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# Methodology: Short rotation Paulownia tree cultivation

Carbon farming through Paulownia trees, in order to increase the carbon sequestration capacity on former fallow, crop or pasture land.

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# List of Definitions

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| Above Ground Biomass (AGB) | All living vegetative material above the soil including stem, stump, branches, bark, seeds, and foliage |
| Additionality | Refers to the concept that any carbon removal or reduction Project should result in greenhouse gas emissions improvements that would not have occurred without the Project. In other words, the Project's positive impact on reducing or removing emissions should be "additional" to what would have happened under the business-as-usual scenario. |
| Allometric equation | Mathematical models used to estimate a specific biological parameter (e.g., total tree biomass or volume) based on easily measurable variables (such as tree diameter at breast height or height). These equations are vital for accurately assessing biomass and carbon storage in Short rotation forestry projects. |
| Baseline Scenario | Hypothetical reference case that best represents the conditions most likely to occur in the absence of a proposed GHG project. |
| Below Ground Biomass (BGB) | It includes all living biomass of live roots. Fine roots of less than two mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter. |
| Buffer pool | A Buffer Pool is a reserve of Carbon Credits established to cover potential losses in GHG Projects, ensuring the integrity of emissions reductions or removals over time. The size of the Buffer Pool is aligned with the level of (reversal) risks associated with the GHG Project. |
| Carbon Dioxide equivalent - $CO_2e$ | A metric used to compare the emissions of various greenhouse gases based on their Global Warming Potential (see GWP definition). It expresses the impact of different gases in terms of the equivalent amount of CO2, facilitating a standardized approach to assessing overall greenhouse gas emissions. |
| Carbon Fraction | The proportion of biomass that is composed of carbon. This value is critical in calculating the total carbon storage in tree biomass, as it allows for the translation of biomass weight into equivalent carbon content. |
| CDM | The CDM, contained in Article 12 of the Kyoto Protocol, allows governments or private entities in industrialized countries to implement emission reduction projects in developing countries and receive credit in the form of “certified emission reductions,” or CERs, which they may count against their national reduction targets. The CDM strives to promote sustainable development in developing countries, while allowing developed countries to contribute to the |

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| | goal of reducing atmospheric concentrations of greenhouse gases. |
| Conservativeness | In the context of greenhouse gas accounting and reporting, conservativeness refers to the principle of applying cautious assumptions, values, methodologies, and procedures when estimating greenhouse gas emissions and removals. This approach ensures that any potential uncertainties in data or methods result in underestimations rather than overestimations of emissions. The principle of conservativeness is critical to maintaining the integrity of GHG inventories, ensuring that emission reductions or removal are real, measurable, and verifiable. By adhering to this principle, organizations can avoid overstating their environmental performance and contribute to more accurate and reliable climate action reporting |
| Diameter at Breast Height (DBH) | It is a standard method of expressing the diameter of the trunk of a standing tree. It is measured at a standardized height of 1.3 meters above ground level. DBH is a fundamental component of forest inventory systems, which track tree growth, assess forest health, and manage timber resources effectively. It is often used in allometric equations and is crucial for determining the growth rate, timber volume, and carbon sequestration potential of trees in short rotation forestry projects. |
| Emission factors | Emission factors are coefficients that quantify the amount of greenhouse gases released into the atmosphere per unit of activity, substance, or process. They are essential tools in calculating emissions based on fuel consumption, industrial processes, or agricultural practices, facilitating the estimation of a project's total greenhouse gas emissions. |
| FAO | The Food and Agriculture Organization is a UN agency leading international efforts to defeat hunger, improve agriculture, and ensure food security. FAO offers essential guidance and data on forestry through its publications, contributing significantly to global knowledge on sustainable forest management and conservation. |
| GHG project | Activity or activities that alter the conditions of a GHG Baseline and which cause GHG emission reductions or GHG removal enhancements. The intent of a GHG Project is to convert the GHG impact into Carbon Credits. |
| GHG protocol | GHG Protocol establishes comprehensive global standardized frameworks to collect, account, calculate, and manage greenhouse gas (GHG)<br>emissions from private and public sector operations, value chains and mitigation actions. |
| Global Warming Potential (GWP) | A metric that measures the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO2). GWP is calculated over a specific time period, typically 100 years, providing a common scale for comparing the climate impact of different gases. |
| Harvest Cycle | The period between the planting and harvesting of trees in Short rotation Paulownia tree cultivations. This cycle is characterized by the rapid growth and biomass accumulation of trees, culminating in their harvest for timber, biomass energy, or other uses. |

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| IPCC | The Intergovernmental Panel on Climate Change is a United Nations body, assessing science related to climate change to provide policymakers with regular scientific updates. |
| Leakage | In the context of a GHG Project, leakage refers to the unintended increase in greenhouse gas emissions outside the Projects Boundaries as a direct result of the Project's activities. |
| Monitoring | The systematic observation and recording of parameters or conditions over time. In short rotation forestry projects, monitoring involves tracking tree growth, health, and other ecological factors to evaluate carbon sequestration effectiveness and overall forest health. |
| Permanence | Permanence refers to the assurance that the carbon reductions or removals achieved by a GHG Project will remain effective and won't be reversed over time. |
| Specific Wood density | It is a measure of how much a certain volume of wood weighs, expressed in kilograms per cubic meter ($kg/m^3$). It reflects the compactness of the wood's structure, varying across different tree species and influenced by growth conditions. This density is crucial in forestry for assessing the timber quality and calculating the volume of wood material. |
| Sprouting | In the context of forestry, sprouting is often observed after a tree has been cut down or damaged, where new shoots grow from the stump or roots of the tree. This natural regeneration mechanism allows trees to recover from felling, ensuring survival and continued growth |
| Tree height | It refers to the vertical distance from the base of the tree (at ground level) to its highest point, typically the tip of the highest branch. It is a key variable in allometric equations to estimate tree biomass and volume. |
| Volume | In forestry terms, volume refers to the total cubic space occupied by the trunk (wood) biomass. It is a critical measure for estimating the amount of wood and biomass available in a forest stand, typically expressed in cubic meters. |

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# List of Abbreviations

| | |
|---|---|
| AGB | Above Ground Biomass |
| BEF | Biomass Expansion Factor |
| BGB | Below Ground Biomass |
| DBH | Diameter at Breast Height |
| GHG | Greenhouse Gas/gases |
| POD | Project overview document |
| SSRs | Sources, Sinks, and Reservoirs |
| THT | Total Height of the Tree (including crown) |
| IPCC | Intergovernmental Panel of Climate Change |
| FAO | Food and Agriculture Organization of the United Nations |
| CDM | Carbon Development Mechanism |

# Summary

This methodology document serves as a comprehensive guide for evaluating the impact on greenhouse gas (GHG) emissions mitigation (reductions and enhanced removals) of short-rotation Paulownia tree cultivation, achieved through detailed measurements and calculations. Paulownia's fast growing biomass is meant to be used into bio-based construction materials or products with a long lifespan, thus keeping the $CO_2$ sequestered for several decades.

This document aims to offer clarity and coherence in understanding the process of establishing baseline carbon stocks and evaluating the role of Paulownia trees as a long-term carbon sink through the use of their wood in various applications. This methodology is based on rigorous research and utilizes established methodologies and standard values as detailed in scientific literature and reports from recognized Climate Change and Carbon Management Frameworks, including the IPCC, CDM, FAO, and the GHG Protocol. Each step is specifically outlined, offering a clear path to measure, monitor, and quantify $CO_2$ sequestration of the project from the establishment of the plantation until the delivery of the wood that will be processed into timber and will be used in long-lifespan constructions.

Through systematic data collection, assessment methodologies, and utilization considerations, this document aims to assist project developers in comprehensively evaluating the carbon sequestration potential of Paulownia tree plantations.

# 1. Introduction

## 1.1. Paulownia characteristics

Paulownia species such as *Paulownia tomentosa*, *Paulownia elongata*, known for their rapid growth and adaptability to various environmental conditions, are emerging as significant species in biomass production and carbon sequestration efforts (Jakubowski, 2022). Recognized as one of the fastest-growing tree species globally, Paulownia's capacity for quick growth and high biomass yield make it ideal for short-rotation forestry (Yadav et al., 2013) . This characteristic is particularly valuable in the context of climate change, as it can sequester large amounts of atmospheric CO2 in both its above-ground and below-ground parts (Joshi, 2015). Native to China and found in diverse regions worldwide (Europe, the USA, and Australia), Paulownia exhibits traits such as resistance to rot, dimensional stability, and a high ignition point, enhancing its timber's market value (Jakubowski, 2022). Its versatility and the increasing demand for wood and wood-based materials position Paulownia as a vital resource for sustainable forestry and renewable energy sources. Some examples of Paulownia wood products are veneers, blockboards, engineered wood, plywood, furniture, kitchen items, and instruments (Jakubowski, 2022). Lastly, Paulownia's unique ability to regenerate through sprouting is a key component of this process. After each harvest, new shoots emerge from the stumps, utilizing the established root system to rapidly grow, thereby enabling continuous carbon absorption without the need for replanting. This cycle of growth, harvest, and regeneration allows for ongoing carbon sequestration, efficiently reducing atmospheric CO2 levels.

## 1.2. Applicability of methodology

This methodology applies to GHG projects that want to cultivate fast-growing Paulownia trees for their carbon sequestration abilities, capturing carbon in both their above-ground and below-ground (root systems) biomass. These Paulownia plantation projects can be regarded as a sequence of activities in which Paulownia based products will be monitored from cultivation until the delivery of the harvested wood to the timber construction companies. .

A project can consist of multiple harvest cycles since the harvesting can be repeated multiple times as it is mentioned based on the physiology of Paulownia species. It is necessary for project developers to establish a specific procedure or process that verifies the use of harvested timber as construction material, thereby securing the long-term storage of the carbon. Detailed description and guidelines can be seen in the next chapter “1.3. Permanence“.

Additionally this methodology document aims to increase the cooperation of parties like landowners, farmers, building material processors, and area developers. Applicability of this methodology, in terms of geographical boundaries, is limited to the European Union and in terms of cultivations:

- Traditional cultivation: This type of cultivation is 100% harvested in years 7-10
- Mid-harvest cultivation: This cultivation type contains a mid-harvest between year 4-6 (depending on growing seasons)

The methodology is not applicable under the following conditions:

- Land use change to cultivating Paulownia involves deforestation
- Land that has been deforested within the last 10 or 20 years
- Plantations meant to harvest biomass for biofuels, or wood pellets for the biomass energy generation
- Plantations occuring on protected areas (e.g. Natura 2000, National Parks)
- Plantations occurring on lands of significant historical or societal value
- The use in construction of Paulownia based products instead of other products with a higher emission factor (e.g. steel, concrete). For this so-called “material switch” intervention, another methodology can be used.

This methodology document has been written in line with the Proba Standard[1].

## 1.3. Permanence

Permanence is a crucial aspect as it reflects the time period during which the sequestered carbon remains out of the atmosphere, which is critical for long-term carbon accounting and climate impact mitigation. In accordance with Proba Standards, this methodology is specifically applied to projects where harvested timber from Paulownia plantations is used for construction. This use ensures the sequestration of carbon for a minimum of 40 years, complying with the lifecycle of the constructed materials.

Given that over half of the current housing stock in the EU was constructed before 1970, it is expected a minimum lifespan of 40 years for these buildings, with 120 years being a plausible duration[2]. Moreover, with recent policy developments such as circular economy legislation, it is

[1] https://proba.earth/hubfs/Product/The_Proba_standard.pdf?hsLang=en
[2] https://research.tue.nl/nl/publications/assessment-of-the-sustainability-of-flexible-building-the-improve

becoming more probable that buildings and the materials that they are made of will last beyond a century.

