Chapter

CDR and Tropical Forestry: Fighting Climate Change One Cubic Meter a Time

Ederson Augusto Zanetti, Frederick N. Numbisi, Vithal Karoshi, Roberto Rochadelli, Allan Sbardelotto, Joesio Siqueira and Alain Levy Boussamba

Abstract

In the coming decades, there will be a global increase in demand for biomass and in advocating GHG emission removal technology and practices. In the agriculture and forestry context, intensification of land use is the most promising solution—together with processing efficiency—in balancing consumption, rated as human appropriation of net primary production (HANPP), with Net Primary Production (NPP) from atmospheric CO_2 fertilization. Forest plantations, croplands, cultivated pastures, lianas, palms and other secondary vegetation have shown yield gains from CO_2 fertilization, while native forest (trees) experience short-lived increases in growth rates and are out-competed by fast-growing components—secondary vegetation. There is evident path of degradation in non-managed, native tropical forests fueled by atmospheric CO_2 fertilization. Following such BAU scenario, tropical forests would experience important dwindling in tree cover on a temporal scale. An alternative IFM scenario is proposed combining contemporary silviculture techniques, adapted land use intensification and HWP increase. This would contribute additional atmospheric CO_2 removals, certifiable as CDR goods able to generate carbon credits and financial incentive for cultivation of improved native tree species. These CDR credits can be included in tropical countries' NDC and presented at UNFCCC as an ITMO for fighting global climate change.

Keywords: tropical forest, HWP, IFM, CDR, NDC, ITMO

1. Introduction

Carbon Dioxide Removal (CDR) comprises anthropogenic activities that remove CO_2 from the atmosphere and store it in a durable way in geological, oceanic and terrestrial reservoirs or in products. Such activities include existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but they exclude natural absorption of CO_2 not directly caused by human activities. The latest report from Working Group III (WG III) of the

Intergovernmental Panel on Climate Change (IPCC) includes CDR to offset hard-to-abate residual emissions [1]. In the European Union (EU), the European Climate Law commits the Union to reach climate neutrality by 2050. Both greenhouse gas (GHG) emission reductions and CDR will be needed to achieve the objective of climate neutrality by 2050. The European Green Deal includes rules on certifying carbon removals to expand sustainable carbon removals and encourage the use of innovative solutions to capture, recycle and store CO_2 by farmers, foresters and industries [2]. Carbon removal certification is proposed as a potential preamble to establishing a carbon trading system for land sector removals, as from 2030 [3]. In the USA, Assembly Bill A8597NYS Enacts the carbon dioxide removal leadership act. § 76–0103, establishing a market for certified CDR of a minimum of 0.1 M tCO2e in 2025 and which can reach up to 60 M tCO2e/year, at a maximum price of US$ 350/tCO2e [4]. Industrial tropical hardwood timber is a clear example of a high-quality CDR, coming from forestry, one of the best available Nature Based Solutions NBS.

In the next four decades, population is expected to grow by 40%, the world economy by a factor of 3, and agricultural production by 60–100%. The capacity of land to produce biomass is one critical limiting resource, and humans can influence through inputs and management, resulting on large Net Primary Production (NPP). Biomass provides humans with food, fiber, and fuel, and generates the terrestrial carbon sink that helps to mitigate climate change. The total Human Appropriation of Net Primary Production (HANPP) grew from 13% in 1910 to 25% in 2005. Global biomass harvest ($HANPP_{harv}$) and consumption of biomass products have risen in almost perfect correlation with global population growth.[1] Over the twentieth century, human induced land use productivity was the main anthropogenic action responsible for reducing global HANPP from 2.1 to 1.6 t. Thus, less production land may be needed to supply 1 ton of biomass for human consumption. By increasing yields over the last 50 years, farmers brought cropland closer to replicating the productivity of native vegetation.[2] In cultivated pastures, in 1961 there were 29 tons of grazed biomass (dry matter) used for the production of 1 ton of animal products; by 2005, this ratio was down to 17. Asia, Africa, and Latin America experienced[3] the expansion of agriculture and cropland yield gains[4], increased from 41–69%[5]([5] By contrast, with cropland and cultivated pastures, land use efficiency of natural pasture and native forest did not increase, with a $HANPP_{luc}$ = zero for woodland and for non-degraded natural grasslands. Although the importance of rising yields has been well known, HANPP

1 "HANPP" is the total carbon produced annually by plant growth. Total HANPP, measured in units of carbon, is the sum of two subcategories: HANPPluc and HANPPharv. HANPPharv is the quantity of carbon in biomass harvested or otherwise consumed by people, including crops, timber, harvested crop residues, forest slash, forages consumed by livestock, and biomass lost to human-induced fires. HANPPluc is the change in NPP, also measured as annual carbon flow, as a result of human-induced land use change. The calculation of HANPPluc requires the estimation of the NPP that would be generated by the potential natural vegetation if vegetation were left unaltered—NPPpot. From NPPpot, we can also calculate HANPP as a percentage of the potential productivity. Global HANPP measured in GtC/y grew by 116% and by 2005 reached 14.8 GtC/y. As a percentage of the potential plant growth of native vegetation (NPPpot).

2 Which meant that HANPPluc decreased.

3 Very high growth rates in HANPP; as a percentage, HANPP doubled or even tripled in these regions during the last century.

