

Carbontribe Methodology

Mangroves Projects

1. Introduction	2
2. Project design	3
2.1 Project Description	3
2.1.1 Project Scope	3
2.1.2 Purpose and Objectives	4
2.1.3 Project Boundaries	4
2.1.4 Stakeholder Engagement	5
2.2 Baseline Description	6
2.2.1 Baseline Validation	6
2.3 Additionality	6
2.4 Leakage Analysis	7
2.5 Monitoring and Verification	8
2.5.1 Monitoring	8
2.5.2 Verification	8
3. Quantification of Estimated Removals	9
3.1 Process Flow	9
3.2 Annual Carbon Sequestration	11
3.3 CO ₂ Removal from Above-ground biomass (AGB)	11
3.4 CO ₂ Removal from Below-ground biomass (BGB)	12
3.5 CO ₂ Removal from Dead Organic Matter (DOM)	13
3.6 CO ₂ removal from Soil Organic Carbon (SOC)	13
3.7 Project Emissions	14
3.8 Leakage	14
3.8.1 Calculations of Leakage	15
3.9 Overview of Parameters and Sources	16
3.10 Monitoring Requirements	17
4. References	19

1. Introduction

Since the 1980s, global mangrove ecosystems have experienced significant declines, primarily driven by human activities such as deforestation, the expansion of aquaculture, and the extraction of soil for coastal development. These activities have resulted in substantial loss of mangrove areas, reducing their ability to serve as vital carbon sinks. Efforts to restore these coastal wetlands, including mangrove revegetation, offer a promising avenue to counteract these losses. The success of such restoration initiatives, however, depends on the re-establishment of the original environmental conditions necessary for mangrove growth.

This document details Carbontribe's methodology for mangrove-based projects, presenting a systematic approach to quantifying and verifying CO₂ sequestration. These efforts focus on restoring and conserving mangroves to address degradation caused by human activity. Mangroves are among the most effective natural carbon sinks, storing substantial CO₂ in their above-ground biomass and, more importantly, within their sediment-rich soils. Given their unparalleled capacity for carbon storage, implementing precise methodologies is crucial to ensuring the accuracy and credibility of such projects in addressing climate change.

The methods outlined in this document are grounded in the IPCC 2006 Guidelines for National Greenhouse Gas Inventories and the 2013 Wetlands Supplement, which offer internationally recognized frameworks for carbon accounting in wetland ecosystems, including mangroves. Building on these foundational principles, the methodology incorporates innovative, technology-driven solutions tailored to the unique requirements of mangrove restoration and conservation. In alignment with the Core Carbon Principles established by the Integrity Council for the Voluntary Carbon Market (ICVCM), the approach ensures that carbon credits generated are real, additional, permanent, and independently verified. This hybrid model, combining scientific rigor with adaptive, site-specific tools, delivers accurate and reliable carbon sequestration estimates while upholding global best practices in climate mitigation, environmental integrity, and ecosystem restoration.

2. Project design

This section presents the foundational framework for developing and implementing Carbontribe's mangrove projects, ensuring alignment with our common methodology and adherence to best practices. Chapter 3.2 will thereafter focus on the two first steps of the Carbontribe project cycle; conceptualization and onboarding as well as feasibility and design.

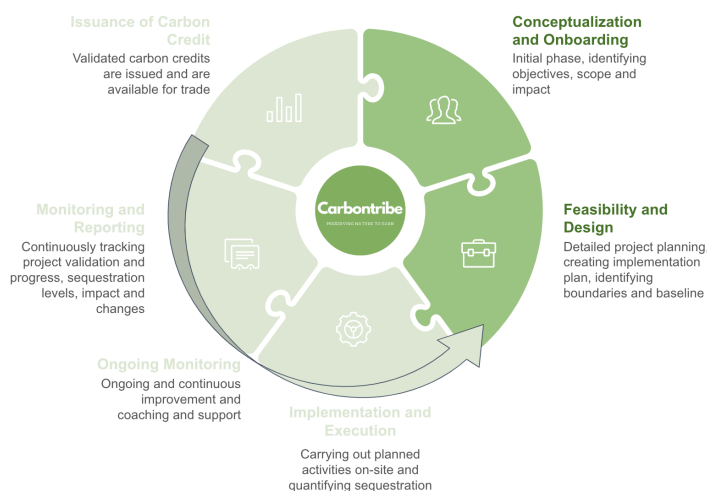


Figure 2: Initial Phases of the Project Cycle

The initial section of this chapter focuses on defining the project's scope and objectives, while the latter part provides a detailed overview of project planning, including the identification of project boundaries and baseline estimation.

