. Stratification involves the division of the Project Area into sub-zones based on the selected indicators listed in 2.2. Clusters refer to the grouping of naturally similar sub-zones, identified by the algorithm. For each sub-zone, median values for every



indicator are calculated, which minimises the impact of outliers and ensures a robust analysis.

2.2. **Identification of Environmental Indicators.** A broad array of environmental indicators covering ecological, climatic, and land use aspects are identified to determine sub-zones within the Project Area. Indicators include:

- Landcover⁷
- Elevation⁸
- Slope (Derived from Elevation)
- Forest Height⁹
- Soil Physical and Chemical Parameters (bulk density, coarse fragment, clay content, pH, SOC)¹⁰
- Biomes from [IUCN classification](#)
- Distance to Roads¹¹

3. Selection of Control Plots

3.1. **Concept.** Areas or sub-zones that share similar characteristics to the clusters, located outside of the Project site and referred to as control plots, are identified using the K-Nearest Neighbors (KNN) algorithm.

3.2. **Indicators.** The selection of control plots relies on the set of indicators selected in 2.2, as well as important political factors such as political

⁷ Zanaga, D., Van De Kerchove, R., Daems, D., De Keersmaecker, W., Brockmann, C., Kirches, G., Wevers, J., Cartus, O., et al. (2022). ESA WorldCover 10 m 2021 v200. Available at: [URL](#). (Accessed 03/11/2023)

⁸Farr, T. G., et al. (2007). 'The Shuttle Radar Topography Mission'. Rev. Geophys., 45, RG2004. Available at: [URL](#). (Accessed 03/11/2023)

⁹ P. Potapov, X. Li, A. Hernandez-Serna, A. Tyukavina, M.C. Hansen, A. Kommareddy, A. Pickens, S. Turubanova, H. Tang, C.E. Silva, J. Armston, R. Dubayah, J. B. Blair, M. Hofton. (2020). 'Mapping and monitoring global forest canopy height through integration of GEDI and Landsat data'. Remote Sensing of Environment, 112165. Available at [URL](#). (Accessed 03/11/2023)

¹⁰ Poggio, L., de Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E., and Rossiter, D.: SoilGrids 2.0: producing soil information for the globe with quantified spatial uncertainty, SOIL, 7, 217–240, Available at: [URL](#). (Accessed 03/11/2023)

¹¹OpenStreetMap contributors. (2017). Available at: [URL](#)



physical boundaries. This ensures that the selected control plots are found in the same country and governed under the same jurisdiction as the Project Area.

💡 Land tenure and land ownership is not included in this methodology due to the lack of global, and in many cases national land tenure registries that are available for public use.

3.3. **Exclusion of Inappropriate Areas**¹². Regions within the study area unsuitable to be considered control plots are systematically excluded. These include:

- **Protected areas.** Their conservation status does not ensure a real representation of a business-as-usual scenario.
- **Active carbon projects.** Does not ensure a real representation of a business-as-usual scenario, as both the project and control plot are subject to the same treatment.
- **Commercial plantations.** These areas are not control areas, because a different treatment is applied. Commercial plantations differ significantly from restoration projects in incentive structures, in that there is typically a strong economic incentive for planting and harvesting the trees.

3.4. This approach guarantees that only genuinely comparable plots are considered for the Project, enhancing the precision of the selection process.

¹² IUCN and UNEP-WCMC (2022), The World Database on Protected Areas (WDPA) [On-line], Cambridge, UK: UNEP-WCMC. Available at: www.protectedplanet.net. Accessed through Global Forest Watch in (10/2023). www.globalforestwatch.org. Available at: [URL](#).



4. Dynamic Evaluation

Prior to each Verification, ERS performs a dynamic evaluation of the initial baseline.

4.1. Refinement of Control Plots

ERS verifies the relevance of control plots using the methodology detailed in the [Selection of Control Plots](#). If it is found that the current control plots are no longer representative or applicable, the process involves regenerating new control plots.