4 Measured in HANPPharv on cropland as a ratio of NPPpot.

5 That increase, spread-out over-all cropland in 2005, generated 2.5 GtC/y of crops, which met 49% of the total increase in human consumption from 1910.

provides a useful measure of these efficiency gains because it equates all crops based on their carbon content, relates it to the productivity in global land ecosystems and, hence, demonstrates the magnitude of human-induced changes to the global carbon cycle [5].

Human induced land use improves HANPP also in the tropics. At the tropics, there is large availability of hardwoods. Tropical hardwoods are more durable, rot and marine animals resistant, stronger and cheaper than overall global hardwoods [1], which makes them standout when competing on the global markets. They have characteristic longer lifespans among timber species making them very attractable to consumers wishing lumber with special qualities such as durable, colorful, fragrant wood at their homes, offices and industries. When it comes to forestry and the tropics, the role of timber in removing atmospheric CO_2 and their transformation into industrial and energy wood might offer opportunity in accounting emission removals in tropical countries. An acknowledgement of such roles might influence national policies and decision making towards including CDR as part of goals to reach carbon neutrality and in accounting NDC (National Determined Contributions).

The consumption of tropical timber products has potentials in reducing the overall carbon footprint of construction globally, and the supply of woods with long lifespan will enhance the stocks of carbon in society or urban settlements. Tropical forest productivity is directly linked to applied silvicultural practices. In managed forests, forest biological processes react to silvicultural treatments that determine the short- and long-term productivity and stock increase or decrease. Replacing natural regeneration by human induced silviculture practices increases standing stocks and the positive effects of contemporary silvicultural techniques is improvement in harvesting volumes. Globally, about ¾ of forest plantation are established using country's native species [6]. Increasing productivity is a way to remove atmospheric CO_2 and transform it into industrial and energy wood. Both processes can be certified as CDR. This tropical industrial and energy hardwoods certified as CDRs can contribute to reduce emissions at the consumers level. Tropical wood CDRs are goods which include potential carbon credits that can, therefore, be used by consumers to reduce their overall negative GHG balance due to consumption rates and value chains.

In this study, we address the uncertainties and challenges of GHG accounting and monitoring in the forestry sector by jointly reviewing different components that may contribute to effective GHG assessment in tropical forests context, especially with consideration of local needs and spatial dynamics of land use activities, vegetation and forest transitions fueled by climate change and increasing atmospheric CO_2 stock, and aligning sustainable forest management models to both ecosystem enhancement and economic opportunities of CDR in NDCs.

2. Methodology

This work is a review of current themes under the UNFCCC process that are relevant to forestry. This review, in collating studies across different dimensions that can potentially contribution to CDR assessment and accounting in tropical forestry, investigates current trend of primary and secondary forest transitions in the context of tropical forest management and HWP, the approaches of quantifying anthropogenic activities and their contribution to CO_2 emissions and removals, the integration of sustainable forest management models with livelihood opportunities and incentives for CDRs.

Making reference to different reviewed studies in literature, which only provide different single assessments of the components of forest GHG assessment, we conduct an multi-disciplinary and quantitative review of the potential of tropical forest as CO_2 sinks in relation to nature- and made-induced changes in land use, and as well other socioeconomic needs fueled by local and global market transitions. With a target towards tropical forests, we review current themes under the UNFCCC process that are relevant to forestry. Thus, some aspects of GHG estimation in forests were not within the scope of this review. For instance, we do not include components such as atmospheric CO_2 reduction by direct removal such as CO_2 Capture and Removal and CO_2 flux measurements.

Central to this review, among others, is the increasing CO_2 fertilization of secondary vegetation growth which out-competing old forest trees, and the need for assessing CDR contribution from anthropogenic actions, which have high uncertainty and variability between local contexts and across geographic scales. Build upon reported evidence of atmospheric CO_2 enrichment of vegetation growth and transition in tropical forests, we compare a Business As Usual (BAU) scenario of native forests without management interventions versus an alternative scenario of human interference with Sustainable Forest Management practices based on contemporary silviculture and HWP production and consumption. In the following sections, we present the different themes of our integrated review. Based on these multi-dimensional components, together with qualitative and quantitative insights from the reviewed studies, we highlight potential options for both sustainable forest managements and monitoring, and as well enhancement of GHG estimations for NDC and CDR incentives.

3. Results and discussion

3.1 Tropical forest biomass and GHG monitoring

Forests have been recognized and acknowledge in both IPCC reports and the Paris Agreement to contribute substantially in achieving climate change mitigation goals [7–9]. However, it is currently challenging to spatially quantify and temporally monitor the extent to which forests impact atmospheric greenhouse gas (GHG) concentrations. In terms of atmospheric CO_2, loss (CO_2 emission) and gain (CO_2 removal) can co-occur on pixels or areas undergoing forest management or other forms of disturbance and regrowth.[6] These actions and dynamic land-use patterns occur at spatial and temporal scales not often captured by global models and estimates of GHG flux [10]. Nonetheless, estimates of GHG emissions and sinks by most developing countries, translated into NDCs, are mainly based on default emission factors that do not necessarily reflect country specifics in terms of forest structure and status of forest transitions.[7]

Global models and maps of GHG fluxes are based of inventory database that do not reliably represent the contexts in tropical forests with consideration of the high local or regional variability in forest structure and anthropogenic changes [10, 11].

[6] If we are unable to quantify them, we would not reach the goal of reliable monitoring and sustainable management. Regarding GHG fluxes, opposing fluxes simultaneously occur at local and regional scales at magnitudes that depend on the location and time of disturbance or management actions.

