Comments to Science Advisory Board
Biogenic Carbon Emissions Panel

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Submitted: October 19th, 2011
To be delivered verbally: October 25th, 2011
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Attachment: *Forest Carbon Accounting in Products – A Proposed Methodology*

Thank you for the opportunity to comment on the EPA's proposed framework. We hope that your expertise will address the concern that the proposed framework will not achieve EPA's stated objective of "accurately reflect[ing] the carbon outcome" of biomass use by stationary sources.

The Environmental Paper Network is a non-profit that facilitates a powerful movement of independent environmental organizations, strategically leveraging their collective expertise and resources, to initiate change and environmental improvement in the pulp and paper industry. You can learn more about us and see a list of our members, which includes some of the largest conservation organizations in the country, at EnvironmentalPaper.org.

We support the comments in the conservation group joint letter that was submitted by Clean Air Task Force et al to the Scientific Advisory Board (SAB) on October 18th, 2011. We too strongly support EPA's effort to develop a methodology for properly quantifying biogenic carbon emissions from stationary sources. By moving beyond the assumption that bioenergy is inherently carbon-neutral, EPA has taken a critically important first step.

The EPN is concerned with this question because, as you likely know, the forest products industry is the largest user of bioenergy in the US. My comments focus on the feedstock of wood and forests.

Bioenergy may have a role to play in certain circumstances. But in order to know if, when, where and how we need to use the best science and establish a framework that can effectively regulate these emissions to avoid a damaging increase in atmospheric CO_2. I am here to submit comments and be present at the meeting, because the proposed framework does not meet that standard, and it must be revisited.

The really critical issue at stake is whether the United States will account for this carbon dioxide pollution. Carbon dioxide released from burning trees and wood is equal to carbon dioxide from other sources. And the carbon released into the atmosphere from cutting trees for energy will not be replaced for decades, even under the most ideal circumstances. And, in the meantime, if the forest was not

harvested, in general, that forest would not only hold that carbon, but would accumulate additional carbon. In any framework that is adopted, this loss of potential storage must be accounted for, and currently it is not.

We, as a society, should support those landowners who maintain carbon in forests on their lands and debit those who remove and release that carbon into the atmosphere. As we do so, we should not give away free credit to those who are depleting forests resources because the OTHERS are maintaining them. Under this framework, we are asking the entire society to give a polluter the credit for what others actually do, without responsibility to the polluter. That contributes to a situation where it is impossible to manage emissions of the pollutant effectively.

A source of this flaw is the proposed frameworks approach of using the threshold level as the trigger. If the framework was brought to address this from the facility level, it would:

- More accurately capture the true cost of behavior
- Be easier for regulators to manage
- Be less speculative, and
- Be informed by more rapidly available data, avoiding a significant time-lag

It would also:

- Reduce problems of double and triple counting for "credit" from the carbon absorption of these forests that the proposed framework has
- Incentivize efficiency (the current framework does not)
- Provide a means to address very large emitters, who are exempted in a zone that is a net-growth zone, which then soon after turns to a zone that is a net-loss, and has major emitters with zero incentive to reduce emissions.

On behalf of an active Working Group of the Environmental Paper Network, named the *Working Group on Forest Carbon Accounting in Products*, I am submitting a draft paper for your consideration as you approach your study of the EPA framework. The working group set out to design a methodology for more accurate forest carbon accounting in products, based on the latest scientific research, and reviewed by experts in the field.

This *Working Group* has shared its drafts with a lengthy list of academic reviewers, and some of you have received those drafts already. The current draft contains additional components written by academics at the Yale School of Forestry and at Appalachian State University. The paper is still only a draft, and it is focused thus far entirely on the emission impacts from the activity at the moment of the activity, without any time factor included. In the coming months, we will be studying how to incorporate the time factor in the most optimal way possible.

Our working group looks at the questions of how to determine the full climate impact of using wood for products and energy in a life cycle assessment. Admittedly, this paper is not a mirror image of the question being asked by the EPA for you to consider. But it is extremely useful information to help you consider the exact question you've been asked to consider. I urge you not to exclude or dismiss it for its focus on a product life-cycle, as it would be arbitrary and an unfortunate loss to do so.

We submit this paper to the SAB during this process, and in draft form, because we feel it is critical to illuminate the true impacts, and to demonstrate that methods can be developed to account for emissions and give us a framework for comparing and reducing them. This "activity-based" approach is more demonstrable, comparable, and informative on the direct impacts of a stationary source.

The paper also evokes several other important considerations for the SAB, including:

- CO_2 emissions from biomass energy do not only occur from the smokestack but the proposed framework does not take advantage of existing models of how to calculate this "leakage."
- The landowners and the stationary emitters are not the same people/entities in many and probably most cases, therefore using a regional threshold approach is not viable for achieving the desired outcome.

Thank you very much for the opportunity to speak today, and for your consideration of my written comments, including the DRAFT report of our Working Group. The Environmental Paper Network and our members are eager to work with EPA and the SAB Biogenic Carbon Emissions Panel to develop the best, most accurate methodology for determining a stationary source's net emissions of biogenic carbon.

Respectfully,

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Forest Carbon Accounting in Products – A Proposed Methodology

The Environmental Paper Network

4th Draft

19 October 2011

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1. Context

Greenhouse gas (GHG) emissions from biomass have been highlighted in recent studies for their notable absence in accounting methods. In order to create a comprehensive and accurate accounting methodology, all sources need to be considered carefully.

"The accounting now used for assessing compliance with carbon limits in the Kyoto Protocol and in climate legislation contains a far-reaching but fixable flaw that will severely undermine greenhouse gas reduction goals. It does not count CO_2 emitted from tailpipes and smokestacks when bioenergy is being used, but it also does not count changes in emissions from land use when biomass for energy is harvested or grown. This accounting erroneously treats all bioenergy as carbon neutral regardless of the source of the biomass, which may cause large differences in net emissions. For example, the clearing of long-established forests to burn wood or to grow energy crops is counted as a 100% reduction in energy emissions despite causing large releases of carbon." [1]
From: *Fixing A Critical Climate Accounting Error* (Searchinger et al, October 2009)

In addition to keeping track of these changes for issues of completeness, the emissions from biomass sources are steadily growing and may be significant, particularly in land use changes. These land use changes not only potentially create a net increase in greenhouse gas in the atmosphere, but also influence other entries in the carbon accounting budget.

"…planting fast-growing energy crops on otherwise unproductive land leads to additional carbon absorption by plants that offsets emissions from their use for energy without displacing carbon storage in plants and soils. On the other hand, clearing or cutting forests for energy, either to burn trees directly in power plants or to replace forests with bioenergy crops, has the net effect of releasing otherwise sequestered carbon into the atmosphere, just like the extraction and burning of fossil fuels. That creates a carbon debt, may reduce ongoing carbon uptake by the forest, and as a result may increase net greenhouse gas emissions for an extended time period and thereby undercut greenhouse gas reductions needed over the next several decades." [2]
From: A letter to Speaker Pelosi and Majority Leader Senator Reid from 90 scientists (Schlesinger et al., May 2010).

The changes in stocks of biomass products and changes in land use affect both short and long term carbon stocks. Accurately tracking those changes is not only important for national accounting methods, but for some parties these emissions and land use changes may comprise a large fraction of the carbon affected by their activities.

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[1] Searchinger, T. D. et al. (2009) Fixing A Critical Climate Accounting Error. *Science*. 326: 23. October 2009.
[2] Schlesinger, W. H. et al. (2010) Letter to Speaker Pelosi and Majority Leader Senator Reid. Signed by 90 scientists. 17 May 2010.

"Harvesting forest biomass and associated management changes and conversion of land, releases immediate and significant GHG emissions - creating a carbon debt - that can take decades or even centuries to repay through recapture in soils and vegetation." [3]

From: *Bioenergy: a carbon accounting time bomb.* A report by Birdlife International, the European Environmental Bureau and Transport & Environment. (June 2010).

Such concerns are also applicable to the wood products and paper sectors where manufacturers are increasingly making carbon neutral claims. Within those claims is the assumption that wood material is always carbon neutral because 'the forests grow back.' Where carbon neutrality claims are made, forest carbon accounting is rarely undertaken. If carbon is accounted for varying methodologies are applied which can result in widely differing results that can even give reverse conclusions.[4]

There has also been an increasing amount of discussion on the importance of time on these emissions. Although time is an issue for all carbon stocks, the issue of time is fundamentally important to long-lived carbon containing products. Since wood products comprise a large variety of long-lived stocks, the issue of time and issues related to biomass will soon become unavoidably entangled. Although this document only scratches the surface of the time issue, the accounting methods for dealing with time issues depend heavily on accurately tracking emissions from biomass sources.

2. Purpose

The purpose of the Working Group on Forest Carbon Accounting in Products has been to develop an accounting methodology of forest carbon emissions that can be used as a component in life cycle assessment (LCA) or carbon footprinting of forest products. The methodology is presented in this paper, it calculates the Forest Carbon Footprint.

The aim has been to make a methodology that is as accurate as possible and answer the key question: what is the impact of forest products on atmospheric levels of greenhouse gases? The methodology is designed to calculate the resultant Forest Carbon Footprint of forest products throughout the

[3] Anon. (2010) *Bioenergy: a carbon accounting time bomb.* Birdlife International, European Environmental Bureau and Transport & Environment. June 2010.

[4] Kujanpää, M., T. Pajula & C. Hohenthal (2009) Carbon footprint of a forest product – challenges of including biogenic carbon and carbon sequestration in the calculations in Koukkari, H. & M. Nors, (eds.). (2009) *Life Cycle Assessment of Products and Technologies.* LCA Symposium, VTT, Espoo, Finland. VTT Technical Research Centre of Finland. 6 October 2009. pp 28.

production chain; that is, the release of forest carbon to the atmosphere as a result of industrial processes through the supply chain. It is intended to reflect the intent of carbon footprinting or LCA: to give policy makers or consumers the best estimate of the product's climate impact and to reveal opportunities for reducing those impacts.

3. Background

In recent years it has been widespread to assume that forest material is 'carbon neutral' on the basis of the understanding that new trees will simply re-capture any carbon dioxide liberated during the use and oxidation of wood. This position may stem from a misinterpretation of the IPCC rules that require national level carbon accounting to record emissions from land-use change separately from energy emissions. To count forest carbon emissions twice as both land-use related emissions and energy emissions would be to double count. Therefore at the national level these emissions are only counted once in the land-use accounts with the IPCC advising to not count them again as energy emissions. However this does not mean that wood and other biomass are carbon neutral and it is becoming increasingly apparent that proper carbon accounting is needed at the product level rather than making the assumption that all forest products and biomass are 'carbon neutral' as is widely the case at the moment.[5] To that end this paper seeks to set out a methodology for forest carbon accounting in products.

To date, those undertaking to assess the carbon footprint of products that utilize wood from forests and plantations have had few methodological options for calculating the climate impact. The Working Group on Forest Carbon Accounting in Products asked a number of experts in the fields of LCA and forest carbon accounting to provide insight into how to create a methodology for use in LCA or a carbon footprint that would capture the biomass emissions or carbon debt (Forest Carbon Footprint). Although the comments varied on a number of issues, some important themes emerged and certain viewpoints were widely held. For example, the experts largely agreed that:

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[5] Harmon, M.; T. Searchinger; & W. Moomaw. (2011). Letter to the Washington State Legislature. February 2, 2011.
And: Johnson, E. (2009). Goodbye to carbon neutral: Getting biomass footprints right. *Environmental Impact Assessment Review*. 29 (2009) 165 – 168.
And: Searchinger, T. et al. (2009). Fixing a Critical Climate Change Error. *Science*. Vol 326, 527-528. 23 October 2009.
And: Kujanpää, M., T. Pajula & C. Hohenthal (2009) Carbon footprint of a forest product – challenges of including biogenic carbon and carbon sequestration in the calculations in Koukkari, H. & M. Nors, (eds.). (2009) *Life Cycle Assessment of Products and Technologies*. LCA Symposium, VTT, Espoo, Finland. VTT Technical Research Centre of Finland. 6 October 2009.

