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Methodology

AGB Benchmark

Summary

Equitable Earth uses externally developed above-ground biomass (AGB) models to calculate greenhouse gas (GHG) removals, drawing on a range of providers available in the market. To identify the most suitable source of AGB data, Equitable Earth conducted a comprehensive benchmarking exercise comparing multiple providers. This document outlines the methodologies used and the results of that assessment.

The findings indicate that while AGB estimations differ among providers, Chloris Geospatial and Kanop emerge as the top performers, consistently producing the most reliable results.

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Introduction

The Equitable Earth (formerly ERS) Research & Development (R&D) team conducted a benchmarking exercise to identify the most suitable AGB provider aligned with the specific technical and operational needs of Equitable Earth.

This benchmarking followed a structured, multi-step methodology designed to ensure an objective and comprehensive evaluation of potential AGB data providers. This effort was grounded in the availability of a high-quality reference dataset covering approximately 50,000 hectares of diverse landscapes in Mozambique. Derived from Terrestrial Laser Scanning (TLS) and Airborne Laser Scanning (ALS), this dataset provided a scientifically rigorous basis for evaluating the performance of each provider's AGB estimates.

The following sections of this report outline the benchmarking methodology in detail, describing the steps taken and the criteria applied in assessing provider performance. Key focus areas included the accuracy of AGB estimates, approaches to uncertainty quantification, and the technical infrastructure available, particularly for APIs and automated estimation capabilities.

Normative References

This document must be read in conjunction with the following documents:

- M001 - Methodology for Terrestrial Forest Restoration
- Terms & Definitions

Methodology

Data Acquisition

The benchmarking began with acquiring a detailed AGB dataset for 50,000 hectares of diverse terrain in Mozambique. This dataset, meticulously gathered using TLS and ALS technologies, provided a robust, high-resolution reference for our comparative analysis.

Participant Engagement

We engaged various AGB data providers in this exercise, inviting them to provide AGB estimates for the specified reference area. Each participant received precise geographic coordinates and used their proprietary models and methodologies to produce AGB estimates.

Comparative Analysis

The comparison of AGB maps presents specific challenges, including potential pixel misalignment resulting from localisation inaccuracies. To address these limitations, Equitable Earth applied two complementary assessment methods:

- **Visual Comparison:** AGB maps were generated for the reference area using a uniform value scale across all providers. This allowed for a preliminary assessment of spatial consistency and the identification of major discrepancies in AGB estimates.

- **Geometrical Analysis:** To evaluate the performance of providers beyond the pixel level, Equitable Earth conducted a spatially aggregated analysis. This involved selecting defined sub-polygons within the reference area and calculating the total AGB reported by each provider within these units. This method enabled a more reliable assessment of each provider’s capacity to estimate AGB at scales relevant for project-level carbon accounting.

Evaluation Criteria

The benchmarking exercise was designed to be comprehensive, beyond a simple comparison of estimates precision. Besides evaluating the accuracy of AGB outputs, Equitable Earth assessed the methodologies employed by each provider to quantify uncertainty. The analysis also included a review of technical infrastructure, with specific attention to the availability, reliability, and functionality of Application Programming Interfaces (APIs) and automated estimation capabilities.

Limitations & Future Improvements

This evaluation focused on a defined 50,000-hectare area within Mozambique's tropical dry forests. Equitable Earth selected this specific area due to its ecological heterogeneity, encompassing dense, mixed, and sparsely vegetated forest zones. This diversity provided a robust and representative reference dataset for model benchmarking.

However, AGB models may perform differently across distinct biomes, each with unique vegetation structures and biomass characteristics that may require tailored evaluation strategies.

To address this, future benchmarking phases will aim to expand the analysis across multiple ecological regions, improving the representativeness of the assessment results.

Technical Comparison

This section presents the assessment of the technical capabilities of each provider against the operational and integration requirements set by Equitable Earth. The evaluation focused on the following essential criteria:

1. **Automation and integration.** The provider must offer an API or equivalent system that supports fully automated estimation and data retrieval. The solution must be integrated seamlessly into the certification workflow without requiring manual intervention.

2. **Output format:** Results must be delivered in a standard Raster GeoTIFF format, accessible via direct download.

3. **Uncertainty reporting:** Each output must be available with a clearly defined uncertainty or error range.

4. **Multi-polygon capability:** The system must support accurate processing and reporting of results across multiple spatial polygons in a single request.

5. **Timeliness:** The provider must be capable of delivering complete results within 24 hours of the request.

	API access	Raster export	Uncertainty	Results in 24h
Participant A	🟡	🟢	🟢	🟢
Participant B	🟡	🟢	🟡	🟢
Participant C	🟢	🟢	🟢	🟡
Participant D	🟢	🟢	🟢	🟡
Participant E	🟡	🟢	🟡	🟢

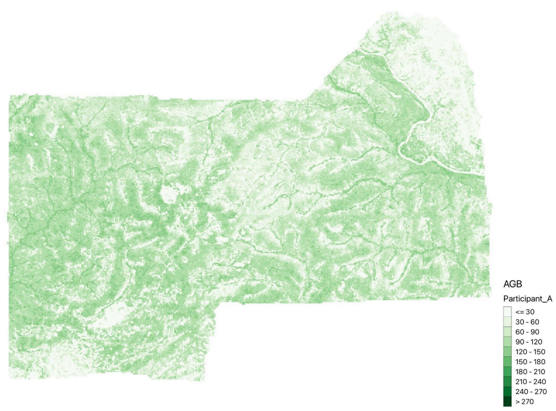
🟢: Perfectly handled **🟡: Adequately handled** **🔴: Incorrectly handled**

AGB Comparison

Equitable Earth conducted an initial visual review at the global scale to assess overall distribution patterns and guide subsequent analysis