To guarantee that the wood is used as planned rather than for short-term storage products (e.g., wood pellets for biomass power stations, single use bio-plastics), the project developer will adhere to strict requirements and controls. During the verification event, which may occur up to three years post-harvest, the final use of the wood products will be investigated as part of the verification audit (contracts). This audit will confirm:

- The total volume of wood products sold and their corresponding carbon content (tCO2e).
- The alignment of these volumes with the Proba Credits that will be issued based on the harvest cycles.
- The business agreements between the project developer and their customers mandate a 40-year storage period and specify the proportion of the wood destined for long-lasting products and the duration of their use.
- The auditor must include wood processors or makers of Paulownia wood products to the scope of the Verification audit. This information must ensure and provide traceability down the supply chain.

### 1.3.1. Assessment and management of non-Permanence risk

Addressing non-permanence risk is vital for ensuring the long-term success of carbon sequestration projects. Non-permanence risk refers to the possibility that sequestered carbon might be released back into the atmosphere due to several factors. This risk should be assessed at the project level and based on the guidelines of CDM "Inputs on modalities and procedures for alternative approaches to addressing the risk of non-permanence" in order to ensure effective management and mitigation strategies.

The risk of non-permanence in carbon sequestration projects, such as those involving Paulownia timber used in construction, encompasses both natural and anthropogenic factors. Natural risks include events such as fire, storms, pests, and diseases, while anthropogenic risks involve human activities like unauthorized harvesting,land-use change, or the biomass being used for short-lived products (e.g. pellets for energy production) instead of products with a long lifespan.

A life cycle assessment (LCAs) of the products that are made out of the Paulownia wood in later stages of the project (presented in the POD) will assist in identifying the specific carbon storage duration and end-of-life of the products. It is stated in the "Land Sector and Removals Guidance"[3] document, “products that incorporate biogenic based carbon are capable of storing carbon for the duration of the product and its materials’ lifetime”. In future versions of this methodology, a specific LCA focused on the use of Paulownia wood will be developed and included. This LCA assessment will provide more information regarding potential leakage during the process of the raw material (e.g. wood waste).

## 1.4. Risks

For every short rotation Paulownia tree cultivation project, the Project Developer should at least assess and address the following risks that can affect the calculations of the carbon estimations and measurements.

- Risk of overestimation of carbon stocks
- Risk of the occurrence of human activities that reduce product volumes
- Risk of regulatory changes
- Reversal risk of fire
- Reversal risk of other weather events (eg. frost and storms)
- Reversal risk of water availability
- Reversal risk of pests and diseases
- Risk of leakage
- Long term continuity of the plantations
- Low demand for construction materials originated from Paulownia wood

## 1.5. Crediting Period

[3] https://ghgprotocol.org/sites/default/files/2022-12/Land-Sector-and-Removals-Guidance-Pilot-Testing-and-Review-Draft-Part-1.pdf

For Paulownia plantation projects, the Crediting Period must cover at least one full harvest cycle, typically 7 to 10 years (the project developer should define the exact period based on the project's specific cultivation plan). After the determined harvest year, the Project Developer can apply for a Renewal of the Crediting Period, as described in the Proba Standard Section 3.2[4]. The project Developer must re-assess the baseline scenario and project emissions with the new context, and where possible update the carbon sequestration potential of the plantation based on the project's characteristics.

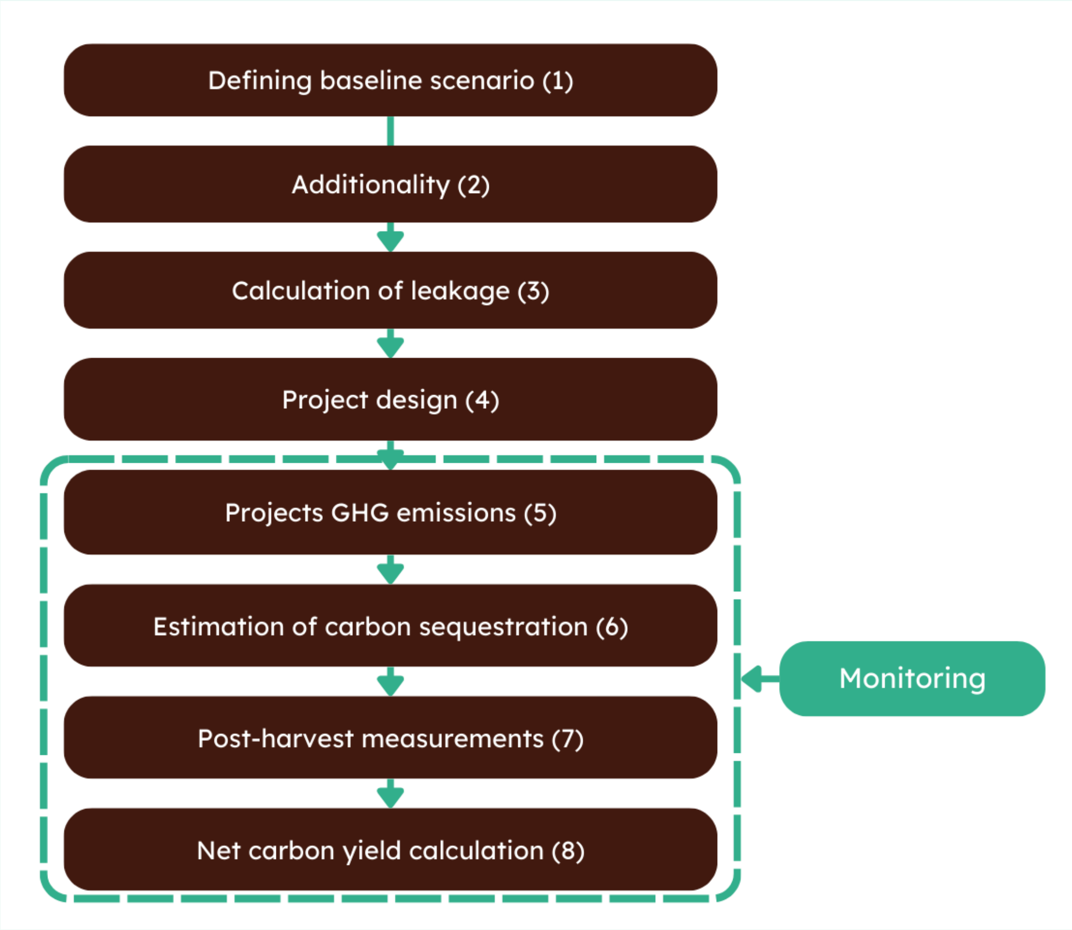
### 1.6. Co-benefits

This methodology doesn't prescribe any calculation methods for quantifying additional benefits resulting from Paulownia plantation projects. Proba expects that every Paulownia plantation projects contribute to at least one or more UN Sustainable Development Goals[5], and expects that project developers, farmers or landowners will take these into account when preparing and designing a project.

## 2. Process Overview

The flowchart below demonstrates each phase in the process of estimating and measuring carbon storage in Short rotation Paulownia tree cultivation projects. It shows each step, from the start of the plantation to the end calculations of the carbon storage (net carbon yield).

[4] https://proba.earth/hubfs/Product/The_Proba_standard.pdf?hsLang=en
[5] https://sdgs.un.org/goals




## 2.1. Defining baseline scenario

Before initiating the planting process, it is crucial to establish a comprehensive understanding of the baseline scenarios and their respective carbon stocks. This initial step involves an examination of sinks, sources, and reservoirs (SSRs). SSRs encompass the dynamic elements influencing carbon fluxes within the ecosystem, including the capacity of the land to sequester carbon (sinks), factors contributing to carbon emissions (sources), and existing reservoirs or storage of carbon within soil and vegetation.

When determining the baseline, a project developer should use a baseline reference period of 3 to 10 years, to estimate the GHG balance  of what would happen over the project period in the absence of the project.  This is in line with the GHG Protocol Agricultural Guidance[6] that recommend to use a base period of at least three years. In this way crop rotation cycles will be included and average GHG fluxes are more accurate.

Three distinct scenarios characterize baseline carbon stocks based on the land's prior usage:

a) Empty land//fallow land

c) Pasture land/Grassland

b) Crop land (conventional farming)

Table 1 provides an overview of sources and sinks of both baseline scenarios. Both scenarios are further explained.

*Table 1: GHG sources and sinks of baseline scenarios to be considered*

| | | Baseline scenarios | | |
|---|---|---|---|---|
| GHG sources | GHG type | Empty/Fallow land | Pasture | Crop land (conventional |

[6] https://ghgprotocol.org/sites/default/files/2022-12/GHG%20Protocol%20Agricultural%20Guidance%20%28April%2026%29_0.pdf

| | | | | |
|---|---|---|---|---|
| | | | land/Grassland | farming) |
| *Plowing activities* | CO2 | NO | NO | YES |
| *Mowing* | CO2 | NO | YES | NO |
| *Livestock* | CH4 | NO | YES | NO |
| *Drainage/tillage* | CO2, CH4, N2O | NO | NO | YES |
| *Planting crops/trees machinery* | CO2 | NO | NO | YES |
| *Irrigation installation machinery* | CO2 | NO | Optional | YES |
| *Transport of employees* | CO2 | NO | Optional | YES |
| *Water pump electricity* | CO2 | NO | Optional | YES |
| *Fertilizer use* | CO2, CH4, N2O | NO | Optional | YES |
| *Harvesting machinery* | CO2 | NO | NO | YES |
| | | | | |
| Carbon sinks/pools | GHG type | Empty/Fallow land | Pasture land/Grassland | Crop land (conventional farming) |
| *Soil organic carbon (SOC)* | CO2 | YES | YES | YES |

| | | | | |
|---|---|---|---|---|
| *Non-tree biomass (Grass, Herbs, etc)* | $CO_2$ | NO | Optional | Optional |
| *Litter (Small branches, Leaves, Lying dead wood, etc)* | $CO_2$ | NO | NO | Optional |
| *Above Ground Biomass (AGB)* | | NO | NO | Optional |
| *Stem* | $CO_2$ | | | |
| *Branches* | $CO_2$ | | | |
| *Bark* | $CO_2$ | | | |
| *Leaves* | $CO_2$ | | | |
| *Below Ground BIomass (BGB)* | | NO | NO | Optional |

Note: The categories listed in the baseline scenarios table represent a broad framework; however, they may require adjustment to align with the specific characteristics and requirements of each project. It is the responsibility of the project developer to provide evidence and justify the inclusion or exclusion of particular categories.

### 2.1.1. Scenario 1: Empty/Fallow land

Description: for this scenario, research has shown that the land:

- Has not been used for the past 10 year for human activities that have an impact on the land
- Has no clear plan for future use, and it is restricted to be part of a development project (agriculture, housing, industrial etc.) during the project period and buffer.

Sources: In the absence of recent or intensive land-use practices like agriculture, deforestation, or degradation, GHG emissions are expected to be notably low. Minimal human activities and insignificant microbial decomposition of organic matter characterize this scenario.

Sinks: Limited natural sinks due to the relatively undeveloped state of the land. Soil organic carbon and existing vegetation are anticipated to exhibit minimal or negligible carbon sequestration potential. It is assumed, in agreement with *IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (2003)*[7] that the net GHG removals by sinks in the baseline equals zero.