To ensure a structured onboarding process, potential project participants will complete a comprehensive form addressing each stage of the process described below (form available in a separate document). This step-by-step engagement facilitates alignment with our methodology, ensures adherence to established best practices, and sets the foundation for achieving the project's objectives effectively.

2.1 Project Description

2.1.1 Project Scope

This methodology exclusively applies to projects categorized as Afforestation, Reforestation, and Revegetation (ARR) within mangrove ecosystems, focusing on measurable greenhouse gas (GHG) removal. Projects must meet the following applicability conditions:

1. **Eligible Project Activities**: Activities must involve the establishment, restoration, or enhancement of mangrove forests on lands classified as barren, degraded, or deforested at the project start date. Additionally, the project must focus solely on ARR activities and exclude activities classified as REDD (Reducing Emissions from Deforestation and Forest Degradation).

2. **Project Start Date:** The start date is defined as the date when measurable ARR activities begin (e.g., site preparation, planting). Evidence, such as documented plans or satellite imagery, must be provided to validate the start date. The methodology allows retroactive projects with a start date up to 10 years prior to validation, provided they include verifiable evidence.
3. **Exclusions:** Activities unrelated to ARR (e.g., REDD, conservation without active enhancement, or activities targeting only avoided emissions) are explicitly excluded due to differences in accounting methodologies and environmental outcomes. Mangrove restoration projects with overlapping boundaries with other carbon offset projects are not eligible to prevent double counting of carbon credits.
4. **Ownership and Rights:** Project participants must demonstrate clear ownership or rights to implement ARR activities in the project area. This includes legal land ownership, lease agreements, or formal written consent from landowners or relevant authorities.

2.1.2 Purpose and Objectives

The project needs to define its overarching goal, which includes carbon sequestration, the restoration or enhancement of mangrove ecosystems, and the delivery of biodiversity and community co-benefits. This should encompass the specific environmental outcomes aimed for and these objectives should be clear, measurable, and aligned with the overall sustainability goals of the project.

2.1.3 Project Boundaries

Carbon Pools and GHG Sources: The project needs to define the carbon pools and GHG sources associated with both the project and baseline scenarios. These include above-ground biomass, below-ground biomass, soil organic carbon, and dead organic matter. Developers are required to provide detailed data on these carbon pools, along with methods for measuring and monitoring carbon stocks.

Geographical Boundaries: The geographical boundaries define the physical area in which the mangrove restoration or protection activities will take place. It is essential to clearly delineate these boundaries to avoid overlap with other carbon offset projects. Carbontribe then cross-check and overlay the new project boundaries onto the existing repository database to detect any spatial overlap or inconsistencies.

Carbontribe will validate the project area and analyse land cover usages. For that, project developers are required to provide geographic information in a standardized format. This information must be submitted in the form of a KML file or a text file with an array of geographic coordinates. Below are the specific requirements and conditions for this submission:

Submission Format

1. **KML File:**

- The KML (Keyhole Markup Language) file must accurately delineate the project boundary.
- It must include a single, contiguous polygon or set of polygons representing the entire project area.
- The KML file must be formatted to be compatible with common GIS (Geographic Information Systems) and GPS software such as Google Earth, ArcGIS, and QGIS.

2. **Array of Coordinates:**

- If a KML file is not submitted, the project boundary may alternatively be defined by an array of geographic coordinates (latitude and longitude) separated by commas. Each row has to be separated by a new line.
- The coordinates must be listed sequentially to form a closed loop that represents the boundary.

File Specifications

1. **Coordinate System:**

- All coordinates must be provided in the WGS84 datum (EPSG:4326).

2. **Boundary Precision:**

- Ensure the precision of the boundary coordinates is sufficient to prevent ambiguity, with at least six decimal places (e.g., 37.774929, -122.419416).

3. **File Integrity:**

- The file must be free of errors and validate against standard KML or GIS file validators.