Reference AGB vs Participant AGB

Participant A



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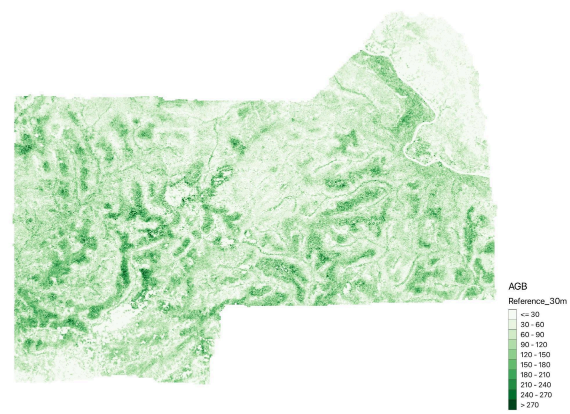
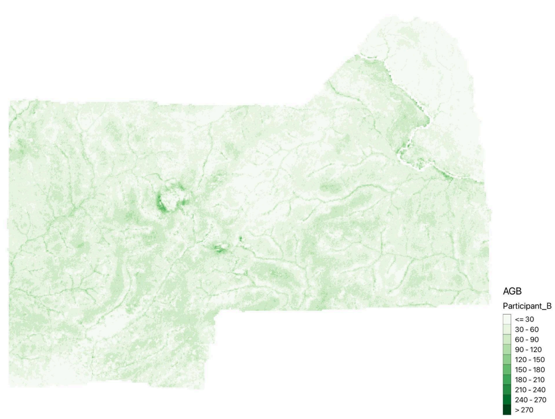


Participant B



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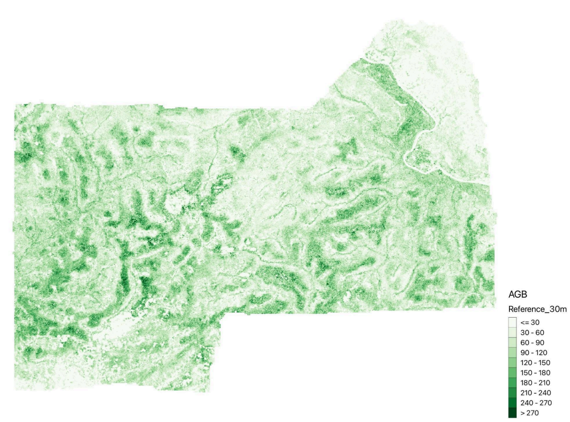
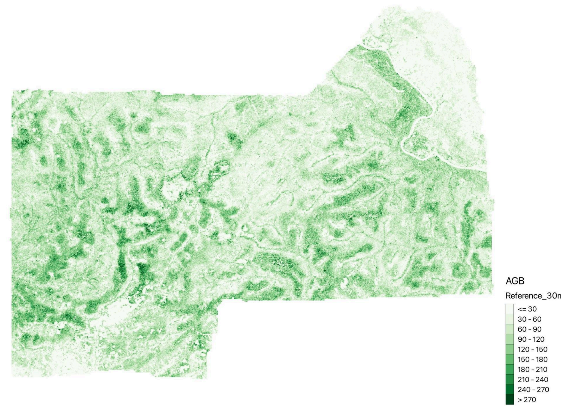