Reservoirs: Both soil organic carbon and existing vegetation reservoirs are likely to be minimal, aligning with the land's prolonged fallow period and reduced anthropogenic influence.

For each GHG project using this methodology and having this baseline scenario, this results in the following assumption:

| ***Sources=0, Sinks=0, Reservoirs=0, GHG baseline=0*** |
| --- |

Note: These assumptions are fitted to the scenarios where there are no trees or small shrubs. If there is evidence indicating the presence of mature trees on the empty/fallow land, the carbon sinks and reservoirs should be evaluated properly.

### 2.1.2. Scenario 2: Pasture land/Grassland

Description: In this scenario, the land designated for Paulownia tree plantation previously served as Pasture land/Grassland, primarily utilized for grazing livestock. This land typically features a mix of grasses and other ground cover, managed to support animals such as cattle, sheep, or goats.

Sources: On pasture land, the main sources of emissions include methane (CH4) from livestock digestion and manure, as well as CO2 emissions from soil disturbance due to grazing.

[7] https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf

Sinks: The grasses and soil in pasture lands act as carbon sinks, capturing CO2 from the atmosphere through photosynthesis and soil organic matter accumulation.

Reservoirs: The primary carbon reservoirs in pasture lands are the soil organic carbon (SOC) and the biomass of grasses and other vegetation.

### 2.1.3. Scenario 3: Previously Cropland, conventional farming

Description: In this scenario, the land where Paulownia trees are planted was formerly used for agricultural annual crops (cereals, crop rotation system).

Sources: The historical use of the land for crop cultivation implies potential greenhouse gas (CO2, NO2) sources, including emissions from synthetic fertilizers, plowing, machinery, and various soil management practices. Assessments typically follow a Scope 1, 2, 3 approach.

Note: Historical data of similar cultivation can be used, or emission factors specific to the region can be used for the calculations.

Sinks: Despite prior cultivation, some carbon sinks might persist in residual vegetation or soil organic carbon. In case specific data for residual vegetation and soil organic carbon assessment is not readily available, refer to Appendix 1.2 for further guidance.

Reservoirs: While reservoirs in the form of SOC and existing vegetation might exist, their quantity and capacity may have been impacted by previous agricultural practices. These reservoirs might exhibit reduced capacity due to the land's historical use.

Regarding the calculations of the Baseline emissions, refer to Appendix 1, where relevant emission factors databases, methodologies, and calculation tools are presented.

## 2.2. Additionality

Following the establishment of the baseline scenario and the estimation of the associated GHG emissions, demonstrating the additionality of Short rotation Paulownia tree cultivation projects is essential in order to issue credits under the Proba Standard. The additionality demonstration in this methodology follows the guidelines of CDM and aligns with international standards. Project developers are instructed to use CDM's: Methodological tool Combined tool to identify the baseline scenario and demonstrate additionality for this purpose.

Projects must adhere to all three additionality definitions: regulatory, financial and prevalence as explained in the Proba Standard. In many situations, both in developed and developing countries, the relevant information for the determination of additionality is not readily available. Data availability whether financial, technological, or social issues, should guide the choice of additionality testing approach.

### 2.2.1. Regulatory

Regulatory additionality assesses whether the project activities go beyond legal requirements. It evaluates whether the project activities are mandated by existing laws or if they exceed regulatory requirements. Project developers must assess the regional and national regulatory environment relevant to the project. They should provide a comprehensive legal review, including documents from relevant laws and regulations, to demonstrate that the project is not a legal obligation.

### 2.2.2. Financial

Financial additionality determines whether the project is financially viable without carbon credit revenues. This criterion evaluates whether the project would be financially feasible without the income from carbon credits. An investment analysis should be conducted to compare costs and benefits between the GHG project, the chosen baseline scenario, and alternative scenarios. This analysis should include all relevant financial aspects, such as capital and operational costs, projected revenues, and potential financial risks. The analysis should be tailored to the specific financial situation of the project developer to ensure accuracy. It should include costs related to monitoring emissions and removals, (Scope 3 emissions from product use). Appropriate financial indicators such as Internal Rate of Return (IRR), Net Present Value (NPV), payback period, and cost-benefit ratio should be used. Transparency is key, and all assumptions and input data should be provided to allow for validation by third parties. For instance, if the project requires significant upfront investment and ongoing maintenance costs that cannot be recovered through market revenues alone, the investment analysis should demonstrate that carbon credits are essential for financial viability.

### 2.2.3. Prevalence

Prevalence additionality, or common practice analysis, evaluates whether the proposed project activities are already widely adopted in the project area. This criterion determines whether the project activity is not a common practice in the region that takes place. A common practice analysis should be conducted to evaluate the extent to which similar activities have been implemented in the project area. This involves an analysis of historical and current land use practices within the region. A detailed report comparing the proposed project to existing similar activities should be provided, including data on the prevalence of such activities and justifying any differences. For example, if short rotation Paulownia tree cultivation projects are not commonly practiced in the region due to market barriers, technological barriers (absence of technical knowledge among local farmers) or other factors, the project can demonstrate its uniqueness and innovative approach.

### 2.2.4. Barrier Analysis

The Project Developer must provide a barrier analysis to identify and document obstacles that prevent the project from being realized without carbon finance. This criterion identifies significant barriers that would prevent the project from being implemented without carbon credit revenue. Types of barriers include investment barriers, institutional barriers, technological barriers, and social barriers. Evidence of these barriers should be provided through market studies, expert opinions, regulatory analysis, and stakeholder consultations. For instance, if the project faces significant technological barriers due to the unavailability of high-quality Paulownia seedlings or advanced cultivation techniques, these challenges should be documented and explained how carbon finance can help overcome them.

The Project Developer must provide a barrier analysis to identify and document obstacles that prevent the project from being realized  without carbon finance. The CDM "Guidelines for objective demonstration and assessment of barriers"[8] provide help for identifying, assessing, and reporting barriers.

## 2.3. Leakage

Following the establishment of baseline scenarios, it's imperative to address potential leakage to ensure a comprehensive understanding of a project's net carbonyield. Leakage occurs when project-induced carbon sequestration efforts inevitably lead to increased GHG emissions or diminished sequestration outside the project area. This phenomenon may occur when converting cropland or pasture land into a Paulownia plantation. This leads to the relocation of agricultural activities. Such displacement might result in those activities being reestablished in new locations, consequently generating emissions. Mitigating such leakage involves careful project design and

[8] https://cdm.unfccc.int/EB/050/eb50_repan13.pdf

management strategies to minimize external impacts, ensuring a project's net carbon impact accurately reflects its environmental contribution.

Baseline Scenario 1

As the project area is set on formerly unused land, there is no risk of leakage, as no activity was performed on the planted land prior to the project.

Baseline Scenarios 2, 3

If the land was used for crops or pasture, the Project analyzes the consequences of the discontinuation of the production within the relevant geographical scope. For example, if the land was used for potatoes, will the farming of potatoes be moved to another location within the economic zone? In which proportion?

Using historical data on land use and trends in the economic region and running interviews with market stakeholders can help make an assumption for the leakage. If the leakage risk is high, then the net carbon yield calculation should be corrected accordingly to avoid overestimating the potential yield. Further explanation of how it should be incorporated in the calculation of net carbon yield please refer to section 2.8. Annual Net Carbon Yield and Total Net Carbon Yield.

### 2.3.1. Quantifying and managing Leakage

Estimating displaced activities: The initial phase involves estimating the volume of agricultural production (grains and cereals) or the amount of livestock that will be displaced by the Paulownia plantation project. Understanding the land's current agricultural yield or livestock  and the market demand for these two is crucial. This step lays the foundation for assessing the broader impacts of the project on local and potentially international markets.

Assessing market dynamics: Following the estimation of displaced activities, the project developer examines how the reduction in local crop production influences market dynamics. This includes potential increases in imports or a shift in production to other domestic or international regions, factoring in the project's broader economic ripple effects.

Evaluating Land-Use changes: Should agricultural production relocate, the project developer assesses the consequent land-use changes in the new area. This entails evaluating whether the transition leads to the creation of new agricultural lands, possibly at the expense of natural habitats, and the associated GHG emissions from such conversions.

Drawing from established guidelines such as those from the IPCC and CDM, the developer can accurately estimate and quantify the leakage.

- A/R Methodological tool Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity
- Methodological tool Project and leakage emissions from biomass

Calculating Leakage: The project developer then quantifies the total GHG impact of leakage, expressing this as a percentage of the baseline emissions. This calculation offers insight into the scale of leakage compared to the project's anticipated environmental benefits.

Considering indirect effects: Indirect effects, such as alterations in market prices due to reduced crop and livestock availability and their influence on production decisions elsewhere, are also considered. These effects necessitate a broader view of the project's impact on agricultural markets and production patterns.

Monitoring and updating estimates: Acknowledging the dynamic nature of leakage, the project developer commits to regular monitoring and updating of estimates based on actual observed changes in agricultural and land-use patterns over time.

Documentation and verification: Finally, thorough documentation of all methodologies, data sources, and assumptions used in the leakage analysis is maintained. This documentation is crucial for the verification process, especially pertinent if the project aims to generate carbon credits.

## 2.4. Plantation design

This chapter provides guidance for project developers on designing a Paulownia plantation project optimized for carbon sequestration. A crucial aspect of this design is the strategic layout and structure of the plantation. This foundational planning plays an important role in determining the effectiveness of ongoing monitoring activities. Precision in data gathering is important for a thorough assessment of the project's carbon sequestration performance. The actions that the project developer should follow are described below:

1. Site Preparation:
    a. Conduct soil quality assessments, considering Paulownia's specific soil preferences. This includes recent soil samples, topography evaluation, and existing vegetation assessment.

   b. Review land history, particularly previous agricultural use, as Paulownia species can benefit from or be hindered by certain soil conditions.
   c. Pinpoint the exact geographical coordinates or identify the specific location, taking into account Paulownia's climatic requirements.
2. Selection of Paulownia species or varieties:
   a. Choose between different Paulownia species/varieties, considering local climate and soil conditions. Tree density per hectare may vary based on the tree species and environmental factors of the plantation site.
   b. Consider the crown size of different Paulownia species/varieties, ensuring sufficient sunlight and growth potential for effective carbon sequestration.

3. Planting Density and Layout:
   a. Determine optimal planting density to balance growth rate, tree shape, and biomass production based on the chosen Paulownia species/varieties.
   b. Layout should facilitate efficient maintenance and harvesting, considering factors like access routes and machinery operation.
   c. Table 2 illustrates the table template that is required by the project developer to utilize for the collection of the necessary data that need to be submitted related to the Paulownia plantation's attributes (input data).

*Table 2: Paulownia plantation's input data*

| Location | Paulownia species | Amount of hectares (ha) | Amount of plots/ha | Density/Number of trees (trees/ha) | Distribution between rows (m) | Distribution between trees (m) |
|---|---|---|---|---|---|---|
| ... | ... | ... | ... | ... | ... | ... |

Note: The amount of trees per plot and the amount of plots per hectare can vary depending on the project's spatial scale and harvesting plans.

