TECHNICAL NOTE

GREENHOUSE GAS PROTOCOL CALCULATION TOOL FOR FORESTRY IN BRAZIL

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ABSTRACT

Brazil is one of the world's top 10 emitters of greenhouse gases (GHGs) and a significant part of net emissions in 2015 (1,368 Tg CO_2eq) came from deforestation and land use change (24,3%) and agriculture (31,4%) according to Brazilian Ministry of Science, Technology, Innovation and Communication (MCTIC 2017). As reported by The Greenhouse Gas Emissions and Removals Estimates (SEEG) – an initiative of the Brazilian Climate Observatory – the total Greenhouse Gas (GHG) net emission was 1,497 Tg CO_2eq and the emissions from deforestation and land use change and agriculture represents 24% and 32.8%, respectively (SEEG 2018).

Brazil's Nationally Determined Contribution (NDC) commitment calls for reducing GHG emissions 37 percent below 2005 levels by 2025 and 43 percent by 2030.

Reforestation is among the most cost-effective forms of sequestering carbon on a large scale and mitigating global warming, while at the same time ensuring the provision of environmental services, jobs, and income opportunities. Despite the potential, many questions remain: how much carbon can a tree remove and maintain during its lifetime, considering GHG emissions and removals throughout the forestry management process? How can the private sector be engaged in this process? And how this process can be measurable, verifiable, and reportable?

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WRI Technical Notes document methodology underpinning research publications, interactive applications, and other tools.

To answer these questions, WRI Brasil, together with a team of experts and stakeholders from the private and public sectors and experts from forestry, agroforestry, and agriculture developed the GHG Protocol Calculation Tool for Forestry in Brazil. It is a calculation and reporting tool to measure GHG emissions and removals on rural properties that have direct control of their management operations.

The calculation tool is organized by forest typology:

- homogeneous plantations of eucalyptus (*Eucalyptus* ssp. *and Corymbia* spp.), pines (*Pinus* ssp), and parica [*Schizolobium parahyba* var. *amazonicum* (Huber x Ducke)];
- heterogeneous plantations (multi-species planting of native and exotic tropical species for timber use); and
- agroforestry systems (AFS), comprising 307 species.[1]

The tool allows producers and other companies in the forestry value chain to integrate GHG emissions reporting in their production and annual planning strategies. It specifically allows companies to identify opportunities for emissions reductions and GHG removal, track progress toward emissions reduction goals, communicate results to investors and end-consumers, and respond to national and international demands for less-carbon intensive products.

Users can apply local and reliable emissions factors in their accounting processes, and employ a calculation method based on the recommended approach of Intergovernmental Panel on Climate Change (IPCC) and the national GHG inventory, all in a single excel worksheet.

INTRODUCTION

Forestry and Climate Change

The main objective of the 2015 Paris Agreement on Climate Change is to drive ambitious efforts to limit the average global temperature increase to 2.0°C above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels by the end of this century. According to the Fifth Assessment Report of the IPCC, global scenarios consistent with a likely chance of keeping temperature change below 2°C include the following measures:

- sustainable use of bioenergy;
- large-scale measures relating to land-use change and forests; and
- tripling to nearly quadrupling the share of zero- and low-carbon energy supply globally by the year 2050.

The IPCC Special Report on Global Warming of 1.5°C, released in October 2018, highlights the critical need for urgent climate action (IPCC 2018). The report clearly shows the need to focus not only on reducing GHG emissions, but also on removing carbon from the atmosphere and storing it in biomass or soils. Carbon removal is necessary to achieve zero net emissions and to compensate if the planet warms by more than 1.5˚C.

Forests are natural carbon sinks and play a critical role in the global carbon cycle, regulating rainfall patterns and the climate. Stopping deforestation and planting forest species in degraded areas helps to retain forests as carbon sinks and capture carbon through tree growth. Recognizing the critical role that forests play in reducing global emissions, a global effort has pledged to restore a total of 350 million hectares (Mha) of degraded land by 2030 (Bonn Challenge). Land-use change and forestry are one of the majors' contributors to global emissions of the GHG that drive climate change, together to energy and agriculture sectors (IPCC 2014). Therefore, leadership and innovation from the plantation sector are vital in making progress in reducing these emissions and in abating the worst effects of climate change. Action in this sector also makes good business sense.

The Need for a Calculation Tool for Forestry in Brazil

The Brazilian government has committed to reduce GHG emissions 37 percent below 2005 levels by 2025, mainly through forest plantation activities. Afforestation and reforestation[2] project activities are among the most cost-effective forms of mitigating global warming (Olsen 2007; FAOSTAT 2017) while ensuring the provision of environmental services, jobs, and income opportunities.

In 2015, estimated net emissions from agriculture (including forestry) and land-use change contributed 31.4 percent and 24.3 percent, respectively, of Brazil's GHG emissions. In terms of gross emissions, agriculture (including forestry) and land-use change contributed 26 percent and 38 percent, respectively, of national GHG emissions (MCTI 2017).

The Brazilian forestry sector manages 13.4 Mha, with 7.8 Mha of planted trees (72.7% eucalyptus, 20.4% pine and 6.9% other species) and nearly 5.6 Mha comprising protected areas, including areas of legal reserve, areas of permanent preservation, and areas of private natural heritage reserve.[3] The sector produces 91 percent of wood used for industrial purposes in the country and accounts for 6.2 percent of Brazil's gross domestic product (IBÁ 2018).

Institutional investments in mainstream reforestation in Brazil today are estimated at US$35 billion (New Forests 2015 apud Batista et al. 2017). According to FAO data, planted forests account for only 2.5 percent (about 10 Mha) of total forest cover in the world (Batista et al. 2017). To meet the growing demand for timber, 100 Mha of forest plantations globally will be needed by the year 2050.

Over the past few years, the request for specific technical guidelines for the world's agriculture sector, including forestry,[4] has grown considerably. However, uncertainties remain in measuring the amount of carbon held in landscapes. Modeling studies or landscape and regional analyses based on remotely sensed data often use biome scale averages of carbon stocks and sequestration rates, and do not include management practices and their major impact in sequestration and emissions rates (Golicher, Canterello and Newton 2012). The assumptions used to estimate the effect of interventions at the site level have rarely been formally tested against empirical evidence. Improving such site-level data gathering is, therefore, an important part of the evidence generated by this tool, as well as a critical component for measuring the forestry sector's impact on climate change. There are also risks around potential reversal (restored areas that revert to degraded land) and how such risks should be accounted for in calculating carbon capture.

The Greenhouse Gas Protocol Corporate Standards provides a high-level, cross-sector accounting framework. However, it does not address many accounting and reporting issues specific to emissions and removals from forestry. These include the following:

- Obtaining accurate, site-specific flux data when environmental conditions vary a lot across landscapes.
- Setting and tracking progress toward emission reduction goals against a background of highly variable GHG fluxes.
- Carbon (C) removal and accounting for changes in the management and ownership of different carbon pools.
- The fact that forestry activities do not immediately result in GHG fluxes (e.g., delayed emissions from decomposition of post-harvest detritus).
- The types of organizational structures and operational practices specific to the forestry sector.

This tool outlines recommended methodologies to address these and other issues important to the sector while incorporating requirements into the Corporate Standard.

The tool has a number of specific objectives:

- Increase consistency and transparency in GHG accounting and reporting within the Brazilian forestry sector.
- Help companies cost-effectively prepare GHG inventories that are true and fair accounts of their climate impact.
- Include the reporting and mitigation of non-mechanized source GHG emissions[5] in their annual production and planning strategies.
- Enable GHG inventories to meet the decision-making needs of both internal management and external stakeholders (e.g., investors) and so provide for the more effective management of forestry GHG fluxes.

1.3 Who Should Use This Tool?

A GHG emissions inventory is the foundational tool that allows farmers or companies to understand their GHG emissions and build effective climate change strategies. GHG inventories help reveal their exposure to GHG-related risks; identify emissions reduction opportunities; create baseline data and reduction targets for tracking performance; and communicate performance to key audiences, including internal management and external stakeholders. Performance goes beyond managing GHG emissions: for example, studies show that 38 percent of mammal species and 41 percent of bird species threatened in Brazil, particularly in the Atlantic Forest (60%) and Brazilian Savanna (36%), the most threatened biomes in Brazil, are found in areas that belongs to the Brazilian forest companies (IBÁ 2018).

Of 7.8 Mha of planted forests in Brazil in 2016, 34 percent belong to companies in the pulp and paper industry. In second place, with 29 percent, are independent operators and participants in out-grower schemes who invest in forestry plantations as a source of income from the sale of roundwood. In third place is the charcoal-fired steel industry, which operates 14 percent of plantation area (IBÁ 2018). These sectors are the target audience of this GHG calculation tool.

The next section of this technical note briefly summarizes appropriate uses of the tool. Section 3 presents the emissions report and its components, characterizing the emission sources. Section 4 addresses the choice of methods and levels of detail.

Appendix 1 provides additional information regarding methods and Appendices 2–8 provide more detail about the calculation variables.

THE CALCULATION TOOL

The GHG calculation tool focuses on sources of GHG emissions and removals in corporate or farm-level accounting and reporting. It is organized into three forest types: **homogeneous systems (eucalyptus, pine and parica),[6] heterogeneous systems (multi-species planting) and agroforestry systems (AFS), comprising 307 species**.

The estimation of species productivity in the heterogeneous and agroforestry planting systems took account of different phytoecological regions because the growth potential of species differs according to the environmental conditions where planting is carried out. The methodology described in this technical note is built into an accompanying interactive Excel spreadsheet tool.

The methods used in the calculation tool for Eucalyptus, Parica, Pine and native species are based on the same guidelines used by the Third Brazilian Inventory of Anthropic Emissions of Greenhouse Gases (published in 2016), on the IPCC Guidelines 2006 for National Greenhouse Gas Inventories, as well as on scientific publications, which are referenced in the tool.

We prioritized the use of Brazilian emission factors and used Tier 2 emission factors. In cases where Tier 2 metrics were not available, we used Tier 1 emission factors, based mainly on the IPCC 2006 Guidelines. The Tier 3 emission factors are specific to each type of climate and management system, among other factors. Tier 3 was used in the tool only to determine the biomass carbon of native vegetation, according to the Third National Communication (MCTIC, 2016) and the Tier 3 approach in Good Practice Guidance (IPCC 2003). (For an explanation of Tiers 1, 2, and 3, see Section 4, Box 1.)

The GHG calculation tool has been discussed and user-tested by the most important Brazilian forestry sector corporations: Fibria, Amata, and Klabin.
At Amata and Fibria, the tool was extensively applied using data from internal operations. The results of the GHG balance were similar to the values of the internal inventories of both companies, leading to approval of the tool by both companies.

At Klabin, the tool was well received and Klabin volunteered to apply the tool at its production units.

In addition, the tool was presented to The Brazilian Tree Industry (IBÁ), which sent suggestions for improvement that were incorporated into its development.
At government level, the calculation tool was presented to the Environment Secretariat of Sao Paulo (SMA / SP), which showed interest in applying the tool at the SMA's projects in agro-forestry areas.

Statistical tests comparing the tool's GHG balance sheet results with internal results obtained by the institutions mentioned above were not performed.

The tool also includes default values, according to the average growth rate and size of forest species, that should be used in cases where the tree species of the user have not been considered.