2.1.4 Stakeholder Engagement

Stakeholder engagement is essential for ensuring the success and sustainability of mangrove restoration projects, as it fosters collaboration, builds trust, and ensures that local needs and priorities are met. To achieve this, projects should actively involve local communities, governments, environmental organizations, and other relevant stakeholders throughout all stages of the process. This can be done by holding regular meetings, conducting consultations, and creating opportunities for feedback during the planning, implementation, and monitoring phases.

In areas where Indigenous peoples and local communities are impacted, projects must adhere to Free, Prior, and Informed Consent (FPIC) principles. This involves early engagement, clear communication of project details, and securing documented consent before implementation. Compliance measures, records of consultations, and participatory decision-making processes—are required to ensure alignment with community rights and environmental standards, particularly in high-risk regions.

To maintain accountability, all relevant documentation, including stakeholder engagement records, FPIC agreements (where applicable), and evidence of compliance, must be submitted as part of the application process. This ensures that projects meet ethical and legal standards while fostering long-term community support and environmental impact.

2.2 Baseline Description

The baseline represents the "before" scenario, reflecting the state of the ecosystem prior to any restoration activities. Since the focus is exclusively on Afforestation, Reforestation, and Revegetation (ARR) projects, only areas where new mangroves are being established are considered. As such, the baseline carbon stock is assumed to be zero, as these areas were either previously barren, degraded, or not historically covered by mangroves. This baseline serves as a reference point for calculating the net carbon benefits of the project and ensuring additionality—confirming that carbon sequestration would not have occurred without the ARR intervention.

To ensure accurate carbon accounting, any existing mangrove areas within the proposed project boundary must be excluded. Developers are responsible for identifying and excluding these areas during project planning and submission to ensure the focus remains solely on the establishment or restoration of new mangrove ecosystems.

2.2.1 Baseline Validation

To validate that the area was non-forested at the baseline period, the following steps are required:

1. **Official Certification**
Project developers must submit a certificate from the landowner or relevant government entity, confirming that the land was not classified as forested during the baseline period.
2. **Carbontribe Land Cover Analysis**
If an official certificate is unavailable, Carbontribe will conduct a land cover analysis using historical remote sensing data. This analysis will verify land use and vegetation cover up to 5 years prior to the baseline period, ensuring that the area meets the eligibility criteria for ARR projects.

2.3 Additionality

In mangrove restoration projects, additionality ensures that carbon credits represent real, measurable, and surplus carbon removals that would not have occurred without the project. To demonstrate additionality, the activities carried out must be clearly distinct from the baseline scenario, which assumes zero carbon sequestration for new mangrove areas. The project must result in outcomes—such as the establishment or restoration of mangrove ecosystems—that would not have happened without the intervention.

To establish additionality, the following key tasks must be undertaken:

1. **Clear Description of Activities:** Projects must detail the specific activities they are implementing, such as planting new mangroves, restoring hydrological conditions, or improving soil retention. These activities should be outlined with clear timelines and objectives that highlight their role in establishing or restoring mangrove ecosystems.
2. **Comparison with Previous Land Use:** The project must demonstrate how these activities differ from prior land use practices, whether it be agriculture, development, or degraded land that would otherwise not regenerate. Evidence of past land use, such as historical records or satellite imagery, should be provided to show that the land would not naturally revert to mangroves without intervention.
3. **Deforestation Assessment:** Projects must assess if any deforestation has taken place within the last five years in the proposed area. Historical satellite imagery can be used to verify whether the land has been cleared, supporting the case that the restoration activities are reversing prior degradation and facilitating carbon sequestration.

By demonstrating these factors, projects can validate their additionality, ensuring that the carbon sequestration achieved is directly attributable to the restoration activities, and would not have occurred in the absence of the project.

2.4 Leakage Analysis

In addressing leakage in mangrove restoration projects, Carbontribe emphasizes the importance of minimizing the displacement of carbon emissions from the project area to surrounding regions, as this can undermine the carbon sequestration benefits. Leakage occurs when activities within the project area inadvertently lead to environmental degradation or deforestation in adjacent or nearby areas, offsetting the intended carbon removal.

To minimize leakage, Carbontribe ensures careful project design by clearly defining project boundaries and conducting thorough baseline assessments. This helps identify potential risks of emissions displacement before the project begins. In addition, monitoring surrounding ecosystems for any signs of degradation are essential measures. This approach helps ensure that restoration efforts do not cause negative environmental impacts outside the project's designated area.