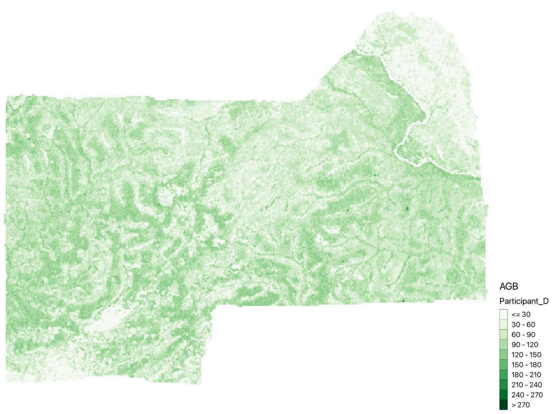
Participant C

Reference

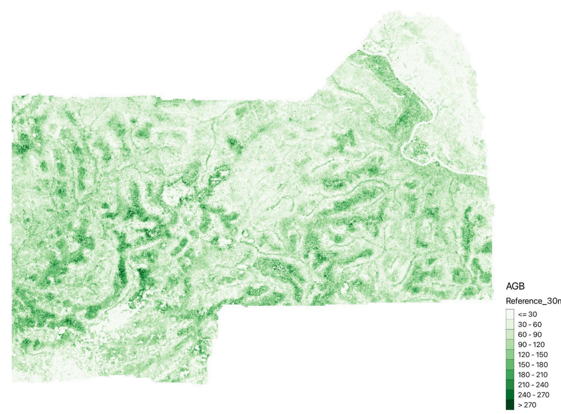
Participant D



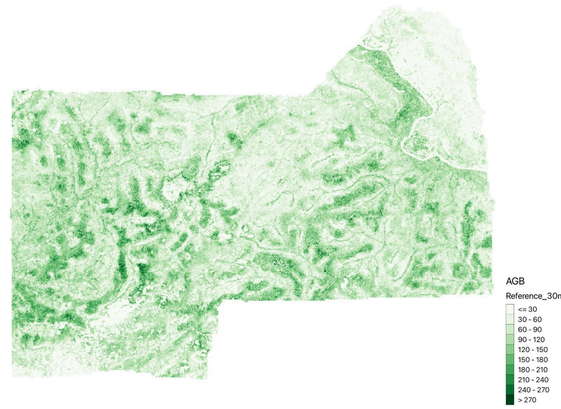
Reference



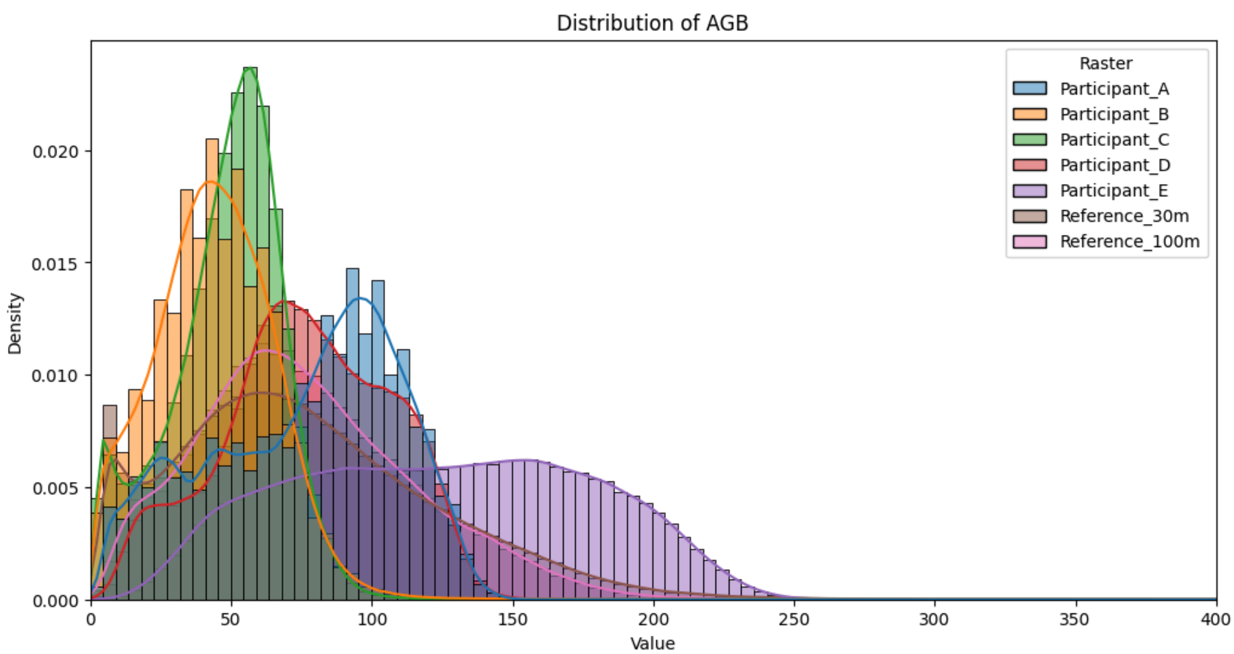
Participant E



Reference

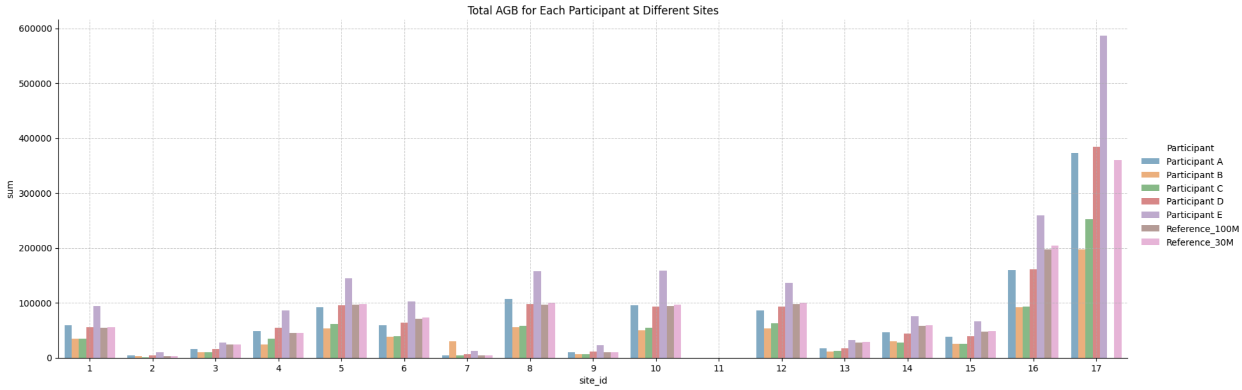


Distribution Comparison



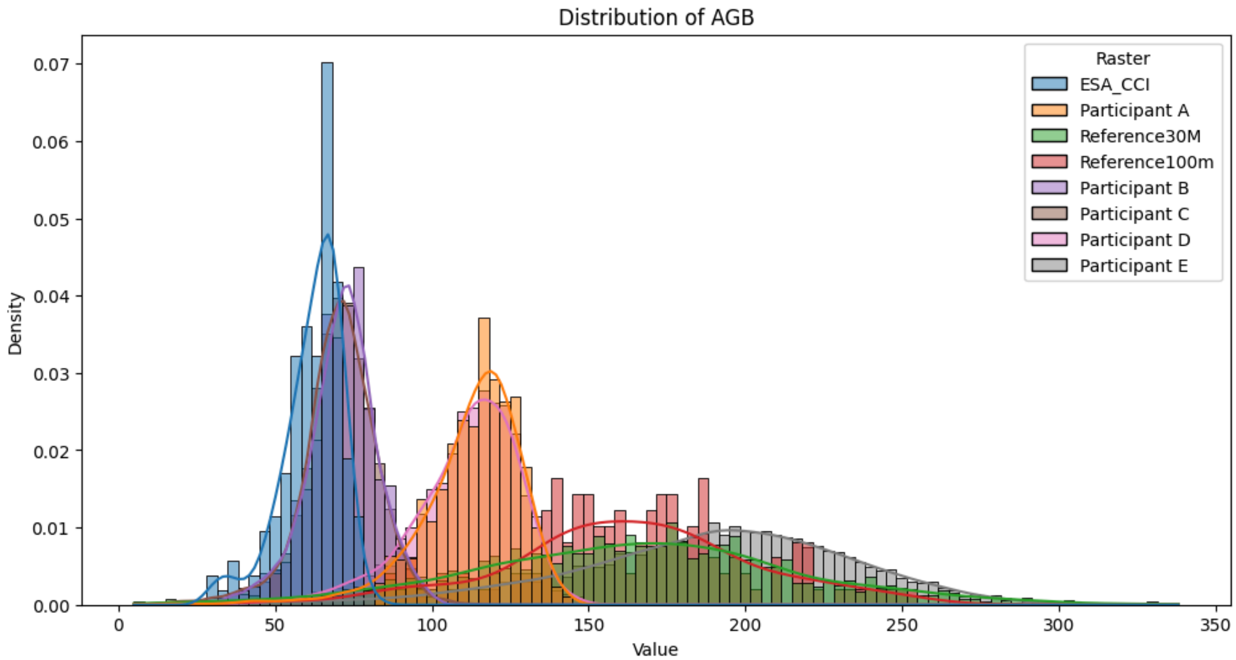
Area Comparison