The emission and removal sources considered by the tool are as follows:[7]

- GHG emission sources
  - Addition of soil liming

- Addition of synthetic nitrogen fertilizers
- Addition of organic fertilizers
- Green manure
- Addition of urea
- Addition of gypsum ($CaSO_4$)
- Purchased electricity
- Secondary sources (atmospheric deposition of NH3 and NOx, leaching, and surface runoff)
- Land-use change
- Biomass burning
- Fuel consumption on machinery
- Fuel Consumption on management activities
- Decomposition and the combustion of organic matter

Following a forestry sector company's request, the tool also allows inclusion of data on the amount of fuel used to transport material from the place of production (farm) to its final destination (industry or exportation port). This information is part of the scope 3 (scope 3 accounts the indirect emissions that occur transport for wood commercialization).

- GHG removal sources
  - CO_2 removals due to carbon stock change occurring as a result of land conversion within or between land-use categories (e.g., adoption of no-till practices or land-use change)
  - Biomass increase
  - Increase in soil carbon from the biomass burned (2% of the biomass burned is converted into coal and remains in the field)[8]

These sources align with the calculation methods of the Third National Communication of Brazil to the United Nations Framework Convention on Climate Change (UNFCCC), coordinated by the Department of Science, Technology, and Innovation.

Emissions from litter decomposition, that is, methane (CH_4) and nitrous oxide (N_2O) fluxes between soil, litter, and atmosphere, were not considered. The emissions or removals of methane from decomposition are variable and dependent on the climatic conditions of the inventoried site (rainfall and temperature values) (Godoi 2012; Gomes 2014; IBARR 2015).

All calculations and variables are described and explained in Appendix 2–8.

THE EMISSIONS REPORT

Scope Definitions

The emissions report is divided into three scopes, classified according to the degree of responsibility or control from the corporation inventoried by emissions sources—direct sources (sources that belong to or are controlled by the corporation inventoried) and indirect sources (sources that belong to or are controlled by other actors, but result from the activities of the corporation inventoried). This separation must be done in a judicious and transparent manner since it allows effective GHG emissions management and can help in the management of GHG risks and opportunities involving the whole value chain. The categories are:

Scope 1: direct emissions from activities owned or controlled by the company or farmer. They are further subdivided as follows:

- Mechanized sources – emission sources that use fuel or electricity and generate GHG emissions from the combustion process. Examples include mechanical harvesting and application agricultural inputs such as fertilizers.
- Non-mechanized sources – emission sources that emit GHGs from biochemical processes. They vary widely according to the locally prevailing climatic conditions. These emissions are often linked to nitrogen and carbon cycles. Non-mechanized source examples include soil liming.
- Removal of native vegetation – emissions resulting from removal or suppression of native vegetation for other uses (land-use change). Emissions from this practice are considered to be non-renewable since there is a permanent displacement of a relatively constant and self-regenerating carbon reservoir. The new land use may involve a smaller and non-self-regenerating carbon reservoir.

Scope 2: indirect emissions arising from the generation of electric and thermal energy that is purchased and consumed by the company or farm.

Scope 3: all other indirect emissions not reported in Scope 2 that occur in the value chain of the company or farm, both upstream and downstream. That is, Scope 3 emissions are a consequence of activities by the company or farm but they arise from sources that do not belong to or are not control by them. Scope 3 emissions are further classified into 15 subcategories, eight upstream and seven downstream, according to the GHG Protocol Corporate Value Chain (Scope 3) Standard guidelines (GHG PROTOCOL 2011).

All scope 1 and 2 sources must be reported in an inventory. Scope 3 sources are optional under the Corporate Standard, although measuring and reporting on significant scope 3 sources is recommended. Also, with the exception of land-use change, all CO_2 fluxes to/from carbon pools that are owned or controlled by the reporting company or farm should be reported separately from the scopes in special categories as “Emissions and removals from biogenic process” and “Emissions and removals from land use change[9]”.

To ensure consistency regarding GHG emissions and removals, the calculation tool follows the national communication recommendations and their respective reference reports (Brasil 2016), as also indicated by the Corporate Standard (CS) of the GHG Protocol, as far as emissions and removal of GHGs are known. The measured and reported results for scopes 1, 2, and 3 emissions and removals from land-use change and emissions and removals from biogenic processes for rural properties with direct control of their management operations are disaggregated as follows:

- Scope 1: direct emissions (fertilization, liming, addition of gypsum – $CaSO_4$, diesel, gasoline, and ethanol) and carbon stored in native vegetation that was converted for other uses;
- Scope 2: purchased electricity;
- Scope 3: indirect emissions – only transport of commercial wood products;
- Biogenic emissions: burning of biofuel (biodiesel and ethanol) and 98 percent of emissions arising from burning biomass (see below);
- Biogenic removals: 2 percent of biomass burned becomes charcoal that is incorporated into the soil;
- Emissions and removals from land-use change: soil carbon and plant biomass (except vegetation native to other uses[10]). CO_2 emissions from land-use change are reported separately in the “emissions summary” worksheet Table 2. Emissions and removals from land use and land-use change (metric tons – t – of CO_2 equivalent);
- CO_2 emissions and removals from biogenic processes are reported separately in the “emissions synthesis” worksheet in Table 3. Emissions and removals by biogenic processes (metric tons of CO_2 equivalent).

The GHG calculation tool’s final reporting balance includes an evaluation of the immobilized carbon net emissions (in the biomass and soil) that result from the establishment of forestry plantations.

At the end of the disaggregated report we include an extra table showing the balance between scopes 1 and 2 emissions and removals from land-use change, and biogenic emissions and removals. Such a decision to maintain the balance of net emissions is important to align with the national GHG Inventory and Brazil’s Nationally Determined Contribution (NDC), which must be achieved by private sector investments, which is more interested in the final balance than the emissions and removals reported separately.

The final balance is reported in the “emissions summary” worksheet Table 4.

Soil Carbon Content over Time

Several experiments in Brazil have shown that the carbon content of soil varies over time (Alves et al. 2006; Urquiaga et. al. 1998). The research of Moraes et al. (1996), used the carbon-13 isotope to determine carbon content of forest and pasture, and showed that the stabilization of carbon content occurred between 13 and 20 years after land-use change.

On the basis of this result, the calculation tool uses the time period of 20 years for soil carbon stabilization. This 20-year value is the default time horizon in national GHG inventories submitted to the United Nations Framework Convention on Climate Change (UNFCCC).

Biogenic Carbon

A significant share of CO_2 emissions related to the agricultural and forestry sectors are generated from biomass burning (biological material made of carbon, hydrogen, and oxygen). Burning biomass results in emissions is considered by some researchers neutral in terms of climate impact because the CO_2 is generated through a biological cycle (not a geological cycle, as in the case of CO_2 of fossil origin). Other studies, such World Resources Report: Creating A Sustainable Food Future (WRI 2019), have a different perception regarding this issue.

Still, the use of biomass and its by-products as alternative fuels is considered by some researchers to be an important contribution to reducing GHG emissions. In this tool biogenic carbon accounting is divided into two categories in the tool:

- Biogenic emissions: burning of biofuel (biodiesel and ethanol), burning 98 percent of the biomass
- Biogenic removals: 2 percent of the biomass burned becomes charcoal incorporated into the soil

All biogenic carbon shall be reported in an inventory.

Carbon Removals

This category covers all carbon removed from the atmosphere by activities carried out directly by the company or farm conducting the inventory. Carbon removal includes the carbon accumulation due to land-use changes[11] (e.g., conversion of pasture or degraded area to eucalyptus, pine, parica or other species), to increase of aboveground biomass, and to changes in systems (e.g. conventional agriculture conversion to a no-tillage system, agroforestry system or forestry).

All carbon removals shall be reported in an inventory for a period of up to 21 years following clear-cutting of the eucalyptus, pine, parica, and 40 years following establishment of the agroforestry system and planting of diverse species.

Net Emissions

The final balance, or net emissions report, evaluates the carbon stored (in biomass and in the soil) due to forest plantation. Thus, at the end of the disaggregated reports, the tool reports the balance between scope 1 and 2 emissions and removals from land-use change; and biogenic emissions and removals.

It should be noted that the net emissions balance is aligned with the National GHG Inventory and the Brazilian NDC. That is, the most useful information for the forestry sector and government is the net balance of GHGs in the inventoried activity.

The net emissions are calculated according to the formula below:

Net Emissions=Scope 1 and 2 emissions+emissions and removals from Land Use Change+biogenic emissions and removals

The net emissions shall be reported in an inventory for a period of up to 21 years following clear-cutting of the eucalyptus, pine, parica, and 40 years following the establishment of the agroforestry system and planting of diverse species.

Due to the voluntary nature of reporting, Scope 3 emissions related to the transportation of wood are reported separately.

Other Gases

Forestry activities are often responsible for emissions of greenhouse gas precursors. These gases include carbon monoxide (CO) and nitrogen oxides (NO_{x}).

These emissions are optional to report.

Final Emissions Report

The balance of carbon removals and emissions in each forestry system is calculated year by year. All carbon exports due to cutting or thinning in the plantations are counted in the year of the cutting or thinning activity. Thus, the annual report is a snapshot at a given planting age, of a productive unit, in the year reported in the inventory. This way, the tool allows the user to observe the total carbon exported from the system in each harvest period.

The final report is the result of the emissions and removals balance of the entire analysis period and includes removals, emissions, and exports due to cutting or thinning within the period. For *eucalypt*, *pinus* and *paricá* the tool analyzes the balance for a period of up to 21 years, which corresponds to the maximum cycles of exploitation practiced for these species in Brazil.

For multi-species plantations and agroforestry systems, the period of analysis is 40 years, considering that these systems have longer production and exploitation cycles.

Emissions from fuel consumed to transport products to the final destination are also reported separately as Scope 3 (non-mandatory reporting).

CHOICE OF METHODOLOGY AND LEVELS ADOPTED (TIER 1, TIER 2, AND TIER 3)

The IPCC has developed a series of principles and methodological procedures to guide the development of national inventories of GHG emissions so that they can be compared to each other. Within these principles and procedures are a set of Tiers (levels or layers). A Tier represents the level of methodological complexity that a country inventory may adopt (Box 1).

Box 1. | **The IPPC Tier Concept**

The IPPC has classified methodological approaches into three different Tiers, according to the quantity of information required and the degree of analytical complexity (IPCC 2003, 2006).

Tier 1 employs the gain-loss method described in the IPCC Guidelines and the default emission factors and other parameters provided by the IPCC. There may be simplifying assumptions about some carbon pools. Tier 1 methodologies may be combined with spatially explicit activity data derived from remote sensing.

Tier 2 generally uses the same methodological approach as Tier 1 but applies emission factors and other parameters that are specific to the country. Country-specific emission factors and parameters are those more appropriate to the forests, climatic regions, and land-use systems of the country. More highly stratified activity data may be needed in Tier 2 to correspond with country-specific emission factors and parameters for specific regions and specialized land-use categories.

At Tier 3, higher-order methods include models and can utilize plot data provided by national forest inventories tailored to address national circumstances. Properly implemented, these methods can provide estimates of greater certainty than lower tiers, and can have a closer link between biomass and soil carbon dynamics. Such systems may be GIS-based combinations of forest age, class/production systems with connections to soil modules, integrating several types of monitoring and data. Areas where a land-use change occurs are tracked over time. These systems may include a climate dependency, and provide estimates with inter-annual variability.

Source: Reddplus.org. "Integrating remote-sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests." https://www.reddcompass.org/mgd-content-v1/dita-webhelp/en/d0e11.html#d0e11. Accessed 25 September, 2019.