Real-time monitoring through satellite imagery is employed to track the growth and health of the restored mangroves and detect any unauthorized activities or changes in land use. This technology also helps verify that carbon sequestration is happening as planned, with transparent tracking of the project's carbon removal.

By combining careful planning with continuous monitoring, Carbontribe ensures that the carbon sequestration benefits of mangrove restoration projects are genuine and additional, minimizing the risk of leakage and ensuring that the carbon credits generated reflect real, lasting carbon removals rather than simply shifting emissions elsewhere.

2.5 Monitoring and Verification

Monitoring and verification are essential elements of Carbontribe's methodology, ensuring the integrity of carbon sequestration outcomes and the credibility of carbon credits generated. These processes are aligned with international best practices and scientific guidelines, such as those outlined in the IPCC 2006 Guidelines and the 2013 Wetlands Supplement.

2.5.1 Monitoring

Carbontribe's monitoring framework focuses on systematic data collection to track carbon sequestration, ecological health, and compliance with baseline and leakage parameters. This includes quantifying changes in above-ground and below-ground biomass, soil organic carbon levels, and other project-specific indicators.

To enhance accuracy, Carbontribe integrates on-the-ground field measurements with advanced technological tools such as remote sensing, geographic information systems (GIS), and computer vision models (for details, refer to our *Satellite Data* and *Computer Vision Model* chapters *Common Methodology and Framework*). These tools enable precise tracking and allow for early detection of deviations from projected outcomes, ensuring adaptive management throughout the project lifecycle. For the applicable parameters, if a Tier 1 approach is chosen, Carbontribe will manage the monitoring process. However, if a higher-tier approach is selected or necessary, the applicant will assume responsibility for overseeing the monitoring

2.5.2 Verification

Verification involves an independent assessment by third-party auditors to validate the monitoring data and ensure compliance with established methodologies. This step confirms that the carbon sequestration outcomes are measurable, verifiable, and accurately reported. By relying on independent verification, Carbontribe maintains transparency and credibility in its carbon crediting processes.

By combining rigorous monitoring with third-party verification, Carbontribe ensures that its projects deliver quantifiable climate and environmental benefits. This continuous feedback loop also facilitates improvements in project implementation, fostering innovation and reinforcing our commitment to reliable, impactful carbon market participation.

3. Quantification of Estimated Removals

This chapter focuses on Step 3 of the project cycle, implementing the project and quantifying carbon sequestration to measure the direct impact. Carbontribe's methodology for mangrove ARR (Afforestation, Reforestation, and Revegetation) projects follows the guidelines set forth in the IPCC 2013 Wetlands Supplement, particularly Section 4.2.3, ensuring compliance with globally recognized standards for carbon accounting in wetland ecosystems.

The IPCC framework offers multiple "Tiers" for calculating carbon sequestration, depending on the data available and the precision needed. Tier 1 represents the most basic level, relying on default values and general models for carbon estimation. The calculations presented in this methodology use Tier 1 default values as the starting point. However, if more appropriate, project-specific data becomes available, Carbontribe will adjust the calculations to apply higher Tiers (Tier 2 or Tier 3), which provide more localized and precise carbon estimates.

This approach allows Carbontribe to ensure that calculations remain both accurate and feasible, depending on the data at hand, while still adhering to the best practices outlined by the IPCC. The following sections describe the calculations for annual carbon sequestration, detailing the specific components that contribute to the overall sequestration estimate.

3.1 Process Flow

Accurately quantifying forest coverage and estimating CO₂ sequestration potential is crucial for understanding the role of forests in mitigating climate change. Carbontribe leverages computer vision models and remote sensing technologies to classify forest and non-forest areas, monitor critical forest parameters, and estimate annual carbon sequestration rates. This methodology integrates high-resolution satellite imagery, machine learning algorithms, and ecological equations to provide a comprehensive, scalable solution for forest monitoring and carbon accounting.

Step 1: Data Acquisition and Preprocessing

- Satellite imagery data is collected from various sources such as remote sensing platforms.
- The collected data undergo preprocessing, including noise reduction, radiometric correction, atmospheric correction, and geographic alignment, to ensure compatibility with the computer vision models.

Step 2: Forest Classification Using Computer Vision

- A computer vision model is trained to classify regions as forest or non-forest at pixel level. Training data includes labeled examples of both categories.
- The model processes high-resolution satellite images to identify forested areas based on spectral, textural, and structural features.
- The output is a classified map highlighting forest and non-forest regions at pixel-level.

