The methodology behind the article: An estimation of TreeSisters' CO_2 uptake

What do we account for?

This estimation accounts for carbon uptake by the trees from the so-called 'above ground biomass' (trunks, branches and shoots, leaves) and from the belowground biomass (live roots). We do not account for carbon in leaf litter, nor for carbon sequestered by soil over time.

In fact, trees shed fine roots and leaves into their surroundings, which get decomposed into very small particulate organic matter by small vertebrates and invertebrates (worms and crustaceans in mangroves), with the help of many microorganisms, and end up stored in the soils.

This is hard to calculate though if we did this would increase the figures of carbon sequestered.

Moreover, when referring to mangrove forests, we do not account for benthic macroalgae colonising the mangrove's roots and microalgae carpeting the mangrove's floor, and phytoplankton floating in the water, which also photosynthesise and are responsible for accumulating large amounts of carbon in mangrove soil over time.

How long does it take?

We assume that 20 years is the average period of reforested lands to mature enough to recover their functional value and reach stable carbon stock.

However it is important to note that a comprehensive study[1] shows that it may take about 80 years for full carbon biomass recovery, following disturbance in tropical forests. Recent studies

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[1] Martin, Philip A., Adrian C. Newton, and James M. Bullock. "Carbon Pools Recover More Quickly than Plant Biodiversity in Tropical Secondary Forests." *Proceedings of the Royal Society B: Biological Sciences* 280, no. 1773 (December 22, 2013): 20132236. Available [here](#).

have found that full or partial recovery of soil carbon content[2] from reforestation following agriculture abandonment, may take from 40 years to over 120 years[3].

Moreover, it is important to note that it takes over 100 years to recover plant biodiversity, while it would take 150 years to recover faunal biodiversity[4]. It takes up to 300 years for a regenerating Atlantic forest in Brazil to approach the level of plant diversity in mature forest. It will take even more time to recover all the understory species[5], which is why we are also working towards halting destruction of mature forests in the first place.

Carbon dioxide uptake estimation: step-by-step guide

In a nutshell, TreeSisters carbon uptake estimation is based on the values of carbon sequestration for natural forests, forest plantations, and mangroves, given by the Intergovernmental Panel on Climate Change (IPCC).

While different methods with different degrees of complexity, TreeSisters Carbon uptake potential has been computed through the simplest calculation method in its implementation which does not require any field input data.

Science teachers are welcome to make this into a maths resources for youth, while you educate about the carbon sequestration potential for trees.

Our methodology is as follows: for each project, we multiply the estimated reforested area in hectares, hence the surface under reforestation, by the amount of carbon dioxide (CO_2) to be sequestered in tonnes per 1 hectare over a 20-year period[6].

Estimated reforested area X CO_2 sequestration potential

To estimate the amount of CO_2 sequestered by 1 hectare, we use default values from the IPCC. We assume there are primarily three main factors that impact forest productivity and thus CO_2 uptake, namely: climate domain, ecological zone, and forest management practices—coarsely labeled by the IPCC as intensive (plantation forestry) or extensive (natural forest).

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[2] to reach pre-deforestation state.
[3] Yang, Liqiong, Pan Luo, Li Wen, and Dejun Li. "Soil Organic Carbon Accumulation during Post-Agricultural Succession in a Karst Area, Southwest China." *Scientific Reports* 6 (November 23, 2016). Available here.
[4] Martin, Philip A., Adrian C. Newton, and James M. Bullock. "Carbon Pools Recover More Quickly than Plant Biodiversity in Tropical Secondary Forests." *Proceedings of the Royal Society B: Biological Sciences* 280, no. 1773 (December 22, 2013): 20132236. Available here.
[5] Liebsch, Dieter, Marcia C. M. Marques, and Renato Goldenberg. "How Long Does the Atlantic Rain Forest Take to Recover after a Disturbance? Changes in Species Composition and Ecological Features during Secondary Succession." *Biological Conservation* 141, no. 6 (June 1, 2008): 1717–25. Available here.
[6] The average reference transition period for reforested land to sequester carbon before reaching saturation.

Hereafter is how we compute the required 2 figures:

1- Estimated reforested area (hectare)
For each project, we divide the number of trees funded[7] by the project's tree density. Here, we make the assumption that the tree density as defined by our experienced tree partners, is enough to reach the reforestation goal.