Although developed for use in national inventories, the concept of tiers is also being applied to regional or local-level estimates. Where possible, this GHG calculation tool has adopted Tier 2, that is, specific data at the Brazilian level. Tier 1 (IPPC default values) is used only in the absence of specific information. Tier 3 was used in the tool only to determine the biomass carbon content of native vegetation, according to the Third National Communication (MCTIC 2016) and the Tier 3 approach in Good Practice Guidance (IPCC 2003).

Further detail regarding the uncertainties at each level can be found in the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,* Chapter 6 "Quantifying Uncertainties in Practice" (IPCC 2006).

CONCLUSION

This document presents the development process of the GHG Protocol Calculation Tool for Forestry in Brazil, which aims to provide a practical and robust method to measure the GHG emissions and removals from the forestry sector in the country. The method is aligned with the broad GHG Protocol method but it is applicable only to the Brazilian forestry sector under specific science-based emissions factors.

The application of the GHG Protocol Calculation Tool for Forestry in other sectors and/or other countries requires a combination with other specific tools that reflect specificities of the sectors and/or local realities. This tool does not estimate uncertainties and does not provide inventory error analysis, which would require an additional and detailed assessment.

The tool follows a regular review process to update and internalize any substantial change or development in the Brazilian forest sector. Having been framed as an Excel spreadsheet, it is locked and users cannot change the original features. Nevertheless, the method can be easily replicated and applied to different practical cases, with the necessary adaptations.

The GHG Protocol Calculation Tool for Forestry was built after the launch and initial implementation of the GHG Protocol for Agriculture, established in 2012, which was developed with the same aim of providing a practical and robust method to measure GHG emissions and removals from the agriculture sector in Brazil. Therefore, the lessons learned during the creation and implementation of the agricultural tool were useful to minimize the errors and adjustments needed for the development of the forest tool. A validation process with key stakeholders in the country was also conducted during the development phase, which optimized the efficiency and robustness of the process.

A well-structured GHG inventory is the first step that should be taken by the forestry sector to understand its emissions profile and develop appropriated mitigation strategies. The GHG Protocol Calculation Tool for Forestry supports the development of such inventories, combining a widely used and reliable method and specific emission factors for Brazil, while also promoting more transparency and access to relevant information.

REFERENCES

Alves, B.J.R.; Urguiaga, S.; Aita, C.; Boddey, R.M.; Jantalia, C.P.; Camargo, F.A.O. Manejo de sistemas agrícolas, Impacto no sequestro de C e nas emissões de Gases de efeito estufa. Porto Alegre, Genesis. 216 p. Embrapa Agrobiologia. 2006.

Arco-Verde, M. F.; Schwengber, D. R. Avaliação silvicultural de espécies florestais no Estado de Roraima. Revista Acadêmica: Ciências Agrárias e Ambientais, Curitiba, v. 1, n. 3, p. 59-63, jul./set. 2003.

Athanázio-Heliodoro, J. C. Qualidade da madeira de árvores de Guapuruvu (Schizolobium parahyba (vell.) blake) com 15 anos provenientes de área de recuperação florestal. 2015. xv, 150 f. Dissertação (mestrado) - Universidade Estadual Paulista Júlio de Mesquita Filho, Faculdade de Ciências Agronômicas de Botucatu, 2015. Available at: <http://hdl.handle.net/11449/135924>. Last accessed in February 2017.

Batista, A.; Prado, A.; Pontes, C.; Matsumoto, M. VERENA investment tool: valuing reforestation with native tree species and agroforestry systems. 2017. Available at: <https://wribrasil.org.br/sites/default/files/VERENA_technical-note.pdf> Last accessed in April 2018.

Brasil. Lei nº 12.651, May 25th, 2012. 2012. Available at: <http://www.planalto.gov.br/ccivil_03/_Ato2011-2014/2012/Lei/L12651.htm>. Last accessed in May 2017.

_______. Lei nº 13.033, September 24th, 2014. 2014. Available at: <https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2014/lei/l13033.htm>. Last accessed in May 2017.

_______. Lei nº 13.263, March, 23th, 2016. 2016. Available at: <http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2016/lei/L13263.htm>. Last accessed in May 2017.

_______. Terceiro inventário de emissões anuais de gases de efeito estufa no Brasil. Ministério da Ciência, Tecnologia e Inovação. Secretaria de Políticas e Programas de Pesquisa e Desenvolvimento. Brasília: MCTIC. 2016.

Brienza Junior, S., Maneschy, R. Q., Mourão Júnior, M., Gazel Filho, A. B., Yared, J. A. G., Gonçalves, D. Gama, M. B. Sistemas Agroflorestais na Amazônia Brasileira: Análise de 25 anos de pesquisas. 2010. Pesquisa Florestal Brasileira, Colombo, n.60, p.67-76, dez. 2009. Edição Especial

Brown, S. Measuring carbon in forests: current status and future challenges. 2002. Environmental Pollution 116 (2002) 363–372.

Cairns, M., Brown, S., Helmer, E. et al. Root biomass allocation in the world's upland forests. 1997. Oecologia. 111: 1. https://doi.org/10.1007/s004420050201

Carvalho, J.L.N., Avanzi, J.C., Silva, M.L.N., Mello, C.R., Cerri, C.E.P., 2010. Potencial de sequestro de carbono em diferentes biomas do Brasil. *Revista Brasileira de Ciência do Solo*, vol. 34, no. 2, pp. 277-290. Available at: <http://dx.doi.org/10.1590/S0100- 06832010000200001>. Last accessed in January 2018.

Carvalho, C.S.; Ribeirinho, V.S.; Andrade, C.A.; Grutzmacher, P.; Pires, A.M.M. Composição Química da Matéria Orgânica de Lodos de Esgoto. 2015. Revista Brasileira de Ciências Agrárias, v. 10, n. 3, p. 413-419. Available at: <http://dx.doi.org/10.5039/agraria.v10i3a5174>. Last accessed in January 2018.

Chave, J. et al. Regional and phylogenetic variation of wood density across 2456 neotropical tree species. Ecological applications, v. 16, n. 6, p. 2356-2367, 2006.

Corte, A. P. D.; Sanquetta. C. R. Quantificação do estoque de carbono fixado em reflorestamentos de Pinus na área de domínio da Floresta Ombrófila Mista no Paraná. 2007. Cerne, Lavras, v. 13, n. 1, p. 32-39, jan./mar. 2007.

Costa, J. A. Qualidade da madeira de Eucalyptus urograndis, plantado do Distrito Federal para a produção de celulose kraft. Dissertação. Universidade de Brasília. 86 p. 2011.

DEFRA. Department for Environment Food and Rural Affairs. The DA GHGI Improvement Programme 2009-2010: EU ETS Task. Available at: <https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1005251111_DA_GHGI_Improvement_Report_EUETS_May2010r.pdf>. Last accessed in April 2017.

EMBRAPA. A Evolução do Conhecimento sobre o Paricá para Reflorestamento no Estado do Pará. Comunicado técnico 158. Belém/PA. 2006.

FAOSTAT. 2017. Online database. Available at: <http://faostat.fao.org/>. Last accessed in January 2018.

Fearnside, P. M. Fogo e emissão de gases de efeito estufa dos ecossistemas florestais da Amazônia brasileira. Estud. av. vol.16 no.44 São Paulo Jan./Apr. 2002. Available at: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-40142002000100007>. Last accessed in January 2017.

_______. Greenhouse gases from deforestation in Brazilian Amazonia: net committed emissions. Climatic Change. March 1997, Volume 35, Issue 3, pp 321–360.

_______; Barbosa, R. I.; Pereira, V. B. Emissões de gases do efeito estufa por desmatamento e incêndios florestais em Roraima: fontes e sumidouros. Revista AgroAmbiente On-line, v. 7, n. 1, p. 95-111, January to April 2013. Available at: <http://philip.inpa.gov.br/publ_livres/2013/Fearnside%20et%20al_Emiss%C3%B5es%20GEE-desmatamento-inc%C3%AAndios_RR_2013.pdf>. Last accessed in February 2017.

Ferez, A. P. C. Efeito de práticas silviculturais sobre as taxas iniciais de sequestro de carbono em plantios de restauração da Mata Atlântica. 2010. 106f. Dissertation (Master of Science) – Universidade de São Paulo, São Paulo, 2010.

Feuchard, L. D. Influência do espaçamento de plantio e idade de colheita na qualidade da madeira de eucalipto para celulose. 2015. Dissertation (Master in Forest Sciences)– Universidade Federal do Espírito Santo. 53 p. 2015.

Forster, H. W.; Melo, A. C. G. de. Biomassa aérea e de raízes em árvores de reflorestamentos heterogêneos no Vale do Paranapanema, SP. 2007. IF Sér. Reg., São Paulo, n. 31, p. 153-157, jul. 2007.

GHG PROTOCOL, Corporate Value Chain (Scope 3) Standard. 2011. Available at: <http://www.ghgprotocol.org/standards/scope-3-standard>. Last accessed in January 2017.

Godoy, S. G. de. Fluxo de gases de efeito estufa em solos do pampa gaúcho sob Silvicultura. Dissertação. Universidade Federal do Pampa. 83 p. 2012.

Golicher, D., Canterello, E. and Newton, A. 2012. What is the evidence of the impact on net carbon sequestration from REDD+ (with a focus on tropical forests)? CEE protocol 10-011. Collaboration for Environmental Evidence: www.environmentalevidence.org/SR10011.html.

Gonçalez, J. C.; Santos, G. L.; Silva Júnior, F.G.; Martins, I. S.; Costa, J. A. Relações entre dimensões de fibras e de densidade da madeira ao longo do tronco de Eucalyptus urograndis. Sci. For., Piracicaba, v. 42, n. 101, p. 81-89, mar. 2014.

Guidotti, V; Freitas, F.L.M.; Sparovek, G.; Pinto, L.F.G.; Hamamura, C.; Carvalho, T.; Cerignoni, F. Números detalhados do Novo Código Florestal e suas implicações para os PRAs Sustentabilidade Em Debate, IMAFLORA, Piracicaba, SP (2017), p. 10. Available at: <https://www.researchgate.net/publication/317278692_NUMEROS_DETALHADOS_DO_NOVO_CODIGO_FLORESTAL_E_SUAS_IMPLICACOES_PARA_OS_PRAs_PRINCIPAIS_RESULTADOS_E_CONSIDERACOES>. Last accessed in December 2018.

Gusson, E. Avaliação de métodos para a quantificação de biomassa e carbono em florestas nativas e restauradas da Mata Atlântica. 2014. 113f. Thesis (Doctorate in Forest Resources) – Universidade de São Paulo, São Paulo. 2014.

Higa, A. R. et al. Variação da densidade básica da madeira de P. elliottii var. elliottii e P. taeda. IPEF, Piracicaba, v. 7, p. 79-89, 1973.
IBÁ. Relatório Anual de 2017. 2018. Available at: <https://iba.org/images/shared/Biblioteca/IBA_RelatorioAnual2017.pdf>. Last accessed in June 2018.

Ibarr, M. A. Estoque de carbono e fluxos de óxido nitroso e metano do solo em plantios de pinus e floresta nativa. 2016. Dissertation (Master in Soil Science). Universidade Federal do Paraná, Curitiba. 2016

IBFlorestas. Instituto Brasileiro de Florestas. Available at: <www.ibflorestas.org.br>. Last accessed in June 2018.

IPPC (Intergovernmental Panel on Climate Change). Revised 1996. Guidelines for National Greenhouse Gas Inventories. 1996.

