# Tree-Nation Carbon Calculation Methodology

**Global structure**



# Introduction

Tree-Nation's mission is to help reforest the world. We team up with reforestation, afforestation, agroforestry, and conservation projects around the world to fund their activities, converting their reforestation effort into a volume of trees that can be sponsored on our platform.

Traditional certification standards, such as VCS, Gold Standard, Plan Vivo, calculate $CO_2$ per hectare of grown forest, using methodology-based sampling and on-site measurement. This works well for large, mature projects, but creates a high barrier to entry for smaller or newer ones.

Tree-Nation takes a different approach: sponsors fund individual trees, particularly newly planted ones. This lets sponsoring companies make their environmental commitment tangible, "gifting" a tree to a customer or employee, linked to a real, trackable planting rather than an abstract $CO_2$ value.

To support this, Tree-Nation developed its own methodology to estimate the $CO_2$ sequestration of each individual tree planted through the platform, calculated on a per-tree basis using the physical characteristics of each species, rather than per hectare. This allows Tree-Nation to fund a broad and diverse range of projects,  from large-scale to modest, that would otherwise have no access to funding under traditional certification pathways.

The methodology defined here provides the ex-ante carbon estimation basis used across the Tree-Nation system. It applies to all Tree-Nation projects regardless of the Tree-Nation certification pathway they follow.

The model is intentionally conservative: precision is deliberately traded for prudence, so that any sponsor can confidently claim the resulting value as an offset. A "low" estimate is a good estimate for the purposes of the platform.

# How This Differs From Traditional Carbon Certifications

Tree-Nation's methodology departs from traditional certification in two defining ways. Where traditional certifications build a custom paper model per project, anchored in a counterfactual baseline of what would have happened without the project, Tree-Nation determines the $CO_2$ capture potential of a tree over its lifetime directly from the established biological characteristics of its species. And where traditional methodologies calculate carbon at the hectare level, Tree-Nation calculates per tree, since each species' characteristics, and therefore its contribution value, vary considerably.

| Traditional certification | Tree-Nation methodology |
|---|---|
| Calculated per hectare | Calculated per tree |
| Crediting up to 100 years | Crediting capped at 10 years |
| Sample-based verification at least every 5 years | Continuous verification via remote sensing & geolocated field data |
| Expensive | Low cost |
| Limited selection of species | Unlimited |
| Limited plantation methods | Unlimited |
| Large projects only | All project sizes |

The trade-off is precision, which Tree-Nation offsets by applying a prudence ratio that lowers the final $CO_2$ value. The goal is not to produce the single most accurate number, but a number any sponsor can confidently claim as their offset — a conservative estimate is, for this purpose, the right estimate.

# Carbon Estimation Logic: Overview

Tree-Nation estimates carbon uptake at the tree level using species-specific biological models. Each tree's expected $CO_2$ uptake over its first 10 years is calculated using:

- species growth characteristics (fast, moderate, or slow-growing)
- tree morphology (trunk height and trunk diameter) and wood density
- climate type of the region (tropical, subtropical, temperate, boreal, dry)
- average species lifespan and growth period
- expected survival rate and planting-site culling
- management factors
- prudence adjustments

Soil moisture has been identified as a relevant variable, but is not yet integrated into the calculation.

The model is intentionally conservative in several ways: input measures are capped to median rather than ideal specimens, since scientific literature tends to report best-case data; survival and culling rates are built directly into the calculation; prudence coefficients reduce the risk of overestimation; results are cross-checked, where available, against existing certification calculations and scientific literature on comparable species and systems; and per-tree results are capped at 500 kg of $CO_2$.

This produces a risk-adjusted estimate of $CO_2$ uptake per tree over 10 years, reflecting expected real-world performance rather than ideal growth conditions.

# The $CO_2$ Sequestration Formula

Tree-Nation calculates expected carbon sequestration using a species-level formula based on tree structure and biological growth parameters. The calculation follows six stages, expanding the four-stage summary into the full technical detail maintained internally.

**Step 1: Tree Volume Estimation**

Tree volume is estimated from species morphology by modelling the trunk as a cylinder, using the trunk diameter range, height range, and wood density of the species. Two additional carbon pools are then added on top of trunk volume: branches and leaves (+15%), and roots (+20%). Prudence coefficients are applied throughout to keep estimates conservative.