[7] For instance, the nature of forest degradation, the composition of intact forests, and state type of secondary forests.

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Based on two decades temporal series of observational spatial data, Harris et al. [10] introduced a global spatial framework for GHG fluxes in forests of any geography. However, existing forest GHG flux assessment frameworks and models are unable to discriminated the contributions from anthropogenic versus non-anthropogenic effects and likewise, between managed and unmanaged land. To achieve such distinctions, adaptable combinations of field inventory and spatial data are needed to unravel and aggregate local to regional estimates. In the context of tropical forests, the use of spatial data from radar or synthetic aperture radar (SAR) systems have remarkable potentials in providing weather- and daylight-independent information of land features.

In spatial data modeling, remote sensing procedures offer unprecedented advantages (resources, time, and cost) in large-scale biomass and GHG estimation in forests and other land uses.[8] However, by design, current satellite-based earth observation platforms have orbiting patterns and image capturing intervals over tropical forests that provide low temporal data, which do not guaranty the parallel monitoring of anthropogenic activities within tropical forests in a timely manner. Thus, there is large time-lapse between the on-going deforestation actions and potential remote sensing data[9] to support the monitoring of both GHG emission and CO_2 removal[10] [12].

In the Brazilian Amazon for instance, most data used today are still from old studies carried out by RADAMBRASIL surveys, from the late 1950s to the early 1970s using side-looking airborne radar imagery combined with 1-ha ground plots at approximately 3000 points, often reached by helicopter. Even with these limitations, the use of the RADAMBRASIL surveys[11] is still not easily compensated for by applying more sophisticated remote sensing interpretation to a small set of ground-based plots[12] [13].

Unlike spatial data captured from optical sensors, radar sensors have the characteristic advantage of penetrating cloud cover, which is predominant over most tropical

[8] In the context of tropical forests, the application of remote sensing procedure for biomass mapping and monitoring is receiving wide attention and progress. Several compounding factors may be accountable for low rate of remote sensing application and technology transfer to tropical forest monitoring. Among these factors, technical capacity is increasingly a lesser hurdle compared the situation a decade prior. There are growing freely accessible archives of satellite-based remote sensing images (data) such as data provided from NASA Landsat missions and the operational mission of the European Space Agency (ESA) Copernicus program, which have jointly reduced the hurdle of access to remote sensing data.

[9] The closest being a minimum of 12 days across the tropics for ESA's Space-borne Sentinel operational satellites.

[10] Thus, in current times, most of the challenges in remote sensing monitoring of tropical forest GHG flux may center around the nature of available data for applications in tropical forest contexts—different data are needed for different contexts and as well in addressing the wide uncertainties for tropical forests in global projections and maps of GHG flux.

[11] It has been daunting to many research groups: the reports are a vast labyrinth of over 50,000 pages, written in Portuguese and historically with limited availability at any single location. However, ignoring this enormous body of work represents a loss that

[12] Unlike spatial data captured from optical sensors, radar sensors have the characteristic advantage of penetrating cloud cover, which is predominant over most tropical forests during seasonal monsoons and vegetation proliferation. Though radar images can potentially capture vegetation information across seasons, radar or SAR image processing workflows have been largely unreported for the myriad potential applications in tropical forests. Using satellite-based radar data.

forests during seasonal monsoons and vegetation proliferation. Though radar images can potentially capture vegetation information across seasons, radar or SAR image processing workflows have been largely unreported for the myriad potential applications in tropical forests. Using satellite-based radar data, there are increasing efforts in delineating and quantifying sectoral anthropogenic actions and land use [14, 15] and above-ground biomass [16, 17] in tropical forests.[13] Notwithstanding these growing efforts, most estimates of forest biomass and GHG emission for project-based and national assessments still rely largely on extrapolations from often scant field inventories using either allometric models or application of remote sensing data at spatial scales that mask variability across geographies and local details—the scale of most anthropogenic activities. In tropical forest landscapes, the majority of anthropogenic actions and land use changes occur widely at smallholder scales that range in spatial extent between 0 and 2 hectares; this is undermining the increasing tendencies of large-scale plantation establishment beyond the aforementioned range. Context-dependent information on anthropogenic contributions to atmospheric CO_2 emissions and removals are, therefore, needed to reliably account and aggregate impacts at a global level. Thus, multi- and cross-sectoral efforts towards climate change adaptation and achieving the objectives of the Paris Agreement should consider a per-hectare assessment, m^3 production and monitoring frameworks to match the realities and needs in tropical forests, and offer a more inclusive incentive for communities to engage in and benefit from CDR activities.

3.2 Carbon fertilization and tropical forestry NPP

Net Primary Productivity (NPP) refers to the balance between carbon gain through photosynthesis (gross primary productivity, GPP) and losses through autotrophic respiration (Ra).[14] Practically, it is not possible to precisely measure forest NPP in terms of this difference. At the ecosystem scale, NPP is measured over a long period such as a year. As per Clark et al. [18], NPP comprises new biomass produced by plants, soluble organic compounds that diffuse or are secreted into the environment such as root or phytoplankton exudation[15], carbon transfers to microbes through symbiotic association with roots as found in mycorrhizae and nitrogen-fixing bacteria, and the volatile emissions that are lost from leaves to the atmosphere. However, most field measurements of NPP consider only 'new plant biomass produced' and, therefore, probably underestimate the true NPP by at least 30%. For our practical understanding, we can say 'NPP is the net carbon gain by plants'. NPP is an important

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parameter in many forestry models that are used to assess the future mitigation potential of the sector. A forest management project can exploit NPP for carbon sequestration in forests and biomass production for climate change mitigation [19].