_______. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Kanagawa: Institute for Global Environmental Strategies.

_______. 2006. Guidelines for National Greenhouse Gas Inventories. IGES, Hayama, Japan.

_______. 2013.Climate Change 2013: The Physical Science Basis. Switzerland: UNEP, WMO.

_______. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.

_______. 2014: Impacts, Adaptation, and Vulnerability. Summaries, Frequently Asked Questions, and Cross Chapter Boxes. A Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Barros, V.R.; Field; C. B.; Dokken, D. J.; Mastrandrea, M. D.; Mach, K. J.; Bilir, T. E.; Chatterjeee, M.; Ebi, K. L.; Estrada, Y. O. Genova, R. C.; Girma, B.; Kissel, E. S.; Levy, A. N.; Maccracken, S.; Mastrandrea, P. R.; White, L. L. (eds.). United Kingdom and New York: Cambridge University. 2014.

_______. 2018: Special Report: Global warming of 1.5°C. Working Group I Technical Support Unit. Switzerland.
Jacovine, L. A. G., Souza, A. P., Leite, H. G., Trindade, C. Descrição de uma metodologia para valiação dos custos da qualidade na colheita florestal semimecanizada. Ciência Florestal, v.9, n.1, p. 143-160, 1999.

Kiehl, J. E. Fertilizantes orgânicos. Piracicaba: Agronômica Ceres, 1985. 492p.

Lemos, E. C. M. Emissão de dióxido de carbono e estoque de carbono em sistemas convencionais e alternativos de produção agropecuária no Nordeste paraense. Dissertação – Universidade Federal do Pará. 2011. 90p.

Lima, A. M. N. et al.; Frações da matéria orgânica do solo após três décadas de cultivo de eucalipto no Vale do Rio Doce-MG. R. Bras. Ci. Solo, 32:1053-1063, 2008.

LOPES, A.S. Manual de fertilidade do solo. São Paulo: ANDA/POTAFOS. 1989. 53p.

Melo, R. R., Silvestre, R., Oliveira, T. M., Pedrosa, T. D. Variação Radial e Longitudinal da Densidade Básica da Madeira de Pinus Elliottii Engelm com Diferentes Idades. 2013. Ciência da Madeira (Braz. J. Wood Sci.), Pelotas/RS, v. 04, n. 01, May 2013. DOI: 10.12953/2177-6830.v04n01a07.

MCTIC – Ministério da Ciência, Tecnologia, Inovação e Comunicações. Terceira Comunicação Nacional do Brasil (TCN) à Convenção-Quadro das Nações Unidas sobre Mudança do Clima. Brasília. 2016.

_______. Estimativas anuais de emissões de gases de efeito estufa no brasil – 40 edição. Ministério da Ciência, Tecnologia, Inovações e Comunicações – MCTIC. Secretaria de Políticas e Programas de Pesquisa e Desenvolvimento – SEPED. Brasília: 2017. 91p.

_______. SIRENE – Sistema de registro nacional de emissões. Ministério da Ciência, Tecnologia, Inovação e Comunicações (MCTIC). Available at: <http://sirene.mcti.gov.br/web/guest/emissoes-em-CO$_2$-e-por-setor>. Last accessed in January 2017.

Mendes, I. S. et al., 2014. Idade de plantio de eucalipto e fluxos de óxido nitroso e metano em argissolo no sul do brasil. Anais do Salão Internacional de Ensino, Pesquisa e Extensão. Universidade Federal do Pampa v. 6, n. 2. 2014. Available at: <http://seer.unipampa.edu.br/index.php/siepe/article/view/8035>. Last accessed in April 2017.

Moraes, J.F.L.D.; Volkoff, B.; Cerri, C.; Bernoux, M. Soil properties under Amazon forest and changes due to pasture installation in Rondonia, Brazil. Geoderma, v.70, p.63-81, 1996.

Moreira. C. S. Estoques de carbono no solo em áreas de reflorestamento: bases para projetos de mecanismos de desenvolvimento limpo. Tese. Universidade de São Paulo. 188 p. 2010.

Neves, J. C. L. Produção e partição de biomassa, aspectos e hídricos em plantios clonais de eucalipto na região litorânea de Espírito Santo. Tese. Universidade Estadual do Norte Fluminense. 202 p. 2000.

Oliveira, D. Análise operacional e custos de sistemas de colheita de madeira em povoamentos de eucalipto. Irati, PR: Unicentro, 2013. 116 f. (Dissertação de Mestrado em Ciência Florestal), Universidade Estadual do Centro-Oeste, Irati. Available at: <http://tede.unicentro.br:8080/jspui/bitstream/tede/464/1/PR%20DIEGO%20DE%20OLIVEIRA.pdf>. Accessed in March 2017.

Olsen, Karen Holm. The clean development mechanism's contribution to sustainable development: a review of the literature. Climatic change, v. 84, n. 1, p. 59-73, 2007. Available at: <https://link.springer.com/article/10.1007/s10584-007-9267-y>. Last accessed in December 2018.

PBMC, 2014. Base científica das mudanças climáticas. Contribuição do Grupo de Trabalho 1 do Painel Brasileiro de Mudanças Climáticas ao Primeiro Relatório da Avaliação Nacional sobre Mudanças Climáticas [Ambrizzi, T., Araujo, M. (eds.)]. COPPE. Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil, 464 pp.

Pereira, A. F. Madeiras Brasileiras - Guia de combinação e substituição. 1. ed. São Paulo: Editora Blucher, 2013. 130p. (Apoio financeiro da FAPEMIG). Available at: <ISBN: 978-85-21207-35-1>. Last accessed in January 2017.

Pereira, B. L. C.; Carneiro, A. C. O.; Carvalho, A. M. M. L.; Colodette, J. L.; Oliveira, A. C.; Fontes, M. P. F. Influence of Chemical Composition of Eucalyptus Wood on Gravimetric Yield and Charcoal Properties. BioResources, Raleigh, v. 8, n. 3, p. 4574–4592, 2013.

Ribeiro, F. A.; Zani Filho, J. Variação da densidade básica da madeira em espécies/procedências de Eucalyptus spp. IPEF n.46, p.76-85, jan./dez. 1993.

SEEG (Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa). 2018 Disponível em: http://plataforma.seeg.eco.br/total_emission

Sette JR, C. R.; Oliveira, I. R.; Tomazello Filho, M.; Yamaji, F. M.; Laclau, J. P. Efeito da idade e posição de amostragem na densidade e características anatômicas da madeira de Eucalyptus grandis. Revista Árvore, Viçosa-MG, v.36, n.6, p.1183-1190, 2012.

Simõoes, D. Avaliação econômica de dois sistemas de colheita florestal mecanizada de eucalipto. 2008. 105 f. Dissertação (Mestrado em Agronomia/Energia na Agricultura)-Faculdade de Ciências Agronômicas/Universidade Estadual Paulista, Botucatu, 2008.

Soares-Filho, B. S. Impacto da revisão do Código Florestal: como viabilizar grande desafio adiante? Brasília: Secretaria de Assuntos Estratégicos, 2013. Available at: <http://www.sae.gov.br/site/wp-content/uploads/Artigo-codigo-florestal.pdf>. Last accessed in December 2018.

Souza, F. M. L., Estudo comparativo da madeira e polpação de Eucalyptus urophylla e do híbrido E. urophylla x E. grandis em dois modelos silviculturais. Dissertação (Mestrado) – Universidade Estadual Paulista Faculdade de Ciências Agronômicas, Botucatu, 70p. 2012.

Suzano. Cultivo mínimo do eucalipto na Cia Suzano. A.V. Lemos. I Simpósio de "Técnicas de Plantio e Manejo de Eucalyptus para Uso Múltiplo". Apresentação em PowerPoint: 60 slides. 2006. Available at: <http://www.tume.esalq.usp.br/simp/arquivos/atus.pdf>. Accessed in March 2017.

Trugilho, P. F.; Lima, J. T.; Mendes, L. M. Influência da idade nas características físico-químicas e anatômicas da madeira de Eucalyptus saligna. Available at: <http://www.almanaquedocampo.com.br/imagens/files/Eucal%C3%ADpto%20idade%20e%20caracter%C3%ADsticas%20 da %20madeira.pdf>. Last accessed in March 2017.

UNFCCC (United Nations Framework Convention on Climate Change). Afforestation and Reforestation Projects under the Clean Development Mechanism: A Reference Manual. Bonn, Germany, 2013. 65 p. Available at: <https://unfccc.int/resource/docs/publications/cdm_afforestation_bro_web.pdf> Last accessed in December 2018.

Urquiaga, S.; Cadish,G.; Alves, B.J.R.; Boddey, R.M.; Giller, K.E.; Influence of decomposition of roots of tropical forage species on the availability of nitrogen. Soil Biology and Biocchemistry, v.30. n. 14, p.2099-2106, 1998. Embrapa Agrobiologia.

Vidaurre, G.B. Caracterização Anatômica, Química e Físico-Mecânica da Madeira de Paricá (Schizolobium amazonicum) Para Produção de Energia E Polpa Celulósica. 2010. 74f. Thesis (Doctorate in Forest Science) – Universidade Federal de Viçosa, Viçosa. 2010.

________, G. B.; Carneiro, A. C. O.; Vital, B. R.; Santos, R. C.; Valle, M. L. A. Propriedades energéticas da madeira e do carvão de Paricá (Schizolobium amazonicum). Revista Árvore, Viçosa-MG, v.36, n.2, p.365-371, 2012.

WRI. Policy and Action Standard Agriculture, Forestry, and Other Land Use (AFOLU) Sector Guidance. 2015

WRI. World Resources Report: Creating A Sustainable Food Future. Chapter 7: Avoid Competition from Bioenergy for Food Crops and Land. 2019.

WRI BRASIL. Cálculos de Carbono nos Cenários do Projeto Verena. Report by Shigueo Watanabe Jr. 2016.