4. Incorporating a mortality ratio:

   a. This ratio reflects the expected percentage of tree losses based on specific characteristics of the project location, including climatic conditions, pest prevalence, and management practices.
   b. Apply the mortality ratio annually to reflect expected losses, adjusting the count of surviving trees in the plantation.
5. Biodiversity Considerations:
   a. Monitor the impact of Paulownia plantation on local biodiversity and ecosystems.
   b. Recommendation to make use of sterile hybrid trees that do not affect the local flora.
   c. Regulatory and CPVO Compliance: Ensure plantation adherence to all local, national, and EU environmental and plant protection regulations, securing the CPVO [9] code for Paulownia varieties to fulfill legal requirements and improve traceability.
   d. EU Compliance for Paulownia: Countries within the EU are deemed suitable for Paulownia species plantations, based on the EU's invasive alien species report.[10]
6. Socio-economic Factors:
   a. Engage with local communities to ensure the project supports local needs and sustainable development.
   b. Consider job creation, community benefits, and potential impacts on local land use and resources

## 2.5. Determine project emissions

It is important to clearly define the project boundary and include all relevant emission sources to accurately assess the total carbon benefit potential (Net carbon yield, Phase 6). Additionally, regular updates of the SSRs occurring during the implementation phase will ensure that any changes in emission sources are accounted for and properly addressed. In Table 3 emission sources included in or excluded from the project boundary can be seen.

*Table 3: Project emissions to be considered*

| | | | | |
|---|---|---|---|---|
| One-time | Irrigation installation machinery | CO2 | Yes | This equipment consumes fossil fuels during operations |

[9] https://cpvo.europa.eu/en
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02016R1141-20220802&from=EN

| | | | | |
|---|---|---|---|---|
| | Plowing machinery | $CO_2$ | Yes | This equipment consumes fossil fuels during operations |
| | Herbicide application machinery | $CO_2$ | Yes | This equipment consumes fossil fuels during operations |
| | Fertilizer application machinery | $CO_2$ | Yes | This equipment consumes fossil fuels during operations |
| | Emissions from soil | $CO_2$<br>$NO_2$<br>$CH_4$ | Yes | Emissions resulting from soil disturbances associated with land preparation and planting activities. |
| | Transport of young trees | $CO_2$ | Yes | Vehicle use for young trees transportation generates $CO_2$ emissions through fossil fuel combustion |
| | Planting trees machinery | $CO_2$ | Yes | This equipment consumes fossil fuels during operations |
| | Transport of employees | $CO_2$ | Yes | Vehicle use for employee transportation generates $CO_2$ emissions through fossil fuel combustion |
| | | | | |
| Recurring | Maintenance machinery | $CO_2$ | Yes | Machinery used for maintenance operations utilizes fossil fuels, contributing to GHG emissions |
| | Harvesting machinery | $CO_2$ | Yes | Similar to planting and maintenance machinery, harvesting equipment consumes fossil fuels |
| | Fertilizer emissions | $NO_2$ | Yes | These type of emissions occur from the soil because of the fertilizer applications |
| | Water pump electricity | $CO_2$ | Yes | Electricity consumption for water pumping often relies on fossil fuel-powered sources, leading to $CO_2$ emissions.<br><br>If it can be proven that electricity from renewables is used, this source becomes zero. |

| | | | | |
|---|---|---|---|---|
| | Transport of employees | $CO_2$ | Yes | Vehicle use for employee transportation generates $CO_2$ emissions through fossil fuel combustion |
| | Transport of timber | $CO_2$ | Yes | Vehicle use for timber transportation generates $CO_2$ emissions through fossil fuel combustion |

### 2.5.1. Total Greenhouse gases (GHG) sources

Throughout the growth stages of the Paulownia trees, a range of emissions that occur only once and others that are generated from ongoing activities need to be calculated separately. These emissions collectively account for the total greenhouse gas (GHG) sources (equation 1) of the short rotation Paulownia tree cultivation project.

$$PEtotal = GHGonetime + GHGreccuring \quad \textbf{(eq. 1)}$$

Where:

| | |
|---|---|
| $PE_{total}$ (eq. 1) | Total amount of GHG sources during project's period |
| $GHG_{one-time}$ | Total amount of GHG emissions prior to and during the planting period |
| $GHG_{reccuring}$ | Total amount of GHG emissions during the monitoring visits (growth period) and harvesting period |

To accurately calculate total greenhouse gas (GHG) sources and to avoid GHG emissions underestimations in this period, it is critical to include both one-time emissions that occur during the implementation phase (such as land preparation and planting) and recurring emissions that arise from ongoing activities like monitoring visits and harvesting.

### 2.5.2. One-time project emissions

These equations encompass emissions from activities carried out prior to and during the planting period. Given that these activities, such as preparing the soil, installing irrigation systems, and transporting saplings and employees, occur only once in the project's lifetime, their associated emissions represent a unique subset of the project's total GHG footprint.

The project developer has two options for accounting for these emissions:

Immediate Deduction After First Harvest: This approach involves deducting  the total emissions calculated from these equations once, immediately following the first harvest. This method acknowledges the upfront nature of these emissions, attributing them entirely to the project's initial phase.

Spreading Across 40 Years: Alternatively, the total emissions can be evenly distributed over a 40-year period, reflecting a long-term view of the project's impact. In this scenario, each year accounts for 1/40th of these initial emissions. This method considers the emissions impact over the project's lifespan, aligning it with the long-term lifespan of the Paulownia plantation

Note: During the lifespan of the project, any revisions to the Global Warming Potential (GWP) values and emission factor (EF) may require a recalculation of the project emissions. This ensures that the project remains aligned with the most current scientific and regulatory standards

$$GHGonetime = GHGprior, plant + GHGdur, plant$$ **(eq. 2)**

Where:

| | |
|---|---|
| $GHG_{one\text{-}time}$ (eq. 2) | Total amount of GHG emissions prior to and during the planting period |
| $GHG_{prior,plant}$ (eq. 3) | Total amount of GHG emissions before planting |
| $GHG_{dur,plant}$ (eq. 4) | Total amount of GHG emissions during the planting period |

Prior to the planting period (equation 3), quantifying emissions requires a thorough evaluation of various management practices. This assessment encompasses emissions resulting from the use of machinery during the installation of irrigation systems, plowing, and potential herbicide, pesticide, and fertilizer applications. Prior to planting, these treatments are used to prepare the soil and control weeds, ensuring a favorable environment for tree growth. Additionally, it extends to accounting for emissions related to employee transportation to the site.

$$GHGprior, plant = GHGma, ir + GHGma, plo + GHGma, herb + GHGempA, trans + GHGma, fert\ldots$$ **(eq. 3)**[11]

Where:

[11] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_14_An2_SumEqua.pdf

| | |
|---|---|
| *$GHG_{prior,plant}$ (eq. 3)* | Total amount of GHG emissions before planting |
| *$GHG_{ma,ir}$* | GHG emissions due the usage of irrigation machinery |
| *$GHG_{ma,plo}$* | GHG emissions due to the plowing machinery |
| *$GHG_{ma,herb}$* | GHG emissions due to the herbicide application machinery |
| *$GHG_{ma,fert}$* | GHG emissions due to the fertilizer application machinery |
| *$GHG_{empA,trans}$* | GHG emissions due to the transportation of the employees"A" |

During the planting period (equation 4), the quantification of emissions is based on assessing the various aspects of tree planting activities. This involves evaluating emissions generated from machinery operations, the transportation of saplings (young trees), and employee transportation during the initial phase of tree planting.

$$GHGdur, plant = GHGma, pla + GHGsapl, trans + GHGempB, trans + \ldots$$ **(eq. 4)**[12]

Where:

| | |
|---|---|
| $GHG_{dur,plant}$ | Total amount of GHG emissions during the planting period |
| $GHG_{ma,pla}$ | GHG emissions due the usage of planting machinery |
| $GHG_{trans,sapl}$ | GHG emissions due to the transportation of the young trees |
| $GHG_{empB,trans}$ | GHG emissions due to the transportation of the employees"B" |

[12] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_14_An2_SumEqua.pdf

### 2.5.3. Recurring emissions

These equations encompass emissions from activities conducted during the growth (monitoring visits), such as the use of maintenance machinery, electricity for irrigation, transportation of the employees and the application of fertilizers. Additionally, during the harvesting stage, which occurs every 7-10 years based on Paulownia species/variety attributes, emissions originate from harvesting machinery operation, employee transportation, and timber transport. These recurring emissions form a continuous component of the project's GHG footprint, requiring regular assessment and management.

$$GHGreccuring = GHGdur, grow, year + GHGdur, harv, period$$ **(eq. 5)**

Where:

| | |
|---|---|
| $GHG_{reccuring}$ | Total amount of GHG emissions during the monitoring visits (growth period) and harvesting period |
| $GHG_{dur,grow,year}$ | Total amount of GHG emissions during monitoring visits the (growing period) the year "y" |
| $GHG_{dur,harv,period}$ | Total amount of GHG emissions during the Harvesting period "p" |

During the growth period (equation 6) of the trees, quantifying emissions involves assessing the impact of maintenance machinery, the electricity consumption from water pumps used for irrigation, and fertilizer application if any. This encompasses monitoring emissions generated during the various phases of tree development.

$$GHGdur, grow, year = GHGma, main + GHGel, ir + GHGfert, emis + \ldots$$ **(eq. 6)**[13]

Where:

| | |
|---|---|
| $GHG_{dur,grow,year}$ | Total amount of GHG emissions during monitoring visits the (growing period) the year "y" |

[13] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_14_An2_SumEqua.pdf

| | |
|---|---|
| $GHG_{ma,main}$ | GHG emissions due to the machinery used for maintenance |
| $GHG_{fert,emis}$ | GHG emissions from the soil due to fertilizer application |
| $GHG_{el,ir}$ | GHG emissions due to the electricity that was consumed by the water pump (irrigation system) |

During the Harvesting period (equation 7) which will be scheduled at regular intervals every few years based on the growth rate and maturity of the tree species, calculating emissions is crucial. This involves assessing emissions from harvesting machinery, employees, and timber transportation. These factors contribute significantly to the project's environmental footprint throughout the harvest cycle.

$$GHGdur, harv = GHGempC, trans + GHGma, harv + GHGtimb, trans + \ldots$$

**(eq. 7)**[14]

Where:

| | |
|---|---|
| $GHG_{dur,harv}$ | Total amount of GHG emissions during the Harvesting period |
| $GHG_{empC,trans}$ | GHG emissions due to the transportation of the employees"C" |
| $GHG_{ma, harv}$ | GHG emissions due to the machinery used for harvesting |
| $GHG_{timb,trans}$ | GHG emissions due to timber transportation |

[14] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_14_An2_SumEqua.pdf

In this methodology document, both recurring and one-time emissions are identified and addressed. However, project developers are instructed to provide a detailed timeline table in the project overview document. This table should outline all project activities and their respective timings on an annual basis. The project developer must use relevant emission factors for each activity. Based on these timelines, the project emissions should be calculated and deducted annually in the NCYannual, which will be detailed in a later chapter. This approach ensures that emissions are accurately accounted for each year

In Appendix 1, databases containing  information on emission factors can be found, offering insights into emissions associated with various activities.

## 2.6. Estimation of Carbon Sequestration

The Project developer is responsible for estimating and adequately presenting the carbon sequestration potential of their Paulownia plantation. This key phase builds upon the use of essential formulas which are based on scientific standards. In order for these biomass estimates to be translated into carbon storage, the carbon fraction of biomass and the conversion of this carbon into $CO_2$ equivalent will be applied.

The carbon sequestration potential should be precisely calculated and presented using the **tool** that was developed for this purpose. Project developers should input their data and generate accurate estimates. Example templates that closely resemble the actual sheets in the tool are included in each of the following sections.

Note: The tool includes detailed instructions and also offers some features to be customized, allowing project developers to tailor the calculations to their specific plantation conditions and management practices.