Step 3: Monitoring Key Forest Parameters

- For areas classified as forest, the monitoring process aligns with IPCC guidelines to estimate forest biomass and carbon stocks accurately. More detailed information what parameters and how exactly we conduct the monitoring can be found in the following chapters
- Wherever possible, further literature reviews will be conducted to obtain detailed information such as country-specific factors, forest type-specific allometric equations, and regional emission factors. This ensures that monitoring results are both scientifically robust and tailored to local ecological contexts.
- These parameters are monitored over time at the specified frequency to track changes and trends in forest health and growth.

Step 4: CO2 Sequestration Estimation

- Using the monitored parameters, relevant equations or biomass models are applied to estimate carbon storage.

Step 5: Blockchain Storage

- All relevant data, including forest classification outputs, monitored parameters, and CO2 sequestration estimates, are securely stored on a decentralized blockchain platform.
- Data links, metadata, and timestamps are recorded to ensure traceability and tamper-proof documentation.

Step 6: Digital Asset Creation:

- A digital asset in the form of a Non-Fungible Token (NFT) is created to represent the carbon sequestration results for a specific geographic area and time period.
- The NFT includes embedded data or links to external datasets, including:
 - Detected forest areas
 - Parameter estimates and methods
 - Scientific equations and values used in the calculations
 - Documentation on compliance with IPCC methodologies and any country-specific factors
- The blockchain-stored data and NFT serve as a transparent and auditable foundation for issuing carbon credits.
- This process ensures that credits are backed by scientifically verified data, reducing the risk of fraudulent claims

3.2 Annual Carbon Sequestration

The total CO₂ removed by the project per year is calculated as:

$$CO_2 \text{ Removed (tCO}_2\text{/year)} = CO_2 \text{ from AGB} + CO_2 \text{ from BGB} + CO_2 \text{ from DOM} + CO_2 \text{ from SOC} \\ - \text{Leakage (tCO}_2\text{/year)} - \text{Project Emission (tCO}_2\text{/year)}$$

In this equation:

- **CO₂ from AGB:** Carbon dioxide removed by above-ground biomass (trees, plants, etc.)
- **CO₂ from BGB:** Carbon dioxide removed by below-ground biomass (roots and soil-bound organic matter)
- **CO₂ from DOM:** Carbon dioxide stored in dead organic matter, like decaying plant material
- **CO₂ from SOC:** Carbon dioxide sequestered in soil organic carbon (carbon stored in the soil)

Each of these components is multiplied by a **C to CO₂ factor** to convert carbon (C) into CO₂ equivalents.

Finally, **Leakage** refers to any emissions that occur outside the project area as a result of the project's activities, while **Project Emission** includes any emissions generated by the project itself, such as from energy use or land preparation. These values are subtracted from the total carbon sequestration to reflect the net impact of the project.

3.3 CO₂ Removal from Above-ground biomass (AGB)

The annual CO₂ removal of the Above-ground Biomass (AGB) is calculated with the following equation:

$$CO_2 \text{ by AGB (tCO}_2\text{/year)} = \text{AGB Sequestration Rate (tC/ha/year)} \times \text{Area (ha)} \times \text{C to CO}_2 \text{ factor}$$

The Above-Ground Biomass (AGB) Sequestration Rate (tC/ha/year) represents the annual amount of carbon stored in the above-ground biomass of mangrove trees per hectare. This metric is expressed in metric tons of carbon (tC) sequestered per hectare annually and serves as a key indicator of how effectively mangrove vegetation absorbs atmospheric carbon dioxide (CO₂) and incorporates it into its biomass.

The IPCC 2013 Wetlands Supplement (Table 4.4) provides default values for AGB sequestration rates categorized by climate domain and region. Additionally, IPCC Chapter 4, Volume 4 (Table 4.10) includes further details based on ecological zones and specific mangrove tree species. These sources provide Tier 1 default values, which are widely accepted for general use when more detailed, localized data is unavailable. To ensure accuracy in the Above-ground biomass (AGB) sequestration rates used:

1. **Tier 1 Approach:** Default rates provided by the IPCC are used in cases where site-specific data is not available.
2. **Refined Approaches (Tier 2 or 3):** When available, project-specific data or values derived from peer-reviewed studies are prioritized. For example, mangrove restoration projects dominated by species such as *Rhizophora mucronata* can apply updated sequestration rates that reflect the species' specific growth conditions and regional ecological characteristics. These may be obtained through recent scientific literature or direct field measurements.