**Fixed model parameters:**

| Parameter | Description | Value |
|---|---|---|
| h_trunk_coef (trunk_tree_ratio) | Ratio of trunk size to full tree size (including crown). Applied as: h_avg × h_trunk_coef = h_trunk | 45% |
| d_coef (average_specimen_reductor) | Literature typically studies ideal specimens; this coefficient reduces estimates to a more average specimen | 60% (baseline; reduced further for all species under the Version 5.0 radius-estimation improvement — current per-species figures held in the species database) |
| radius_cap | Cap on trunk radius, to avoid excessive values | 0.5 m (50 cm) |
| branches_coef (branches_stored_co2) | Additional $CO_2$ stored in branches and leaves, on top of the trunk | 15% |
| roots_coef (roots_stored_co2) | Additional $CO_2$ stored in roots, on top of the trunk | 20% |
| c_to_co2 (carbon_co2_ratio) | Ratio of carbon mass to $CO_2$ mass | 3.67 |

**Default values (used only when species data is missing):**

| Parameter | Description | Value |
|---|---|---|
| h_avg_default | Average tree height, if no data available | 5 m (currently unused) |
| d_avg_default | Average trunk diameter, if no data available | Not yet set (currently unused) |
| tree_density_default | Wood density, if no data available | 0.50 $g/cm^3$ |

Species data requirements:

| Field | Description |
|---|---|
| h_min / h_max (m) | Minimum / maximum tree height |
| d_min / d_max (cm) | Minimum / maximum trunk diameter |

| Field | Description |
|---|---|
| tree_density (g/cm$^3$) | Wood density of the species |

**Derived (measurable) values:**
radius (m) = (d_min + d_max) / 2 × d_coef / 2 / 100, capped at radius_cap if it would otherwise exceed it.
h_trunk (m) = (h_min + h_max) / 2 × h_trunk_coef

Both outputs are in meters, ready to plug into the cylinder volume formula that follows, which yields volume in m$^3$.

**Step 2: Carbon Content Calculation**

Tree biomass is converted to carbon using wood density and dry-mass ratios:

- Convert tree density from g/cm$^3$ to kg/m$^3$ = (g/cm$^3$) x 1000
    - Derivation of the ×1000 factor:
        - Volume conversion: 1 m$^3$ = (100 cm)$^3$ = 1,000,000 cm$^3$ (cubed)
        - Mass conversion: 1 kg = 1,000 g (linear)
        - Combined: 1 g/cm$^3$ × (1,000,000 cm$^3$/m$^3$) ÷ (1,000 g/kg) = 1,000 kg/m$^3$
- Wood mass (kg fresh biomass) = Volume of the tree (m$^3$) × treedensity (kg/m$^3$)
- Dry mass = Wood mass × 65% (dry mass ratio)
- Carbon sequestered per tree (kg) = Dry mass × 50% (carbon content of dry wood)

**Combined formula:** C sequestered per tree (kg) = Volume (m$^3$) × wood density (kg/m$^3$) × 65% × 50%

Wood density varies with species genotype and environmental conditions — luminosity, water availability, temperature, soil fertility, spacing, and management. Dry wood has an elemental composition of approximately 50% carbon, 6% hydrogen, and 44% oxygen, with trace inorganics, which is what justifies the 50% carbon ratio above.

**Intermediate mass/carbon breakdown (internal detail):**

| Quantity | Formula |
|---|---|
| tree_density (kg/m$^3$) | tree_density (g/cm$^3$) x 1000 |
| mass_trunk (kg) | Volume of trunk (m$^3$) × tree density (kg/m$^3$) = π × radius$^2$ × h_trunk × tree_density (kg/m$^3$) |
| dry_mass_trunk (kg) | mass_trunk (kg) x 0.65 |
| carbon_stored_in_trunk (kg) | dry_mass_trunk (kg ) x 0.5 |

| Quantity | Formula |
|---|---|
| carbon_stored_in_branches (kg) | carbon_stored_in_trunk × branches_coef |
| carbon_stored_in_roots (kg) | carbon_stored_in_trunk × roots_coef |
| carbon_stored_in_tree (kg) | carbon_stored_in_trunk × (1 + branches_coef + roots_coef) |

**Step 3: Conversion to $CO_2$**

Carbon mass is converted to $CO_2$ equivalent using the standard molecular conversion ratio: **$CO_2$ = Carbon × 3.67**

This reflects the relative molecular weights of $CO_2$ and carbon: atomic weight of C = 12, atomic weight of O = 16, atomic weight of $CO_2$ (C + 2×O) = 44, giving 44 ÷ 12 = 3.667.

At this stage: CO2_per_tree_pre (kg) = carbon_stored_in_tree × c_to_co2 — the pre-adjustment $CO_2$ volume, before growth, management, and prudence factors are applied.

**Step 4: Growth & Climate Adjustments**

Growth-rate and climate parameters scale the raw $CO_2$ estimate to reflect how quickly and how well a species grows in its planting region.

| Climate region | Growth factor (100% = optimum growing conditions) |
|---|---|
| Tropical | 90% |
| Subtropical | 70% |
| Warm temperate / dry | 43% |
| Dry | 37% |
| Cool temperate | 35% |
| Boreal | 28% |
| Default (unknown region) | 50% |

| Growth rate class | Growth-period ratio (share of lifespan to near-full growth potential) |
|---|---|
| Fastest-growing | 50% |

| Growth rate class | Growth-period ratio (share of lifespan to near-full growth potential) |
|---|---|
| Fast-growing | 60% |
| Moderate | 70% |
| Slow | 80% |
| Default (unknown) | 80% |