### 2.6.1. Standard Values and Allometric Equation:

The use of standardized values and allometric equations is essential for the estimation procedure of the plantation's carbon sequestration potential. These values and equations have been researched and validated to provide reliable estimates of plantation growth and carbon sequestration potential. Table 4 provides a detailed presentation of the data set that are applied and used as inputs in the tool. These data are tailored for the Paulownia species, and based on scientific literature/research.

*Table 4: Standardized values and Allometric equation for Paulownia species*

| Parameter | Value | Source |
|---|---|---|
| Wood Density (ρ) | 275 kg/m³ | Multiple references (see Appendix 1) |
| Carbon Content | 47% | IPCC 2006[15] |
| Biomass Expansion Factor (branches, twigs, etc) | 1.3 | IPCC, Good Practice Guidance for Land Use, Land-Use Change and Forestry[16] |
| Allometric Equation (eq. 8) | $ln(VOL) = f(ln(DBH^2 * THT))$ | Berg et al., 2020[17] |
| Below Ground Biomass (BGB) "root-shoot ratio" | 15% of AGB | ICIMOD (2015)[18], MacDicken (1997)[19], Nabin et al., (2018)[20] |
| C to CO2 | 3.67 | Pearson et al. (2007) |

Note: Refer to Appendix 2.1 for more information on these standard values and the allometric equation.

[15] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf
[16] https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf
[17] https://doi.org/10.1007/s11676-019-01021-9
[18] https://lib.icimod.org/record/31838
[19] https://www.researchgate.net/publication/237434580_A_Guide_to_Monitoring_Carbon_Storage_in_Forestry_and_Agroforestry_Projects#fullTextFileContent
[20] https://bioeconomysolutions.com/wp-content/uploads/2020/10/Carbon-Sequestration-Ability-of-Paulownia-tomentosa-Steud.pdf

## 2.6.2. Applying Information from the “Plantation Design” Phase

The data gathered in the Plantation Design Phase will be inputted into the tool designed for calculating the plantation's overall carbon sequestration potential. Essential details such as the total area in hectares density of trees per hectare (of each Paulownia plantation location) and tree mortality rate, are necessary for estimating the total amount of carbon that is sequestered across the entire project spatial boundaries.

## 2.6.3. Growth Rate Assumptions:

Assumptions about averages of DBH and THT will be utilized for preliminary estimations. These will be based on data from similar Paulownia projects (climatic conditions, soil composition) and scientific sources. They will inform initial estimations of biomass (based on biophysical attributes, volume, and wood density) of the trees.. If the project developer possesses substantial growth rate data that closely aligns with the climatic conditions and soil composition of the location where the plantation will occur, the potential use of this data can be discussed and be used in the calculation tool.

*Table 5: Average values derived from tree measurements (Inputs) and estimated biomass of AGB, BGB, and Plant Waste (Outputs), based on established assumptions.*

| | Biophysical Attributes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Assumptions | **Year** | **Height of the trees with crown, THT (m)** | **Tree diameter , DBH (m)** | **Stem volume (m3) based on *Berg et. al., 2020*** | **Stem Biomass (kg)** | **Above Ground Biomass, AGB (kg)** | **Plant Waste (kg)** | **Below Ground Biomass, BGB (kg)** |
| | 1 | ... | ... | ... | ... | ... | ... | ... |
| | 2 | ... | ... | ... | ... | ... | ... | ... |
| | 3 | ... | ... | ... | ... | ... | ... | ... |
| | .... | .... | .... | ... | ... | ... | ... | ... |
| | 8 | ... | ... | ... | ... | ... | ... | ... |

## 2.6.4. On-Field Data Collection:

A year after the project's initiation, the project developer has to collect the annual data of each of the sample trees in a  spreadsheet (THT and DBH). Every sample tree should have a unique "Tree ID", so it can be identified and measured annually (monitoring procedures). In Appendix 3.3 an example template of the annual Data Collection is illustrated. From these measurements averages will be extracted and will be used as inputs for the Table 6 "On field measurements" which assists in the annual calculations of the carbon sequestration.

To ensure thorough and representative data collection across diverse environmental conditions within Paulownia plantations, our methodology prescribes a balanced and strategic sampling approach. A statistically robust sample of trees at each plantation location should be established, while reflecting a broad diversity of tree measurements. This diversity is essential for capturing a comprehensive dataset that accurately represents the variability in the plantation's  biophysical attributes. Based on the total number of trees per location, a specific number of trees should be sampled to ensure representativeness. Please refer to the A/R Methodological Tool "Calculation of the number of sample plots for measurements within A/R CDM project activities". Moreover, an uncertainty percentage based on sampling error should be established to accurately account for variations and ensure reliable measurements (details in section "2.3. Uncertainty calculation"). This should be provided in detail in the Project overview document.

Advanced technologies equipped with camera modules, remote sensing, and communication systems, with the capability to measure biophysical attributes of the plants in agricultural systems and plantation, are widely used today. If project developers have access to these technologies and can ensure and showcase that the collected measurements are characterized by high accuracy and reliability, their use is acceptable/admissible for this methodology. Furthermore, the inclusion of these technologies in monitoring and reporting  activities may also be considered.

Regarding the volume measurements, project developers can utilize scientifically derived formulas. These formulas are integral to forestry and carbon stock assessment due to their ability to provide accurate volume estimates based on measurable tree attributes (DBH and THT). In the context of short rotation Paulownia tree cultivation projects, pruning plays a crucial role in shaping the growth pattern of the trees. Regular pruning from the second year onwards encourages the trees to grow taller and straighter, with fewer side branches, thereby enhancing their wood quality. This pruning technique aligns the tree growth more closely with a cylindrical form, making another formula applicable for volume estimation and subsequently as a cross checking technique with Berg's formula.

*Huber's formula[21]:* Primarily used for trees with relatively uniform stem diameters along their length. It calculates the volume of a tree by multiplying the cross-sectional area at breast height (DBH) by the tree's total height. This formula is particularly effective for columnar-shaped trees.

Using the volume measurements obtained and their correlation with THT and DBH, a refined regression analysis will be conducted on Berg's et al., (2020) formula. This analysis will result in updated coefficients, offering a more precise representation of the relationship between the biophysical attributes of the tree and their volume.

Detailed guidelines on the sampling process, measurement techniques, equipment to be used, and data collection templates that the project developer may utilize can be found in *Appendix 3.*

*Table 6: Average values derived from tree measurements (Inputs) and estimated biomass of AGB, BGB, and Plant Waste (Outputs), based on field measurements.*

| | Biophysical Attributes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Year** | **Height of the trees with crown, THT (m)** | **Tree diameter , DBH (m)** | **Stem volume (m3) based on *Berg et. al., 2020*** | **Stem Biomass (kg)** | **Above Ground Biomass, AGB (kg)** | **Plant Waste (kg)** | **Below Ground Biomass, BGB (kg)** |
| On-field | 1 | ... | ... | ... | ... | ... | ... | ... |
| | 2 | ... | ... | ... | ... | ... | ... | ... |
| | 3 | ... | ... | ... | ... | ... | ... | ... |
| | .... | .... | .... | ... | ... | ... | ... | ... |
| | 8 | ... | ... | ... | ... | ... | ... | ... |

[21] https://ojs.upsi.edu.my/index.php/EJSMT/article/view/2458/2248

## 2.6.5. Monitoring and Reporting

Regularly monitoring and reporting on the plantation's growth and tree health are crucial for a comprehensive understanding of the project's progress. This entails selecting a diverse range of trees with different growth characteristics within the plantation, ensuring that the sampled trees proportionally represent the range of growth observed across the plantation. Measurements should be scheduled within a designated annual time frame (same season) to avoid external factors that affect tree ecophysiology, such as trunk shrinkage and leaf fall due to seasonal conditions. This procedure ensures consistency and accuracy in data collection. Any changes due to losses from pests, diseases, extreme weather conditions, or other environmental challenges should be recorded. For that reason, the number of trees per hectare should be reassessed each year based on the mortality ratio that the project developer established in Phase 3. The monitoring and reporting activities should be performed by individuals with the adequate knowledge to conduct the monitoring, evaluation and process of the outcomes.

As mentioned in previous sections, there are certain advanced technologies that can assist in the monitoring and reporting regarding the Paulownia plantations. Such technologies not only can facilitate detailed and continuous monitoring of the plantations but also can allow for the reliable assessment of plant health and growth dynamics, which are essential for effective plantation management and reliable calculation of the carbon sequestration potential.

## 2.6.6. Evaluating assumptions against on field data

In this step, the project developer will compare the initial assumptions to the actual on field measurements, by using the tool to conduct a comparative analysis. This table will compare the total CO2 stored in AGB (ton), total CO2 stored in Plant waste (ton), total CO2 stored in BGB (ton), AVG Annual CO2 sequestration in trees (ton) per Year as calculated from both the annual averages of the initial assumptions and the actual field data.

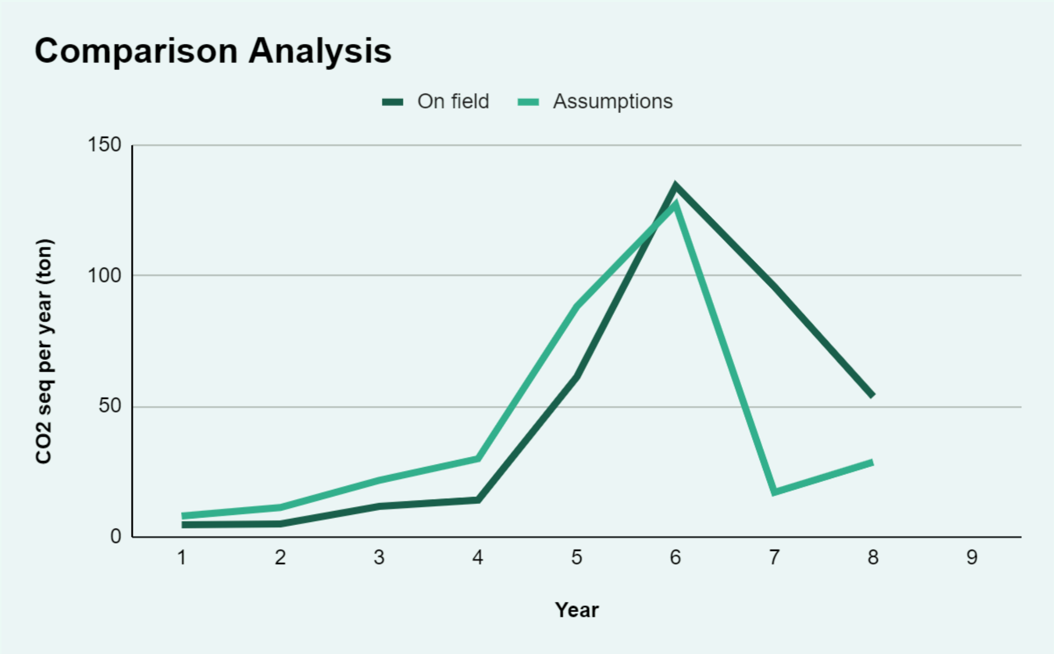
*Table 7: Comparative Analysis Data Table*

| Carbon Dioxide sequestration potential of the plantation | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total number of trees** | **Total CO2 stored in AGB (ton)** | | **Total CO2 stored in Plant waste (ton)** | | **Total CO2 stored in BGB (ton)** | | **Annual CO2 sequestration in trees (ton)** | |
| | | assumpti | on-field | assumpti | on-field | assumpti | on-field | assumpti | on-field |

| | | ons | | ons | | ons | | ons | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | |
| 2 | | | | | | | | | |
| .... | | | | | | | | | |
| 8 | | | | | | | | | |

Alongside the table, a graph will be provided to visually depict the variations of the amount of $CO_2$ that is sequestered annually between the assumed and actual measurements.