- Soil emissions are significant and must be a part of the methodology's calculation.[6]
- Carbon storage within the landscape and in harvested wood products are the key factors for consideration.

At the same time, there were divergent opinions about other methodological issues, such as:

- The correct time-frame for assessing emissions compared to land-use demand over space and time.
- The use of attributional or consequential analysis.
- The correct way to account for the future carbon storage (sometimes referred to as 'forest re-growth') on the impacted landscape and whether forest re-growth and growth foregone (had the forest not been harvested) should be accounted for when calculating the forest carbon footprint; or whether that assessment is even possible or useful.

Accounting for the climate impact of using forest biomass to make products or energy is complex and fraught with a number of challenges not encountered when accounting for fossil fuel emissions. These challenges include accounting for growth of carbon stocks over time, choosing a baseline for growth, additionality, leakage, stand-level versus landscape-level approaches amongst others. As one recent author observed, "Including biogenic carbon dioxide in carbon footprint calculations is challenging. Without [a] widely used methodology, biogenic CO_2 can be used in a purpose oriented way, depending on the product under examination as well as the goal and the scope of the study."[7] These challenges are further complicated by the fact that future carbon stocks may be affected by any number of external factors, negatively and positively, such as: changes in tax structure; programs that will encourage other land uses, or encourage the preservation of carbon stocks; or changes in demand for forest and agricultural products. A methodology for estimating the climate impact of using forest-derived biomass to make products or energy must overcome these challenges.

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[6] In this methodology we are using as a basis for our methodology and therefore incorporating the IPCC Tier 1 equations that calculate forest carbon emission impacts. The IPCC currently only enough evidence to include emissions from organic soils, it does not count emissions from mineral soils in Tier 1. We are therefore following the IPCC lead despite the evidence from individual studies. We will be seeking to encourage further the research on losses from mineral soil, particularly in th case of conversion of natural forests to plantation.

[7] Kujanpää, M.; T. Pajula & C. Hohenthal (2009) Carbon footprint of a forest product – challenges of including biogenic carbon and carbon sequestration in the calculations in Koukkari, H. & M. Nors, (eds). (2009) *Life Cycle Assessment of Products and Technologies*. LCA Symposium, VTT, Espoo, Finland. VTT Technical Research Centre of Finland. 6 October 2009. pp 31.

The Intergovernmental Panel on Climate Change (IPCC) offers some useful tools to develop accurate methodologies. However, the IPCC methodology must be modified to apply it to activity-based accounting as opposed to the national-based accounting for which it was originally developed.

Assessing emissions for a carbon footprint and assessing emissions in a policy context must be differentiated. A carbon footprint estimates the emission or impact of a single product derived from particular inputs and processes, while estimates for policy purposes estimate the use of land, inputs and processes across the landscape and economy. The methodology set out here aims to address the former, single product, scenario.

The Forest Carbon Footprint methodology proposed in this paper differs from other potential methodologies in the following ways:

- It separates the Forest Carbon Footprint from other GHG emissions,.
- It requires few input values.
- It focuses the estimate on input values that have the greatest certainty and requires no future estimated values.
- It requires no arbitrary time framework or estimates of the future storage on the same parcel or stand (Time issues related to forest re-growth will however be considered in the next phase (phase two) of this methodology).

4. System Boundaries and Definitions

Life Cycle Assessment (LCA) Measures the environmental impacts of a product. It is a cradle-to-grave analysis that includes the impacts of raw material procurement, production, transport, use, and disposal (or reuse) of a product.

Product Carbon Footprint A type of LCA that focuses only on the climate impact of a product.

Forest Carbon Footprint A specific product carbon footprint that measures the climate impact of the forest biomass used in wood and paper products. It calculates the balance of carbon dioxide in the atmosphere that results from the harvesting and use of wood from forests and plantations. It can be expressed as either carbon debt or carbon dividend.

Carbon Debt Where the forest carbon footprint shows net emissions of biogenic carbon.[8]

Carbon Dividend Where the forest carbon footprint shows a net sequestration of biogenic carbon.

Biogenic Carbon Carbon produced by living organisms or biological processes.

Slash/Brash Branches and other residue left on the forest floor after the cutting of timber.

Both carbon footprints and LCAs require a definition of the system boundaries to ensure the completeness of the assessment.

While all of the significant impacts should be considered in an LCA or carbon footprint, this methodology focuses solely on the forest carbon footprint. It does not therefore include GHG emissions from fossil fuels used in machinery or transport or from any other source; it focuses only on what happens to biogenic carbon that originates in a forest. An outline of the system boundaries for wood and paper products is shown below in the form of a Carbon Mass Balance diagram, although particular products might have more steps or processes involved.

[8] Following the definition of Carbon Debt as set out in Searchinger *et al*'s *Fixing a Critical Climate Accounting Error* (2009).

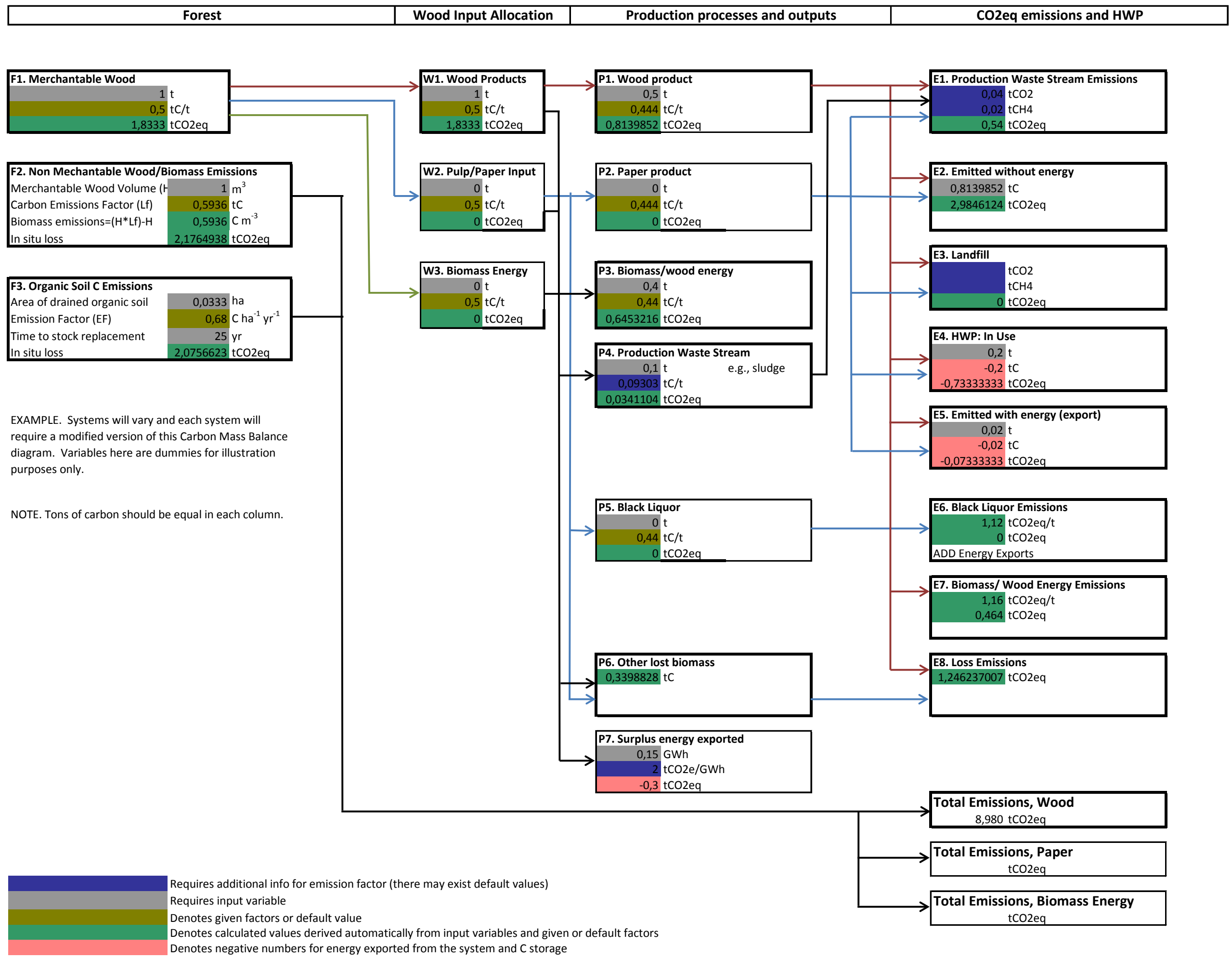

Figure 1: *Carbon Mass Balance diagram for wood and paper production and the associated forest carbon flows.*

If the LCA or carbon footprinting methodology includes any element of accounting for forest carbon anywhere in the production process then this will need to be removed/adjusted for, to avoid double counting when adding in the Forest Carbon Footprinting methodology featured in this paper

The Forest Carbon Footprint methodology presented here uses generalized, non site-specific data particular to climate domain (e.g. temperate) and ecological zone (e.g. temperate oceanic forest). Both the methodology and the data are derived from IPCC Tier 1 equations and associated data tables. We have reproduced the relevant tables in the Appendices of this paper for ease of use. Of course if site-specific data is available then it is preferable that that data is used as it will result in a more accurate Forest Carbon Footprint, in these cases IPCC Tier 2 or Tier 3 equations should be used.

The IPCC explains that: 'the carbon cycle includes changes in carbon stocks due to both continuous processes (i.e. growth, decay) and discrete events (i.e. disturbances like harvest, fire, insect outbreaks, land-use change and other events). Continuous processes can affect carbon stocks in all areas in each year, while discrete events (i.e. disturbances) cause emissions and redistribute ecosystem carbon in specific areas (i.e. where the disturbance occurs) and in the year of the event.'[9]

The Forest Carbon Footprint methodology will measure the climate impact of both discrete and continuous events. In order to simplify the calculations, discrete and continuous events will be looked at separately in two different phases: Phase one, which is presented in the current document, captures the carbon emissions as a consequence of discrete logging activities at a given point in time (Forest Carbon Footprint$_{\textbf{discrete}}$). Phase two will be presented in a future document and will look at including carbon changes from some of the continuous events that occur over time in the forest (Forest Carbon Footprint$_{\textbf{discrete \& continuous}}$).

There are some impacts from the harvest of wood that occur for several years after the harvest event, such as the release of carbon dioxide at the forest site as wood and debris (slash/brash) decay and the decay of wood products. These factors must be given a value at time period zero. For Harvested Wood Products (HWP) this is the total merchantable wood removal minus the estimated amount of products in long-term use and that are maintained in landfills. For biomass decay this is the portion of wood left on-site after harvest (slash/brash) that decays over a 20-year time horizon. For drained organic soils, it is the emissions until the resource is replaced (equivalent to the rotation length). These factors are accounted for in the methodology presented here (Forest Carbon Footprint$_{\textbf{discrete}}$) because they directly relate to the discrete harvest event and the management to enable that event to happen (i.e. soil drainage).