APPENDIX 1 – METHODOLOGY

The process to engage forestry companies, landowners, government, researchers, and civil society lasted 10 months, from February to December of 2017. The following process took a period of approximately three months:

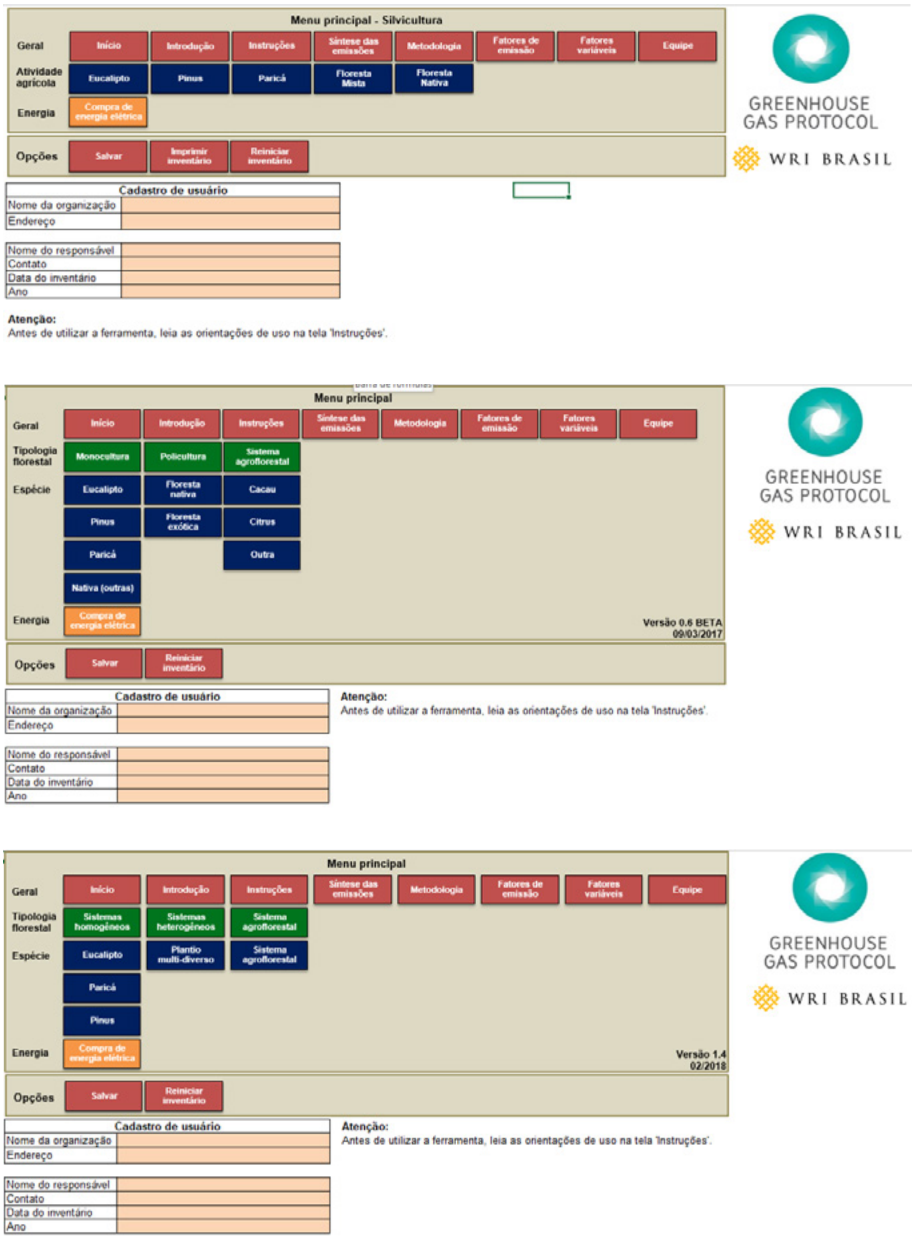
- A first meeting where the team outlined the case for a GHG Protocol to forestry sector representatives, described who might use it, why and how, and presented the methodology of the tool.
- One week to rework the tool, based on feedback from the first meeting.
- One month for partners to input their data to the GHG Protocol tool and make additional comments new considerations.
- Two weeks for the GHG technical team to adjust the tool.
- A final presentation to approve the GHG Protocol Forestry tool.

With Amata, the process began at the end of February of 2017 (02/24/2017), when the GHG technical team introduced the GHG calculation tool to Amata's expert staff (Matheus Felipe Zonete – Forest Planning Manager and Açucena Tiosso – Environmental Analyst). After this first meeting, the GHG technical team reworked the tool and sent it to Amata on 10 March. Amata technical staff commented on the new version by 24 April. The final meeting occurred on 6 June, 2017 at Amata's headquarters in Sao Paulo, and the GHG Protocol Calculation Tool for Forestry in Brazil was approved. The same process was followed with Fibria, Klabin and the Secretariat for the Environment of the State of Sao Paulo (SMA/SP).

With the IBÁ, civil society, and researchers the process was faster, involving only a first meeting and comments made during the meeting or by e-mail later.

The evolution of the tool through successive versions is shown in Figure A1:

Figure A1. | **Development of the GHG Calculation Tool for Forestry in Brazil**



APPENDIX 2 – AGRICULTURAL INPUTS: SYNTHETIC NITROGEN FERTILIZERS (EXCEPT UREA), ORGANIC FERTILIZERS, UREA, AGRICULTURAL LIMESTONE, GYPSUM, GREEN MANURE

Table A1 presents the factors used to calculate the emissions of inputs used in forestry.

Table A1. | **Factors used to calculate emissions from agricultural inputs used in forestry**

SOURCE	DESCRIPTION	CO_2	N_2O	UNIT OF MEASUREMENT	REFERENCES
Urea	-	0.7		kg CO_2/kg	IPCC 2006
Limestone	Calcitic	0.4		kg CO_2/kg	IPCC 2006
Limestone	Dolomitic	0.5		kg CO_2/kg	IPCC 2006
Gypsum	-	0.4		kg CO_2/kg	BRASIL, 2016; FEARNSIDE, 1997; et al., 2013 e 2002; SEEG, 2016
Synthetic fertilizers	Except urea		0.0113	kg N_2O/kg N	Brasil 2015
Urea	-		0.0088	kg N_2O/kg N	Brasil 2015
Manure	Cattle, horses, swine, sheep		0.0002	kg N_2O/kg fertilizer	Kiehl 1965
Manure	Aviculture		0.0004	kg N_2O/kg fertilizer	Kiehl 1965
Organic Compounds	-		0.0002	kg N_2O/kg fertilizer	Kiehl 1965
Sludge	Organic fertilization	2.7		% Carbon	Carmo et al. 2014
Composted sludge	Organic fertilization	0.7		% Carbon	Carmo et al. 2014
Green manure	Grassy		0.0004	kg N_2O/kg fertilizer	Kiehl 1965
Green manure	Leguminous		0.0002	kg N_2O/kg fertilizer	Kiehl 1965
Green manure	Other sources		0.0002	kg N_2O/kg fertilizer	Kiehl 1965

APPENDIX 3 - INDIRECT N_2O EMISSIONS (ATMOSPHERIC DEPOSITION, LEACHING, AND SURFACE RUNOFF)

The calculation of secondary N_2O emissions considered two main sources: atmospheric deposition of NH3 and NOx, leaching, and surface runoff. Data on the use of synthetic nitrogen fertilizers (NFERT) were used. It is assumed that part of the N applied to the soil is volatilized in the form of NH3 and NOx and returns to the soil through atmospheric deposition, to be emitted again in the form of N_2O.

N_2O emission from atmospheric deposition

$$N_2O((G))=[(N_{FERT}+FRAC_{GASF})]\times EF_3$$

Where:
$N_2O_{(G)}$ = N_2O emission associated with atmospheric deposition (kg N_2O-N);

N_{FERT} = amount of N applied in the form of synthetic fertilizer (kg N/year);

$FRAC_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x (kg [NH_3-N and NO_x-N]/kg N applied);

EF_3 = emission factor for atmospheric deposition (kg N_2O-N/kg [NH₃-N and NO_x-N] emitted) (IPCC 2006).

Table A2 presents the $FRAC_{GASF}$ and EF_3 values.

Table A2. | Parameters for N_2O emissions from atmospheric deposition

PARAMETERS	VALUE	SORCE OF INFORMATION	TIER
$FRAC_{GASF}$	0.1	IPCC 2006	1
EF_3	0.01	IPCC 2006	1

Emission of N_2O from leaching or surface runoff

To calculate the amount of N from leaching or surface runoff, it is also applied data on the use of synthetic nitrogen fertilizers (NFERT).

$$N_2O((L))=N_{FERT}\times FRAC_{LEACH}\times EF_4$$

Where:
$N_2O(L)$ = emission of nitrous oxide associated with leaching or surface runoff (kg N_2O-N);

N_{FERT} = amount of N applied in the form of synthetic fertilizer (kg N/year);

$FRAC_{LEACH}$ = fraction of all N added to soils that are lost through leaching and runoff (kg N leached or runoff/kg of fertilizer);

EF_4= emission factor for N_2O from leaching/runoff (kg N_2O-N/kg N leached/runoff).
Table A3 presents the parameters for N_2O emissions calculation from leaching or surface runoff.

Table A3. | parameters for N_2O emissions calculation from leaching or surface runoff

PARÂMETRO	VALOR	FONTE	TIER
$FRAC_{LEACH}$	0.3	IPCC 1996	1
EF_4	0.025	IPCC 1996	1

APPENDIX 4 – LAND-USE CHANGE

The emissions calculation for land-use change used the carbon change rates characteristic of different types of land-use modification. Tables A4–A8 show the rates for change in land-use under Eucalyptus, Parica, Pine, multi-species planting, and agroforestry systems.

The negative signs (–) indicate an increase in soil carbon (removal of CO_2eq from the atmosphere) and the positive signs indicate emission of CO_2eq.

Table A4. | Soil carbon Change rates (t CO_2 eq/ha/year) for major changes in soil use - *Eucalyptus*

PREVIOUS SOIL USE (TCO_2EQ/HA/YEAR)						
AGE AFTER PLANTING	AGRICULTURE	PASTURE	DEGRADED PASTURE	NATIVE VEGETATION	DEGRADED LAND	REFERENCES
1	−0.48	−0.48	1.35	−0.91	−1.54	Lima et al. 2008; Moreira 2010
2	−0.96	−0.96	0.87	−1.83	−1.54	
3	−1.44	−1.44	−1.44	−2.74	−1.54	
4	−1.92	−1.92	−1.92	−3.65	−1.54	
5	−2.39	−2.39	−2.39	−4.56	−1.54	
6	−2.87	−2.87	−2.87	−5.48	−1.54	
7	−3.35	−3.35	−3.35	−6.39	−1.54	
8	−2.87	−2.87	−2.87	−5.69	−1.54	
9	−2.39	−2.39	−2.39	−5.00	−1.54	
10	−1.92	−1.92	−1.92	−4.30	−1.54	
11	−1.44	−1.44	−1.44	−3.61	−1.54	
12	−0.96	−0.96	−0.96	−2.91	−1.54	
13	−0.48	−0.48	−0.48	−2.21	−1.54	
14	0.00	0.00	0.00	−1.52	−1.54	
15	0.11	0.11	0.11	−1.45	−1.54	
16	0.23	0.23	0.23	−1.38	−1.54	
17	0.34	0.34	0.34	−1.30	−1.54	
18	0.46	0.46	0.46	−1.23	−1.54	
19	0.57	0.57	0.57	−1.16	−1.54	
20	0.69	0.69	0.69	−1.09	−1.54	
21	0.69	0.69	0.69	−1.09	−1.54	

Table A5. | Soil carbon Change rates (t CO_2 eq/ha/year) for major changes in soil use - PARICA

PREVIOUS SOIL USE (T CO_2 EQ/HA/YEAR)						
AGE AFTER PLANTING	AGRICULTURE	PASTURE	DEGRADED PASTURE	NATIVE VEGETATION	DEGRADED LAND	REFERENCES
1	−0.42	−0.40	1.43	−0.66	−1.47	Lima et al. 2008; Moreira 2010
2	−0.84	−0.80	1.03	−1.33	−1.47	
3	−1.26	−1.20	−1.20	−1.99	−1.47	
4	−1.68	−1.61	−1.61	−2.65	−1.47	
5	−2.10	−2.01	−2.01	−3.32	−1.47	
6	−2.51	−2.41	−2.41	−3.98	−1.47	
7	−2.93	−2.81	−2.81	−4.64	−1.47	
8	−3.35	−3.21	−3.21	−5.31	−1.47	
9	−3.77	−3.61	−3.61	−5.97	−1.47	
10	−4.19	−4.01	−4.01	−6.64	−1.47	
11	−4.61	−4.42	−4.42	−7.30	−1.47	
12	−5.03	−4.82	−4.82	−7.96	−1.47	
13	−5.45	−5.22	−5.22	−8.63	−1.47	
14	−5.87	−5.62	−5.62	−9.29	−1.47	
15	−6.29	−6.02	−6.02	−9.95	−1.47	
16	−6.70	−6.42	−6.42	−10.62	−1.47	
17	−7.12	−6.82	−6.82	−11.28	−1.47	
18	−7.54	−7.23	−7.23	−11.94	−1.47	
19	−7.96	−7.63	−7.63	−12.61	−1.47	
20	−8.38	−8.03	−8.03	−13.27	−1.47	
21	−8.38	−8.03	−8.03	−13.27	−1.47	