This approach balances the use of standardized guidelines with the integration of site-specific data to enhance the credibility and accuracy of carbon accounting in mangrove afforestation and reforestation projects.

3.4 CO₂ Removal from Below-ground biomass (BGB)

The below-ground biomass (BGB) represents the roots and other subterranean components of mangrove trees that store carbon. CO₂ removal from BGB refers to the carbon dioxide absorbed from the atmosphere and subsequently stored in these below-ground components as part of the tree's natural growth and carbon cycle processes and is calculated with the following equation:

$$CO_2 \text{ by BGB (tCO}_2\text{/year)} = \text{BGB to AGB ratio} \times CO_2 \text{ by AGB (tCO}_2\text{/year)}$$

The BGB to AGB ratio is a proportion that indicates how much carbon is stored below ground for every unit of carbon stored above ground. This ratio varies by species, ecological zone, climate, and environmental factors. Mangroves typically exhibit higher BGB to AGB ratios than other forest types due to their adaptation to waterlogged and saline conditions, which promote extensive root systems. The IPCC 2013 Wetlands Supplement offers default ratios categorized by region and species, serving as a Tier 1 default method. If site-specific data or species-specific studies are available (Tier 2 or 3 approaches), these should be applied for greater accuracy.

This accurate estimation of below-ground biomass (BGB) sequestration rates is critical for quantifying carbon storage in mangrove ecosystems. To achieve this:

- **Tier 1 Approach:** Default ratios of BGB to AGB provided in global standards, such as the IPCC Wetlands Supplement (Table 4.5), are applied when specific site data is unavailable. These defaults ensure consistency and a reliable starting point.
- **Refined Approaches (Tier 2 or 3):** Site-specific measurements or species-based ratios derived from recent scientific literature are prioritized when available. For example, projects featuring dominant species like *Rhizophora mucronata* may use updated, regionally-relevant BGB-to-AGB ratios from peer-reviewed studies or field data, reflecting actual sequestration conditions.

3.5 CO₂ Removal from Dead Organic Matter (DOM)

As shown in the overall equation, one of the components contributing to CO₂ removal is Dead Organic Matter (DOM). In mangrove ecosystems, DOM includes decaying materials such as dead wood, fallen leaves, and other organic matter. These materials capture and store carbon that was initially absorbed from the atmosphere during the growth of the plants. Over time, as this organic matter decomposes, it continues to play a role in carbon cycling within the ecosystem. The corresponding equation for calculating the CO₂ removal from DOM is as follows:

$$CO_2 \text{ by DOM (tCO}_2\text{/year)} = \text{DOM Sequestration Rate (tC/ha/year)} \times \text{Area (ha)} \times \text{C to CO}_2 \text{ factor}$$

However, according to the IPCC 2006 Guidelines, the transfer of carbon into DOM (from dead wood, fallen leaves, and other organic material) is generally assumed to be in equilibrium with the transfer out of DOM. This balance is based on the understanding that over time, the input of organic matter through leaf drop and other biological processes is counteracted by the decomposition and export of organic material, such as through tidal movements. As a result of this natural equilibrium, the net change in carbon stored in DOM is considered negligible, meaning that the amount of carbon entering and leaving the DOM pool is roughly equal.

To mitigate the risk of overestimation, Carbontribe adopts a conservative approach and assumes that the annual change in CO₂ removal from DOM is zero. This precaution prevents potential double-counting and ensures that carbon impacts from biomass and soil carbon stocks are fully captured without duplication.