5. Uncertainty and Error

There are numerous sources of error and uncertainty in the data on emissions and sequestration. Some of the sources can potentially be eliminated, some can be reduced, but many are unavoidable. As with all models that simulate real systems, even though there are significant errors involved in accounting for emissions and sequestrations, the results and proposed methodologies are still very useful. It also is important to realize that the methods outlined in this document are 'living' methods, proposed in a way that can adapt and change as new information and methods are introduced.

[9] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 4, chapter 2, pp 2.9.

All potential methodologies to calculate forest carbon footprints are therefore limited by assumptions and reliability of data; for example, some of the data required for different methodologies and their levels of certainty include:

Data Required	**Uncertainty**
Quantity of wood	Very low
Rate of re-growth	Medium
Rate of forgone growth	Medium
Rate of growth	Medium
Predicting alternate land-uses (for the forest/plantation in question)	High
Replacement time (of the forest/plantation in question)	Low to medium
Longevity of wood products and fate after disposal	High

Sources of error and uncertainty include:

- The collection and reporting of emissions and sequestration data, including choice of sample sites, missing data and whether data has been collected throughout the year;
- The extrapolation of data from sample sites to give national/ecological zone/climate domain averages;
- The use of model estimates (in this case data provided by IPCC) based on national averages to estimate emissions for given activity sites;
- The need to correct data if it is subsequently found to be wrong;
- Unknown or unforeseen affects that reduce the reliability of the data e.g. forest fire;
- Changes in management regime;
- The climate may adapt as GHGs increase in the atmosphere and sequestration patterns may change.

In this document, we make the assumption that the national data *does* scale down and is relevant at the activity level, keeping the same values and the same level of uncertainty.

Using the IPCC Tier 1 data tables, we must be careful to track changes, improvement, and updates to those tables. Any changes may not just affect our current calculations, but there is also potential that corrections to previous values may need to be made.

We discuss uncertainty and error in more detail and how uncertainty might be calculated at the activity level in Appendix 3 of this paper.

6. Considerations of Time and Space

Biomass requires both space and time to grow and entails trade-offs pertaining to how land is allocated for different purposes. Using land to store carbon and provide other ecosystem services is one option, while using the land for the production of food, lumber, fiber for paper production, or fuel for biomass energy production are other options. In some cases the land can be used for more than one option at the same time, but doing so reduces the ability to maximize the potential of any one option. For example, carbon storage in a forest harvested on a short rotation is low compared to carbon storage in an unharvested forest. Such a short rotation regime, to varying degrees, requires harvest that brings storage to near zero (for above-ground biomass) every few decades. Food and ethanol production mean that above ground carbon storage in biomass is near zero on a continuous basis. Converting natural forest and old-growth forest to biomass production can mean a near-permanent loss of above ground, and in part, below ground storage of carbon. In many cases, biomass energy or product consumption requires either a land area that precludes natural levels of carbon storage over extensive areas or a one-time and more-or-less ‘permanent’ – from the perspective of GHG accounting – drawdown of carbon storage on the landscape, such as through the removal or drainage of organic soils (e.g. peat).

The phase two paper of this project will develop the time element for the methodology and will follow this paper. It will explore the potential different approaches to including the time element including: The concept of biomass replacement time or carbon payback period and the inclusion of forest re-growth and growth foregone due to harvest.

7. The Proposed Methodology

The Forest Carbon Footprint methodology proposed here attempts to overcome some of the challenges mentioned in the background section above by reporting biomass emissions separately from fossil fuel emissions.

A Forest Carbon Footprint is made up of various forestry activity emissions, including shorter term, emissions (e.g. from slash/brash after harvest) and much longer-term ('permanent') emissions (e.g. from the drainage of organic soils (such as 'peat') or their extraction)[10]. The Forest Carbon Footprint will show either Carbon Debt or Carbon Dividend; reporting the result separately in a LCA/carbon footprint, the climate impact and resource use of sourcing and harvest decisions will be clarified, and avoid direct comparisons with fossil emissions.

Other sources of emissions that comprise a product's total carbon footprint, such as emissions due to transportation and manufacturing are not considered in this methodology because accounting methods for these activities are already well established and they are inputs to the manufacturing process that are not derived from wood. Forest Carbon Footprint figures are just a portion of the total carbon footprint emissions (see *Table 1*): the broader carbon footprint for the product includes all other factors such as transport, chemical use and other production impacts.

The overall carbon footprint calculation will result in separate estimates and should be reported as follows:

Table 1: Example of carbon footprint reporting using separate Forest Carbon Footprint and emissions categories

Carbon Footprint (Example)	
Fossil and other non-biomass GHG emissions	2.0 CO_2e / tonne
Forest Carbon Footprint (Carbon Debt)	4.8 CO_2e / tonne
Total GHG emissions (all sources)	6.8 CO_2e / tonne

Where:

[10] Note that following the IPCC methodology (see later), where an organic soil is drained – or remains drained for forestry activity – the loss of soil carbon is not considered replaceable and so is a permanent component of the Carbon Debt..

Fossil and other non-biomass GHG emissions are those emissions associated with producing the product beyond the system boundaries of the forest biomass itself and may include fuel for transportation or processing, chemicals and other factors..

8. The Forest Carbon Footprint Equation

The harvesting of trees leads to a redistribution of carbon between different pools: Forest carbon accumulated in trees and soils will be redistributed among the atmosphere, timber and soils. Therefore, the **Forest Carbon Footprint** of a discrete harvesting event (Forest Carbon Footprint$_{\mathbf{discrete}}$) is equal to the carbon removed from the forest and transferred to non-forest 'pools' (L), plus soil and below-ground carbon emissions *in situ* (S), less the carbon stored in products in use and in landfills (HWP), less the carbon emitted to the atmosphere when burned to create energy (EE) but not part of the product LCA (i.e., energy sold for third-party use and its impact is therefore counted elsewhere)[11]:

$$\textbf{Forest Carbon Footprint}_{\textbf{discrete}} = \sum_n L_n + \sum_p S_p - HWP - EE \quad (1)$$

Equation 1. *Forest Carbon Footprint resulting from a discrete harvesting event, expressed in tonnes of C*[12].

Where:

L	*= total carbon transferred from the forest or plantation biomass to another carbon pool; in tonnes of C (taken from IPCC equation 2.12);*
S	*= estimate of emissions incurred from soils disturbance, in tonnes of C (taken from IPCC equations 2.24-2.26);*
HWP	*= harvested wood products - an estimate of carbon stored long-term as products in use and in landfills; in tonnes of CO2eq.*
EE	*= energy exports; in tonnes of CO2eq.*
n	*= group of merchantable wood with same characteristics in type and origin.*
p	*= parcel of land with same climate and soil characteristics.*

Both L and S should be calculated for each wood[13] type, climate and land soil where known. The carbon content in biomass (L) will be redistributed between timber and slash/brash. The IPCC Tier

[11] The Forest Carbon Footprint for the exported energy or biomass should be accounted for within the recipient business's products or energy LCA/carbon footprint.

[12] Tonnes is the metric unit equivalent to 1 Mg (i.e. 10^6 g).

1 approach assumes that slash/brash carbon is released entirely into the atmosphere in the year of the event[14]. Energy exports includes energy produced in the manufacturing process from the biomass but sold to a product or process outside of the system boundaries such as energy exports or sales to the electricity grid.

8.1. IPCC Equation for wood removals

The IPCC *Guidelines for National Greenhouse Gas Inventories*[15] contains an equation for calculating the emission of carbon dioxide from wood removals ($L_{wood\text{-}removals}$) (Equation 2.12). IPCC equation 2.12 lays out the means to estimate carbon dioxide emissions from the use of biomass based on wood removals from the forest site. This equation was developed for annual accounting inventories and serves as the basis for our methodology. It was adjusted for LCA/carbon footprints to Equations 2a and 2b below, which account for the fact that the Forest Carbon Footprint is a measurement for activity-based accounting and not national inventories. The amount of wood removal from the forest site can therefore be estimated from the total wood use for a given product. details the use of the IPCC equations and calculations.

Transfers of carbon from forest ecosystems (L) are calculated as follows:

$$\mathbf{L = H * BCEF_r * (1 + R) * CF} \qquad \textbf{(2a),}$$

That can be simplified as:

$$\mathbf{L = H * L_f} \qquad \textbf{(2b)}$$

Equations 2a and 2b: *On-site carbon loss due to wood removals. Adjusted from IPCC Equation 2.12, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, 'Annual Carbon Loss in Biomass of Wood Removals'.*

Where,

$$\mathbf{L_f = BCEF_r * (1 + R) * CF} \qquad \textbf{(3)}$$

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[13] this method only accounts for C stored in woody plants and trees, which can accumulate large amounts of carbon over their life span (IPCC, vol 4 chp2, pp 2.11)

[14] The carbon from biomass that is killed during a disturbance (less removal of harvested wood products) is assumed to be released entirely to the atmosphere in the year of the event in IPCC Tier 1 calculations (IPCC, 2006. Vol4, chp 2, pp 2.21).

[15] Intergovernmental Panel on Climate Change. Land-use, land-use change and forestry. Cambridge University Press. 2000.

Equation 3: *Carbon Emissions factor (tonnes of C/m³)*

Where:

L	*= carbon loss due to wood removals in tonnes of C;*
H	*= volume of wood removal or merchantable volume over bark[16] in cubic meters;*
$BCEF_r$	*= a biomass conversion and expansion factor that transforms removals in merchantable volume to total biomass removals (including bark). It takes into account the wood remaining on site (slash/brash) that will decay or be burned and released to the atmosphere; in tonnes of biomass removal/m³ of removals.*
R	*= a factor for below-ground biomass in roots and stumps;*
CF	*= carbon fraction of dry matter (assumed to be 0.5 on average for wood) in tonnes of d.m.*

8.2. IPCC Equation for soil changes

Soil losses are estimated using a separate equation.

The IPCC *Guidelines for National Greenhouse Gas Inventories* contains another equation to calculate changes in carbon stocks in soils that served as the basis for our methodology (ΔCsoils) (Equation 2.24). It was adjusted for LCA/carbon footprints to *Equation 4* below, which accounts for the amount of organic carbon stored in the soil (S) that has been lost because of logging activities. Appendix 2 details the use of the IPCC equations and calculations.

Forest soils can either be mineral or organic. Carbon (C) can be found either as organic or inorganic forms. No methods are currently provided for estimating changes in soil inorganic C as this is not covered by IPCC methodology. As agreement in the international community for soil inorganic C surfaces, the resulting methods will be adapted for use in this context. Therefore the equation only accounts for changes of organic C in mineral and organic soils.