Indeed, our experienced tree planting partners have estimated the number of trees required to reforest 1 hectare under each project's particular restoration goals and practices. For our Tree Partners that reforest by planting trees, the tree density represents the net number of pioneer and/or climax trees per hectare required to start off the forest dynamics that lead to a fully functional forest ecosystem in the long-run. For our Tree Partners who reforest using Assisted Natural Regeneration (ANR)[8], it is rather the tree density goal they work towards.

Tree density is calculated from the average tree spacing provided by our Tree Partners as follows: 1-meter spacing for mangrove restoration (equivalent to a planting density of 10,000 trees per hectare) and 3-meter spacing for other tropical forests and agroforestry projects (1,089 trees per hectare).
Then we divide the number of trees funded by the tree density to have an estimate of area that was reforested.

2- CO_2 sequestration (tonnes per hectare)

2.1- Aboveground tree biomass (tonnes per hectare) - the tree biomass found in the trunk, branches, shoots and leaves.

Default values of aboveground biomass of forests per hectare, corresponding to the project's ecological zones, continent, and forest management type, are obtained from table 4.7 (natural forests) and table 4.8 (forest plantations) of the IPCC 2006 Guidelines here. For mangroves, it is retrieved from table 4.3 of the 2013 supplement to 2006 IPCC report here.

When the IPPC gives us a range, we take the average value. For projects which restore forest and plant trees in agroforestry systems, we compute a weighted average from the values found for natural forests and forest plantations. We actually estimate that the aboveground biomass of growing agroforestry trees is equivalent to forest plantations.

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[7] a "purchase order" to be honoured by our tree partners. It is trees that are potentially establishing; meaning growing roots and trunks and branches, thanks to the level of funding received. The number of funded trees accounts for predictable tree loss and replacement 2 years after planting. This is possible because of the communities' experience and after care.

[8] a forest recovery method which aims to help forests recover or regenerate faster than they would naturally. It consists of suppressing any factors that prevents tree seeds from germinating, surviving, and growing, and thus stopping forests from taking root.

2.2- Above and below ground tree biomass (tonnes per hectare) - tree biomass found in the roots.

Default "root-shoot" ratios (R), the ratios of belowground to aboveground biomass are obtained from table 4.4 from the 2006 IPCC report Volume 4 Chapter 4 here for terrestrial forests, and from table 4.5 of the 2013 supplement to 2006 IPCC Report here for mangrove forests. The "root-shoot" ratio for mangrove forests is 0.49.

Above and below ground tree biomass is calculated as the product of above ground biomass times 1+R.

2.3- Carbon fraction (tonnes per hectare)
In global assessments, the carbon fraction of tree biomass has been assumed to be about 50% of tree biomass. In tropical species it varies from 41.9% to 51.6%, as found here. Hence we multiply tree biomass by the average factor of 0.467.

2.4- Carbon fraction converted into CO_2 (tonnes per hectare)
Carbon dioxide uptake is obtained by multiplying the carbon fraction (tonnes) by the atomic weight ratio between CO_2 and C (44/12), hence by a factor of 3.67 -- in other words, for every tonne of carbon sequestered in a tree, 3.67 tonnes of CO_2 were absorbed.

Limitations

1. Our calculation is an estimation of the carbon dioxide uptake by the trees only (above and below ground). It does not account for carbon found in the litter/dead wood and in the soil, which requires a more detailed methodology with field data measurements.
2. We assume the period of 20 years to be the time needed for forest carbon stocks to fully recover to the IPCC average densities. While forests have the fastest recovery during that period, it may take from 75-300 years for the carbon stock to fully recover to the level of mature forests. And we also assume that the annual carbon uptake over 20 year recovery period is linear, when we compute annual carbon uptake of our projects.
3. We assume that our project areas are in deforested land that is completely tree-free or absent of trees, while in fact our projects mostly start with more than 10% tree cover.
4. We are estimating the full carbon uptake in our project areas without regard to the potential "without project" carbon pathways - i.e. without presuming a particular future baseline scenario.
5. We assume the forest to be homogeneous by using default values given by the IPCC which don't account for the local variations/specificities that may occur due to spatial variations in soil types and conditions.
6. We approximate the carbon density by following the following rules when obtaining values for the IPCC report:

- ❖ When the IPCC proposes a given value and a range, we use the given value. For example, where table 4.7 (above-ground biomass in forest) of the 2006 IPCC report proposes the following value: 220 (ranging from: 210-280) tonnes of carbon per hectare for the category "subtropical humid forest", then we use the given value of 220 tonnes per hectare.
- ❖ When the value proposed by the IPCC is a range and there is no given value, we calculate the midpoint of the range and use that as the value.
- ❖ When a project covers both tropical and subtropical domains we use the smallest default value which is for subtropical domains because they are less productive, in order to stay conservative. For example, this is applicable to WeForest's project in India, which covers a variety of forest ecosystems—from tropical moist deciduous to subtropical evergreen (cloud) forests, and even subtropical semi-evergreen forests.
- ❖ When a project reforests using two forest management practices, such as 'community forest' for livelihood purpose and 'natural forest' for conservation purpose, with an unknown breakdown we use the average value. For example, we gather the values of table 4.7 (above-ground biomass in forests) and of table 4.8 (above-ground biomass in forest plantations), respectively for 'community forest' and 'natural forest' regeneration 'plantation forests' and 'forests' and compute the average. If a breakdown is provided, we calculate accordingly.
- ❖ Where the IPCC proposes 2 default values of above-ground biomass in forest plantations—one for over 20 year-old plantation and one for plantations that are less than 20 years—we chose the lesser value of plantation below 20 years. While the majority of agroforestry trees are fruit trees with long life expectations, we are mitigating against the possibility that trees might be cut down when they are no longer productive.

How does it compare with other estimates?

Winrock International − a recognized leader in U.S. and international development, with recognized expertise in Carbon accounting from the forestry sector, has developed an online tool called the [FLR Carbon Storage Calculator].

The FLR Carbon Storage Calculator estimates the amount of carbon stored by the multiple reforestation activities across the globe: natural regeneration, planted forests and woodlots, agroforestry, and mangrove restoration.

TreeSisters and the FLR estimations are comparable because both methods assess Carbon sequestration for the same 'carbon pools', or reservoirs in forests (Carbon in the aboveground biomass and a calculated estimate of belowground growth/live roots).

Howevern TreeSisters' method is based on IPCC default values while the FLR Carbon Storage Calculator's estimations is based over 335 scientific peer-reviewed manuscripts and published reports. TreeSisters' method is based on the assumption that it takes 20 years to reach the same carbon level as in mature forests, whereas the FLR calculator estimates carbon sequestration based on yearly carbon sequestration rate.

Here is the estimated carbon stored by the projects (tCO2) by TreeSisters and the FLR Carbon Storage Calculator:

Project Name	Trees for Life, India (PGH)	Kalamboro mangrove, MDG (Eden)	Dry-deciduous forest, MDG (Eden)	Terai-Duar in Nepal (Eden)	Mount Kenya (ITF)	Atlantic Forest, Brazil (WeForest)	Khasi Hills, India (WeForest)	Mt Bamboutos, Cameroon (ITF)
tCO2 - TreeSisters	33,604	168,279	27,732	**145,979**	153,712	**103,617**	**107,158**	59,490
tCO2 - FLR calculator	42,395	141,326	23,066	**86,827**	134,082	**62,654**	**62,654**	65,089

Figures are quite similar, except for "Terai-Duar forest restoration in Nepal (Eden Reforestation Projects)" , "Brazil - Restoration of the Atlantic Forest" (WeForest) and "Restoring the Khasi Hills forests" (WeForest), where our figures are double the estimates of the FLR calculator. This is possibly because the default values from the IPCC are for mature forests. Langner *et al.* determined that when the IPCC defaults are used for non-intact tropical forests, their overestimation of biomass growth could be up to 35% of what pan-tropical biomass maps predict." [9]

Calculation available here.

[9] Bernal, Blanca, Lara T. Murray, and Timothy R. H. Pearson. "Global Carbon Dioxide Removal Rates from Forest Landscape Restoration Activities." *Carbon Balance and Management* 13, no. 1 (November 20, 2018): 22. Available here.