The increasing in human-induced CO_2 emissions indirectly implies that forest worldwide will grow faster and reduce the amount of atmospheric CO_2 which stays airborne—an effect known carbon fertilization, which is high in the tropics. There has been increasing carbon sink on land since the 1980s; living woody plants were responsible for more than 80% of the sources and sinks on land[16,17] [20]. Globally, vegetation is locking away more carbon as atmospheric CO_2 levels rise. Plants are growing faster, fueled by a more CO_2-fertile atmosphere. Carbon stocks (i.e., standing plant production) are related to, but do not refer to the same thing as, NPP (i.e., rate of growth of plant production). Increased CO_2 concentrations reduce photorespiration, which translates into greater plant productivity—NPP.[18] Giving plants more CO_2 increased net primary productivity by 24% on average.[19] Factorial simulations with multiple global ecosystem models suggest that CO_2 fertilization effects explain 70% of the observed greening trend.[20] CO_2 fertilization effects explain most of the greening trends in the tropics. Results show a considerable increase in net primary production (NPP) over the last century, mainly due to the CO_2 fertilization effect.

Pastures uptake 5–50 tCO_2-eq/ha/year of atmospheric CO_2 and also hold Nitrogen, which is turned by each animal into something like 0,5 tCO_2-eq/year of carbon-based products—protein.[21] The associated methane emissions is a result of the balance between the atmospheric CO_2 removed by pastures and what gets process through animals' digestive system. The more animals are grazing, the more atmospheric CO_2 is turned into protein and other products—including fertilizers [21], resulting on a process of removing the gas and returning into Society as useful goods.

In identifying potential plant species with higher NPP capabilities for carbon sequestration, Vithal and Nadagoudar [19] found that Bamboo has the highest NPP(17.523).[22] Secondary vegetation like Lianas, palms, bamboo and other non-tree life forms have been omitted from a number of Amazonian biomass studies, which often fail to report what biomass components are included[23] [13]. For Brazil as a whole, an average aboveground carbon stock of 120 tCO2e/ha in savanna woodlands

[16] with soil, leaf litter, and decaying organic matter making up the rest. But they also saw that vegetation retained a far smaller fraction of the carbon than the scientists originally thought.

[17] Globally, vegetation is locking away more carbon as atmospheric CO_2 levels rise. Plants are growing faster, fueled by a more CO_2-fertile atmosphere. Carbon *stocks* (i.e., standing plant production) are not the same thing as NPP (i.e., rate of growth of plant production).

[18] although warmer temperatures counteract this effect by increasing photorespiration somewhat

[19] Terrestrial Ecosystem Model (TEM) predicts that doubled CO_2 will increase 16.3% of the global NPP. Under real conditions on the large scale where water and nutrient availability are also important factors influencing plant growth, experiments show increases under unstressed conditions.

[20] followed by nitrogen deposition (9%), climate change (8%) and land cover change (LCC) (4%).

[21] while returning fertilizers and gases to the environment.

[22] followed by rubber (15.970), oil-palm (14.500), *Samanea* and *Erythrina* (13.350), coconut (12.150), *cassia* (10.350), *eucalyptus* (10.009), alnus (10.000), *sesbania* (9.433), *prunus* (9.000), *leucaena* (8.739), *acacia* (9.000) and *casuarinas* (7.550).

[23] Standardization for non-tree components, together with trees <10 cm DBH, removes almost all of the difference between aboveground live biomass.

classified as "forestland"[24], and 45 tCO_2-eq/ha in those classified as "shrublands" (65.6% of the area), giving a weighted average of 75 tCO_2-eq/ha[25] [13].

Net primary productivity (NPP) of a closed-canopy[26] forest stand was assessed for three years in a free-air CO_2-enrichment (FACE) experiment. NPP increased 21% in stands exposed to elevated CO_2, and there was no loss of response over time. Wood increment rate cumulated significantly during the first year of exposure, but subsequently return to its initial value, reducing the potential of the forest stand to sequester additional C in response to atmospheric CO_2 enrichment[27] [22]. Currently, there is limited pool of knowledge regarding the long-term impacts of CO_2 enrichment in tropical rainforests [22]. Young trees and other small plants responded well to higher CO_2, but it remains undetermined how more mature trees would react. Brazilian Amazonian trees are dying faster than they are growing. On land, reports suggest a decline in the tropical forest CO_2 sink, increased plant mortality and decreased plant productivity. Under low Nitrogen conditions[28], plants will have difficulties to transform elevated CO_2 into production[29] [5].

Standing undisturbed tropical forest sites over the last 50 years lost total volume of trees to secondary invasive vegetation, making them naturally net emitters of CO_2. As regards above-ground live biomass and carbon flux, the world's remaining intact tropical forests have been reported to be largely out-of-equilibrium [23, 24]. Following the current increasing trend of forest degradation over deforestation [25, 26] and dwindling resilience to changing climates and rainfall patterns [27, 28], it is anticipated in the next 50 years that tropical forest sites are to yet another part of its volume stocks to the increasing competition from secondary vegetation. With this trend, large protected areas at isolated areas in the Amazon region that are retained in unmanaged conditions should hold less biomass volume yearly than their managed and plantation counterparts. The CO_2 fertilization up-take is much faster by secondary vegetation, and old forests trees are losing their competitiveness every year, without harvesting and silvicultural treatments.