Table A6. | **Soil carbon Change rates (t CO_2 eq/ha/year) for major changes in soil use - PINE**

PREVIOUS SOIL USE (T CO_2 EQ/HA/YEAR)						
AGE AFTER PLANTING	AGRICULTURE	PASTURE	DEGRADED PASTURE	NATIVE VEGETATION	DEGRADED LAND	REFERENCES
1	−0.48	−0.48	1.35	−0.24	−0.07	IBARR 2016; Adapted from: Lima et al. 2008; Moreira 2010
2	−0.96	−0.96	0.87	−0.48	−0.15	
3	−1.44	−1.44	−1.44	−0.72	−0.22	
4	−1.92	−1.92	−1.92	−0.96	−0.29	
5	−2.39	−2.39	−2.39	−1.20	−0.37	
6	−2.87	−2.87	−2.87	−1.43	−0.44	
7	−3.35	−3.35	−3.35	−1.67	−0.51	
8	−2.87	−2.87	−2.87	−1.91	−0.59	
9	−2.39	−2.39	−2.39	−2.15	−0.66	
10	−1.92	−1.92	−1.92	−2.39	−0.73	
11	−1.44	−1.44	−1.44	−2.63	−0.81	
12	−0.96	−0.96	−0.96	−2.87	−0.88	
13	−0.48	−0.48	−0.48	−3.11	−0.95	
14	0.00	0.00	0.00	−3.35	−1.03	
15	0.11	0.11	0.11	−3.59	−1.10	
16	0.23	0.23	0.23	−3.82	−1.17	
17	0.34	0.34	0.34	−4.06	−1.25	
18	0.46	0.46	0.46	−4.30	−1.32	
19	0.57	0.57	0.57	−4.54	−1.39	
20	0.69	0.69	0.69	−4.78	−1.47	
21	0.80	0.80	0.80	−5.02	−1.54	

Table A7. | Soil carbon Change rates (t CO_2 eq/ha/year) for major changes in soil use - multi-species planting

PREVIOUS SOIL USE (T CO_2 EQ/HA/YEAR)						
AGE AFTER PLANTING	AGRICULTURE	PASTURE	DEGRADED PASTURE	NATIVE VEGETATION	DEGRADED LAND	REFERENCES
1	−0.42	−0.40	1.43	−0.66	−1.47	Lima et al. 2008; Lemos 2011
2	−0.84	−0.80	1.03	−1.33	−1.47	
3	−1.26	−1.20	−1.20	−1.99	−1.47	
4	−1.68	−1.61	−1.61	−2.65	−1.47	
5	−2.10	−2.01	−2.01	−3.32	−1.47	
6	−2.51	−2.41	−2.41	−3.98	−1.47	
7	−2.93	−2.81	−2.81	−4.64	−1.47	
8	−3.35	−3.21	−3.21	−5.31	−1.47	
9	−3.77	−3.61	−3.61	−5.97	−1.47	
10	−4.19	−4.01	−4.01	−6.64	−1.47	
11	−4.61	−4.42	−4.42	−7.30	−1.47	
12	−5.03	−4.82	−4.82	−7.96	−1.47	
13	−5.45	−5.22	−5.22	−8.63	−1.47	
14	−5.87	−5.62	−5.62	−9.29	−1.47	
15	−6.29	−6.02	−6.02	−9.95	−1.47	
16	−6.70	−6.42	−6.42	−10.62	−1.47	
17	−7.12	−6.82	−6.82	−11.28	−1.47	
18	−7.54	−7.23	−7.23	−11.94	−1.47	
19	−7.96	−7.63	−7.63	−12.61	−1.47	
20	−8.38	−8.03	−8.03	−13.27	−1.47	
21	−8.38	−8.03	−8.03	−13.27	−1.47	
22	−8.38	−8.03	−8.03	−13.27	−1.47	
23	−8.38	−8.03	−8.03	−13.27	−1.47	
24	−8.38	−8.03	−8.03	−13.27	−1.47	
25	−8.38	−8.03	−8.03	−13.27	−1.47	
26	−8.38	−8.03	−8.03	−13.27	−1.47	
27	−8.38	−8.03	−8.03	−13.27	−1.47	
28	−8.38	−8.03	−8.03	−13.27	−1.47	
29	−8.38	−8.03	−8.03	−13.27	−1.47	
30	−8.38	−8.03	−8.03	−13.27	−1.47	
31	−8.38	−8.03	−8.03	−13.27	−1.47	
32	−8.38	−8.03	−8.03	−13.27	−1.47	
33	−8.38	−8.03	−8.03	−13.27	−1.47	
34	−8.38	−8.03	−8.03	−13.27	−1.47	
35	−8.38	−8.03	−8.03	−13.27	−1.47	
36	−8.38	−8.03	−8.03	−13.27	−1.47	
37	−8.38	−8.03	−8.03	−13.27	−1.47	
38	−8.38	−8.03	−8.03	−13.27	−1.47	
39	−8.38	−8.03	−8.03	−13.27	−1.47	
40	−8.38	−8.03	−8.03	−13.27	−1.47	

Table A8.| **Soil carbon Change rates (t CO_2 eq/ha/year) for major changes in soil use - agroforestry systems**

PREVIOUS SOIL USE (T CO_2 EQ/HA/YEAR)						
AGE AFTER PLANTING	AGRICULTURE	PASTURE	DEGRADED PASTURE	NATIVE VEGETATION	DEGRADED LAND	REFERENCES
1	–8.73	–1.61	0.22	–3.08	–7.33	Lima et al. 2008; Lemos 2011
2	–8.73	–1.61	0.22	–3.08	–7.33	
3	–8.73	–1.61	–1.61	–3.08	–7.33	
4	–8.73	–1.61	–1.61	–3.08	–7.33	
5	–8.73	–1.61	–1.61	–3.08	–7.33	
6	0.00	–1.61	–1.61	–3.08	0.00	
7	0.00	–1.61	–1.61	–3.08	0.00	
8	0.00	–1.61	–1.61	–3.08	0.00	
9	0.00	–1.61	–1.61	–3.08	0.00	
10	0.00	–1.61	–1.61	–3.08	0.00	
11	0.00	–1.61	–1.61	0.00	0.00	
12	0.00	–1.61	–1.61	0.00	0.00	
13	0.00	–1.61	–1.61	0.00	0.00	
14	0.00	–1.61	–1.61	0.00	0.00	
15	0.00	–1.61	–1.61	0.00	0.00	
16	0.00	–1.61	–1.61	0.00	0.00	
17	0.00	–1.61	–1.61	0.00	0.00	
18	0.00	–1.61	–1.61	0.00	0.00	
19	0.00	–1.61	–1.61	0.00	0.00	
20	0.00	–1.61	–1.61	0.00	0.00	
21	0.00	0.00	0.00	0.00	0.00	
22	0.00	0.00	0.00	0.00	0.00	
23	0.00	0.00	0.00	0.00	0.00	
24	0.00	0.00	0.00	0.00	0.00	
25	0.00	0.00	0.00	0.00	0.00	
26	0.00	0.00	0.00	0.00	0.00	
27	0.00	0.00	0.00	0.00	0.00	
28	0.00	0.00	0.00	0.00	0.00	
29	0.00	0.00	0.00	0.00	0.00	
30	0.00	0.00	0.00	0.00	0.00	
31	0.00	0.00	0.00	0.00	0.00	
32	0.00	0.00	0.00	0.00	0.00	
33	0.00	0.00	0.00	0.00	0.00	
34	0.00	0.00	0.00	0.00	0.00	
35	0.00	0.00	0.00	0.00	0.00	
36	0.00	0.00	0.00	0.00	0.00	
37	0.00	0.00	0.00	0.00	0.00	
38	0.00	0.00	0.00	0.00	0.00	
39	0.00	0.00	0.00	0.00	0.00	
40	0.00	0.00	0.00	0.00	0.00	

We emphasize that the carbon change rates in the soil are estimates and still under investigation. In future, we hope to include change rates specific to soil texture and different Brazilian regions, depending on the available literature.

In addition, the values of carbon change rates in the soil are constant, since there is still inadequate information on depletion curves or carbon abatement over time in the different agricultural and forest systems. More regional studies of this nature are needed

APPENDIX 5 – CARBON STORAGE IN FOREST BIOMASS

Eucalyptus, pine and parica

For the carbon removal calculation by forest biomass in eucalyptus, parica and pine plantations, the company or farmer reports the volume or productivity per hectare of planting. This will automatically open a list of productivity ranges for users to select the option that best suits their planting, from 2 to 80 m^3/ha/year.

Multi-species planted forests

In the case of this forest module, the timber productivity of native species relates to their respective growth rate, divided into three groups:

- rapid growth rate: up to 15 years for clear-cutting;
- moderate growth rate: up to 25 years for clear-cutting; and
- low growth rate: up to 40 years for clear-cutting.

The company or farmer selects the timber species and if the timber species are not included in the available species list, the user has the option to select the default for each growth group.

Agroforestry systems

The agroforestry systems (mixing agricultural and planting systems) module for the timber productivity of native species relates to their respective growth rate, divided into three groups:

- rapid growth rate: up to 15 years for clear-cutting;
- moderate growth rate: up to 25 years for clear-cutting; and
- low growth rate: up to 40 years for clear-cutting.

Note: trees may be harvested before the maximum growth periods estimated for each group. Carbon present in the biomass is included in the calculation of exports for the year in which the harvest takes place. If these wood species are not harvested at the end of the maximum estimated growth period, the carbon stored in the biomass is kept constant from this age and computed in the final balance of the removals. The fruit species yields relate to their respective growth and size, divided into the following groups:

- Fast growth rate and high stature
- Fast growth rate and medium stature
- Fast growth rate and low stature
- Moderate growth rate and high stature
- Moderate growth rate and medium stature
- Moderate growth rate and low stature
- Low growth rate and high stature
- Low growth rate and medium stature
- Low growth rate and low stature

The company or farmer selects the timber and fruit species of interest. In addition, because it is an agro-foretry system, the user has the option to indicate the growth period of annual species in the area, adding 0.5 metric ton of C per hectare/year into the system with the presence of these species (Carvalho et al. 2010).

For the five modules of the tool, the carbon stored in the biomass is determined according to the equation below:

$$CO_2Biomass=Vol\times Dens\times C\_f\times 44/12$$

Where:

CO_2Biomass = CO_2 eq removal associated with total biomass in metric ton per hectare

Vol. = volume (m^3) per hectare or per tree

D = basic wood density, kg. m^{-3}

CF = carbon fraction of dry matter

44/12 = conversion factor from C to CO_2 (dimensionless).

Moreover, the tool calculates the CO_2 eq removal in different biomass compartments as shown in Table A9.