[16] Volume overbark: growing stock or merchantable wood measured outside. It includes bark, that adds 5-25% of total volume. The average calculated from TBFRA data is 11%. Volume underbark: growing stock or merchantable wood without the bark. Another method is to apply a Bark factor on the following equation: $H= IRW_h*BF$, where IRW is Industrial Roundwood Harvest and BF is the Bark Factor (IPCC, vol 4, chp 12).

$$\mathbf{S = S_{mineral} - L_{organic}} \qquad \textbf{(4),}$$

Equation 4: On-site carbon loss due to changes in mineral and organic soils. Adjusted from IPCC Equation 2.24, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, 'Annual Change in Carbon Stocks in Soils'

Where,

S = *Soil Organic Carbon (SOC) stored in the soil lost because of logging activities, tonnes C*
$S_{Mineral}$ = *carbon loss/ gain from mineral soils, tonnes C*
$L_{Organic}$ = *carbon loss from drainage of organic soils, tonnes C*

The methodology outlined in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* considers that – where forest lands remain forest lands – there is no loss of organic carbon from mineral soils due to practices such as harvest. This assumption only holds under the IPCC Tier 1 scenarios, which rely on the same broad categories of SOC stocks and loss rates that we use in this report. When specific practices and parcels of lands are considered, there are losses of carbon from mineral soils. For this reason we include mineral soils in this report because we anticipate that in later versions, as the recommendations become more specific to a particular parcel of land, that reliable estimates of carbon loss from mineral soils will be factored into the methodology. The second reason for including soil carbon in the methodology is that under IPCC Tier 1 scenarios, drainage of organic soils (defined in Appendix 2) for practices such as forestry are associated with significant and 'permanent' losses of organic carbon.

8.3. Harvested Wood Products

When wood is removed from a forest ecosystem or plantation, it enters one of several 'carbon pools.' These carbon pools include products in use, landfills, and the atmosphere. In order to balance the estimate of wood removals and subtract that portion from the emissions estimate, we must estimate the amount of the product that is stored over the long term in landfills and in the products themselves. Long-term storage in landfills and products in use is defined as that portion of those products that has not oxidized (converted to CO_2) or converted to methane (CH_4) over a 100-year time frame.[17] Formulae to estimate long-term storage in wood products have been developed by many countries and could be applied

[17] U.S. Department of Energy. *Technical Guidelines, Voluntary Reporting of Greenhouse Gases (1605(b)) Program. January 2007.* P. 232.

directly in many cases to Life Cycle Analyses / carbon footprints. Care must be taken to ensure that the application of Harvested Wood Products (HWP) estimates is as objective and unbiased as possible for any product.

Estimation techniques for HWP are available for some countries and these standard estimates should be used wherever possible. Table 6 in a report by the U.S.D.A. Forest Service, *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*, by Smith et al.,[18] is an example of a well-developed methodology for estimating carbon remaining in products for sawlogs and pulpwood. The table is reproduced in Appendix 4 as .

In this paper we define HWP as the quantity of wood in products in use or landfill that will persist for 100 years.[19]

8.4. Energy Exports

Energy export is energy that is generated by the forest biomass (and other energy sources that may be generated in the particular facility, mill or other entity being assessed) that is not used in that facility for the products under assessment. This is can be sales of steam or electricity to another party or to the grid.

9. Using the Methodology

This methodology applies to the calculation of Forest Carbon Footprint (*Equation 1*).

$$\textbf{Forest Carbon Footprint}_{discrete} = \sum_n L_n + \sum_p S_p - HWP - EE \quad (1)$$

[18] Smith, James E., Linda S. Heath, Kenneth E. Skog, and Richard A. Birdsey. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.* United States Department of Agriculture Forest Service, Northeastern Research Station. General Technical Report NE-343. April 2006.

[19] U.S. Department of Energy. *Technical Guidelines, Voluntary Reporting of Greenhouse Gases (1605(b)) Program. January 2007.* P. 232 uses a 100 year timescale.

Steps required to calculate L and S are compiled in the flow chart below (Figure 2), which is organized as a generic decision tree that asks key questions. It will guide users through the calculation of carbon or emissions incurred due to biomass removal and soil disturbance.

Sections 9.1 and 9.4 will set out the data required and work through a detailed example respectively.

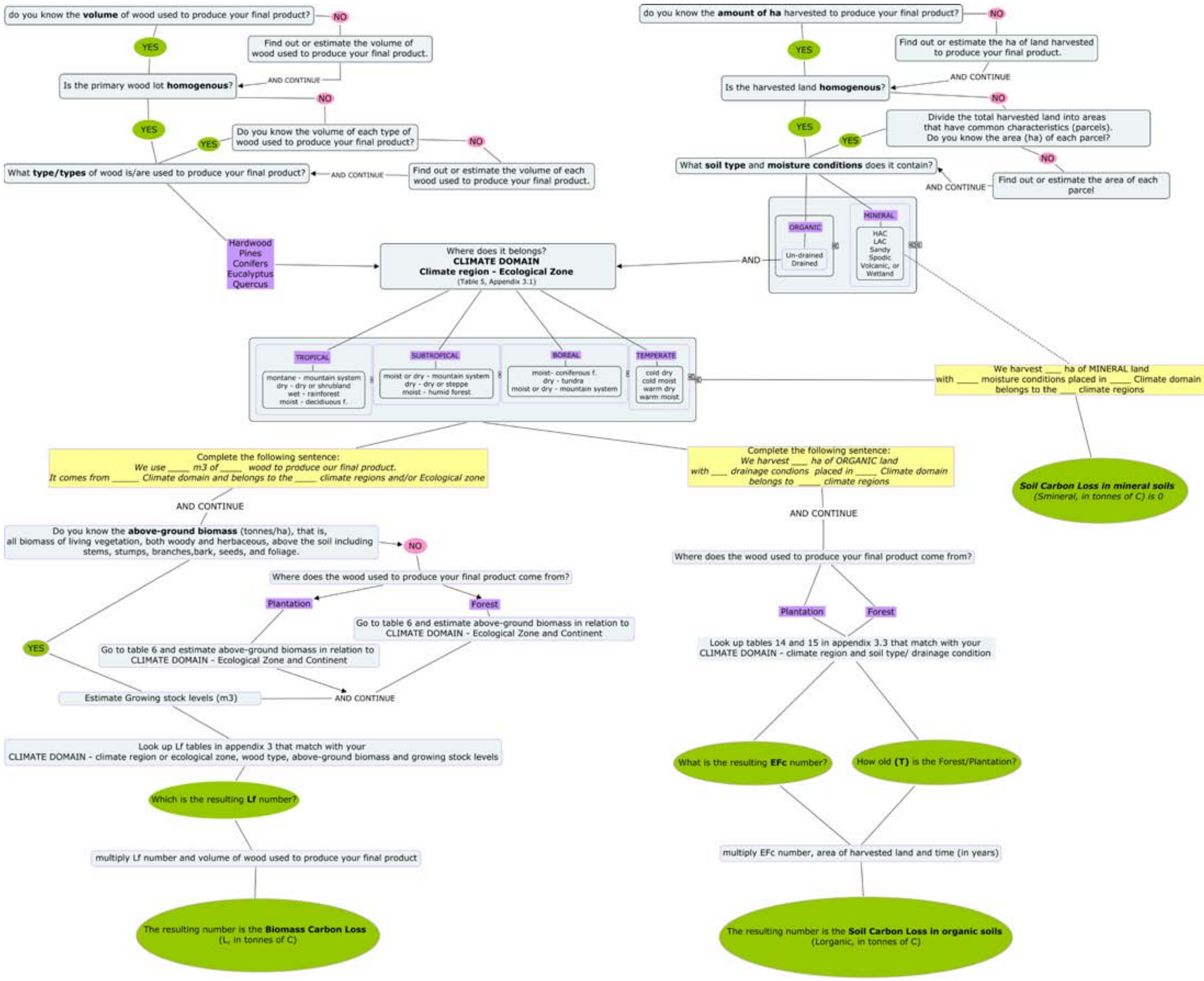

Figure 2: Decision tree flow chart to calculate L and S

9.1. Data Requirements

Using the methodology described in this paper requires gathering the following data and information:

A) To calculate L

1. Volume of wood used as an input to the process (H), in m^3. *Required value.*
2. Wood types, by genus, used as an input to the process or product: *Quercus, Pinus, Eucalyptus*, … (only for temperate climate domains). *Required information.*
3. Climate domain and Ecological Zone origin of wood used as an input to the process: Boreal, Temperate, Mediterranean, Subtropical or Tropical/ humid, dry, steppe, mountain system, rainforest, moist deciduous, shrubland. *Required information. See* Table 5 *in Appendix 4- 4.1 to distinguish between climate domain, climate region and ecological zone.*
4. Above-ground biomass (tonnes ha^{-1} or tonnes of d.m. ha^{-1}). *Optional information. For default values, see* Tables for L calculations.
5. Table 6 *and for more detailed values see* Table 16 *and* Table 17 *in Appendix 3- 4.4*
6. Estimated stand age at harvest. *Required information.*
7. Estimates of growing stock levels in m^3. *Required value (see Lf tables* Table 7 *in Appendix 4- 4.2)*

B) To calculate S

1. Area of harvest with same biophysical conditions of soil and climate that have been harvested to obtain the wood used as an input of the process (ha). *Required value*
2. Type of soil: organic or mineral. *Required information*
3. Climate domain origin of wood used as an input to the process: Boreal, Temperate, Mediterranean, Subtropical and Tropical. *Required information.*
4. Type of mineral soil. *Required information*

C) To calculate HWP (the term is discussed further in a section below)

1. Determine the forest rotation length. HWP is the quantity of wood in products in use or landfill that will persist for 100 years.[20] Estimation techniques for HWP are available for some countries and these standard estimates should be used wherever possible.[21] *Required information*

D) To calculate EE (the term is discussed further in a section below)

1. Total energy produced at the facility by type (e.g., steam at 160 psi or electricity) and quantity (gigawatt-hours, GWh). *Required value*
2. Energy surplus for each type of energy (percentage). *Required value*
3. Emissions factors for each surplus energy type or for the grid regionally. The emissions factor and the source of the information must be clearly recorded and stated as different information sources/energy providers may vary widely.[22] A table of sample emissions factors is available in at *Appendix 5*. *Required information.*

9.2. Units

In using this methodology it is important to pay careful attention to the units involved.

A) To calculate L

- biomass stocks should be given in units of dry matter[23]
- changes in C stocks are given in units of C
- merchantable volume includes bark. Therefore, underbark data needs conversion to overbark before using BCEFr. Conversion is done by using bark percentages of the default Bark Factor (BF) 1.13.

B) To calculate S

[20] U.S. Department of Energy. *Technical Guidelines, Voluntary Reporting of Greenhouse Gases (1605(b)) Program. January 2007.* P. 232 uses a 100 year timescale.

[21] For example, the following source document estimates HWP carbon stocks after harvest for sawn wood products and pulp-based products for the US: Smith, James E., Linda S. Heath, Kenneth E. Skog, and Richard A. Birdsey. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.* United States Department of Agriculture Forest Service, Northeastern Research Station. General Technical Report NE-343. April 2006.

[22] This methodology does not detail the methods for calculating the non-biomass portion of the energy and therefore other sources must be referenced for that portion of the energy mix to determine non-biomass emissions.

[23] As used in the IPCC, biomass expansion factors always transform dry-weight of merchantable components including bark to aboveground biomass, excluding roots.

- S is composed of two terms, the first for mineral soils ($S_{mineral}$) and the second for organic soils ($L_{organic}$), that are then summed. Both of these terms, and their summation (S) have units of tonnes C ha^{-1}. Reference values to calculate these terms are given in tables 14 and 15, and these reference values are based on measured soil organic carbon concentrations in the surface 30 cm of soil, multiplied by the mass of soil (derived from bulk density estimates) in this surface layer
- In calculating $L_{organic}$, a rate (i.e. change per unit time) term (EF) is used in units of tonnes C ha^{-1} yr^{-1}. To convert this to a carbon stock term (i.e. tonnes C ha^{-1}), the term is multiplied by the rotation length (years) of the forested plot of land.