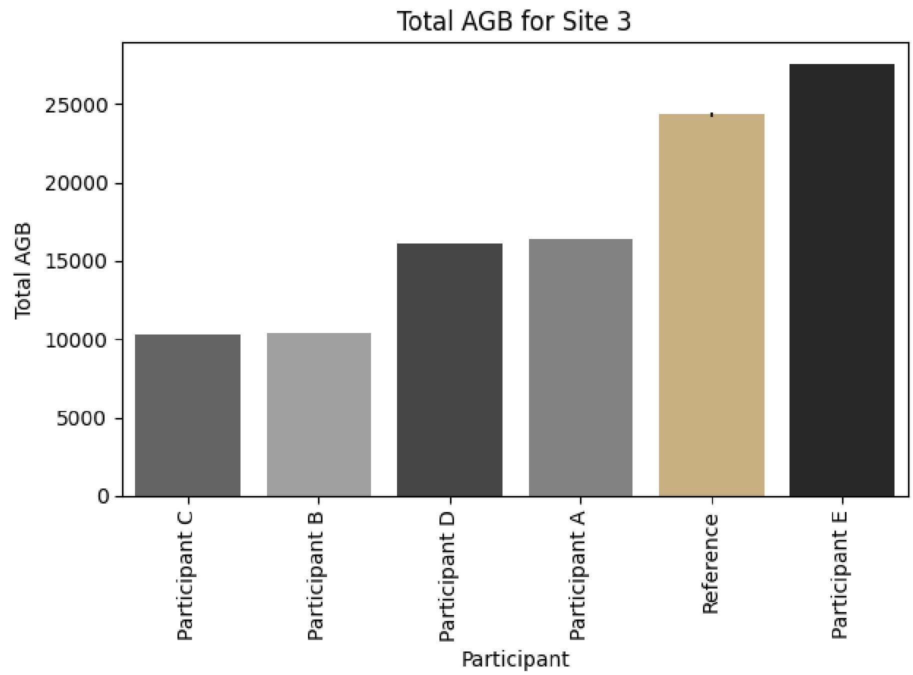
Equitable Earth identified specific zones within the benchmark area and calculated their total AGB. Equitable Earth selected this approach to align with the standard workflow used in the certification process, where the total AGB of the restoration area is extracted to estimate the project baseline.



A summary of selected relevant sites is provided below:

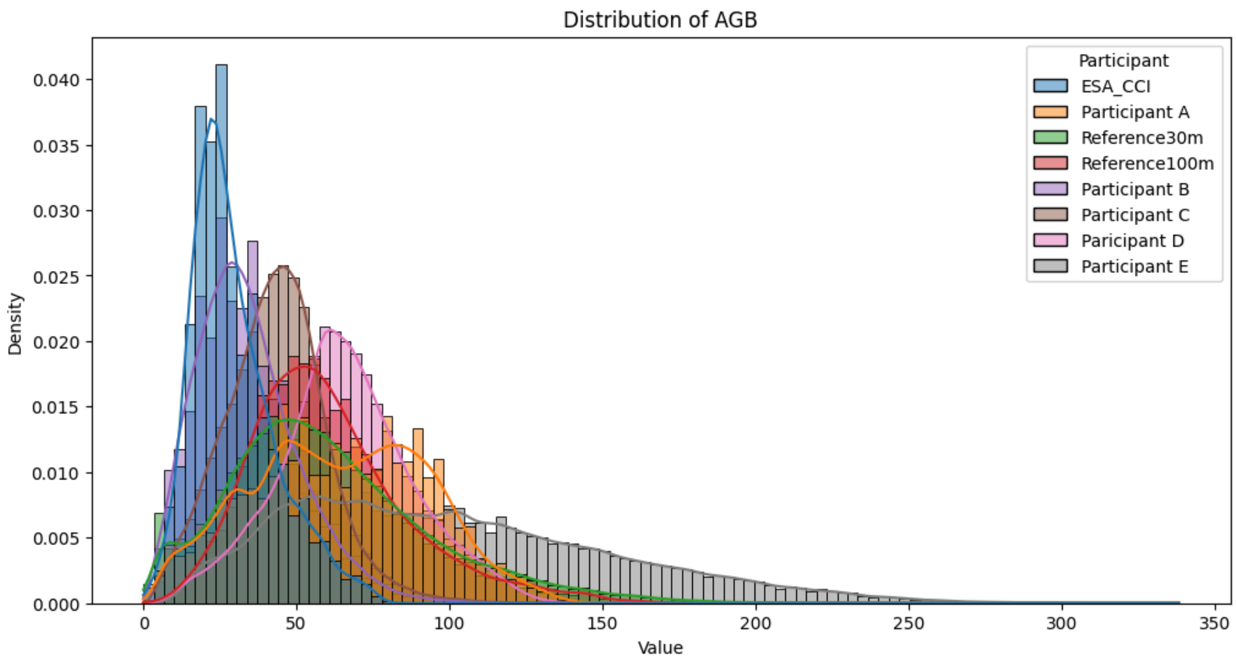
Site 3 - High AGB Values - 145 ha

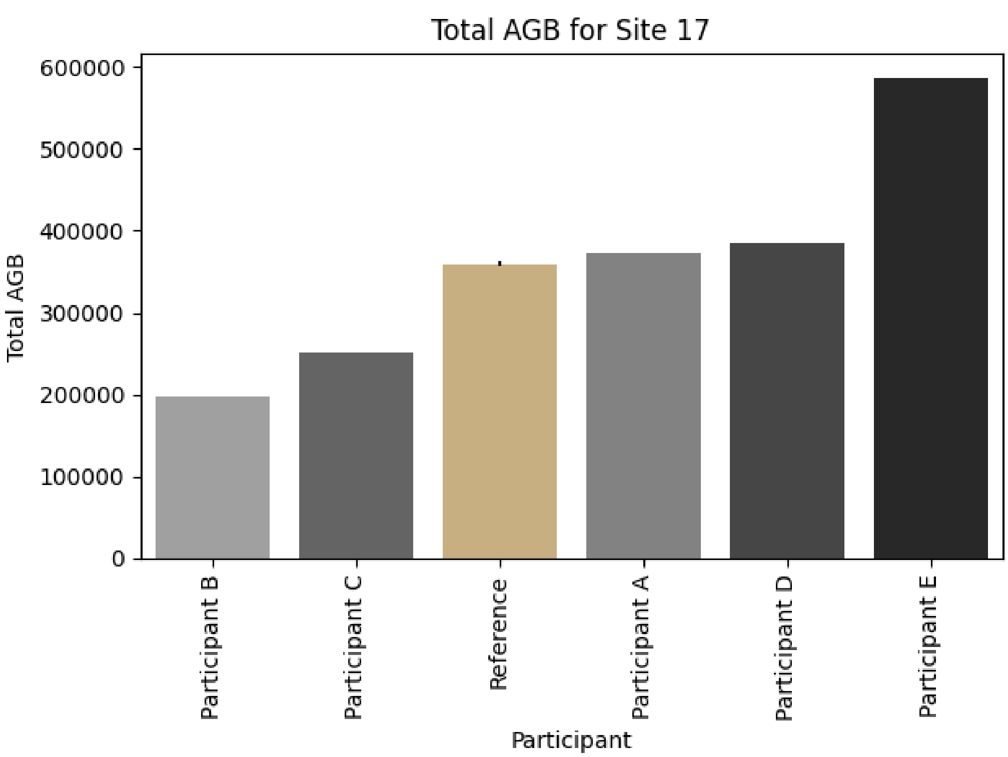




	Mean AGB	Median AGB	Std AGB	Max AGB	Sum AGB	Diff
Reference	169.20	169.45	59.99	395.07	24346.44	0.00
Participant A	112.18	115.00	16.96	143.00	16393.51	-33%
Participant B	71.33	72.00	11.46	104.00	10430.35	-57%
Participant C	70.47	71.01	12.33	116.54	10304.20	-58%
Participant D	110.42	113.24	17.67	153.04	16135.64	-34%
Participant E	188.40	192.60	44.10	326.91	27546.00	+13%