Today[30], spatial biomass analyses[31] show major differences between all of the resulting biomass maps, including those with largely overlapping ground-based

[24] 34.4% of the total savanna woodland area.

[25] Conversion from the original text in Mgha-1 using 1:1 ratio for m, and 3,67 factors for C-CO_2.

[26] Liquidambar styraciflua (sweetgum).

[27] Most of the extra C was allocated to production of leaves and fine roots. These pools turn over more rapidly than wood.

[28] CO_2 may not much affect plant productivity because of lack of Nitrogen in the soil. Plant acclimatization and water availability.

[29] Moreover, in the long term, elevated CO_2 condition may cause the accumulation of carbohydrates in the plant tissues which may reduce the photosynthetic rates or decrease photosynthetic response to elevated CO_2.

[30] Usually, continuous Forest Inventory data, with a proportion of 0.1% (for the effective area) of sampling, is used to determined standing stocks volumes from which biomass estimates are made. A number of fixed size plots of 10 meters wide by 250 meters long, used for monitoring tree increment and mortality.

[31] Using space-borne LiDAR (Light Detection and Ranging) from the US National Aeronautics and Space Agency (NASA) Geoscience Laser Altimeter System (GLAS) on the Cloud and Land Elevation Satellite (ICESat), together with optical data from MODIS imagery and radar data from the Global Quick Scatter meter (OSCAT).

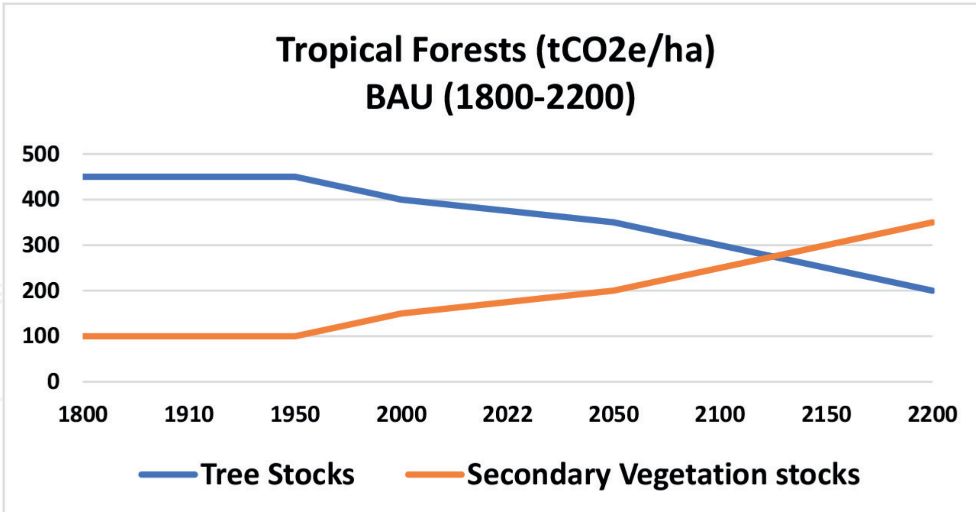

Figure 1.
Tropical forests standing stocks BAU scenario over 400 years (Illustrative proxy by authors).

datasets.[32] The way forward will require using remote sensing data together with ground-based measurements, with progress needed in both areas [13]. From RADAM Brasil studies, the highest dense tropical forest at the Amazon region used to hold average between 420 and 480 m^3/ha, toping 520–580 m^3/ha of tree biomass [29]. Nowadays, average biomass of standing stocks range from 248.92 ± 61.78 t/ha, passing by 293.19 ± 27.74 t/ha, and reaching up to 356 ± 47 t/ha [30, 31], based on measurements for trees ≥10 cm DBH (diameter at breast height: diameter at 1.3 m above the ground or above any buttresses) with a 12% correction for small trees [13]; roughly, making it 270 to 320 m^3/ha and topping 310 to 400 m^3/ha[33], circa of 25 to 35% less volume than 50 years earlier, as stated at RADAM Brasil early studies.

As illustrated in **Figure 1**, following the current BAU (Business As Usual) scenario and considering a 400 years' time frame, tropical forests are going to become less and less tree covered as the atmospheric CO_2 levels rises and if no management interventions are implemented (the data is illustrative, a proxy from the previous findings and this section highlighting increasing secondary vegetation in natural unmanaged tropical forests).

The graph in **Figure 1** illustrates that secondary vegetation gains competitiveness over trees as the atmospheric CO_2 becomes more and more available, reducing the overall carbon stock of forest stands. The process is ongoing and tends to speed up with the increase of CO_2 and reduction of tree cover, which favors even more secondary vegetation growth. The associated gains in productivity of secondary vegetation can be can be compared to those from Croplands. The Brazilian agricultural sector, for instance, has portrayed continuous productivity increase over the last 30–40 years [18], showcasing the positive effect of atmospheric CO_2 enrichment on plant NPP. Meanwhile, the ability of tropical forests trees to absorb massive amounts of carbon has waned [32].

SFM + HWP = CDR.

Degradation is translated as: "change between forest classes (i.e. from "close" to "open") which negatively affects the site and, in particular, reduces its productivity

[32] Expanding the network of ground-based inventories is essential.