C) According to *Equation 1*. FCF is expressed in tonnes of C. To convert tonnes of C into tonnes of CO_2, multiply by 3.6666.

9.3. Calculating the Forest Carbon Footprint

To calculate Forest Carbon Footprint we will use equation 1:

$$\textbf{Forest Carbon Footprint}_{\textbf{discrete}} = \sum_n L_n + \sum_p S_p - HWP - EE \qquad (1)$$

The following example shows L and S calculations for a hypothetical harvesting site in the temperate continental forest zone of Northeastern North America.

Assumption for the example case study:

- The merchantable round wood harvest over bark (H) is 1 m^3 (*required value*)
- The [equivalent] area of *Forest Land harvested* is 0.033 ha (*required value: area of harvest in hectares*);
- It is a 25-year-old pine forest (*required information: estimate stand age at harvest and tree species or genus*),
- The average above-ground growing stock volume is 40 m^3 ha^{-1} (*if not available, default values can be used from* Tables for L calculations

- Table 6 *in Appendix 4- 4.2,or more accurate values at* Table 16 *and* Table 17*in Appendix 4-4.4*
- Growing stock levels of 50 m^3 (*required value: average range*)

9.3.1. Wood removals (L)

To calculate the carbon emissions incurred due to wood-removals component of equation 1 ($\sum_n L_n$), *Equation 3* is applied:

$$\sum_n \mathbf{L_n = (H * L_f)_{\ n}},$$

Where,

L = *Carbon emissions incurred due to wood removals (tonnes C or tonnes of CO2eq)*

Lf = *Carbon emissions factor (tonnes C m^{-3})*

H = *volume of wood removal or merchantable volume over bark (m^3)*

n = *group of merchantable wood with same characteristics in type and origin (A, B, C,…n).*

To calculate L follow the steps in ***Figure 2*** above:

Step 1: Determine the total volume of merchantable round wood over-bark used to produce your final product. If there are different types and origins of wood, then:

- **Step 1a**: Determine each different type of wood in the batch used to produce the final product (i.e. *Pinus, Eucalyptus* etc...);
- **Step 1b:** Determine the volume of each type of wood (m^3). (If it is under-bark, multiply the volume by a factor of 1.13 for the over-bark value[24].);
- **Step 1c:** Determine the origin of each wood type identified according to as many as possible of the following categories: Climate domain, climate region, ecological zone, country of origin (for the categories mentioned check Table 5 in Appendix 4) and land use type (natural forest or plantation) (See Table 2 in Step 5).

Step 2: Estimate the age of the forest or plantation for each group.

[24] Variable H = IRW_H * BF + Fuelwood, BF (bark factor) default value = 1.13 ; Softwoods (1.11), Hardwoods (1.15) (Jenkins *et al*., 2003), at IPCC 2006, vol4 chp 12.

Step 3: Find out or estimate the above-ground biomass of each forest (the origin of each wood group) using Tables for L calculations

Table 6 in *Appendix 4- 4.2* for default values and in Table 16 and Table 17 in *Appendix 4- 4.4* for more detailed values.

Step 4: Find out or estimate the average growing stock volume[25] of each forest

Step 5: Complete the following table (Table 2) to classify each wood group:

Table 2*: Classification of wood groups*

Groups (n)	Wood type	volume (H, m^3)	Climate Domain	Climate Region	Ecological Zone	Country / region	Land use type (plantation or forest)	Forest or plantation Age (yr)	Above-ground biomass (tonnes d.m./ha)	Growing Stock volume (m^3)
A	*pine*	*1*	*Temperate*	*Cool temperate moist*	*Continental forest*	*North America*	*forest*	*25*		*50*
B	Not applicable (use sections B, C, etc. if more than one wood type or source is used as an input).									
C	Not applicable									

Step 6: use the corresponding climate domains table found in Table 7 in *Appendix 4- 4.2* to find the carbon emissions factor (L_f) value for each group.

In our example, Temperate-continental pine forest in North America, 25-yr old, and 50 m^3 ha^{-1} of growing stock volume. The resulting L_f is: 0.5936 tonnes of C m^{-3}.

Step 7: Calculate carbon emissions incurred due to wood removals (**L**) multiplying L_f by the volume of each corresponding type of merchantable round wood over bark. In this example there is only one group, so n=A.

$$\mathbf{L} = (0.5936 \text{ tonnes C } m^{-3} * 1\ m^3)_A$$
$$= 0.5936 \text{ tonnes of C}$$

[25] Growing stock levels determine carbon loss factors. In order to simplify the methodology, and in case this value is unknown, we have simplified the calculations by clustering growing stock volume of all climate domains but humid tropical, in three categories (small, medium and large. See Table 7).

Carbon emissions can also be expressed in tonnes of CO2eq. For the conversions, multiply **L** by 3.6666.

L_{co2eq} = 0.5936 tonnes of C * 3.666 tonnes of CO_2eq per tonnes of C

= 2.1764 tonnes of CO_2eq

These are carbon emissions potentially lost due to the biomass harvested in that forest, including both merchantable wood and that left over from harvest (slash/brash), expressed in tonnes of C (L) or tonnes of CO_2 equivalent (L_{co2eq}).

9.3.2. Emissions from Soils

To calculate S, the following equation is applied:

$$\sum_p \mathbf{S = (S_{mineral} + L_{organic})_p}$$

Where:

$S_{mineral}$= 0, for Tier 1 calculations as explained in Section 8.2.

And:

$L_{organic}$= (A*EF_c) * T

$L_{Organic}$	= *Carbon emissions from drained organic soils, tonnes C*
A	= *Land area of drained organic soils in climate type* c*, ha*
EF	= *Emission factor for climate domain* c*, tonnes C ha^{-1} yr^{-1} (Table 15)*
c	= *Represents the climate zones,* s *the soil types, and* i *the set of management systems.*
T	= *Time; as a default use the stock rotation time (e.g. 25 yr in the example above)*

Following the steps of the methodology to calculate S :

Step 1: Divide the total harvested land into areas that have common characteristics (parcels, p).

Step 2: Find out the area of each parcel.

Step 3: Define soil type and moisture conditions of each parcel

Step 4: Find out the location of each parcel according to climate domain, climate region, ecological zone

Step 5: Fill in the following table to classify each land parcel:

Table 3: *Table to classify soils*

Parcels (p)	Area (ha)	Climate Domain	Climate Region	Country	Soil type	Moisture conditions
a	*0.0333*	*Temperate*	*Cool temperate moist*	*North America*	*mineral*	*Sandy soil*
b	Not applicable as there was one parcel of land					
c	Not applicable					

Step 6a: For the above example use Table 14 in Appendix 4 to find the reference carbon stock (SOC_{ref}) value for each land parcel.

Step 6b: If a drained organic soil underlies the land parcel in question, instead use Table 15 in Appendix 5 to find the emission factor (EF). For example, it is 0.68 tonnes C ha^{-1} yr^{-1} for the temperate climate domain.

Step 7a: For the mineral soil example, calculate soil C stock emissions incurred (S) due to wood removals. In this example, as a Tier 1 calculation, $S_{mineral}$=0 as outlined earlier.

$S_{mineral}$= 0 tonnes of C,

which is equivalent to 0 tonnes of CO_2 eq. (multiply by 3.6666)

These are the emissions stored in the soil expressed in tonnes of C (S) or tonnes of CO_2 equivalent (S_{co2eq}).

Step 7b: For the organic soil example, calculate soil C stock loss (S) due to soil drainage by multiplying the EF by the area of the parcel, and then time to stock replacement (rotation length) (in this example 25 yr). In this example there is again only one parcel, a (p=a).

$L_{organic}$= ($A*EF_c$) * T = (0.0333 ha * 0.68 tonnes of C/ha/yr) * 25 yr = 0.57 tonnes of C

Step 8: If the mineral and organic soil parcels in the examples above were considered part of the same accounting procedure, then calculate S for the entire land area managed:

$S= (S_{mineral}+ L_{organic}) = 0 + 0.57 = 0.57$ tonnes of C

9.3.3. Carbon stored long term in products and landfill (HWP)

Harvested Wood Products constitute continued carbon storage from the forest carbon stock pool into the wood products in use and wood products in landfills over the long term (after 100 years). We discuss this concept further in section 8.3 above.

Step 1: For our example see Table 6 of the US Forest Service's report (Smith *et al* 2006), detailing carbon storage rates in different products (The table is reproduced in Appendix 4 as **Table 4**).[26] Using a 100-year time period: for a softwood forest in the Northeast U.S., sawlogs in use amount to 0.095 of the original quantity while sawlogs in landfills amount to 0.2333. This is a total HWP figure of 0.318.

9.3.4. Energy Exports (EE)

The percentage of the energy that is exported is subtracted from the Forest Carbon Footprint and is assumed to be part of the Forest Carbon Footprint of the other party. We discuss this concept further in section 8.4 above.

Step 1: For our example, the wood processing facility creates 5 GJ of energy from wood waste. It sells 1 GJ of energy back to the local grid.

Step 2: Find the appropriate energy emissions factor, where applicable and apply it to the quantity of energy exported. In our example, we are using wood as the energy source, which has an emission coefficient of 0.11399 tCO_2eq/GJ (from Appendix 5), resulting in an emission of 0.56995 tCO_2eq total.

Step 3: This surplus energy is subtracted from the total Forest Carbon $Footprint_{discrete}$ by subtracting 20% from the wood removals and soil emissions total. In our example, 20% (1

[26] Smith, James E., Linda S. Heath, Kenneth E. Skog, and Richard A. Birdsey. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.* United States Department of Agriculture Forest Service, Northeastern Research Station. General Technical Report NE-343. April 2006.

GJ of a total energy production of 5 GJ), and therefore 0.11399 tCO_2eq of exported emissions, to be subtracted from the total emission. EE = 0.11399 tCO_2eq.

9.4. Example results

The results of applying the Forest Carbon Footprint methodology to the example gives a Carbon Debt of 0.5936 tonnes of C (2.1764 tonnes of CO_2eq).

Wood removals (L) are found to be 0.5936 tonnes of C (or 2.1764 tonnes of CO_2eq).
Soil emissions incurred (S) – for the mineral soil example – are found to be 0 tonnes of C (0 tonnes of CO_2eq).

Adding up wood removals and soil emissions incurred:

L + S = 0.5936 + 0 = 0.5936 tonnes of C (2.1764 tonnes of CO_2eq)

If we assume that the product is sawlogs for solid wood products and an energy export of 20%, we arrive at a HWP fraction of the original wood of 0.318 (using Table 4 of the USDA Forest Service report) that is conserved in the non-atmospheric carbon footprint and thus subtract energy exports and HWP from L + S (13.28632.1764 tonnes of CO_2eq), for a final Forest Carbon Footprint (FCF) of 1.16 tonnes of CO_2eq.

L + S = 2.1764 tonnes of CO_2eq

HWP = 2.1764 * 0.318 = 0.692 tonnes of CO_2eq

EE = 0.11399 tonnes CO_2eq

FCF = L + S – HWP – EE = 2.1764 - 0.11399 - 0.326 = 1.74441 tonnes of CO_2eq

Forest Carbon Footprint (Pine Example)	
Carbon Debt	1.74441 tonnes CO_2eq

A calculation of the uncertainty in this calculation is outlined in Appendix 3 with a total uncertainty of ???%. This value is expected to be lower for higher tier estimate of the Forest Carbon Footprint.