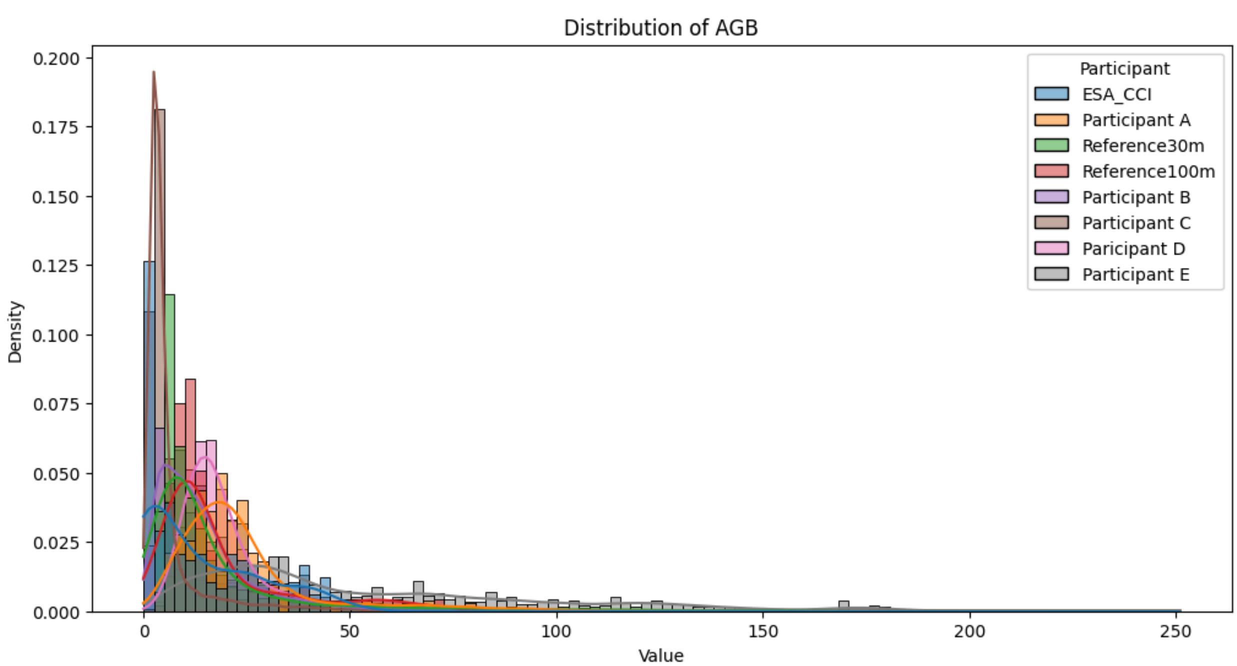
Site 17 - Mixed AGB Values - 5 818 ha

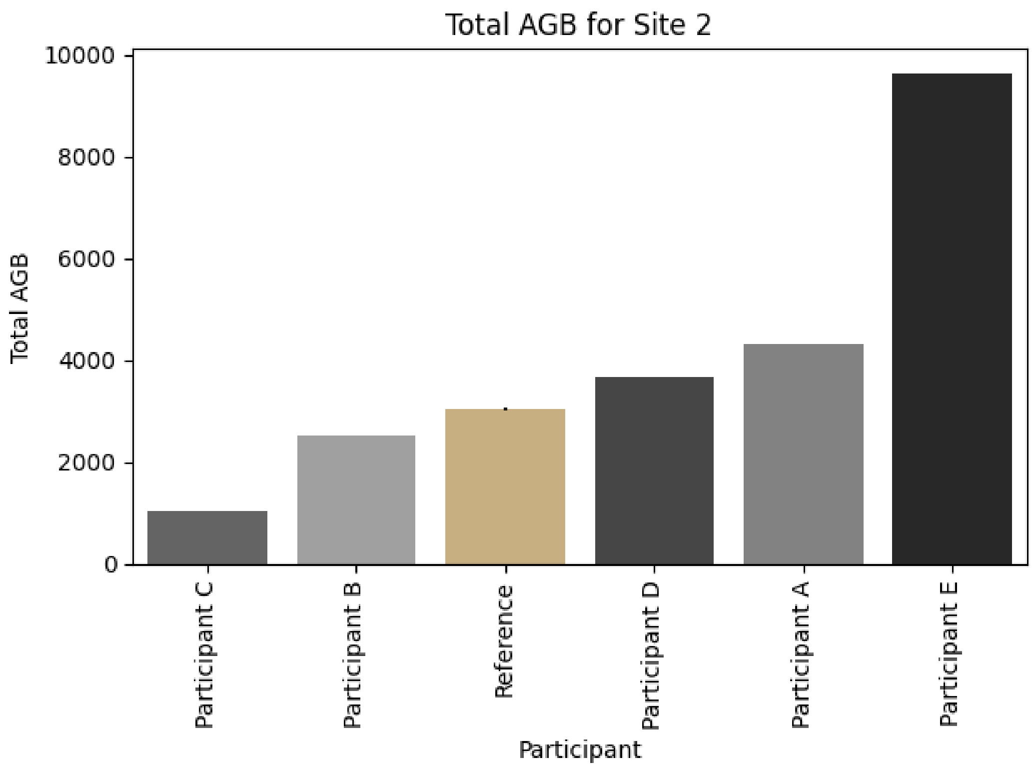




	Mean AGB	Median AGB	Std AGB	Max AGB	Sum AGB	Diff
Reference	61.95	57.23	36.62	385.09	359634.56	0.00
Participant A	64.06	64.00	28.67	151.00	372752.86	+4%
Participant B	33.79	32.00	16.72	134.00	196637.95	-45%
Participant C	43.29	43.38	16.68	156.93	251878.91	-30%
Participant D	66.01	65.13	22.07	206.50	384086.50	+7%
Participant E	100.82	93.59	51.52	356.20	586571.11	+63%