Example of the “Graphical Visualization”:




This process of collecting and analyzing data annually is used for:

- Assessing the project's current progress against its initial assumptions
- Verifying and modifying the prior estimations to ensure they remain accurate over time
- Maintaining transparency regarding its impact on carbon sequestration

The initial steps outlined above, integral to estimating carbon sequestration for the Paulownia plantation, have been incorporated into the tool and are accessible via the following link to the Google Sheet: Google Sheet for Carbon Sequestration Estimation.

In *Appendix 2.2*, an explanation of the equations used in these calculations can be found, while providing insights into their application.

## 2.7. Post-harvest measurements of Paulownia trees

During the initial harvest, which typically occurs between the 7th and 10th year (based on the Paulownia species/variety), project developers are enabled to validate their carbon sequestration estimates through direct measurements. Since these trees are destined for timber, employing destructive sampling methods allows for the actual volume of the trees to be measured.

### 2.7.1. Utilization of “Destructive Sampling”

The goal of collecting annual data and the post-harvest measurement of stem volume is to improve the accuracy (refine coefficients and $R^2$ of the allometric equation 8) of the method to calculate the actual biomass and carbon Yield.

The harvested sample trees, intended for use as timber in construction, will undergo destructive sampling. This process involves felling the trees and measuring their DBH, stem height. A subset of these harvested trees will be also measured for their stem volume, utilizing:

- Water Displacement[22]: Based on Archimedes' principle, this method measures volume by submerging the tree section in water and measuring the amount of water displaced. This method is highly accurate for irregularly shaped sections that do not conform to simple geometric shapes

[22] J. B. DARGAVEL & NELL DITCHBURNE (1971) A Comparison of the Volumes of Tree Stems Obtained by Direct Measurement and by Water Displacement, Australian Forestry, 35:3, 191-198, DOI: 10.1080/00049158.1971.10675553

Further information regarding these volume estimation methods is provided in *Appendix 3.*

### 2.7.2. Data collection

The measurements that will be obtained from the same sample trees, regarding the stem volume, will be systematically recorded in a structured format (tool). This organized data collection enables efficient data management and analysis. Example template for Data Collection is provided in *Appendix 3.3*

## 2.8. Annual and Total Net Carbon Yield

The next step is determining the Annual Net Carbon Yield (NCYannual) of each harvest cycle. In calculating Annual Net Carbon Yield (NCYannual), the baseline emissions from Phase 1 are incorporated as a reference for what emissions would have been without the project. Project emissions identified in Phase 4, including both one-time and recurring emissions, are also included into the NCYannual(y). From the sum of the annual net carbon yield (NCYannual(y)), the total net carbon yield (NCYtotal) will be calculated.

### 2.8.1. Baseline emissions (BE)

Project developers are required to provide a detailed calculation of baseline emissions based on the identified scenario. These baseline emissions must be included in the final calculations of the project's annual and total net carbon yield. The process should follow a clear and transparent documentation protocol, ensuring that all assumptions, data sources, and methodologies are thoroughly documented and easily verifiable in the POD. In order to estimate the NCYannual(y) baseline emissions should be divided into the number of years until the harvest takes place (7-10 years).

### 2.8.2. Leakage % (L)

Project developers must provide a comprehensive calculation of leakage emissions based on the identified baseline scenario. These leakage emissions need to be incorporated into the final calculations of the project's net carbon yield. The calculation process should adhere to a clear and transparent documentation protocol, ensuring all assumptions, data sources, and methodologies are thoroughly documented and verifiable in the POD. Leakage should be presented as a percentage of the baseline emissions due to their interdependence.

Considering the complexity of Leakage related to land use change, it is reccomended fro the baseline scenarios 2,3, 100% or more to be

### 2.8.3. Carbon stored in tree biomass (CStrees)

The carbon stored in tree biomass in the whole plantation includes the Above ground biomass (AGB), the below ground biomass (BGB), and the plant waste percentage which have been calculated in previous phases.

#### Below ground biomass (BGB)

Regarding the BGB's carbon storage, and its inclusion in the annual carbon sequestration, it will vary based on specific project characteristics and decisions that will be made at the project level. Different options may be applied depending on the unique conditions of each short rotation Paulownia tree cultivation project. Its consideration may be related to the leakage and emissions that may occur due to the displacement of the baseline emissions.

Option 1: The BGB will be considered as a carbon pool only once during this first harvest cycle (7-10 years) and its estimation will be based on root to shoot ratio. The reason for this is that after 7-10 years, the root system only continues to grow in a marginal and difficult-to-measure way. Only counting the BGB carbon pool once is aligned with the conservativeness principle and ensures a responsible assessment of the project's carbon sequestration.

Option 2: This displacement of agricultural activities can lead to their reestablishment in new locations, consequently generating additional GHG emissions. In this case project developers can utilize the BGB carbon sequestration in order to mitigate a potential leakage **higher** than 100% of the baseline emissions. The specific amount of GHG emissions that can be offset by the BGB carbon pool should be presented at the project level.

*Note: There is no leakage rate expected for baseline scenario 1. Similarly, for baseline scenario 2, if the pasture land remains pasture after tree planting, no leakage is anticipated. However, if baseline scenarios 2 and 3 are considered to be displaced, then option 2 is applicable.*

#### Plant waste % (PW)

The occurrence of plant waste during the harvesting process and subsequent wood processing within Paulownia plantation projects is acknowledged. To maintain a conservative approach in annual net carbon yield calculations, a specific percentage of plant waste will be deducted from the carbon that is sequestered and the overall estimates will be adjusted accordingly. This percentage is established at the project level, due to the specific equipment and the procedures that will take place. These details should be presented in detail in the POD.

### 2.8.4. Project emissions (PE)

In this methodology document, both recurring and one-time emissions are identified and addressed. Project developers are required to provide a detailed calculation of project emissions, based on the identified inputs and activity timelines. These emissions should be divided into recurring and one-time emissions, calculated yearly using relevant emission factors and considering the frequency per harvest cycle.

Developers must include a detailed timeline table in the project overview document. This table should outline all project activities and their respective timings on an annual basis. In order to estimate the NCYannual(y) the recurring project emissions (GHGrecurring) should be included and deducted from the CStrees of the corresponding year until the harvest takes place (7-10 years). Regarding the one-time project emissions, based on the relevant chapter 2.5.2 One time project emissions can be deducted altogether after the first harvest cycle, or spread across the lifespan of the project.

### 2.8.5. Uncertainty factor % (U)

Project developers are required to include an uncertainty factor in their calculations to account for potential variations and errors in measurements and estimates. This uncertainty factor addresses the level of confidence that sample measurements accurately represent the entire tree population and considers human errors and variability in tree growth rates across the plantation. More information regarding the calculation of uncertainty factor is presented in the Appendix 2.3.

As it is already mentioned and proposed in section 2.6.4. On-Field Data Collection the use of automated and remote sensing tools may enhance measurement accuracy and reduce human error.

### 2.8.6. Buffer pool % (BF)

Lastly, a buffer pool percentage will be also applied. A buffer Pool is a reserve of Carbon Credits established to cover potential losses in GHG Projects, ensuring the integrity of emissions reductions or removals over time[23]. The size of the buffer Pool should be determined based on the assessed

[23] https://proba.earth/hubfs/Product/The_Proba_standard.pdf?hsLang=en

risk level of each project and non-permanence risk, allowing for project-specific adjustments. Incorporating this buffer ensures that the reported NCYannual reflects a proper, conservative estimate, safeguarding against overestimation and aligning with best practices for realistic and responsible carbon accounting. The project developer must guarantee that the wood will be used in long-term carbon storage materials, such as construction buildings, so the permanence and reliability of the carbon sequestration can further guarantee. This assurance means that the carbon stored in the wood remains sequestered for extended periods. A minimum buffer pool based on the Proba standard is 10%. However, considering the project specifications and the information provided by the project developer about the long-term storage of carbon, a higher buffer pool should be considered. This approach ensures greater conservativeness and reliability in the project's carbon accounting.

### 2.8.7. Calculations of NCYannual and NCYtotal

The Annual Net Carbon Yield (NCYannual) for each year y can be calculated using the following equation:

$$NCYannual(y) \; = (CStrees(y) - GHGrecurring(y) - (BE(y) - L(y))) * (1 - U\%)$$

**(eq.9)**

Where:

| Parameter | Unit | Description |
|---|---|---|
| NCYannual(y) | *tCO2e* | Net Carbon Yield for year y |
| CStrees(y) | *tCO2e* | Annual carbon storage in trees’ biomass for year y<br><br>*include BGB only at the 1st harvest cycle<br><br>*include a deduction of a plant waste % |
| GHGrecurring(y) | *tCO2e* | Direct and indirect greenhouse gas emissions due to the project activities for year y<br><br>*GHGone-time will be included in the NCYtotal |

| | | |
|---|---|---|
| BE(y) | *tCO2e* | Estimated GHG emissions that would have occurred under standard baseline scenarios if the project had not been implemented<br><br>*Baseline emissions may be divided and their deduction should spread across the years (based on the timeframe of harvest cycle) |
| L | *tCO2e*<br><br>**Based on % of Baseline emissions* | GHG emissions due to the displacement of agricultural activities for year y<br><br>*related to the baseline scenario |
| U | *%* | Accounts for potential variations and errors in measurements and estimates. |
| y | years | Specific year of the project time period |

*Note: Buffer pool should be indicated in the POD. It is a reserve to cover potential losses, ensuring the integrity of emissions reductions or removals. Buffer percentage can be modified based on the project characteristics and should be accompanied by substantial evidence.*

The total Net Carbon Yield can be calculated by using the equation below:

$$NCYtotal = \sum_{y=1}^{n} NCYannual(y) \quad \textbf{(eq.10)}$$

Where:

| Parameter | Unit | Description |
|---|---|---|
| NCYtotal | *tCO2e* | Net Carbon Yield until the first harvest cycle |
| NCYannual(y) | *tCO2e* | Net Carbon Yield for year y |

| | | |
|---|---|---|
| n | *years* | Total number of years in relation to the duration of the harvest cycle |

For the NCY calculations, the same tool that was used during the whole process may be employed again. This ensures an efficient and consistent approach for calculating the Annual Net Carbon Yield and the Net total Carbon yield

*Table 8: Annual and total Net Carbon yield calculations*

| Net Carbon Calculations | | | | |
|---|---|---|---|---|
| **Year** | **Net Annual Project's yield (in ton CO2)** | | **Net Total Project's yield, 8 years (in ton CO2)** | |
| | assumptions | on-field | assumptions | on-field |
| 1 | | | | |
| 2 | | | | |
| .... | | | | |
| 8 | | | | |

Note: In this example and the tool, the harvest cycle of the plantation is 8 years.

# Appendix 1

## 1.1. Methodologies and tools to assess SOC

Soil organic carbon is likely to change at a slow rate and is also likely to be an expensive pool to measure. However it should at least be estimated and considered, as sequestration of carbon into the soil, or prevention of emissions of carbon from soils, can be important. Specifically, in grazing and cropland systems, failing to include soil organic carbon overlooks a vital source of reductions in atmospheric greenhouse gases. When Paulownia plantations replace former croplands or grasslands, there can be a decrease in soil carbon due to the typically high carbon stocks found in perennial grasslands or croplands.