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Appendix 1. Application of Biomass Expansion Factors to Wood Removal from Logging Activities

Logging activities produce large amounts of wood left over from harvest that are not used and are left in the forest ground. Operational records usually document growing stock, net annual increment or wood removals in m^3 of merchantable volume that excludes non-merchantable above-ground and below-ground wood components, including tree tops, branches, foliage, roots, etc. The amount of wood left over will depend on different factors, such as the activity itself and the ecosystem type.

Should we want to assess change in forest biomass and carbon stocks, wood left over from harvest must be taken into account. Ignoring it would lead to underestimates of these changes. According to IPCC (2006, vol4, chp2, pp 2.21), the carbon in biomass left on the ground after harvesting (thus not removed as harvested wood product) is assumed to be released entirely to the atmosphere in the year of the event.

The methodology applied to account for biomass and carbon stock changes due to harvest follows the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. In particular it is developed in Chapters 2 and 4.

The following paragraphs explain both the methodology, the concepts used and the assumptions made.

1.1. Background

As part of the Carbon Footprint analysis, this study focuses on the application of Biomass Expansion Factors to the calculation of Carbon emissions incurred due to wood harvest for the production of cellulose or wood primary products by the manufacturing industry.

The system boundary for the production of wood and paper products begins with the sourcing of raw materials, principally timber. **Trees are harvested and brought to the mill for processing**. **The harvesting process is associated with changes in biomass forest, thus changes in carbon stocks**.

Plant biomass constitutes a significant carbon stock in many ecosystems. It is present in both above-ground and below-ground parts of annual and perennial plants. Biomass changes over time mainly encompass both biomass growth and biomass loss.

Our system boundary is a track of forest that is partially or totally harvested at a point in time. That forest, being a carbon stock, has been cut. Part of the forest is removed in the form of timber (HWP) and part of it is left on the ground in the form of roots, branches, and other organic leftovers (brash/slash). Therefore, the logging of the forest involves a total biomass loss, which includes both above-ground and below-ground biomass losses.

As time applies, we are analyzing a discrete event because we do not try to capture changes over time due to growth and decay, that is to say, changes in a continuous process.

Furthermore, losses due to fuel wood gathering and natural disturbances are not considered in our system boundary, since neither are the result of harvest or management activities for the wood products that are the subject of the analysis.

In conclusion, **we want to calculate the amount of carbon sink (carbon stored in the forest) that has been removed from the forest in the form of timber and leftovers ($L_{wood\text{-}removals}$); the associated loss of carbon stock in the forest or plantation ecosystem not harvested; and the carbon remaining in the final product.**

The IPCC has developed the methodology to estimate ***Changes in Carbon Stocks in Biomass,*** including both gains and losses. It presents two different and equally valid approaches: ***Gain-Loss method*** and ***Stock-Difference method***. Namely, *Gain-Loss Method* (GLM) based on estimates of annual change in biomass from estimates of biomass gain and loss, and a *Stock-Difference Method* (SDM) which estimates the difference in total biomass carbon stock at time t2 and time t1. The former is a process-based approach, the second a stock-based approach.

GLM

This method considers that *Annual change in Carbon Stock in biomass for Forest remaining forest land (FF)* is the difference between annual gain and loss in biomass stocks.

$$\Delta C_B = \Delta C_G - \Delta C_L$$

Source*: Equation 2.7, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.12*

ΔC_B = annual change in Carbon stocks in biomass for each land sub-category, considering the total area, tonnes C yr^{-1}.

ΔC_G = increase in Carbon stocks due to biomass growth (Carbon gain), tonnes C yr^{-1}.

ΔC_L = decrease in Carbon stock due to harvest, fuelwood removal or natural disasters (Carbon loss), tonnes C yr^{-1}.

Estimates of biomass loss are **based on volumes of wood removals from the forest site**. The amount of wood removal from the forest site can be estimated from the total wood use for a given product.

It is important to bear in mind that round wood removal refers to merchantable wood plus the by-product that is generally left in the forest in the form of non-merchantable biomass.

SDM

This method calculates the *annual biomass change* as the difference between the biomass stock at time t_2 and time t_1, divided by the number of years between the inventories.

$$\Delta C_B = (C_{t2} - C_{t1})/(t_2 - t_1)$$

Source*: Equation 2.8, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.12*

ΔC_B = annual change in carbon stocks in biomass in land remaining in the same category, tonnes C yr^{-1}.

C_{t2} = total carbon in biomass for each land sub-category at time t_2, tonnes C

C_{t1} = total carbon in biomass for each land sub-category at time t_1, tonnes C

Estimates of biomass loss are **based on wood volumes of growing stocks from the forest site**. It requires biomass carbon stock inventories for a given land area, at two points in time.

Furthermore, in the methodology the IPCC[27] differentiates between two subcategories of managed land: land remaining in the same land-use category[28] (i.e. forest land remaining forest land), and land converted to a new land-use category (i.e. forest land converted to cropland). Conversion to another land category may be associated with a change in biomass stocks, e.g., part of the biomass may be withdrawn through land clearing, restocking or other human-induced activities. Land-use conversions from Forest Land to other land uses often result in substantial loss of carbon from the biomass pool.

If there is land conversion, the *Annual Change in biomass stocks* is calculated as:

$$\Delta C_B = \Delta C_G + \Delta C_{conversion} - \Delta C_L$$

Source*: Equation 2.15, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.20*

ΔC_B = annual change in Carbon stocks in biomass on land converted to other land-use category, tonnes C yr $^{-1}$.

ΔC_G = annual increase in Carbon stocks due to biomass growth (Carbon Dividend) on land converted to other land-use category, tonnes C yr $^{-1}$.

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr $^{-1}$

ΔC_L = annual decrease in Carbon stock due to harvest, fuel wood removal or natural disasters (Carbon loss) on land converted to other land-use category, tonnes C yr $^{-1}$.

Going back to our system boundary and objective, our question is:

What is the total biomass loss, thus carbon stock loss, associated with tree harvesting in a forest plot?

[27] For inventory purposes, changes in C stock in biomass are estimated for (i) land remaining in the same land-use category and (ii) land converted to a new land-use category (2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.11)

[28] The length of time that land remains in a conversion category after a change in land use is by default 20 years (the time period assumed for carbon stocks to come to equilibrium for the purposes of calculating default coefficients in the 1996 IPCC Guidelines and retained for GPG-LULUCF and used here also, though other periods may be used at higher Tiers according to national circumstances).

1.2. Our case: wood and paper industries

In order to decide which of the approaches mentioned above can be applied to our case, we need to analyze the available raw data (a) and the impact of a potential land conversion (b).

(a) As mentioned before, the manufacturing industry uses timber or virgin fiber made from harvested trees brought to the mill for processing. This industry will have information about the **volume of merchantable wood removed from the forest site**. So, this is the available data we must deal with. GLM approach calculates annual losses based on annual removals, which mean the amount of wood removed annually from a forest site at a point in time. SDM approach estimates biomass loss based on wood volumes of growing stocks from the forest site. It requires biomass carbon stock inventories for a given land area, at two points in time, before and after wood removal.

Since we have data on wood removals but not on growing stocks from the forest site, nor the area of the harvested forest, and we want to capture the release of CO_2 at a point in time, we will use the **GLM approach**, which calculates annual decrease in carbon stocks due to biomass losses (ΔC_L) as:

$$\Delta C_L = L_{wood\ rem.} + ~~L\ fuelwood~~ + ~~L\ disturb~~.$$

***Source**: Equation 2.11, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.16*

$L_{wood\text{-}removals}$ *= annual carbon loss due to wood removals, tonnes C yr* $^{-1}$
$L_{fuelwood}$ *= annual biomass carbon loss due to fuelwood removals, tonnes C yr* $^{-1}$
$L_{disturbance}$ *= annual biomass carbon losses due to disturbances, tonnes C yr* $^{-1}$

Fuel wood removals and natural disturbances do not apply to the manufacturing industry. Therefore, changes in biomass carbon stocks are only due to harvested wood from forest site.

(b) As per our purpose, we are calculating the amount of carbon that being stored in a specific forest or plantation at a point in time will be lost[29] after harvesting. Subsequent re-growth and forgone growth are captured in the 'replacement time' estimate, that will be developed in phase two of this methodology.

Furthermore, we are only interested in biomass loss that according to the IPCC, '*The annual decrease in C stocks in biomass due to losses on converted land (wood removals or fellings, fuelwood collection, and disturbances) can be estimated using Equations 2.11 to 2.14*'. Resuming, both subcategories calculate biomass loss the same way.

The IPCC equation 2.12 lays out the means to estimate carbon loss from the harvesting of wood for industrial purposes.

$$L_{wood - removals} = \{ H \times BCEF_R \times (1 + R) \times CF \}$$

***Source**: Equation 2.12, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.16*

$L_{wood\text{-}removals}$ *= annual carbon loss due to biomass removals, tonnes C yr* $^{-1}$
H = annual wood removals, roundwood, $m^3\ yr^{-1}$
R = ratio of below-ground biomass to above-ground biomass, in tonnes d.m. below-ground biomass (tonnes d.m. above-ground biomass) $^{-1}$*. R must be set to zero if assuming no changes of below-ground biomass allocation patterns.*
CF = carbon fraction of dry matter, tonnes C (tonnes d.m.) $^{-1}$

[29] We use the word 'lost' as meaning 'transferred to another pool', and not necessarily meaning 'released to the atmosphere', that may or may not be the case.

$BCEF_R$ = *biomass conversion and expansion factor, in tonnes biomass removal (m^3 of removals)$^{-1}$.*

As stated above, the factors for time, potential re-growth and estimated forgone growth are captured in the estimate of the 'replacement time' of the carbon stock in question. This method removes highly uncertain and manipulable estimates of what the future course of a particular stand of forest or plantation may take. This method focuses on the best known and most highly estimable data available to the carbon footprint assessor.

1.3. Application of Biomass Expansion Factors

Assessments of biomass and carbon stocks and changes focus on total biomass, biomass growth and biomass removals (harvest), including non-merchantable components, expressed in tonnes of dry-weight. In the specific case of the wood and paper industry, estimates of biomass changes are based on merchantable volume of wood removal.

Indirect methods to derive above-ground biomass and changes apply discrete transformation factors to merchantable volumes **so as to transform available data from forest inventories -e.g. wood removals- into above-ground biomass**:

(i) **Biomass Expansion Factors** (BEF) expand the dry weight of the merchantable volume of wood removals, to account for non-merchantable components of the tree, stand, and forest. It transforms dry-weight of merchantable volume including bark to above-ground biomass, excluding roots. Before applying such BEFs, merchantable volume (m3) must be converted to dry-weight (tonnes) by multiplying with a conversion factor known as basic wood density (D) in (t/m3). BEFs are dimensionless since they convert between units of weight.

This method gives best results, when the BEFs have actually been determined based on dry weights, and when locally applicable basic wood densities are well known.

(ii) **Biomass Conversion and Expansion Factors** (BCEF) combine conversion and expansion. They have the dimension (t/m3) and transform in one single multiplication growing stock, net annual increment, or wood removals (m3) directly into above-ground biomass, above-ground biomass growth, or biomass removals (t).

BCEF can be applied directly to volume-based forest inventory data and operational records without the need of having to resort to basic wood densities. They provide best results, when they have been derived locally, based directly on merchantable volume.