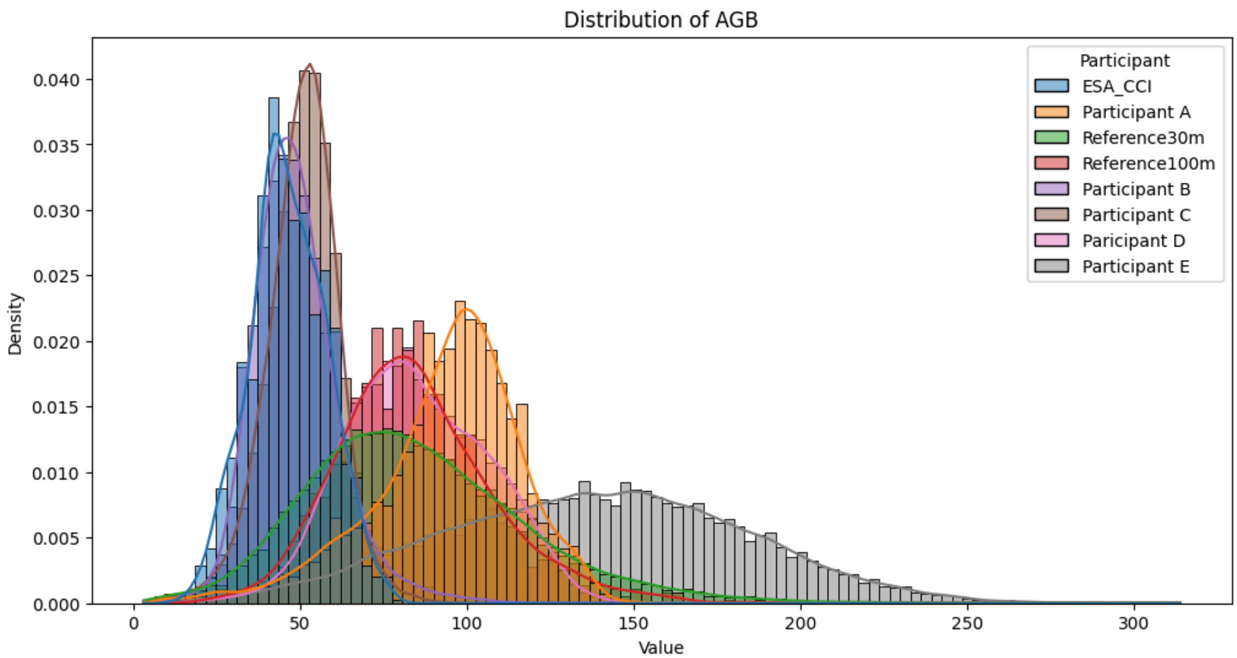
Site 2 - Very Low AGB Values - 180 ha

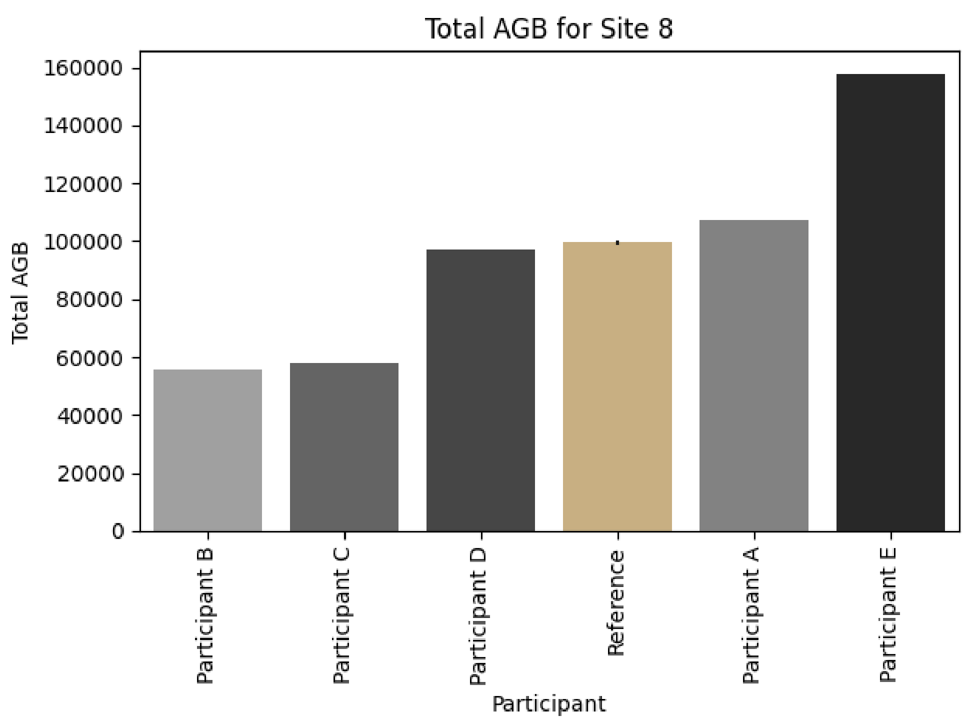




	Mean AGB	Median AGB	Std AGB	Max AGB	Sum AGB	Diff
Reference	16.58	6.54	26.10	230.44	3043.34	0.00
Participant A	24.03	20.00	17.50	117.00	4311.79	+42%
Participant B	14.02	11.00	11.54	93.00	2518.40	-17%
Participant C	5.89	3.42	7.54	60.21	1057.92	-65%
Participant D	20.44	16.64	13.59	105.76	3680.06	+21%
Participant E	53.57	41.20	40.48	250.62	9625.52+	+216%

Site 8 - Mixed AGB Values - 180 ha





	Mean AGB	Median AGB	Std AGB	Max AGB	Sum AGB	Diff
Reference	88.63	86.18	35.04	315.02	99591.13	0.00
Participant A	94.00	97.00	22.21	153.00	107488.20	+8%
Participant B	48.81	48.00	12.95	133.00	55821.88	-44%
Participant C	50.81	51.40	10.89	99.22	58116.53	-42%
Participant D	84.97	83.60	21.19	216.13	97188.31	-2%
Participant E	137.85	138.87	43.74	341.45	157664.83	+58%

Uncertainty Propagation

Estimating net GHG removals for a defined area requires converting AGB data from tonnes of dry matter per hectare per pixel into total tonnes of dry matter for the entire area. This conversion produces the total sequestration estimate. Accurate propagation of uncertainty from the pixel level to the area level is essential to maintain the reliability of these estimates.

Two approaches to uncertainty propagation may be considered:

- Consider variables as independent, and estimate the area-level uncertainty by summing pixel-level variance.
- Consider variables as non-independent, mainly because of the spatial autocorrelation, and apply a Monte Carlo approach.

The Monte Carlo method provides a more robust estimate but presents challenges when lacking multiple AGB maps based on the same region for varied metrics, which may not always be available from providers. This benchmarking compares both approaches: one using multiple AGB maps supplied by providers, and the other using a simulated Monte Carlo approach.

Monte Carlo

In this protocol, we used a control sample of 100 AGB maps from a defined region. For each geometry in the test sample, we calculated the total AGB for each band across all 100 maps by following these steps:

Step 1: Total AGB calculation

Iterate through each pixel within the project area, performing the following steps:

1. Calculate the area covered by the current pixel.
2. Multiply the pixel's mean AGB value by its area to determine its contribution to the total AGB.
3. Sum the contributions from all pixels to compute the total AGB for the project area.

$$\mathbf{AGB}_{total} = \sum_{i,j} \overline{\mathbf{AGB}}_{i,j} \times \mathbf{S}_{i,j}$$

Where $\overline{\mathbf{AGB}}_{i,j}$ represents the mean AGB of the pixel at row i and column j and $\mathbf{S}_{i,j}$ represents the area covered by the pixel.

Step 2: Computing confidence interval for geometry

For each geometry, a confidence interval was derived from multiple AGB estimates through the following procedure:

1. Calculate the sample mean:

$$\bar{x} = \frac{1}{n} \times \sum_{i=1}^{n} x_i$$

where n is the number of samples and x_i is the i^{th} sample.

2. Determine the Standard Error of the Mean (SEM):

$$\mathbf{SEM} = \frac{s}{\sqrt{n}}$$

where s is the sample standard deviation, and n is the sample size.

3. Calculate the Margin of Error (ME) using t-score:

$$\mathbf{ME} = t \times \mathbf{SEM}$$

Where t is the t-score from the t-distribution corresponding to the desired confidence level and degrees of freedom (n − 1). It can be obtained using the inverse of the t-distribution cumulative distribution function (CDF):

$$t = t^{\alpha/2, n-1}$$

4. Compute the Confidence Interval (CI):

$$\mathbf{CI} = (\bar{x} + \mathbf{ME}, \bar{x} - \mathbf{ME})$$

Simulated Monte Carlo

This method applies a simulated Monte Carlo approach that incorporates pixel-level uncertainty to estimate the total AGB for a project area. Prior to simulation, a normality assessment is conducted using the Shapiro-Wilk test. A mean p-value of 0.677 confirms the data can be considered normally distributed.

Equitable Earth performed the following procedure:

Step 1: Normality check using the Shapiro-Wilk test

Before running the Monte Carlo simulation, Equitable Earth assessed that the pixel-level noise in the reference data follows a normal distribution by:

- Running the Shapiro-Wilk test on each array of pixels covering the same area. The null hypothesis of this test is that the data is normally distributed.
- Checking the p-value from the test. A high p-value (typically >0.05) indicates that the null hypothesis cannot be rejected, suggesting that the data is normally distributed.

A mean p-value of 0.677 was obtained, well above the 0.05 threshold, confirming normality.

Step 2: Monte Carlo simulation

The simulation process is performed over multiple iterations to construct a distribution of possible total AGB values. For each iteration, Equitable Earth:

1. Generates simulated AGB maps by adding normally distributed random noise to pixel AGB values, where the standard deviation corresponds to each pixel's uncertainty.
2. Computes the total AGB for each simulation by summing all pixel AGB values, weighted by the area each pixel covers within the project boundary.
3. Stores the total AGB estimate from each simulation iteration.

The process is repeated for the specified number of iterations to produce a robust distribution of total AGB estimates.

Step 3: Confidence interval calculation and margin of error

Calculate the confidence interval and margin of error for the total AGB estimates derived from the simulation results, applying the methodology outlined previously.

Summing Variances

This method consists of converting pixel-level uncertainty to variance and aggregating these variances to estimate the total AGB and variance for the project area.