4.2. Assessment of Control Plots

For each cluster, the mean CO₂ sequestration evolution of all control plots is calculated, following equations (17).

$$(17) \Delta \mathbf{B}_t^c = \sum_{i=1}^n \left[\left(\overline{\mathbf{C}_{t-1,i}^{cp}} - \overline{\mathbf{C}_{t,i}^{cp}} \right) \times A_i \right]$$

Where:

- $\Delta \mathbf{B}_t^c$ = Corrected Baseline at the verification cycle t ; tCO₂e.
- $\mathbf{C}_{t-1,i}^{cp}$ = Mean CO₂ sequestration of the control plots that belong to the cluster i at verification cycle $t-1$; tCO₂e·ha⁻¹.
- $\overline{\mathbf{C}_{t,i}^{cp}}$ = Mean CO₂ sequestration of the control plots that belong to the cluster i at verification cycle t ; tCO₂e·ha⁻¹.
- A_i = Project Area covered by cluster i ; ha.

4.3. Following the assessment of control plots, two distinct scenarios can emerge:



- 4.3.1. **CO₂ sequestration Growth Scenario.** If the average CO₂ sequestration in control plots shows an upward trend from Y0 to the present, suggesting a positive trend in forest growth, the Project will adjust for this CO₂ sequestration increase in the calculation of carbon additionality and units issuance. In such a scenario, the Project cannot claim full credit for the GHG emission removals on its Restoration Sites. A corrective mechanism is used to adjust the overestimated baseline. Refer to the [Units & Issuance](#) section of the [ERS Programme](#) for more details.
- 4.3.2. **CO₂ sequestration Decrease Scenario.** Conversely, if a decline in CO₂ sequestration is detected in the control plots, a corrective mechanism is applied to adjust the underestimated baseline. This mechanism involves adding CO₂ sequestration's additionality to the Project. Refer to the [Units & Issuance](#) section of the [ERS Programme](#) for more details.



Carbon Stock *Accounting*

PRU ACCOUNTING

Total PRUs are calculated following this given formula:

$$(18) \text{ PRU} = C_{\text{potential}} - L^d$$

Where:

- **PRU** = Project Restoration Units; tCO₂e.
- **C_{potential}** = Represents the Project's carbon sequestration potential; tCO₂e.
- **L^d** = Total declared Leakage at Project start; tCO₂e.

VRU ACCOUNTING

PRUs conversion into VRUs is performed every two years after Verification, and throughout the Project's crediting period. Prior to each Verification and so as to ensure the most accurate conversion of units, ERS measures carbon stock in the Restoration Sites, factoring:

1. **Biomass evolution in the Restoration Site.** The evolution of the CO₂ sequestration at the Restoration Site is calculated by comparing the biomass status at verification cycle t , with the biomass status at verification cycle $t-1$. It is important to note that this evaluation includes any reversals that occurred on the Restoration Site during verification cycle t .
2. **Leakage correction.** The leakage evolution observed during the verification cycle t .



3. **Baseline correction.** The CO₂ sequestration evolution observed in the control plots during the verification cycle t .

Refer to the [Units & Issuance](#) section in the [ERS Programme](#) document, and to the [Carbon](#) section in the [M001](#) document for more details.

Total VRUs for the verification cycle t are calculated following this given formula:

$$(19) \mathbf{VRU}_t = \Delta \mathbf{C}_t + \Delta \mathbf{L}_t^c + \Delta \mathbf{B}_t^c$$

Where:

- \mathbf{VRU}_t = Verified Restoration Unit for the verification cycle t ; tCO₂e.
- $\Delta \mathbf{C}_t$ = Net GHG benefits achieved during the verification cycle t ; tCO₂e.
- $\Delta \mathbf{L}_t^c$ = Corrected Leakage at the verification cycle t ; tCO₂e.
- $\Delta \mathbf{B}_t^c$ = Corrected Baseline at the verification cycle t ; tCO₂e.



Uncertainty & *Conservativeness*

This section described how ERS accounts for uncertainty in its quantification methods, and the rules enforced to ensure conservative carbon estimations.

UNCERTAINTY

1. Woody AGB Estimation

AGB estimation is not a direct measurement; it is therefore inherently uncertain. Managing this uncertainty effectively is critical for the credible quantification of tCO₂e removals from restoration activities. To minimise and account for uncertainty related to AGB estimation, ERS implements best practices outlined in the Aboveground Woody Biomass Product Validation Good Practices Protocol¹³. This means that:

- 1.1. AGB error estimation must consider the entire process, from field measurements to modelling errors, including those associated with allometric equations.
- 1.2. The propagation of uncertainty through these various stages must be effectively managed.
 - 1.2.1. ERS's AGB benchmark (*Appendix 1*) demonstrates different methods of AGB uncertainty propagation.
- 1.3. A 95% confidence interval for AGB values must be generated.