Mathematically, BCEF and BEF are related by:

$$BCEF = BEF \times D$$

There are three different BCEF factors, $BCEF_s$, $BCEF_I$ and $BCEF_R$, applicable to growing stocks, net annual increments or wood removals respectively.

As explained before, the data available from the manufacturing industry refers to wood removals, which determine the BCEF and equation to use.

$BCEF_R$: biomass conversion and expansion factors applicable to wood removals; transforms removals in merchantable volume to total biomass removals (including bark).

$BCEF_R$ and BEF_R for wood removal will be larger than that for growing stock due to harvest loss. If a country specific value for harvest loss is not known, defaults are 10% for hardwoods and 8% for conifers (Kramer and Akca, 1982). Default conversion and expansion factors for wood removals can be derived by dividing $BCEF_S$ by (1– 0.08) for conifers and (1-0.1) for broadleaves.

$BCEF_I$: biomass conversion and expansion factors applicable to net annual increment; transforms merchantable volume of net annual increment into above-ground biomass growth.

$BCEF_S$: biomass conversion and expansion factors applicable to growing stock; transforms merchantable volume of growing stock into above-ground biomass.

1.4. Calculating Carbon & Emission Loss due to wood removal (L&E)

Values of Carbon and Emission Loss due to wood removal (L) change with climate domain and climate zones because R, BCEF and CF values depend on forest type and ecological zone.

In order to make the calculations as simple as possible, the equation,

$$L = \{ H \times BCEF_R \times (1 + R) \times CF \} \text{ (in tonnes of C)}$$

has been converted to,

$$L = H \times L_f$$

where, **H** is the volume of wood removed (m^3 per year), and **L_f** is the carbon loss factor (tonnes of C/m^3).

$$L_f = BCEF_R \times (1 + R) \times CF$$

$BCEF_R$ *values are given in Table 4.5, Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.*
R *must be set to zero if assuming no changes of below-ground biomass allocation patterns. Otherwise, values are given in Table 4.3, Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.*
CF *varies between 0.47 and 0.51*

L_f varies for each climate domain: Boreal, Temperate, Mediterranean, Subtropical and Tropical, for BCEF depend on the climate domain and R varies according to the above ground biomass (tonnes/ha).

The tables below show the L_f values for different climate domains, forest type, ecological zones and above-ground biomass values.

Climate domains are classified as: Boreal, Temperate, Mediterranean, Subtropical and Tropical.

L can be expressed in tones of C, or in tones of CO2eq if multiplied by 3.6666.

Appendix 2. Soil factors

2.1. Background

As part of the Carbon Footprint analysis of the wood manufacturing industry, this study focuses on the application of Soil Factors to the calculation of Carbon loss due to wood harvest for the production of cellulose or wood primary products by the manufacturing industry.
The system boundary for the production of wood or cellulose begins with the collection of raw materials and other inputs (primarily energy and chemicals) and ends with the conversion process. **For virgin material, trees are harvested either from natural forests, managed forests or plantations**, and brought to the mill for processing. **Planting, growing and harvesting processes are associated with potential changes in soil carbon stocks**.

The content of carbon (organic and inorganic C stocks) stored in the soil is a balance of carbon inputs and carbon losses that can be altered by management practices and environmental factors. *Inputs* are largely determined by the forest productivity, the decomposition of litter and its incorporation into soil. *Losses* of soil organic C occur through mineralization/respiration, erosion or the dissolution of organic C that is leached to groundwater or lost through overland flow.

C stocks are different in organic[30] and mineral soils: the organic C content of mineral forest soils (to 1 m depth) typically varies between 20 to over 300 tonnes C ha^{-1} depending on the forest type and climatic conditions. Management and land-use activities impacts are typically larger on organic C stocks and dramatically different in organic versus mineral soils.

Human activities, such as crop and forest management can alter C dynamics. **In mineral soils**, management practices within a land-use type can have a significant impact on soil organic C storage, particularly in Cropland and Grassland. Management activities influence organic C inputs through changes in plant production (such as fertilization or irrigation to enhance crop growth), direct additions of C in organic amendments, and the amount of carbon left after biomass removal activities, such as crop harvest, timber harvest, fire, or grazing. Decomposition largely controls C outputs and can be influenced by changes in moisture and temperature regimes as well as the level of soil disturbance resulting from the management activity. **In organic soils**, C losses increase primarily when drainage is improved, for it enhances aerobic decomposition. While drainage of organic soils typically releases CO_2 to the atmosphere, there can also be a decrease in emissions of CH_4 that occur in un-drained organic soils. However, CH_4 emissions from un-drained organic soils are not addressed.

Our system boundary is a track of forest in a mineral or organic soil that is partially or totally harvested at a point in time. This process can promote losses of carbon from the soil.

As time applies, we are analyzing a discrete event because we do not try to capture changes over time due to growth and decay, that is to say, changes in a continuous process.

[30] Organic (e.g., peat and muck) soils generally have a minimum of 12 percent organic carbon by mass (see Chapter 3 Annex 3A.5, for the specific criteria on organic soil classification), and develop under poorly drained conditions of wetlands (Brady and Weil, 1999). All other soils are classified as mineral soil types.

In conclusion, **we want to calculate the amount of carbon stored in the soil (S) that has been lost because of logging activities.**

The IPCC has developed the methodology to estimate '**the annual change in carbon stocks in soils**'.

$$\Delta C_{soils} = \Delta C_{mineral} - L_{organic} + \Delta C_{inorganic}$$

Source: *Equation 2.24, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.29*

ΔC_{Soils} *= annual change in carbon stocks in soils, tonnes C yr* $^{-1}$

$\Delta C_{Mineral}$ *= annual change in organic carbon stocks in mineral soils, tonnes C yr* $^{-1}$

$L_{Organic}$ *= annual loss of carbon from drained organic soils, tonnes C yr* $^{-1}$

$\Delta C_{Inorganic}$ *= annual change in inorganic carbon stocks from soils, tonnes C yr* $^{-1}$ *(assumed to be 0)*

Residue/litter C stocks are not included because they are addressed by estimating dead organic matter stocks.

No methods are provided for estimating the change in soil inorganic C stocks due to limited scientific data for derivation of stock change factors; thus **the net flux for inorganic C stocks is assumed to be zero**.

In that case the resulting equation is:

$$\Delta C_{soils} = \Delta C_{mineral} - L_{organic}$$

<u>Mineral soils</u>: $\Delta C_{mineral}$

The methodology described to **calculate annual changes in organic carbon stocks in mineral soils** accounts for changes in soil C stocks over a finite period of time. Annual rates of carbon stock change are estimated as the difference in stocks at two points in time divided by the time dependence of the stock change factors. The following assumptions are made:

(i) Over time, soil organic C reaches a spatially-averaged, stable value specific to the soil, climate, land-use and management practices; this assumption is widely accepted.

(ii) Soil organic C stock changes during the transition to a new equilibrium of SOC occur in a linear fashion. This assumption simplifies the methodology, although a curvilinear function would better describe this transition.

Soil organic C change is computed based on C stock after the management change relative to the carbon stock in a reference condition (i.e., native vegetation that is not degraded or improved).

Taking all the above into account, '**Annual change in organic carbon stocks in mineral soils**' can be calculated as:

$$SOC_0 - SOC_{0-T}$$

$$\Delta C_{mineral} = \frac{}{D \text{ (or T)}}$$

Source: *Equation 2.25, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.30*

$\Delta C_{Mineral}$= annual change in carbon stocks in mineral soils, tonnes C yr $^{-1}$
SOC_0 = soil organic carbon stock in the last year of an inventory time period, tonnes C
$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of the inventory time period, tonnes C
T = number of years over a single inventory time period, yr
D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr. Commonly 20 years, but depends on assumptions made in computing the factors FLU, FMG and FI. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

In order to calculate SOC, the IPCC differentiates between two approaches:

Approach 1 estimates changes in C stocks without quantification of specific transitions in land use and management over the inventory time period, thus between reference and management change; and

Approach 2 estimates changes in C stocks with quantification of the specific transitions in land use and management over time on individual parcels of land.

The two alternative formulations for '$SOC_0 – SOC_{O-T}$' depending on the Approach used to collected activity data are:

Approach 1

$$\Delta C_{mineral} = \frac{[\sum_{c,s,i} (SOC_{REFc,s,I} * F_{Lu\ c,s,i} * F_{MG\ c,s,i} * F_{I\ c,s,i} * A_{\ c,s,i})]_0 - [\sum_{c,s,i} (SOC_{REFc,s,I} * F_{Lu\ c,s,i} * F_{MG\ c,s,i} * F_{I\ c,s,i} * A_{\ c,s,i})]_{(0-T)}}{D \text{ (or T)}}$$

Source: *Adapted from Equation 2.25 and Box 2.1, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.30&2.34*

Approach 2

$$\Delta C_{mineral} = \frac{\sum_{c,s,p} [\{(SOC_{REFc,s,p} * F_{Lu\ c,s,p} * F_{MG\ c,s,p} * F_{I\ c,s,i})_0 - (SOC_{REFc,s,p} * F_{Lu\ c,s,p} * F_{MG\ c,s,p} * F_{I\ c,s,p})_{(0-T)}\} * A_{\ c,s,p}]}{D \text{ (or T)}}$$

Source: *Adapted from Equation 2.25 and Box 2.1, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.30&2.34*

SOC_{REF} = the reference carbon stock, tonnes C ha $^{-1}$.
F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

F_{MG} = stock change factor for management regime, dimensionless
F_I = stock change factor for input of organic matter, dimensionless
A = land area of the stratum being estimated, ha. All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.
c = represents the climate zones, s the soil types, and i the set of management systems.
p= parcel of land

Organic soils: $L_{organic}$

The basic methodology assigns an annual emission factor that estimates the losses of C following drainage and multiplies it by the drained and managed area. Drainage stimulates oxidation of organic matter previously built up under a largely anoxic environment.

Specifically, '**Carbon loss from drained organic soils**' can be calculated with the following equation:

$$L_{organic} = \sum_c (A * EF)_c * T$$

***Source**: Adapted from Equation 2.26, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.35*

$L_{organic}$= carbon loss from drained organic soils, tonnes C
A = land area of drained organic soils in climate type c, ha
EFc= emission factor for climate type c, tonnes C ha $^{-1}$ yr $^{-1}$
T = time. To convert the product of $A*EF_c$ to a stock multiply by the number of years that the soil will remain drained (in this methodology the default is considered the stock rotation time)

2.2. Example: wood and paper industries

Our purpose is to calculate the amount of carbon stored in the soil at a point in time, but not to capture changes over time. The reason is that timber production - forest harvesting- can influence soil organic C storage by changing erosion rates and subsequent loss of C from a site; some eroded C decomposes in transport and CO_2 is returned to the atmosphere, while the remainder is deposited in another location.

In order to determine how to apply the equations described above to calculate changes in soil carbon, we need to analyze what occurs in the harvesting area (a), the available raw data (b), and information on the transitions in land use management (c).

(a) We assume that harvesting plots do not change over time. It means that both land-use category - forest land remains forest land (FF), cropland remains cropland (CC), etc-, and soil type -which can be mineral, organic, or a combination of both- remain constant over time. When the area is harvested, there is a change in the content of C stored in the soil that can be released to the atmosphere. This amount of C has accumulated over time and has reached a balance between inputs -due to management activities - and outputs due to decomposition-.

(b) There are a few variables that we need to gather in order to apply the equations mentioned before. i) area of harvested land; ii) type of soil of the harvested plot. If this information is not available it will be very difficult to calculate soil carbon emissions.