Table A9.| **Carbon fraction and biomass partition in the shoot, root, and litter (%)**

PART	TECHNICAL DETAILS	FRACTION	REFERENCES
Biomass	Eucalyptus	45	Vidaurre 2010
Biomass	Parica	45	Vidaurre 2010
Biomass	Pine	41	Corte and Sanquetta 2007
Biomass	Timber and fruit species	44	Modified from Forster and Melo 2007; Ferez 2010
Shoot	Eucalyptus	84	Neves 2000
Shoot	Parica	65	Cairns et al. 1997; Brown 2002; EMBRAPA 2006
Shoot	Pine	66	Modified from Cairns et al. 1997; Brown 2002; EMBRAPA 2006
Shoot	Timber and fruit species	70	Modified from Forster and Melo 2007; Ferez 2010
Litter	Eucalyptus	5	Neves 2000
Litter	Parica	10	Cairns et al. 1997; Brown 2002; EMBRAPA 2006
Litter	Pine	10	Modified from Cairns et al. 1997; Brown 2002; EMBRAPA 2006
Litter	Timber and fruit species	10	Modified from Forster and Melo 2007; Ferez 2010
Root	Eucalyptus	11	NEVES 2000
Root	Parica	25	Cairns et al. 1997; Brown 2002; EMBRAPA 2006
Root	Pine	24	Modified from Cairns et al. 1997; Brown 2002; EMBRAPA 2006
Root	Timber and fruit species	20	Modified from Forster and Melo 2007; Ferez 2010

Note: 5% of the parica wood used for lamination is residue and burned after processing. In this case, 5% of carbon considered is biogenic.

In estimating basic wood density, we used specific data for each species from numerous sources in the scientific literature. When using a generic composition of a species group, the basic density applied is an average of all species of these groups, being 530, 680 and 780 kg / m^3, respectively, for the groups of species with rapid, moderate and slow growth rates.[12]

The first version of the tool includes the transition from native forests to other uses. It considers as emissions, for the GHG final balance, the carbon stored in native vegetation and converted to other uses. It also considers different ecological macro-regions to determine the carbon stored in plant biomass, which are Amazonia - Ombrophylous and Seasonal; Amazonia – Cerrado (Brazilian savanna) and Campina; Caatinga; Cerrado (Brazilian savanna); Cerrado (Brazilian savanna) – North; Atlantic Forest – Seasonal; Atlantic Forest – Mix; Atlantic Forest – Ombrophylous; Pampas and Pantanal. The carbon values stored in native vegetation are shown in Table A10.

Table A10. | **Initial carbon stock in the biomass to transition native vegetation.**

BIOME	INFORMATION	CARBON STOCK (T CO_2 EQ/HA)	REFERENCES
Amazonia	Ombrophylous and Seasonal	573.16	Brazil 2016
Amazonia	Cerrado (Brazilian savanna) and Campina	86.38	
Caatinga	-	159.57	
Cerrado	-	115.92	
Cerrado	North	378.63	
Atlantic forest	Seasonal	361.72	
Atlantic forest	Ombrophylous	539.45	
Atlantic forest	Mix	504.34	
Pampas	-	92.10	
Pantanal	-	150.52	

APPENDIX 6 – OPERATIONAL ACTIVITIES

The calculation of direct GHG emissions from the use of fuel in mechanized operations was performed in two ways.

Fuel Consumption

One of the approaches provided by the calculation tool is the GHG emissions from diesel and biodiesel consumption on the production site, and the amount of ethanol and gasoline used in internal operations, which excludes the amount of fuel used to transport material from the place of production to its final destination, considered scope 3.

In this case, calculation carried out uses the emission factors shown in Table A11 and in the equation below:

$$CO_{(2\,fuel)} = Q_{fuel} \times FE_{fuel}$$

Where:
CO_2 fuel = CO_2 emission associated with fuel consumption (kg CO_2e)

Q_{fuel} = amount of fuel consumed (L)

FE_{fuel} = fuel emission factor (kg CO_2/L)

Table A11. | **Diesel and biodiesel Emission factors**

SOURCE	EMISSION FACTOR	INFORMATION	UNIT OF MEASUREMENT	REFERENCES
Diesel	0.00268100	Tier 1	metric ton CO_2/l	IPCC 2006; DEFRA GHG 2009/2010
Diesel	0.00000002		metric ton N_2O/l	IPCC 2006; DEFRA GHG 2009/2010
Diesel	0.00000030		metric ton CH_4/l	IPCC 2006; DEFRA GHG 2009/2010
Gasoline A	0.00221200		metric ton CO_2/l	BRAZIL 2014
Biodiesel	0.002499	Biogenic emission	metric ton CO_2/l	IPCC 2006; DEFRA 2009/2010
Ethanol anhydrous	0.001526		metric ton CO_2/l	Brazil 2014
Ethanol hydrated	0.001457		metric ton CO_2/l	Brazil 2014

In Brazil, pure biodiesel (B100) is mandated to be added to petroleum diesel in proportions that increase in accordance with the legislation in force. In 2008, the mandatory addition of biodiesel (B2) in diesel oil was 2 percent. As of January 2010, it rose to 5 percent biodiesel (B5); and from the second half of 2014, the mandatory percentage of biodiesel increased to B6 in July 2014, B7 in November 2014, B8 in March 2017, B9 in March 2018, and B10 in March 2019 (Table A12).

The calculation tool takes account of all these percentages with the emissions calculated separately for diesel and its renewable fraction.

Table A12.| **Fuel composition**

FUEL	INFORMATION	PROPORTION	REFERENCES
Diesel	Until 2007	100	Brazil 2014
Diesel B2	Mandatory from 2008	98	Brazil 2014
Diesel B5	Mandatory from 2010	95	Brazil 2014
Diesel B6	Mandatory from 07/2014	94	Brazil 2014
Diesel B7	Mandatory from 11/2014	93	Brazil 2014
Diesel B8	Mandatory from 03/2017	92	Brazil 2016
Diesel B9	Mandatory from 03/2018	91	Brazil 2016
Diesel B10	Mandatory from 03/2019	90	Brazil 2016

The allocation of the emissions in the scope is shown in Table A13.

Table A13. | **Allocation of emissions**

EMISSIONS ALLOCATION	DIESEL			BIODIESEL		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Scope 1	X	X	X		X	X
Biogenic Carbon				X		

Mechanized operations estimates

We calculated mechanized operations according to the operating need-by-activity worksheets per hectare. This worksheet estimates the average consumption of diesel and biodiesel during operations and calculates GHG emissions. Due to the elevated number of estimates, this approach introduces an implicit error that is the difference in consumption and the need for hours of each machine according to soil type, soil moisture, species to be cultivated, amount of fertilizer to be applied, and so on.

The average mechanized hours per hectare and fuel consumption in liters per m^3 in plantations of eucalyptus, parica, pine, multi-species planting, and agroforestry systems are shown in Tables A14–A18.

Table A14. | **Mechanized operations for eucalyptus cultivation and operational yield in hours per hectare**

STAGE	OPERATION	DETAIL	OPERATIONAL PRODUCTIVITY	UNIT OF MEASUREMENT	REFERENCES
Permanent	Maintenance of roads and carriers	-	0.00	Mechanized hours / hectare	Consultations with forestry companies
	Fire-breaks	-	0.26		
Stage 1 - Pre-implementation	Waste disposer	-	3.00		
	Chemical weeding	-	1.00		
	Liming	-	1.00		
	Sub soiling/groove	-	2.00		
	Groove/marking	-	2.00		
Stage 2 - Implantation	Mechanized planting	-	0.00		
	Irrigation	-	1.00		
Stage 3 – Post-implantation	Spraying	-	0.60		
Stage 4 – Maintenance	Spraying	-	0.60		
	Mechanized planting	-	1.30		
Harvest/Thinning	Harvest/Thinning	Feller-buncher	0.44	Liter/m^3	Simões 2008; Oliveira 2013
	Harvest/Thinning	Harvester	0.58		
	Harvest/Thinning	Skidder	0.25		
	Harvest/Thinning	Forwarder	0.38		

Note: Estimates include the permanent growth stages, pre-planting, planting, post-planting, maintenance, and operational yield in liters/m^3 at the harvesting and thinning stages.

Table A15. | **Mechanized operations for the Parica cultivation and operational yield in hours per hectare**

STAGE	OPERATION	DETAIL	OPERATIONAL PRODUCTIVITY	UNIT OF MEASUREMENT	REFERENCES
Permanent	Maintenance of roads and carriers	-	0.26	Machanized hours /hectare	Consultations with forestry companies
	Fire-breaks	-	0.26		
Stage 1 – Pre-implementation	Cleansing	-	0.60		
	Liming	-	0.64		
	Sub soiling	-	1.40		
	Harrowing	-	0.70		
	Chemical weeding	-	0.60		
Stage 2 – Implantation	Planting	-	0.00		
	Irrigation	-	1.20		
	Replanting	-	0.20		
Stage 3 – Post-implantation	Chemical weeding	-	1.46		
	Top-dressing	-	0.90		
	Cleansing	-	1.10		
Stage 4 – Maintenance	Chemical weeding	-	1.46		
	Top-dressing	-	0.95		
	Cleansing	-	1.60		
Harvest/Thinning	Harvest/Thinning	Feller-buncher	0.44	Liter/m^3	Simões 2008; Oliveira 2013
	Harvest/Thinning	Harvester	0.58		
	Harvest/Thinning	Skidder	0.25		
	Harvest/Thinning	Forwarder	0.38		

Note: Estimates include the permanent growth stages, pre-planting, planting, post-planting, maintenance, and operational yield in liters/m^3 at the harvesting and thinning stages.

Table A16. | **Mechanized operations for the Pine cultivation and operational yield in hours per hectare**

STAGE	OPERATION	DETAIL	OPERATIONAL PRODUCTIVITY	UNIT OF MEASUREMENT	REFERENCES
Permanent	Terracing	-	3.20	Mechanized hours/ hectare	Prata 2012
	Maintenance of roads and carriers	-	8.00		Consultations with forestry companies
	Fire-breaks	-	1.20		Prata 2012
Stage 1 – Pre-implementation	Stub reduction	Crusher	3.00		Suzano 2006
	Stub reduction	Grater	2.50		Suzano 2006
	Cleansing	Belt	1.50		Suzano 2006
	Cleansing	Roller-knife	3.00		Mendes 2008
	Cleansing	Mechanical grubber	2.00		Consultations with forestry companies
	Cleansing	Chemical	1.00		Prata 2012
Stage 2 – Implantation	Sub soiling	Depth < = 60	1.50		Suzano 2006
	Sub soiling	Depth > 60	2.30		Suzano 2006
	Holes opening	Mechanical trough	1.60		Suzano 2006
	Liming	-	0.40		Suzano 2006
	Planting	-	1.30		Consultations with forestry companies
	Irrigation	-	2.50		Suzano 2006
	Planting fertilization	-	2.80		Prata 2012
Stage 3 – Post-implantation	Cleansing	Mechanical grubber	1.00		Prata 2012
	Cleansing	Chemical	0.60		Mendes 2008
	Top-dressing	-	0.50		Suzano 2006
	Fire-breaks Maintenance	-	0.05		Prata 2012
Harvest/ Thinning	Harvest/Thinning	Feller-buncher	0.32	Liter/m^3	Consultations with forestry companies
	Harvest/Thinning	Harvester	0.66		
	Harvest/Thinning	Skidder	0.27		
	Harvest/Thinning	Forwarder	0.31		

Note: Estimates include the permanente growth stages, pre-planting, planting, post-planting, maintenance, and operational yield in liters/m^3 at the harvesting and thinning stages.