[33] Assuming1:1 ratio from biomass to m,

capacity.[34] The Intergovernmental Panel on Climate Change—IPCC2006 guidelines for GHG inventories from different sectors includes accounting procedures for Dead Wood—DW and Harvested Wood Products—HWP.[35] Thus, wood used for project activities such as fencing of boundaries, furniture, construction, energy and others must be accounted as DW when determining the carbon sequestration and storage in forest areas, including from those without a formal Sustainable Forest Management Plan—SFMP. For areas holding SFMP, the rule is the same regarding DW, and besides this logs, timber, firewood and others imports and exports are also to be accounted for as HWP for the balance of forest carbon areas, carbon sequestration and carbon storage [33]. At harvesting, a large portion of aerial biomass carbon is transferred to HWP (Harvested Wood Products) and will be available at one of the forest product categories. Forest areas biomass volume is used as starting point for HWP carbon estimates, applying specific conversion factors for each log destination. Estimates related to wood products baseline are available under the format of volumes delivered to industrial plants or in terms of their outputs, comprising industrial logs or primary HWP (boards, planks, panels or paper). Carbon availability at those HWP over the years is then estimate allocating other parameters which indicate carbon amount 'in use' and destined to landfills. Thus, HWP Carbon estimates, including recycling, rely largely on data availability.[36]

3.3 Improved forest management in the tropics

Tropical forests are accountable for about 35% of global net primary productivity (NPP).[37] The CO_2 fertilization effect that increases CO_2 concentrations in leaves enhances plants' capacity in fixing carbon through photosynthesis has been considered as a primary mechanism that maintains and enhances tropical forest productivity [34].

The human appropriation of net primary production (HANPP) provides a useful measure of human intervention into the biosphere. The productive capacity of land is appropriated by harvesting or burning biomass and by converting natural ecosystems to managed lands. HANPP has still risen from 6.9 Gt of carbon per y in 1910 to 14.8 GtC/y in 2005, i.e., from 13 to 25% of the net primary production of

[34] Deforestation means: "changing on land use with reduction of tree crow cover below 10% by hectare" while resulting in land degradation afterwards according to IPCC.

[35] Within IPCC2006 Dead Wood (DW) is classified as all kinds of branches, leaves, roots, dead trees and other types of biomass not included as litter or soil. Harvested Wood Products (HWP) are all wood material leaving project activities boundaries—other materials remaining within boundaries are to be accounted as DW.

[36] Estimates of forest products contribution, in terms of carbon, use generic variables, including (i) domestic HWP and imports (tCO_2-eq/year); (ii) annual variation of HWP produced domestically, including annual variations on exported HWP (tCO_2e/year); (iii) annual imports of all kinds of wood and paper (tCO_2e/year); (iv) annual exports of all kinds of wood and paper (tCO_2e/year); and (v) annual HWP (tCO_2e/year). The level of lost on solid products and paper, in a given year, are specified towards the use of a lost constant (k), which by convenience is expressed in terms of half-life in services, in years. Half-life in service describes the number of year necessary for half of the material to change environment, which can be, for example, from a home to landfill, within that sector where it remains stored. Solid wood and paper production, imports and exports are converted from m or tons into tCO_2-eq. For annual estimates calculation the method uses yield data (Consumption = Domestic Production + Imports—Exports).

[37] And store about 72% of global forest biomass carbon (C).

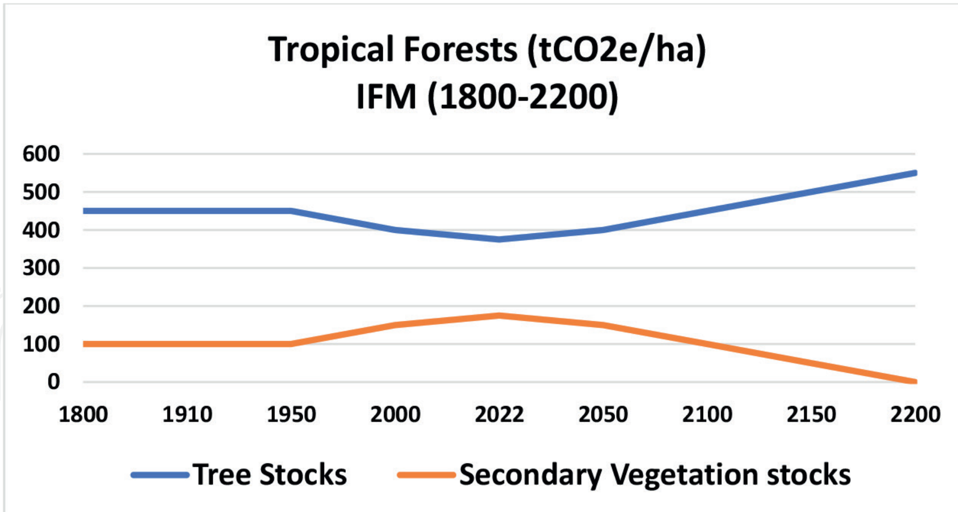

Figure 2.
Tropical forests standing stocks IFM scenario over 400 years (Illustrative proxy by authors).

potential vegetation. Biomass harvested per capita and year has slightly declined despite growth in consumption because of a higher conversion efficiency of primary biomass to products.[38] The rise in efficiency is overwhelmingly due to increased crop yields. HANPP might only grow to 27–29% by 2050, but providing large amounts of bioenergy could increase global HANPP to 44%. This result calls for strategies that foster continuous and increasing land-use efficiency.