Methodologies and tools that can be used for the assessment of SOC are presented below:

- CHAPTER 2 GENERIC METHODOLOGIES APPLICABLE TO MULTIPLE LAND- USE CATEGORIES
- Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM proj
- https://data.apps.fao.org/glosis/?lang=en
- CDM_ARWG30_SOC_Tool_Multizones

## 1.2. Emission to be considered

GHG protocol[24] proposes the agricultural emissions to be divided based on mechanical and non mechanical emissions. The project developer can follow the guidelines of the GHG protocol and include these types of emissions both in the baseline scenarios and during the project emissions of the Paulownia plantation project.

*Table 9: Agricultural emissions to be considered based on GHG protocol*

| Mechanical | Non-mechanical |
|---|---|
| Purchased electricity: CO2, CH4 and N2O | Drainage and tillage of soils: CO2, CH4 and N2O |
| Mobile Machinery (e.g. tilling, sowing, harvesting and transport) | Addition of synthetic fertilizers, livestock waste, and crop residues to soils: CO2, CH4 and N2O |

[24] https://ghgprotocol.org/sites/default/files/2022-12/GHG%20Protocol%20Agricultural%20Guidance%20%28April%2026%29_0.pdf

| | |
|---|---|
| Stationary Machinery (e.g., milling and irrigation equipment) | Addition to urea and lime to soils: CO2 |
| Mobile Machinery for fertilizer application (e.g. tractor) | Enteric fermentation: CH4 |
| etc. | Manure management: CH4 and N2O |
| | Land use change |
| | etc. |

## 1.3. Tier 1, 2 and 3 emission factors

In the context of greenhouse gas (GHG) emissions reporting and inventory management, data and methodologies are categorized into three tiers (Tier 1, Tier 2, and Tier 3), as defined by the Intergovernmental Panel on Climate Change (IPCC). These tiers represent varying levels of accuracy, data specificity, and complexity. Here's a detailed look at each:

*Table 10: Tier 1, 2 and 3 explanation*

| **Tier 1** | **Tier 2** | **Tier 3** |
|---|---|---|
| This is the most basic level of calculation which uses default emission factors provided by the IPCC or other authoritative sources. These factors are generally based on a **broad average of data** and are meant for use when more specific data are not available.<br><br>It is ideal for initial assessments, small-scale projects, or regions where data collection capabilities are limited. It requires the least amount of data and provides estimates that are less precise. | These methodologies are more accurate than Tier 1 and involve **country-specific or region-specific** emission factors. These factors take into account the specific characteristics of fuels or technology used in a particular geographic area.<br><br>They are used when more detailed, reliable data are available and a greater degree of accuracy is required. | This is the most sophisticated level that uses highly **detailed data and advanced statistical or modeling techniques**. This tier often involves continuous emission measurements and may incorporate real-time data collection.<br><br>It is appropriate for detailed monitoring and reporting, often used in large industries or for regulatory compliance where precise data tracking is necessary. |

Use of default emissions factors from the IPCC is mandatory. Country-specific emissions factors (Tier 2) may be utilized only if they are available and provide a more accurate reflection of local conditions. Databases that provide Tier 2 emission factors are presented in Table 11.

*Table 11: Available emission factors online databases Tier1 and Tier 2.*

| Databases | Links |
|---|---|
| FAOSTAT | FAOSTAT |
| European Environment Agency | EEA Member Countries |
| IPCC | EFDB - Main Page |
| UNFCCC | Greenhouse Gas Inventory Data<br>National Inventory Submissions 2023 |
| Our World in Data | Our World in Data |
| $CO_2$ Emissiefactoren (Netherlands) | Lijst Emissiefactoren |

In order for the project developer to identify and estimate uncertainties in relation to the emission factors that will be used, project developer should follow the guidelines of IPCC in the following document:

- 6 QUANTIFYING UNCERTAINTIES IN PRACTICE

## 1.4. Online tools to be used for calculations

Project developers in order to measure the baseline, project emissions, and leakage for the carbon farming projects , can leverage several online websites/tools. In Table 12 a brief overview of what each tool offers is presented.

*Table 12: Available online tools to be used for further calculations*

| Website | Link | Features |
|---|---|---|
| CoolFarmTool.org | Cool Farm Tool | Greenhouse gas emissions calculation based on the cultivation's characteristics |
| Global Soil Information | https://data.apps.fao.org/glos | GSP's open-access Global Soil |

| | | |
|---|---|---|
| System/FAOSTAT | is/?lang=en | Information System is a spatial data infrastructure that brings together soil information collected by national institutions and other data holding entities |

# Appendix 2: Standard values & equations

## 2.1. Standard Values Description

These values are derived from scientific literature, reports, and guidelines from Climate Change and Carbon Management Frameworks (IPCC, CDM, GHG Protocol, etc).

| Parameter | Value | Source |
|---|---|---|
| Paulownia wood density (ρ) | 275 kg/m³ | Various Sources (see Table 12) |
| Carbon Content | 47% | IPCC 2006[25] |
| Biomass Expansion Factor (branches, twigs, roots, etc) | 1.4 | IPCC, Good Practice Guidance for Land Use, Land-Use Change and Forestry[26] |
| Allometric Equation for estimation Phase | $ln(VOL) = f\ (ln\ (DBH^2*THT))$ | Berg et al., 2020[27] |
| Below Ground Biomass (BGB) "root-shoot ratio" | 15% of AGB | ICIMOD (2015)[28] |
| C to CO2 | 3.67 | Pearson et al. (2007)[29], IPCC, FAO |

Paulownia species wood density (ρ): This refers to the mass of wood per unit volume, typically measured in kg/m³. In forestry, wood density is a vital parameter as it influences biomass

[25] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf
[26] https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf
[27] https://doi.org/10.1007/s11676-019-01021-9
[28] https://lib.icimod.org/record/31838
[29] https://www.nrs.fs.usda.gov/pubs/gtr/gtr_nrs18.pdf

calculations and subsequently, the carbon storage potential of trees. An example of how this value was derived can be seen in Table 13.

*Table 13: Procedure of adopting an average value based on scientific sources*

| |
|---|
| In the context of estimating biomass for short rotation Paulownia tree cultivation, a critical parameter is the specific wood density of the trees. Given the lack of readily available data specific to our Paulownia species, a methodical approach to determine a standardized wood density value has been adopted. This approach leverages existing scientific literature to derive an average density that is representative of the species.<br><br>According to a comprehensive study published by Jakubowski (2022), the density of Paulownia wood, at a moisture content of 12%, varies between 220 and 350 kg/m³. The same study presents an average density of approximately 270 kg/m³ for Paulownia wood. Another scientific investigation found the oven-dried wood density of Paulownia to be 268 kg/m³. This value aligns closely with the average presented in the first study. Complementing this, based on ICRAF's tree functional attributes and ecological databases the mean wood density is at 267 kg/m³.<br><br>Given these findings, it has been decided to adopt an average wood density of 275 kg/m³ as a standardized value for this project. This average is derived from a range of values reported in the scientific literature and reflects the typical wood density for Paulownia species under similar conditions. This standardized density will be utilized in our calculations to estimate the biomass based on the volume and density of the trees in our plantation.<br><br>This approach ensures a scientifically grounded and transparent method for biomass estimation, essential for the accuracy and reliability of our project's carbon sequestration calculations. It also underscores our commitment to using the best available data and practices in the absence of species-specific measurements. |

Note: If the project developer possesses data on wood density that has been derived through scientific methods, this specific value can be utilized in place of the standard wood density provided in this document.

Biomass Expansion Factor: This factor is used to estimate the total biomass of a tree, including parts not directly measured, like branches and twigs. It helps in scaling up from known biomass measurements to a whole-tree biomass estimation.

Below Ground Biomass (BGB) "root-shoot ratio": This ratio compares the biomass of a tree's roots to its above-ground parts. It's essential for estimating the total biomass, including the often-unseen root system, which is significant for total carbon storage calculations.

Allometric Equation (Berg et al., 2020): An allometric equation is used to estimate the volume of a tree from easily measurable parameters like diameter at breast height (DBH) and total height (THT). These equations are critical in forestry for estimating tree biomass and, by extension, the carbon storage without directly measuring the entire volume of the tree.

$$ln(vol) = f(ln(DBH^2 * THT)$$ **(eq. 11)**

Carbon Content: This is the percentage of a tree's biomass that is carbon. It's a critical factor in calculating how much carbon is stored in a tree.

C to CO2 Conversion: This factor converts the mass of carbon stored in trees to its equivalent in carbon dioxide ($CO_2$). It's based on the molecular relationship between carbon and $CO_2$ and is crucial for translating carbon sequestration into terms used in greenhouse gas accounting.

## 2.2. Estimation of Carbon Sequestration (Phase 4) and relevant equations

The equations are fundamental to calculating total biomass, both from initial estimations and actual field measurements. This approach allows for a comparative analysis, as outlined in Phase 4, where the estimated biomass from both methods is translated into carbon sequestration and ultimately into $CO_2$ equivalent. These equations are also applied as inputs in the example tables that are illustrated in Phase 4.

1) Calculate Average Stem Volume:

$$ln(Vavg, stem) = f(ln(DBHavg^2 * THTavg))$$ **(eq. 12)**[30]

[30] Berg, E.C., Zarnoch, S.J. & McNab, W.H. Survivorship, attained diameter, height and volume of three Paulownia species after 9 years in the southern Appalachians, USA. J. For. Res. 31, 2181–2191 (2020). https://doi.org/10.1007/s11676-019-01021-9

Where:

| | |
|---|---|
| $Vavg, stem$ | Average Stem Volume per tree (kg/m3) |
| $DBHavg$ | Average Diameter at Breast Height (m) |
| $THTavg$ | Average Total Height (THT) of the tree (m) |
| $f$ | Represents the function defined in the allometric equation, which relates the natural logarithm of the product of the squared average DBH and the average height to the natural logarithm of the average volume |

2) Total Volume of trees:

$$Vtotal = Vavg * Ntrees$$ **(eq. 13)**[31]

Where:

| | |
|---|---|
| $Vtotal$ | Total Stem Volume for the entire plantation (m3) |
| $Vavg$ | Average Stem Volume per tree (m3) |
| $Ntrees$ | Total number of trees in the plantation |

3) Above Ground “stem” Biomass:

$$AGBstem, total = Vtotal * \rho$$ **(eq. 14)**[32]

[31] https://erc.cals.wisc.edu/woodlandinfo/files/2017/09/G3332.pdf
[32] https://www.fao.org/4/w4095e/w4095e06.htm#3.1.1%20general%20equation

Where:

| | |
|---|---|
| $AGBstem, total$ | Total Above Ground “stem” Biomass for the entire plantation (kg) |
| $Vtotal$ | Total Stem Volume of the plantation (m3) |
| ρ | Wood density, a standard value for the Paulownia species (kg/m3) |

4) Total Above Ground Biomass:

$$AGBtotal = AGBstem, total * BEF$$ **(eq. 15)**[33]

Where:

| | |
|---|---|
| $AGBtotal$ | Total Above Ground “stem” Biomass for the entire plantation (kg) |
| $AGBstem, total$ | Total Above Ground “stem” Biomass for the entire plantation (kg) |
| $BEF$ | Biomass Expansion Factor |

5) Total Biomass (including BGB and plant waste):

$$Total\ Biomass\ (AGB, BGB) = AGBtotal * plant\ waste\% + (AGBtotal * RSR)$$ **(eq. 16)**[34]