¹³ Duncanson, L., Armston, J., Disney, M., Avitabile, V., Barbier, N., Calders, K., Carter, S., Chave, J., Herold, M., MacBean, N., McRoberts, R., Minor, D., Paul, K., Réjou-Méchain, M., Roxburgh, S., Williams, M., Albinet, C., Baker, T., Bartholomeus, H., Bastin, J.F., Coomes, D., Crowther, T., Davies, S., de Bruin, S., De Kauwe, M., Domke, G., Dubayah, R., Falkowski, M., Fatoyinbo, L., Goetz, S., Jantz, P., Jonckheere, I., Jucker, T., Kay, H., Kellner, J., Labriere, N., Lucas, R., Mitchard, E., Morsdorf, F., Naeset, E., Park, T., Phillips, O.L., Ploton, P., Puliti, S., Quegan, S., Saatchi, S., Schaaf, C., Schepaschenko, D., Scipal, K., Stovall, A., Thiel, C., Wulder, M.A., Camacho, F., Nickeson, J., Román, M., Margolis, H. (2021). Aboveground Woody Biomass Product Validation Good Practices Protocol. Version 1.0. In L. Duncanson, M. Disney, J. Armston, J. Nickeson, D. Minor, and F. Camacho (Eds.), Good Practices for Satellite Derived Land Product Validation, (p. 236): Land Product Validation Subgroup (WGCV/CEOS), Available at: [URL](#).



2. Current AGB Model Uncertainty

- 2.1. Baccini et al. 2017¹⁴ describe in detail the [Chloris'](#) stock and change product, which explains that the model employed includes for every pixel an estimate of:
 - 2.1.1. total change over the time series (i.e., gain or loss) calculated as the difference between the fitted values at the beginning and end points of the pixel-level trajectories;
 - 2.1.2. the p-value (scaled 0–100) from a modified F-test associated with the pixel-level change estimate where p-values ≤ 5 represent a significant change (i.e., gain or loss) in Aboveground Biomass Density (AGBD) and values > 5 represent a non-significant change (i.e., no gain or loss/stable) in AGBD;
 - 2.1.3. and the standard error associated with the pixel-level change representing uncertainty in the change estimate at the 95% level. The uncertainty associated with the pixel-level estimates of AGBD change can be obtained from the map of standard error.
 - The standard error is estimated from an error propagation analysis carried out at the pixel level across all layers in the time series. The propagation of error, which takes into account geolocation-, allometric-, and model-based errors, feeds first into estimates of the standard error associated with the AGBD prediction at each point in the time series understood most readily as the confidence interval (C.I.) for each pixel-level trajectory. This C.I. envelope is then used to calculate the standard error of the AGBD change. All AGBD change statistics reported are derived from sums of pixel values where the change (i.e.,

¹⁴ Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D. and Houghton, R.A. (2017). 'Tropical forests are a net carbon source based on aboveground measurements of gain and loss'. *Science*, 358(6360), pp.230–234. Available at: [URL](#) (Accessed 3/11/2023)



gain or loss) was determined to be significant (p -value ≤ 5).

- The standard error pixel-level estimates are aggregated to the site level in a process that takes into account the spatial autocorrelation and is used to compute the overall site level uncertainty for the AGBD and change.

CONSERVATIVENESS

ERS adopts a conservative approach when quantifying the GHG emission removals of a Project. This approach is executed in two layers:

1. Evaluating Uncertainty in Estimates

Uncertainty is calculated holistically throughout the quantification process, from field measurements to model outputs. The uncertainty estimation is detailed in the "Aboveground Woody Biomass Product Validation Good Practices Protocol." A more granular exposition on the uncertainty calculation methodology is described in the *Current AGB Model Uncertainty* section.

2. Maximised Conservatism

The conservative approach consistently and systematically selects the uncertainty boundary that leans towards the safe side. This prevents any potential overestimation of GHG emission removals. The calculation takes on different forms to deliberately apply conservativeness at each step of the quantification process. The following sections include details about the conservative approach at each step.

2.1. CO₂ Sequestration Potential

2.1.1. **Initial Carbon Stock.** When quantifying the initial baseline, the upper band of the 95% confidence interval is selected for Woody AGB values. Confidence intervals are provided by the AGB provider. Such selection allows for an overestimation of the current state of the Restoration Site. This selection will implicitly



provide a conservative estimate of the carbon sequestration potential of the Project.