**Additional defaults:**
climate_region_default = 50%; growth_rate_default = 80%; life_span_default = 70 years.
growth_period (years) = life_span × growth_rate
co2_per_year_pre (kg) = CO2_per_tree_pre × climate_region/growth_period

**Step 5: Management Adjustments**

Two field-observed, project-level factors reduce the estimate to reflect real planting-site outcomes:

| Parameter | Description | Default |
|---|---|---|
| survival_rate | Share of trees surviving after 2 years. | 50% (fallback, if no project data) |
| cull_back | Share of trees surviving to adult age after natural competition for space (cull-back) | 70% (fallback, if no project data) |

co2_per_year_post (kg) = co2_per_year_pre × survival_rate × cull_back × model_prudence

**Step 6: Prudence Parameters & Final Caps**

The final stage applies Tree-Nation's prudence coefficient and the structural caps that keep the methodology conservative.

| Parameter | Description | Current value |
|---|---|---|
| model_prudence | Final prudence cut applied to the calculated value, to keep results conservative | 70% |
| co2_anteperiod_cap | Years of tree growth accounted for in the ex-ante calculation | 10 years |
| co2_postperiod_cap | Years of tree growth accounted for in ex-post verification measurement | 20 years (legacy internal parameter; ex-post tracking is superseded in practice by the |

| Parameter | Description | Current value |
|---|---|---|
| | | 10-year ex-ante cap and the 500 kg per-tree cap — see below) |
| Per-tree cap | Maximum $CO_2$ creditable to a single tree, regardless of calculated value | 500 kg $CO_2$ |

**Final ex-ante formula:** co2_offset_exante = co2_per_year_post × co2_anteperiod_cap
(if a tree's project-specific expected lifespan, tree_co2_period, is shorter than the ante-period cap, that shorter value is used instead)

This is the headline $CO_2$ figure displayed against each tree, prudently capped at 500 kg. Where available, results are further refined by contrasting Tree-Nation's values against existing certification calculations and scientific publications on comparable species and systems, and adjusted accordingly.

# Current Parameter Reference

| Parameter | Current value |
|---|---|
| Trunk-to-tree ratio (h_trunk_coef) | 45% |
| Average-specimen reductor (d_coef) | 60% baseline, reduced per-species under v5.0 |
| Radius cap | 0.5 m |
| Branches carbon add-on | +15% of trunk |
| Roots carbon add-on | +20% of trunk |
| Dry mass ratio | 65% |
| Carbon content of dry wood | 50% |
| Carbon-to-$CO_2$ ratio | 3.67 |
| Ex-ante growth period cap | 10 years |
| Per-tree $CO_2$ cap | 500 kg |
| Model prudence ratio | 70% |
| Default survival rate (fallback) | 50% |
| Default cull-back rate (fallback) | 70% |
| Default wood density (fallback) | 0.50 g/cm$^3$ |

| Parameter | Current value |
|---|---|
| Default life span (fallback) | 70 years |
| Default climate region factor (fallback) | 50% |
| Default growth rate factor (fallback) | 80% |

# Governance & Recalculation Notes

The methodology is designed to evolve: hypothesis parameters and defaults are treated as adjustable model inputs, and refined as better data becomes available.

Lifetime $CO_2$ per tree is stored at the point of tree creation. A separate "lifetime_co2" field exists for manual, admin-panel-only edits and is kept outside the automated calculation. A project-level "recalculate" capability is planned to allow species-table values to be refreshed and re-versioned as the model improves.

Soil moisture remains an identified but not-yet-integrated variable, flagged here as a candidate for a future version.

# Glossary of Symbols

| Symbol | Meaning |
|---|---|
| h_min, h_max | Minimum / maximum species height (m) |
| d_min, d_max | Minimum / maximum trunk diameter (cm) |
| tree_density | Wood density of the species ($g/cm^3$) |
| radius | Estimated trunk radius (m), capped at radius_cap |
| h_trunk | Estimated trunk height (m) |
| mass_trunk | Estimated trunk mass (kg) |
| carbon_stored_in_tree | Total carbon stored in trunk + branches + roots (kg) |
| CO2_per_tree_pre | $CO_2$ volume before growth/management/prudence adjustments (kg) |
| climate_region | Growth factor for the project's climate region |

| Symbol | Meaning |
|---|---|
| growth_rate | Growth-period ratio for the species' growth-rate class |
| growth_period | Years to near-full growth potential (life_span × growth_rate) |
| co2_per_year_pre / co2_per_year_post | Annual $CO_2$ rate, before / after management adjustments (kg) |
| survival_rate, cull_back | Field-observed survival and thinning rates |
| model_prudence | Final conservative cut applied to the model (70%) |
| co2_anteperiod_cap | Ex-ante accounting period cap (10 years) |
| co2_offset_exante | Final headline ex-ante $CO_2$ figure per tree, capped at 500 kg |