Table A17. | **Mechanized operations for the multi-species planting cultivation and operational yield in hours per hectare**

STAGE	OPERATION	DETAIL	OPERATIONAL PRODUCTIVITY	UNIT OF MEASUREMENT	REFERENCES
Permanent	Fire-breaks	-	1.20	Mechanized hours / hectare	Consultation with specialists; data provided by forestry companies; SMA 2012
	Areas fencing	-	1.60		
	Fence maintenance	-	0.32		
Stage 1 – Pre-implementation	Cleansing	Mechanical	2.50		
	Cleansing	Chemical	2.00		
Stage 2 – Implantation	Soil preparation	Minimum cultivation, sub soiling	2.00		
	Soil preparation	Harrowing	6.00		
	Liming	-	2.00		
	Planting of seedlings	-	4.00		
	Seed planting	-	2.00		
	Irrigation	Hydrogel	2.00		
Stage 3 – Post-implantation	Basis fertilizer	-	2.00		
	Top-dressing	-	1.00		
	Irrigation	-	2.00		
	Preliminary cleansing	-	2.00		
Harvest/ Thinning	Harvest/Thinning	Feller-buncher	0.44	Liter/m^3	Simões 2008; Oliveira 2013
	Harvest/Thinning	Harvester	0.58		
	Harvest/Thinning	Skidder	0.25		
	Harvest/Thinning	Forwarder	0.38		

Note: Estimates include the permanent growth stages, pre-planting, planting, post-planting, maintenance, and operational yield in liters/m^3 at the harvesting and thinning stages.

Table A18. | **Mechanized operations for the Agroforestry - AFS cultivation and operational yield in hours per hectare**

STAGE	OPERATION	DETAIL	OPERATIONAL PRODUCTIVITY	UNIT OF MEASUREMENT	REFERENCES
Permanent	Fire-breaks	-	1.20	Hourly-machine/ hectare	Consultation with specialists; data provided by forestry companies; SMA 2012
	Areas fencing	-	1.60		
	Fence maintenance	-	0.32		
	Mechanical cleansing	Grubber	0.70		
	Spraying	-	0.80		
	Pruning	Trimmer	1.00		
	Mechanical cleansing	Grubber	1.00		
Stage 1 – Pre-implementation	Mechanical cleansing	Clearing	2.50		
	Chemical cleansing	-	2.00		
Stage 2 – Implantation	Soil preparation	Minimum cultivation, sub soiling	2.00		
	Soil preparation	Harrowing	6.00		
	Liming	-	2.00		
	Planting of seedlings	-	4.00		
	Seed planting	-	2.00		
	Irrigation	Hydrogel	2.00		
	Holes opening	Motor-drilling	1.00		
Stage 3 – Post-implantation	Basis fertilizer	-	2.00		
	Top-dressing	-	1.00		
	Irrigation	-	2.00		
	Preliminary cleansing	-	2.00		
Harvest/ Thinning	Harvest of fruits	-	1.00	Mechanized hours	
	Harvest/Thinning	Chainsaw	1.00	Liter/m^3	

Note: Estimates include the permanente growth stages, pre-planting, planting, post-planting, maintenance, and operational yield in liters/m^3 at the harvesting and thinning stages.

The equation for the diesel consumption calculation in mechanized uses is:

$$Q_{DIESEL} = HM_{ha} \times A_P \times 20$$

Where:

HM/ha = Hourly-machine per hectare (h/ha)

AP = planted area (ha)

20 = average diesel consumption per machine hour (liters/h).

APPENDIX 7 – PURCHASED ELECTRICITY

The average CO_2 emission factors for purchased electricity to be used in inventories are intended to estimate the amount of CO_2 associated with a given electricity source. The average generation emissions calculated take into account all power plants that are generating electricity, not only those that are operating at the margin. If all electricity consumers of the National Interconnected System (SIN) calculated their emissions by multiplying the energy consumed by this emission factor, the sum would correspond to the emissions of the SIN. It therefore serves for general, corporate, or other GHG inventories.

The emission factors for the calculation associated with the purchased electricity are Tier 2 (Table A19).

Table A19. | **Average monthly and annual emission factors between 2006 and 2016**

PREVIOUS SOIL USE (T CO_2 EQ/HA)													
YEAR	JAN	FEV	MAR	APR	MAI	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE
2006	0.0322	0.0346	0.0337	0.0275	0.0317	0.0306	0.0351	0.0336	0.0383	0.036	0.0265	0.028	0.0323
2007	0.0229	0.0195	0.0195	0.0197	0.0161	0.0256	0.031	0.0324	0.0355	0.0377	0.0406	0.0496	0.0293
2008	0.0584	0.0668	0.0599	0.0453	0.0459	0.0521	0.0437	0.0425	0.0411	0.0438	0.0334	0.0477	0.0484
2009	0.0281	0.0237	0.0247	0.0245	0.0405	0.0369	0.0241	0.0199	0.0162	0.0179	0.0181	0.0194	0.0246
2010	0.0211	0.028	0.0243	0.0238	0.0341	0.0506	0.0435	0.0774	0.0907	0.0817	0.0869	0.0532	0.0512
2011	0.0262	0.0288	0.0208	0.0198	0.027	0.0341	0.0308	0.0301	0.0273	0.035	0.0356	0.0349	0.0292
2012	0.0294	0.0322	0.0405	0.0642	0.062	0.0522	0.0394	0.046	0.0783	0.0984	0.1247	0.1168	0.0653
2013	0.1151	0.109	0.0981	0.0959	0.1151	0.1079	0.0838	0.0833	0.084	0.0831	0.093	0.0841	0.0960
2014	0.0911	0.1169	0.1238	0.1310	0.1422	0.1440	0.1464	0.1578	0.1431	0.1413	0.1514	0.1368	0.1355
2015	0.13	0.13	0.14	0.13	0.13	0.14	0.12	0.12	0.12	0.12	0.11	0.11	0.1244
2016	0.0960	0.0815	0.0710	0.0757	0.0701	0.0760	0.0725	0.0836	0.0897	0.0925	0.1002	0.0714	0.0817

Source: http://www.mct.gov.br/index.php/content/view/321144.html#ancora

The formula to calculate the emissions from purchased electricity is:

$$CO_{2\,EE} = EE \times FE$$

Where:

$CO_{2\,EE}$ = CO_2 emission (metric ton CO_2);

EE = electric energy consumption (MW/h)

EF = national emission factor (metric ton CO_2/ MW/h)

APPENDIX 8 – BIOMASS BURNING

During the burning process, 98 percent of the biomass consumed is converted to emissions and the remaining 2 percent is incorporated into the soil as charcoal, and is accounted for as biogenic carbon removal (FEARNSIDE 2002). The CO_2 emissions are also biogenic.

Table A20 presents the CO_2, N_2O and CH_4 fractions of emission of biomass burning in the case of accidentally occurring forest fires.

Table A20. | **Fractions of CO_2, N_2O, and CH_4 in emissions from biomass burning**

SOURCE	FRACTION (%)	REFERENCES
CO_2	73.1	Fearnside 1997; Fearnside 2002; Fearnside et. al. 2013
N_2O	2.6	
CH_4	24.3	

Note: Emission fractions sum to 100% but account for 98% of biomass consumed during burning.

ENDNOTES

1. In agroforestry systems the perennial woody plants are managed in association with herbaceous plants, shrubs, agricultural and forage crops in the same management unit. Multi-species plantations are systems in which exclusively arboreal, perennial and long-cycle species are used, to be managed in order to obtain timber or non-timber products, in different exploration cycles.
2. According to the definitions in Decision 16/CMP.1 (UFCCC 2013), both Afforestation and Reforestation refer to direct human-induced conversion of non-forested land to forested land. The distinction between Afforestation and Reforestation is related to the period of time the land has been non-forested. Afforestation occurs on land that has not been forested for at least 50 years. Reforestation occurs on land that has been forested more recently but has been converted to non-forest land, and was non forested on 31 December 1989.
3. In Brazil, the Federal Law 12.651/2012, also known as the Forest Code, establishes general norms for the protection of native vegetation on rural properties and defines the legal regime of the Legal Reserve areas and permanent protection areas (APP). By this law, the forests and other forms of native vegetation existing in the national territory, with a recognized utility to the lands in which they are located, are common interest goods to all the inhabitants of the country, and the rights of property are allowed within the limitations established by the law. The Legal Reserve (LR) is the minimum percentage that a rural property or land possession should maintain with native vegetation and its function is to ensure the sustainable economic use of the natural resources of the rural property while promoting the conservation of biodiversity and other ecosystem services. This percentage can vary from 20% to 80% of the area of the rural property or land possession, depending on the biome and region in which it is located. Considering the economic use of LR areas, a lot has been discussed about policies to encourage the restoration of these areas through models that balance the production of timber and non-timber so as to contribute to the development of native species silviculture in multi-species systems and, at the same time, to the conservation as a way to implement a green economy in the country.
   The Permanent Protection Areas (APP), are protected areas with the environmental function of preserving the water resources, the landscape, the geological stability and the biodiversity, and of protecting the soil and facilitate the genetic flow of fauna and flora. APP restoration is possible through the implementation of Agroforestry Systems, especially for family farmers properties. For Legal Reserve and APP area that are devoid of native vegetation, the country has created the Environmental Regularization Program (PRA), through which rural property owners should restore native vegetation of protected areas within a maximum period of 20 years. The total environmental liability is estimated to be around 19 to 21 million hectares (Soares-Filho 2013; Guidotti et al. 2017). The Private natural heritage reserve is a private category of conservation unit considered in the Brazilian Conservation Units National System (SNUC).
4. According to the Policy and Action Standard AFOLU Sector Guidance, forestry is considered an agricultural activity. (WRI 2015)
5. Non-mechanical GHG emissions: · Drainage and tillage of soils: CO_2, CH_4, and N_2O · Addition of synthetic fertilizers, livestock waste, and crop residues to soils: CO_2, CH_4, and N_2O · Addition of urea and lime to soils: CO_2 · Enteric fermentation: CH_4 · Rice cultivation: CH_4 · Manure management: CH_4 and N_2O · Land-use change: CO_2, CH_4, and N_2O · Open burning of savannahs and of crop residues left on fields: CO_2, CH_4, and N_2O · Managed woodland (e.g., tree strips, timberbelts): CO_2 · Composting of organic wastes: CH_4 · Oxidation of horticultural growing media (e.g., peat): CO_2.
6. The homogeneous systems present specific calculation modules for the Eucalyptus, Pine and Parica species, since them have been studied for a long time in Brazil, including, for instance, planting and genetic development history, and conduction of plantings techniques.
7. The carbon emissions and removals were based in were based on the guidelines used by the Third National Communication on Anthropogenic Greenhouse Gas Emissions (MCTIC 2016) and the IPCC Guidelines (IPCC 2006).
8. GHG emissions from fires: biomass combustion (56.5% CO_2eq), decomposition (41.6%) and stored as charcoal (1.9%) (Fearnside et al. 2013).
9. This category includes carbon stored in the soil and plant biomass of forest plantations. To emphasize the high carbon stock potential of the forest systems contemplated in the tool is reported separately from the biogenic compartment.
10. CO_2 emissions from conversions of native vegetation to any other type of land use should be counted as Scope 1. These emissions should not be considered as biogenic CO_2 emissions because carbon stored in native vegetation is permanently lost to the atmosphere with the change in land use.
11. According to Corporate Standard rules, except native vegetation converted to other uses, already contemplated, land-use change loses carbon in the biomass at Scope 1.
12. The value of the basic wood density of each species used for each species in the GHG Forestry Calculation Tool is in the "Variable Factors" tab.

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