[33] https://www.fao.org/4/w4095e/w4095e06.htm#3.1.1%20general%20equation
[34] https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf

Where:

| | |
|---|---|
| $Total\ Biomass\ (AGB, BGB)$ | Total biomass of the plantation, including both Above Ground Biomass (AGB) and Below Ground Biomass (BGB) (kg) |
| $AGBtotal$ | Total Above Ground "stem" Biomass for the entire plantation (kg) |
| $RSR$ | Root-Shoot Ratio |

6) Total Carbon Stored in Tree:

$$Ctrees = Total\ Biomass\ (AGB, BGB) * Carbon\ Content$$ **(eq. 17)**[35]

Where:

| | |
|---|---|
| $Ctrees$ | Total Carbon storage in trees |
| $Total\ Biomass\ (AGB, BGB)$ | Total biomass of the plantation, including both Above Ground Biomass (AGB) and Below Ground Biomass (BGB) (kg) |
| $Carbon\ Content$ | Proportion of biomass that is carbon (set at 47%) |

7) C to CO2 conversion (CO2 equivalent):

$$CO2\ Equivalent, total = Ctrees * 44/12$$ **(eq. 18)**[36]

Where:

| | |
|---|---|
| $CO2\ Equivalent, total$ | Carbon storage in trees |

[35] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf
[36] https://www.nrs.fs.usda.gov/pubs/gtr/gtr_nrs18.pdf

| | |
|---|---|
| $Ctrees$ | Carbon storage in trees |
| $44/12$ | Molecular weight ratio of CO2 to carbon. |

8) Annual Carbon storage:

$$Annual\ CO2\ equivalent\ = CO2\ Equivalent, total/Nyears$$ **(eq. 19)**

Where:

| | |
|---|---|
| $Annual\ CO2\ equivalent$ | Total Carbon storage in CO2e per year |
| $CO2\ Equivalent, total$ | Carbon storage in trees |
| $Nyears$ | Number of years until harvest |

## 2.3. Uncertainty calculation

Uncertainty in carbon sequestration projects refers to the confidence level that sample measurements accurately represent the entire population of trees. This section provides a detailed methodology for calculating uncertainty, including a step-by-step example.

Identifying Key Parameters

Measurement and Sampling Uncertainty:

- Measure key tree characteristics such as diameter at breast height (DBH) and total height.
- Conduct systematic sampling across the plantation to ensure representative data.

Quantifying Uncertainty

Use statistical methods to quantify the uncertainty of each parameter. The margin of error can be calculated using the formula:

$$E = Z \times \left( \frac{\sigma}{\sqrt{n}} \right)$$ **(eq 20)**[37]

where:

| | |
|---|---|
| $E$ | The uncertainty's margin error |
| Z | Z-score for the desired confidence level (e.g., 1.96 for 95% confidence) |
| σ | The standard deviation of the sample measurements |
| n | The sample size |

Convert the fixed Uncertainty value to a percentage:

To express uncertainty as a percentage, divide the margin of error (E) by the mean estimate (Q) and multiply by 100:

$$U(\%) = \frac{E}{Q}$$ **(eq 21)**

[37] https://www.fpl.fs.usda.gov/documnts/usda/ah317.pdf

Where:

| | |
|---|---|
| U% | The percentage of uncertainty |
| E | The margin of error or the fixed uncertainty value |
| Q | The mean estimate of the measured characteristic |

# Appendix 3: Empirical Data collection methods

## 3.1. Tree selection and mortality rates

To enhance the reliability of the data, trees at the edges of plantations are avoided in the selection process due to their increased exposure to sunlight, which may affect growth data and potentially misrepresent the average conditions of the plantation. Project developers should also account for mortality rates within the total plantation to ensure that estimates of the live tree population are precise.

Additionally, data collection is carried out at each distinct plantation location to capture the local environmental factors influencing tree growth. By tailoring the sampling strategy to the specific conditions of each location, it is ensured that the collected data supports accurate growth assessments and broader project evaluations. This approach helps to maintain the integrity of the project's data collection efforts.

## 3.2. Recommended equipment:

In this section, the recommended equipment for data collection in Paulownia projects is presented. They are specifically tailored for accuracy and simplicity of use in the field. Additionally, recommended data collection templates are designed to facilitate the systematic recording of data.

### 3.2.1. Measuring the Diameter at Breast Height (DBH) of the Paulownia Tree samples

Measuring the Diameter at Breast Height (DBH) of trees is a key task in forestry, requiring precise tools like diameter tapes, calipers, and Biltmore sticks. Accuracy is crucial, as DBH measurements contribute to understanding tree health and forest dynamics. Proper use and regular maintenance of these tools are essential for reliable data. Due to the pruning techniques used on Paulownia trees, their shape is easier to measure, resulting in lower measurement errors and reduced uncertainty.

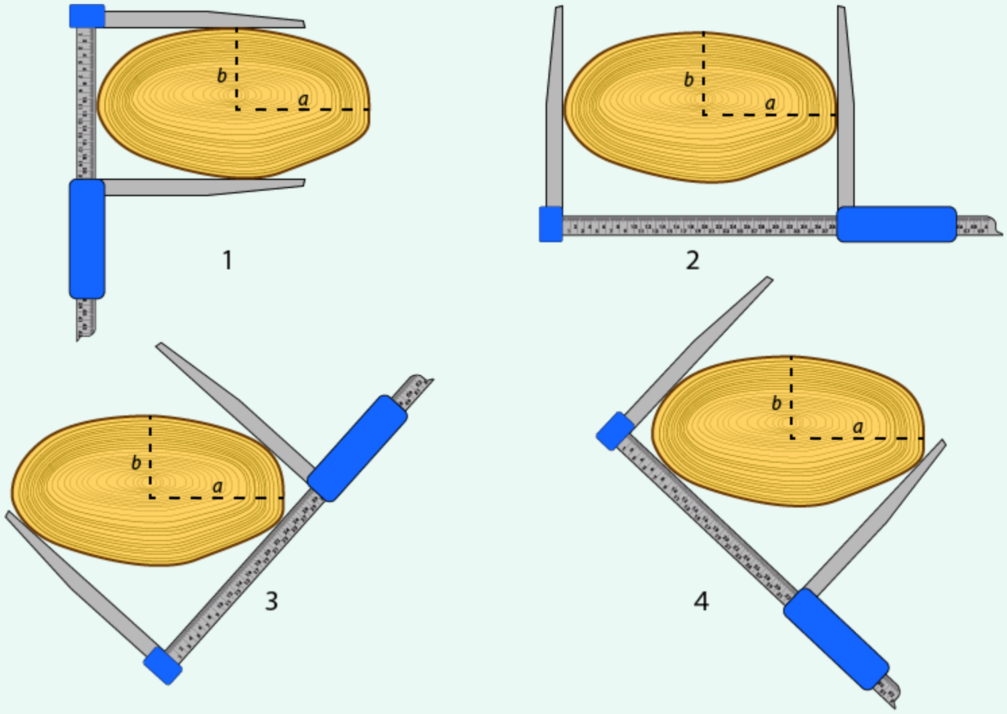
MANUAL DIAMETER: "Calibrated Tree Trunk Thickness Gauge": It is designed for forestry use to accurately measure tree diameters. It has a measuring range of up to 60 cm and weighs 900 grams.

Project developers should start by using the measuring tape or stick to find the point on the tree trunk that is 1.3 meters above the ground. This is the height at which you will measure the DBH. Make sure to measure from the uphill side if the tree is on a slope.

The calipers should be clean in order for the scale to be readable. One arm of the caliper is fixed at the origin of the scale, while the other arm is movable. The fixed arm of the caliper should be placed on one side of the tree at breast height. The adjustable arm should be moved to the opposite side of the tree, ensuring that the arms are pressed firmly against the tree and form a 90˚ angle with the scale.

Project developers should read the diameter directly from the scale where the movable arm meets the scale. This measurement represents the major axis, or the widest diameter of the tree. Then, rotate the calipers 90˚ and measure the diameter at a right angle to the major axis. This measurement is the minor axis. Write down both the major and minor axis measurements.

Example: To calculate the DBH, take the arithmetic mean of the major and minor diameters. The formula is as follows: DBH = (Major Axis + Minor Axis) / 2. For example, if the major axis is 26.7 cm and the minor axis is 25.4 cm, the DBH would be (26.7 + 25.4) / 2 = 26.05 cm.




## 3.2.2. Measuring the Height of a Paulownia Tree

Measuring the height of a tree is essential in forestry and ecological studies, typically done using tools like clinometers or hypsometers for accuracy. Proper technique in using these instruments is crucial for reliable height measurements.

Example: The "BOSCH MEASURING BAR" - GR 500

It is a specialized tool designed for measuring the height of trees, such as the Paulownia.
It features an extension capability of up to 5 meters, making it suitable for use in a variety of conditions


## 3.3. Measurement guidelines

### 3.3.1. Measurement techniques of tree volume

Huber's formula[38]:

It is a widely accepted method in forestry that calculates the volume of a tree by treating it as a geometric shape—either a cone or a cylinder. The formula takes into account the diameter at breast height (DBH) and total tree height (THT). In the case of pruned trees, the cylindrical

[38] https://medcraveonline.com/BBIJ/BBIJ-09-00308.pdf

assumption becomes more accurate, as pruning minimizes irregularities in the tree's shape. The formula is expressed as:

$$V = \pi * THT * (DBH^2/4)$$ **(eq. 22)**[39]

Water displacement: Based on Archimedes' principle, this method measures volume by submerging the tree section in water and measuring the amount of water displaced. This method is highly accurate for irregularly shaped sections that do not conform to simple geometric shapes.

## 3.4. Example on-field measurements



The project developer is tasked with effectively recording detailed annual measurements for each sample tree, encompassing DBH, THT, and selected volume samples, utilizing Excel or Google Sheets for systematic record-keeping. This procedure guarantees that the information is systematically organized and readily available for validation, review, or any subsequent verification processes. To further ensure the data's integrity and validity, it is crucial to maintain comprehensive

[39] https://www.scielo.cl/pdf/bosque/v34n3/art07.pdf

records of all measurements in Portable Document Format (PDF). The inherent characteristics of the PDF format prevent unauthorized modification, thereby safeguarding the data. This approach to meticulous documentation enhances transparency, accountability and upholds the project's reporting and analysis phase to the highest standards of data management and accountability, facilitating straightforward future verification or validation efforts.

*Table 14: Annually data collection and measurements*

| Data Collection/Measurements (annually and harvesting stage) | | | | | | |
|---|---|---|---|---|---|---|
| Employee in charge (Data Collector): | | | | | | |
| **Tree ID** | **Location** | **Date** | **THT(m)** | **DBH(m)** | **Volume(m3) based on Huber's formula** | **Notes** |
| 1 | ... | 15/11/2024 | ... | ... | | ... |
| 2 | ... | 15/11/2024 | ... | ... | | ... |
| 3 | ... | 15/11/2024 | ... | ... | | ... |
| ... | ... | ... | ... | ... | | ... |
| 25 | ... | 15/11/2024 | ... | ... | | ... |

Instructions:

- Date: Enter the date of data collection.
- Data Collector's Name: Record the name of the individual collecting the data.
- Tree ID: The specific trees that the numbers are derived from
- DBH (Diameter at Breast Height): Measure and record the DBH in meters.
- THT (Total Height): Record the total height of the tree in meters.
- Volume: If calculated based on Huber's formula, enter the volume of the tree in cubic meters.
- Notes: Any additional observations or relevant information.

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