3.6 CO₂ removal from Soil Organic Carbon (SOC)

Soil organic carbon (SOC) is an essential component of the carbon sequestration process in mangrove ecosystems. SOC is the carbon stored in the soil as a result of decaying organic matter, plant roots, and other biological processes that convert atmospheric CO₂ into stable organic compounds over time. This carbon storage occurs through the accumulation of organic material in the soil, contributing to long-term carbon sequestration. The calculation for annual CO₂ removal from SOC is:

$$CO_2 \text{ by SOC (tCO}_2\text{/year)} = \text{SOC Sequestration Rate (tC/ha/year)} \times \text{Area (ha)} \times \text{C to CO}_2 \text{ factor}$$

The SOC Sequestration Rate varies across regions and ecosystem types. Default values for SOC sequestration in wetlands, including mangroves, are provided by the IPCC 2013 Wetlands Supplement. These default values are based on global data and represent general trends observed across different wetland and soil conditions. They are considered scientifically reliable and offer a useful baseline for calculating SOC sequestration when more specific site data is not available. However, as SOC sequestration is site-dependent, localized data should be used when available for greater accuracy.

This accurate estimation of soil organic carbon sequestration rates is critical for quantifying carbon storage in mangrove ecosystems. To achieve this:

- **Tier 1 Approach:** Default values from the IPCC Wetlands Supplement (Table 4.12) are used in the absence of site-specific data. These values provide a standardized starting point and ensure consistency in carbon accounting.
- **Refined Approaches (Tier 2 or 3):** When possible, project-specific measurements or species-specific values from peer-reviewed literature should be applied. For example, studies on mangrove species like *Rhizophora mucronata* may provide more accurate data on SOC sequestration rates that reflect local soil conditions and tidal influences.

3.7 Project Emissions

Project emissions refer to the greenhouse gases emitted during activities like land preparation, planting, and maintenance in reforestation projects. For mangrove restoration, project emissions are assumed to be zero, as the activities involved are generally low-impact, such as planting native species and minimizing land disturbance. This assumption aligns with the *IPCC 2013 Wetlands Supplement*, which indicates that emissions are typically low in restoration projects that avoid large-scale land-use changes or disturbances (IPCC, 2013). Mangrove restoration activities typically focus on ecosystem recovery without causing significant emissions, which supports the assumption of negligible project emissions.

If a project is expected to generate significant emissions, IPCC guidelines will be applied to ensure accurate estimation. Examples of such emissions include large-scale land clearing or infrastructure development. If tree and non-tree biomass from the baseline scenario is burned for land preparation, an additional deduction will be made to account for the resulting emissions. CO₂ and non-CO₂ greenhouse gas emissions from fossil fuel use in project activities (e.g., flights, management operations) are considered negligible and may be excluded.

3.8 Leakage

Leakage refers to the unintended displacement of carbon emissions or removal from the project area due to restoration activities. In the case of mangrove restoration, leakage is generally minimal, but it can vary depending on the specific activities and surrounding land-use dynamics. Based on the *IPCC 2013 Wetlands Supplement* and common carbon accounting practices, the following approach is used:

- **Tier 1:** Leakage is assumed to be zero, as mangrove restoration typically involves low-impact activities like planting native species and avoiding land-use changes that could lead to increased emissions. This approach follows the IPCC guidelines that suggest leakage is not a significant risk in such low-disturbance activities.

- **Tier 2:** Leakage is still assumed to be zero, but active monitoring of the surrounding area is implemented. Through the use of a computer vision model, Carbontribe tracks any changes in the landscape around the restoration site. This monitoring helps identify and mitigate potential leakage risks, ensuring that no unintended deforestation or land-use changes occur nearby.
- **Tier 3:** In cases where higher leakage risks are identified, such as potential emissions from nearby deforestation or infrastructure development, a detailed analysis is performed. IPCC guidelines will be followed to assess and quantify potential emissions displacement, ensuring that leakage is accurately accounted for.

3.8.1 Calculations of Leakage

For projects involving mangroves with a higher risk of leakage—such as those displacing coastal activities, aquaculture, or local resource harvesting—leakage must be considered in the calculations. Leakage is determined using the affected area, the percentage of displaced activity, and carbon stock differentials, as per the formula:

$$\text{Leakage} = \text{Affected Area} \times \% \text{Activity Shift} \times \text{CO}_2 \text{ Stock}$$

In cases where the specific displacement location is unknown, average CO₂ stock values for natural mangrove forests in the region or host country are applied.