Step 1: Total AGB and variance calculation

Iterate through each pixel within the project area, performing the following steps:

1. Calculate the area covered by the current pixel.
2. Multiply the pixel's mean AGB value by its area to determine its contribution to the total AGB.
3. Sum the contributions from all pixels to compute the total AGB for the project area.

$$\mathbf{AGB}_{total} = \sum_{i,j} \overline{\mathbf{AGB}}_{i,j} \times \mathbf{S}_{i,j}$$

   Where $\overline{\mathbf{AGB}}_{i,j}$ represents the mean AGB of the pixel at row i and column j and $\mathbf{S}_{i,j}$ represents the area covered by the pixel.

4. Compute the variance contribution of each pixel. The variance for each pixel is the square of the uncertainty value, multiplied by the squared area covered by the pixel.

$$Total\,Variance = \sum_{i,j} (\mathbf{S}_{i,j}^2 \times \mathbf{U}_{i,j}^2)$$

   Where $\mathbf{S}_{i,j}$ represents the area covered by the pixel and $\mathbf{U}_{i,j}$ the uncertainty value of the same pixel.

Step 2: Confidence interval calculation

Use the total standard deviation to calculate the confidence interval for the total AGB.

$$Total\ Std\ Deviation = \sqrt{Total\ Variance}$$

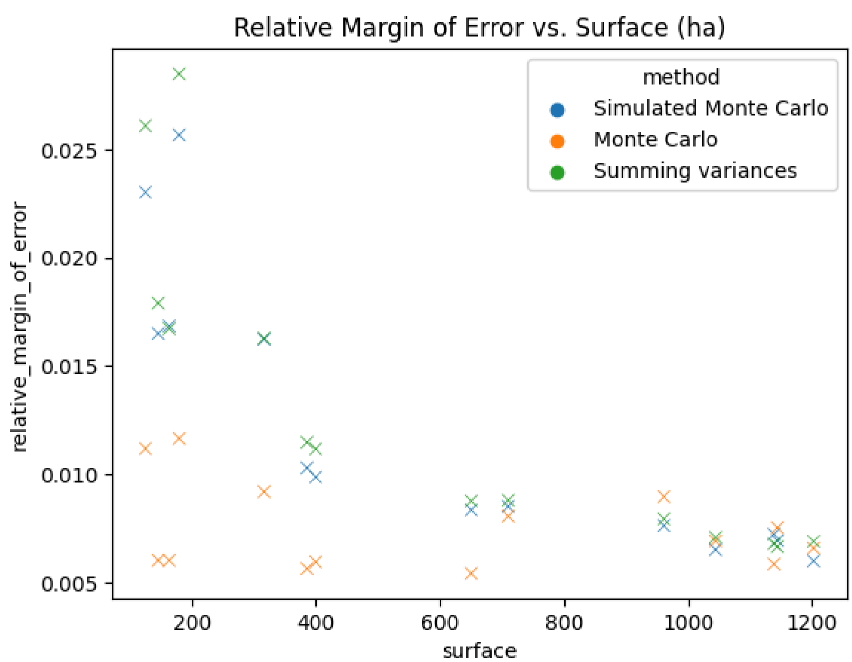
Step 3: Margin of error

Calculate the margin of error using the total standard deviation and the z-score corresponding to the desired confidence level (e.g., 1.96 for a 95% confidence interval).

$$Margin\ of\ error\ = 1.96\ \times\ Total\ Std\ Deviation$$

Results

The primary objective of this comparison was to assess the difference in outcomes generated by the various uncertainty propagation methods. The scatter plot below illustrates the relationship between relative margin of error and surface area for each method, with distinct colours representing each approach.



The analysis indicates that both the simulated Monte Carlo and summing-variance approaches tend to yield higher margin of error estimates in smaller areas. However, this difference diminishes significantly for areas exceeding 1,000 hectares, suggesting greater convergence between methods at larger scales.

More broadly, the results show that for areas larger than 500 hectares, the relative margin of error generally falls below 1%. This highlights the suitability of these methods for large-scale applications and reinforces the importance of selecting an appropriate uncertainty propagation approach based on project area and precision requirements.

Conclusion

For project areas exceeding 1,000 hectares, the choice of uncertainty propagation method has a limited impact on the final AGB estimation. In such cases, the uncertainty associated with total AGB estimates typically falls below 1%, rendering methodological differences relatively insignificant. However, the simulated Monte Carlo technique is the recommended approach in the Aboveground Woody Biomass Product Validation Good Practices Protocol[1] document. Accordingly, Equitable Earth will adopt this method as the standard approach for uncertainty estimation in its assessments.

[1] Duncanson, L., Armston, J., Disney, M., et al (2021). Aboveground Woody Biomass Product Validation Good Practices Protocol. Available at URL (Accessed 26/06/2025)

Uncertainty Comparison

In this section, we aim to compare how participants handle uncertainty calculations. Estimating above-ground biomass is inherently complex and subject to multiple sources of uncertainty. As such, robust uncertainty quantification is essential to evaluate the reliability and scientific validity of the results provided.

Equitable Earth adheres to the best practices described in the Aboveground Woody Biomass Product Validation Good Practices Protocol[2], which defines the following key requirements:

- Uncertainty estimation must account for all steps of the process, including field data collection, allometric modelling, and remote sensing model calibration.
- Propagation of uncertainty must be consistently and transparently managed across each stage.
- A 95% confidence interval must be used when reporting final uncertainty values.

The comparison presented here is based on the specific methodologies employed by each participant to quantify and propagate uncertainty. Given the methodological differences among participants, the analysis was structured to accommodate these variations while ensuring a consistent and equitable basis for evaluation.

[2] Duncanson, L., Armston, J., Disney, M., et al (2021). Aboveground Woody Biomass Product Validation Good Practices Protocol. Available at URL (Accessed 26/06/2025)

	Considers the entire process	Uncertainty propagation	95% confidence interval
Participant A	🟡	🟢	🟢
Participant B	🔴	🟢	🟡
Participant C	🔴	🟢	🟢
Participant D	🔴	🟢	🟢
Participant E	🟡	🟢	🟡

🟢: **Perfectly handled** 🟡: **Adequately handled** 🔴: **Incorrectly handled**

Equitable Earth

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