Harvesting and consumption of tropical timber products stimulates management opportunities of increased productivity, reverting the degradation process due to increase of secondary invasive species volume, and generate profits. With a profitable forestry activity in place, there is incentive to practice forestry and reduce conversion to other land uses. Therefore, tropical timber is a value added CDR that can reduce forest degradation and conversion of forests to other land uses, while increasing CO_2 removals. Advanced silvicultural techniques can be applied to improve productivity [6], taking advantage of the CO_2 fertilization. As illustrated in **Figure 2**, following Improved Forest Management (IFM) contemporary silviculture techniques, the scenario considering a 400 years' time frame shows tropical forests recovering tree volume against the competing secondary vegetation.

Silvicultural practices—planning; individuals' selection; seed collection, genetic improvement; seedling development; fertilization; maintenance; weed, insects and diseases control; harvesting—are applied to reduce the presence of secondary vegetation and introduce CO_2 enriched environment with adapted trees` varieties. This will result in increasing yields and therefore reducing HANPP while supplying society with more industrial, energy wood and other Non-Timber Forest Products (NTFP). The positive effect of IFM techniques are widely known globally, and these have promoted the cultivation of native tree species all over the world [6].

Brazil holds the largest stock of hardwoods in the planet. Some of these tropical hardwoods have characteristics that make them therapeutic, comfortable, charming as well as immune to fungi and insect attacks. Brazilian tropical hardwoods, just as softwoods, possess a diversity of qualities that are hardly reachable by tree species in other parts of the world. These unique qualities are competitive advantages that can be used to enhance Amazon biodiversity cultivation and tropical timber consumption

[38] And decline in reliance on bioenergy.

role. With a growing and promoted timber consumption, rural landholders have markets available to justify necessary investments on Brazilian native tropical timber species cultivation, with the use of IFM[39] [33].

3.4 Quantifying anthropogenic contributions to GHG flux

Following the UNFCCC global estimates of anthropogenic net land-use emission, there is a discrepancy of about 4 Gt CO_2 per year between aggregated national GHG inventories and the global models in IPCC assessment reports. According to Grassi et al. [35] a great proportion of the discrepancy (3.2 Gt CO_2 pr^{-1}) is due to differences in concepts implemented in estimating anthropogenic forest sinks—a representation of environmental changes and managed areas. Such differences between inventories and models of GHG emissions and sinks need to be addressed [36] to enhance monitoring and achieve collective progress towards the goal of the Paris Agreement on global temperature.[40] Following global estimate of GHG fluxes from forest, uncertainties in global gross removals and net flux are mostly attributable to extremely high uncertainty in applying the removal factors from the IPCC Guidelines to old secondary forests[41,42] [10]. Global models and maps of GHG emissions and fluxes are based on spatially clustered inventories that are translated to make predictions across geographies and forest types [37]. Although they provide important insights on global trends, such models may support misleading applications such as using some default values in IPCC recommendations [38] management actions and policy as they do not capture variability and uncertainties across geographies and generalize assumptions of carbon flux to unknown local and regional spaces [12]. Globally, forests store approximately 8.4 billion tCO_2-eq and are capable of retaining some further billions; meanwhile, about 4.2 to 20 billion tCO_2-eq are estimated to be stored within HWP "in use".[43] The 3.4 billion m^3 of yearly global harvested wood is equivalent to just 20% of total yields (some 17 billion m^3/year) [33]. A lot from what is harvested is used for direct and inefficient burning as fuel wood. Increasing the sustainable removal of senescing biomass from forests and harvesting yields would have a profound positive effect to fight global warming. With the use of extra 2 billion m^3/year, industrial woods will be possible to reduce between 14 and 31% of all cement and steel GHG emissions and between 12 to 19% of all fossil fuel consumption by the use of residues from industrial wood production chains for clean energy appliances. With the intensification of sustainable forest management, more CO_2 is sequestered and stored

[39] Biodiversity banking regional strategies implementation and the use of contemporary industries (MDF, HDF etc.) value aggregation will increase social inclusion chances and, by that, project activity sustainability over time.

[40] By and large, inventory data is scarce or absent for tropical forests, and there is large variability in the methodology for and quality of existing data.

[41] To make estimates at large scales, inventory (activity) data vital in making extrapolation from information and models based on spatially continuous data collected from airborne or satellite-based remote sensing procedures.

[42] The absence of 'activity data' constitutes a key impediment to and source of error (over- or underestimation) in estimating GHG emissions and CDR in tropical forests.

[43] World wood production includes more than 1.5 billion m/year of industrial logs, accounting for something like 1.1 billion tCO_2-eq/year, with 420 million m of sawed lumber and 220 million m on plywood and panels—representing some 20% of total in long life-spam forest products, which sequester and store close to 200 million tCO_2-eq each year.

avoiding emissions from alternative materials and still producing renewable energy from harvesting residues. Besides, harvested volumes are renewed. Brazil has by far the largest global stock and growth of "hardwoods", which have the longest life-span between tree species, making them relevant suppliers of HWP storing carbon for many years.