3.9 Overview of Parameters and Sources

Parameter	Unit	Definition	Source type
Planted Area	ha (hectares)	The total area of mangroves planted each year as part of the project.	Project specific data: satellite imagery and landcover classification model
AGB Sequestration Rate	tC/ha/year	Annual rate of carbon accumulation in the above-ground biomass (AGB) of mangroves per hectare.	<p>Default rates (Tier 1) are taken from the IPCC 2013 Wetlands Supplement (Table 4.4) and the 2006 IPCC Guidelines (Chapter 4, Table 4.10), which classify rates by climate domain, region, and species.</p> <p>Climate and ecological classifications follow IPCC Chapter 4, Table 4.1 (FAO, 2001).</p> <p>For regional or site-specific data (Tier 2 and 3), values may be refined using peer-reviewed studies or field measurements.</p>
BGB to AGB ratio	Ratio (unitless)	Proportion of carbon stores below-ground relative to above-ground biomass	<p>Default BGB-to-AGB ratios (Tier 1) are provided in the IPCC 2013 Wetlands Supplement (Table 4.5), categorized by region and mangrove species.</p> <p>Site-specific or species-based ratios (Tier 2 and 3) are prioritized, leveraging data from peer-reviewed studies or field measurements.</p>
SOC Sequestration Rate	tC/ha/year	Annual rate of carbon storage in soil organic carbon (SOC) due to the project	<p>Default SOC sequestration rates (Tier 1) are provided in the IPCC 2013 Wetlands Supplement (Table 4.12), which includes annual emission factors for rewetting organic and mineral soils.</p> <p>For Tier 2 and Tier 3, project-specific measurements or peer-reviewed studies are used.</p>
C-to-CO₂ Conversion	Ratio (unitless)	Conversion factor to calculate equivalent CO ₂ from stored carbon, using	IPCC 2006 Guidelines or standard conversion factor ($44/12 = 3.67$).

		the molecular weight ratio.	
Affected Area	Hectares (ha)	The total area within the project site where activities may cause leakage	Project site assessment, remote sensing data such as GIS mapping, land-use data, or historical satellite imagery
% Activity Shift	Percentage (%)	The estimated percentage of an activity that will be displaced outside the project area	Surveys, interviews with landowners, historical deforestation and land-use change data.
CO₂ Stock	tCO ₂ /ha	The carbon stock per hectare in biomass in the area where displacement occurs	National inventories, IPCC guidelines, peer-reviewed literature, or host-country datasets on carbon stocks

3.10 Monitoring Requirements

The table below outlines the monitoring requirements for each parameter, detailing the methods and frequency of data collection. Monitoring will primarily occur annually to align with the yearly evaluation of carbon credits, ensuring accurate tracking of carbon sequestration, emissions, and potential leakage. In the event that annual monitoring cannot be completed—such as due to satellite imagery vendor failures, data discrepancies, equipment malfunctions, or funding delays—contingency measures will be put in place. These measures may include utilizing alternative satellite vendors, switching to different satellite data sources, or relying on historical satellite data for continuity.

Parameter	How to Monitor	Frequency
Planted Area	Satellite imagery and landcover classification model.	Annually
AGB Sequestration Rate	Monitor default rates provided by IPCC (IPCC 2013 Wetlands supplement table 4.11), verification through regional studies in peer-reviewed literature.	Annually
BGB to AGB ratio	Apply default values from the IPCC 2013 Wetlands Supplement (table 4.5), for consistency, and use site-specific measurements or species-based ratios (Tier 2 or 3) for greater accuracy when available	Annually

SOC Sequestration Rate	Default values from the IPCC 2013 Wetlands Supplement (table 4.12) are used when site-specific data is unavailable. Project-specific or species-specific data from peer-reviewed sources will be used for more accurate and localized estimates if available.	Annually
Project Emissions	Default assumption of zero emissions for low-impact activities (Tier 1); monitor and estimate emissions (fuel use, transport logs etc.) for higher-impact activities using IPCC guidelines for Tier 2/3	Annually
Leakage	Analyze nearby areas using satellite imagery and computer vision models; conduct field surveys to detect land-use changes	Annually

4. References

Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <https://www.ipcc-nggip.iges.or.jp/public/2006gl/>

Intergovernmental Panel on Climate Change (IPCC). (2013). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. Retrieved from <https://www.ipcc-nggip.iges.or.jp/public/wetlands/>

Intergovernmental Panel on Climate Change (IPCC). (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html>

Integrity Council for the Voluntary Carbon Market (ICVCM). (2023). *Core Carbon Principles and Assessment Framework*. Retrieved from <https://icvcm.org/core-carbon-principles/>

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. Retrieved from <https://sdgs.un.org/2030agenda>