2.1.2. **Final Carbon Stock.** When quantifying carbon stock in the Reference Ecosystem, the lower band of the 95% confidence interval is chosen. This leads to an underestimation of the current sequestration of the Reference Ecosystem. This selection will implicitly provide a conservative estimate of the carbon sequestration potential of the Project.

2.1.3. **Carbon Sequestration Potential.** Having applied a conservative approach in the quantification of the initial baseline scenario at the Project Area, and a conservative quantification of CO₂ sequestration at the Reference Site, the GHG emission removal potential which results from the difference between the two, is implicitly conservative.

2.2. **Monitoring.**

2.2.1. While measuring the carbon sequestration of the Project Area every two years, the lower band of the 95% confidence interval is selected. This results in an underestimation of the current sequestration on the Restoration Site.

2.3. **Loss Events**

2.3.1. During the impact assessment of reversals, an inherent challenge is determining the BGB loss through satellite imagery. ERS conservatively considers a complete loss of BGB and deducts the CO₂e stock bound to BGB from the Project issuances.



Appendix 1 – *AGB Provider*

BENCHMARK PROCESS

The selection of an accurate AGB provider is instrumental in ensuring precise carbon estimation. A benchmarking approach was employed to identify the most suitable AGB provider for ERS. The process overview is described below, for more detailed information refer to the [AGB Benchmark](#).

1. Initial Provider Contact

Multiple AGB providers were approached to participate in the benchmarking process. Each received a shapefile document with geographic information of a forested area, to apply their AGB models and determine their values.

2. Model Output Comparison

We employ the AGB model outputs from each provider to gather essential statistical information. This information is compared among the various providers. Furthermore, a detailed comparison is conducted in certain sub-areas of the model against a designated reference model.

3. Selection Criteria

- 3.1. **Precision.** The accuracy of the AGB model in predicting biomass values.
- 3.2. **Uncertainty Analysis.** The methodology for calculating uncertainty and how it is propagated from field measurements all the way to the final AGB model.
- 3.3. **Coverage.** The extent of the area that the model could cover and its flexibility in application.
- 3.4. **Integration Feasibility.** The ease and efficiency of integrating the model into the ERS certification process.



4. Conclusion

Based on the criteria, the most appropriate AGB provider was selected to ensure rigorous, conservative and accurate data is integrated in this quantification methodology. For this version of the methodology, [Chloris Geospatial](#) has been selected as the AGB provider.

5. Iteration

The benchmark process can be repeated at any time, and at least every two years, following [Standard Revision Procedure](#). ERS seeks to use data providers that apply the principles and rigour described in this methodology, as such, an updated benchmark process allows ERS to ensure the proper selection of its AGB provider.

Undertaking a repeated benchmark process in the future can result in changing the AGB provider. Shall ERS take this decision, it will be openly communicated in its methodology documents.



Appendix 2 – *IPCC Data*

ERS selects IPCC¹⁵ default values by climate zone for above and below-ground biomass in grasslands, as described in the table 6.4. and shown below:

IPCC climate zone	Peak above-ground biomass¹ (tonnes d.m. ha⁻¹)	Total (above-ground and below-ground) non-woody biomass² (tonnes d.m. ha⁻¹)	Error ³
Boreal – Dry & Wet ⁴	1.7	8.5	± 75%
Cold Temperate – Dry	1.7	6.5	± 75%
Cold Temperate –Wet	2.4	12	± 75%
Warm Temperate – Dry	1.6	6.1	± 75%
Warm Temperate –Wet	2.7	13.5	± 75%
Tropical – Dry	2.3	8.7	± 75%
Tropical - Moist & Wet	6.2	16.1	± 75%

¹ Data for standing biomass are compiled from multi-year averages reported at grassland sites registered in the ORNL DAAC NPP database [<http://www.daacsti.ornl.gov/NPP/>].

² Total above-ground and below-ground biomass values are based on the peak above-ground biomass values, and the below-ground biomass to aboveground biomass ratios (Table 6.1).

³ Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

⁴ Due to limited data, dry and moist zones for the boreal temperature regime and moist and wet zones for the tropical temperature regime were combined.

¹⁵ Eggleston, H S, Buendia, L, Miwa, K, Ngara, T, and Tanabe, K. (2006) 'IPCC Guidelines for National Greenhouse Gas Inventories. Japan.' Volume 4, Chapter 6, Table 6.4, p 6.27. Available at: [URL](#) (Accessed 03/11/2023).



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info@ers.org | www.ers.org