The International Wood Culture Society (IWCS) is a non-profit organization formed by wood enthusiasts, dedicated to research, education and promotion of wood culture. IWCS advocates for a harmonious living between people and nature, explores the value of wood use from a cultural perspective and supplies a platform for studying wood culture, encouraging its practice and promotion.[44] IWCS established March, 21st as Wood World Day, a data to disseminate the value wood aggregates to daily life [33]. Tropical forestry must be accompanied by similar public and private efforts towards trade and use of tropical hardwoods, creating the synergies that might help in removing huge amounts of atmospheric CO_2 and returning to society noble wood products. The current stocks of billions of m^3 of dying mature trees, ready to be harvested on Brazilian Amazon region alone, have the capacity to remove billions tCO_2-eq from the atmosphere, just by turning them into timber and having new trees planted. Thus, cutting down trees do not necessarily implicate on GHG emissions, and neither is the change of land use directly linked to atmospheric CO_2 generation. The use of wood could also generate millions of jobs and trillions of dollars in revenue over the next decades. Tropical forests hold capacity to regenerate after harvesting, and the magnitude and benefits that this capacity would mean is directly related to silvicultural practices, which will impact global GHG balance positively with broad use of tropical HWP.

3.5 Tropical forestry and the certification of HWP: CDR

As the world will face, in the next few decades, further increase in global population and economic output resulting on large new demands for food, fuel and fiber, this stresses the importance of developing improved practices for sustainable intensification of land use. Production of CDR from increasing forest and HWP atmospheric CO_2 removals, at the same, copes with reducing emissions targets, which makes it a highly competitive credit for global carbon markets. CDR production also represents a significant opportunity to private investors on engaging in Environmental and Social Governance (ESG) activities and into the international carbon markets. Registered carbon credits can supply an income source for landowners, support rural development and facilitate IFM implementation. Logs produced to supply industries with sustainable sources can receive payments directed to improve technology of silviculture, trade and finance towards inclusion of payments for carbon credits. When tropical timber used by society comes from sustainable origins, it increases forestlands atmospheric CO_2 removal capacity.

Production and consumption of tropical timbers need to be within the framework of accepted CDR for global carbon Market development within countries 'National

[44] "Tackle Climate Change: Use Wood" is a European Parliament program directed to strength societal use of wood as a way of fighting atmospheric CO2 accumulation. France has "de Bois-Construction-Environment", England the "Wood for Good", Netherlands "Centrum Hout", Denmark "Trae Information", Finland "Puuinfo", Belgium "Wood Forum", Spain's "Viver Con Madera", Australia "Wood Naturally Better" and Austria and Italy "Promo Legno" are few from national, binational and multilateral networks for the promotion of wood use as a form of global climate change mitigation.

Determined Contribution (NDC) to UNFCCC. Countries around the globe could include tropical timber products as CDRs and purchase these credits as part of the acceptable contributions—Internationally Tradeable Mitigation Opportunities (ITMO) to alter forest degradation and land use change. With Tropical HWP accepted as CDR, global carbon markets can promote increasing carbon stocks within society as a way to reduce global GHG emissions (from cement, iron etc.) while increasing removal of atmospheric CO_2 at the same time. The more tropical timber is sustainably consumed, the better the potentials for the climate. The same goes for all tropical agriculture and pastures products, which are carbon-based products resulting from up-take of atmospheric CO2 and its conversion into useful goods for humanity.

The Bio-economy of Brazilian Amazon ecosystems sustainable management rely on technological interventions. With investments directed to appropriate silvicultural technologies, national wood products from Brazilian native tropical timbers will be highly competitive at international Green Economy markets. Brazilian tropical timber species diversity, productivity and qualities being cultivated under contemporary silvicultural techniques are capable of placing native forest sector among world's greatest. Native forest species biodiversity cultivation ,contributed by the use of Brazilian woods, will be a direct result from consumption incentives. National regulations must incentivize the use and consumption of native timber from sustainable sources as a way of assuring the sustainability of forest biodiversity cultivation.

4. Conclusion

Over the next decades, there will be an increase in the global biomass for biomass and GHG emissions` reduction and removals, and intensification of land use is the most promising solution—together with processing efficiency—for balancing HANPP consumption with NPP from atmospheric CO_2 fertilization. Forest plantations, croplands, cultivated pastures, lianas, palms and other secondary vegetation have shown yield gains from CO_2 fertilization, while trees respond somehow at first, losing the capacity afterwards.

There is evidence showcasing a path of native tropical forest degradation given atmospheric CO_2 fertilization, which is mainly due to favoring secondary vegetation competitiveness against trees at un-managed standing stocks. Following the BAU scenario, tropical forest should become less and less covered with trees over the next century. An alternative IFM scenario is perceived, where IFM plus contemporary silvicultural techniques can reverse the process and produce HWP and NTFP as a result of land use intensification. This will generate additional atmospheric CO_2 removals, certifiable as CDR goods, which are able to generate carbon credits for financing the reduction of secondary vegetation and promote cultivation of improved native tree species. These CDR credits can be included in tropical countries` NDC and presented at UNFCCC as an ITMO for fighting global climate change.

Author details

Ederson Augusto Zanetti[1*], Frederick N. Numbisi[2], Vithal Karoshi[3], Roberto Rochadelli[4], Allan Sbardelotto[5], Joesio Siqueira[6] and Alain Levy Boussamba[7]

1 Green Farm CO2FREE, Curitiba, Parana, Brazil

2 Independent Researcher, Freiburg in Breisgau, Auggen, Germany

3 Lilongwe University of Agriculture and Natural Resources (LUANAR), Lilongwe, Malawi

4 Federal Paraná University (UFPR), Coordinator of "MRV-FUPEF Programm", Curitiba, Parana, Brazil

5 Independent Researcher, Rio Branco, Acre, Brazil

6 STCP Engenharia de Projetos, Curitiba, Parana, Brazil

7 ONG Humanitas, Libreville, Gabon

*Address all correspondence to: eder.zanetti@fulbrightmail.org

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