(c) To decide whether to apply Approach 1 or 2 to calculate soil C in mineral soils, the question to answer would be:

Do we know the specific transitions occurred in the harvested plot over time?

Since the information about activity data must be compiled by the tissue industry, it is reasonable to argue that it would be collected at harvesting periods. Under this assumption, approach 1 will be applied.

Taking all the above into account, **the system under analysis is a set portion of land under a specific land-use category** (i.e. Forest land, plantation) **that accumulates carbon over time** -until an equilibrium between inputs and outputs is reached- **and is harvested at a certain point in time**. Resuming, in *mineral soils* we want to calculate the Soil Organic Carbon (SOC) accumulated in the soil of a specific forest plot.

$$S_{mineral} = [\sum_{c,s,i} (SOC_{REFc,s,I} * F_{Lu\ c,s,i} * F_{MG\ c,s,i} * F_{I\ c,s,i} * A_{c,s,i}))]_0 - [\sum_{c,s,i} (SOC_{REFc,s,I} * F_{Lu\ c,s,i} * F_{MG\ c,s,i} * F_{I\ c,s,i} * A_{c,s,i})]_{0-T}$$

Source: *Adapted from Equation 2.25, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.34. The post-wood removal carbon stocks are designated 0 and the pre-wood removal activity stocks are designated 0-T.*

In organic soils, we want to calculate the carbon loss from drainage, that we will refer to as $L_{organic}$.

$$L_{organic} = \sum_c (A*EF)_c$$

Source: *Adapted from Equation 2.26, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, chp2, pp2.35*

2.3. Application of Soil Factors

In mineral soils

Soil organic C stocks (SOC) are estimated multiplying the reference C stocks (SOC_{REF}) by stock change factors (F_{Lu}, F_{MG}, F_I) that are very broadly defined and include: 1) a land-use factor (F_{LU}) that reflects C stock changes associated with type of land use, 2) a management factor (F_{MG}) representing the principal management practice specific to the land-use sector (e.g., different tillage practices in croplands), and 3) an input factor (F_I) representing different levels of C input to soil. **Each of these factors represents the change over a specified number of years (D), which can vary across sectors, but is typically invariant within sectors**.

The development of stock change factors is likely to be based on intensive studies at experimental sites and sampling plots involving replicated, paired site comparisons (Johnson *et al.*, 2002; Olsson *et al.*, 1996; see also the reviews by Johnson and Curtis, 2001; and Hoover, 2003). In practice, it may not be possible to separate the effects of a different forest types, management practices and disturbance regimes, in which case some stock change factors can be combined into a single modifier.

In organic soils

The basic methodology for estimating C emissions from organic soils is to assign an annual emission factor that estimates the losses of C following drainage. Drainage stimulates oxidation of organic matter previously built up under a largely anoxic environment. Specifically, the area of drained and managed organic soils under each climate type is multiplied by the associated emission factor to derive an estimate of annual CO_2 emissions (source).

Changes in carbon stocks of organic soils strongly depend on the height of the water table and are not calculated for two time series but for climate types. Therefore, changes in carbon loss from drained organic soils will be calculated regardless of changes in land-use and management activity. Default or derived emission factors can be used in the equation, depending on the degree of information available.

2.4. Calculating Soil Carbon Loss due to wood removal (S)

Default values for soil carbon loss in both organic and mineral soil are still very broad. Unless there is specific data on SOC_{REF} , stock change factors and emission factors from the tracks of land used for the provision of timber to the wood and paper industry, huge assumptions will have to be made.

Mineral soils

According to the IPCC (ch4, pp 4.25), 'if using Approach 1 activity data, stock change factors, including input, management and disturbance regime, are equal to 1' using the simplest methodology. Only reference C stocks are needed to apply the method. If more information about the system under analysis is available, then stock change factors and reference C stock can be derived and used. Since we are only analyzing a plot of land, the summation will be reduced to only one summand.

In that case,

$$S_{mineral} = (SOC_{REFc,s,I} * A_{c,s,i}) - (SOC_{REFc,s,I} * A_{c,s,i})$$

SOC_{REF} = the reference carbon stock, tonnes C ha^{-1} (Table 14 at Appendix 4.3)
A = land area of the stratum being estimated, ha. All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.

Organic soils

The basic methodology for estimating C emissions from organic soils is to assign an annual emission factor that estimates the losses of C following drainage. The area of drained and managed organic soils under each climate type is multiplied by the associated emission factor to derive an estimate of annual CO_2 emissions (source).

Since we are only analyzing a plot of land, the summation will be reduced to only one summand, that of a particular climate type. We then multiply the loss rate (EF) by time to give a single value of organic carbon loss based on the stock rotation time.

$$L_{organic} = (A*EF_c) * T$$

$L_{organic}$ = annual carbon loss from drained organic soils, tonnes C yr-1
A = land area of drained organic soils in climate type c, ha
EF = emission factor for climate type c, tonnes C ha $^{-1}$ yr $^{-1}$ (Table15 in Appendix 4.2)
T = time (yr). To convert the product of $A*EF_c$ to a stock multiply by the number of years that the soil will remain drained. As a default value, use the stock replacement time for the parcel of interest

Appendix 3: Error and Uncertainty

There are numerous sources of error and uncertainty in the data on emissions and sequestration. Some of the sources can potentially be eliminated, some can be reduced, but many are unavoidable. The purpose of this section is to clearly define, as accurately as possible, potential sources of error or uncertainty and to discuss briefly why it is important to understand and deal with uncertainty. We outline their cause, an estimate of their magnitude, and suggest recommendations on dealing with them both at the present time and in the future.

We also suggest that, as with all models that simulate real systems, even though there are significant errors involved in accounting for emissions and sequestrations, the results and proposed methodologies are still very useful. It is also important to realize that the methods outline in this document are ``living'' methods, proposed in a way that can adapt and change as new information and methods are introduced. By documenting each of the sources of error and uncertainty here, we hope to slowly address each one, improving the overall method incrementally as we move forward. By keeping the method development as transparent and open as possible, we hope to keep all parties, including ourselves, informed and up to date.

3.0.1 The difference between error and uncertainty.

Although we are lumping the two together in this methodology, the difference between the terms is important. By error, we mean the difference between a measurement and its true value. Error is based on actual measurements such as the volume of merchantable wood harvested. Our calculation or estimation of this value is likely to differ from the true value by some percentage. By uncertainty, we mean that the actual value may vary from sample to sample and we are uncertain of the specific value taken in a particular instance. Uncertainty is related to quantities that are inherently variable such as emissions factors for different types of wood. We might make very accurate measurements of several equal masses of the same type of wood and get different values due to the inherent variation in the wood.

In general these two quantities are somewhat related. If we want to reduce errors, we need to measure more carefully. If we want to reduce uncertainty, we might need to divide our products into more subclasses in order to distinguish characteristics of the wood more clearly. In this paper we will not distinguish in our calculations and will use the term uncertainty for the sum of both, but in order to reduce future uncertainty, it is important to recognize each source and the causes of the overall uncertainty.

3.1 Sources of error and uncertainty

3.1.1 Error and Uncertainty in Data

The most obvious source of error and uncertainty in the collection of emissions and sequestration data comes from the collection of the data itself. Some of the data is derived from models, some from direct measurements and all of it contains some measure of error or uncertainty. There are also frequently tradeoffs between accuracy in one respect at a cost to another.

Much of the data for forestry products is based on sampling which takes representative sites and estimates and makes extrapolations based on that data. Expert guidance determines which sites are chosen and how to approximate the larger data sets using the samples. The data for the sample sites are not taken every year either. Collecting so much data every year is unrealistic, so that data is collected on a rotating basis. Statistical methods are used to extend the observations to both the other sites and to other years where the data is not available. References to these methods are given in the IPCC documentation.

Keep in mind that the data collected is still extensive, but the methods inherently bring in error to the data.

The purpose of most of the data collection is aimed at producing annual estimates. However the sequestrations and emissions are not constant over the course of a year. In sequestration of carbon, the growth rate of trees and other biomass is heaviest during its primary growing season and possible nonexistent in the off-season. It is important to realize in making calculations to realize that the data represents an average over a year and is not relevant on shorter time scales. The effects of inhomogeneous sequestrations and emissions have not been generally established.

Another potential error arises if data has been reported incorrectly, but is then corrected. As an example, for the 2011 United Nations energy statistics, a correction was made to the composition of coal coming out of Russia. While the quantities did not change, the correction in the type of coal changes the implied coal chemistry and hence the output of CO2 emitted by a significant margin. Many factors go into estimates of all CO$_2$ fluxes making errors unavoidable. As collection methods improve (as with Russian coal) methods need to allow corrections and improvements to both current and past data.

A similar error can be made in the expected lifetime of a product. If the expected lifetime of a utility pole is 40 years, what happens when the lifetimes are found to be significantly longer or shorter for a particular region? The change gets pushed back through time and corrections must be made retroactively to make them accurate.

3.1.2 Model Estimates

Some estimates of emissions come from models based on basic assumptions. Some of these models work from the ground up while others distribute national or regional data in allocations based on proportions. These models necessarily make errors and use averages.

In general, stocks of carbon containing products are assumed to decay exponentially from the time of production. While this is reasonably accurate for fuel related products, it is far from accurate for long-lived products. Tier 3 methods allow the use of probability distributions that reflect the true time course of oxidation of these products.

The models also designate various locations for the emissions based on those assumptions and maps are made that reflect locations of emissions and sequestration. For example, just because wood is purchased or a product manufactured in a particular region does not mean that it is emitted in that same region.

3.1.3 Unknown or unforeseen affects

As with most predictions, whether it be economic forecasts or weather forecasts, predictions become less reliable as the length of time increases. The reliability falls because of unpredictable events and the accumulation of small changes. Even if they are rare, these events can significantly affect the data.

Natural (or not so natural) disasters are difficult to predict. A large forest fire creates a large pulse of CO2 into the atmosphere in a very short period of time. A flood or storm may change the usability of existing products or cause damage that necessitates a change in the lifetime of a product. Changes such as these have the potential to wreak havoc on long term, and even short-term, arrangements concerning emissions and sequestration. While we may wish to forgive a party for unforeseen and unintended emissions, the accounting must remain accurate and a large change in CO2 cannot be ignored. In some regions it is also common for changes in land ownership to have sudden affects on the sequestration patterns of that land. The new owner may or may not be bound by the previous agreements or practices of the previous owner. In addition, variations in markets or weather can affect factors such as biomass growth or energy demand.

We may discover that what we thought was a ``permanent" sequestration activity is now not as long lasting as originally thought. We may also discover that as more and more greenhouse gases accumulate in the atmosphere, that the sequestration patterns change from what we predicted. Systems can become saturated and behave nonlinearly in their extremes.

All of these possibilities affect arrangements made between parties, generally long term arrangements (treaties, contracts, formal agreements, etc). While the yearly accounting can be corrected, using data as it comes in, the problem with longer-range forecasts still presents a sizable problem. Using the IPCC data tables, we must be careful to track changes, improvement, and updates to those tables. Any changes may not just affect our current calculations, but there is also potential that corrections (hopefully small and infrequent) to previous values need to be made.

3.1.4 Missing pieces, things that are not counted

Currently some types of land use are not documented into regular accounting methods. Land used for food production is one. So if land is used for food production and the food is shipped overseas, where do the emissions get counted? They don't.

It is also a frequent occurrence for data to be completely missing. A number of reasons may cause missing data, such as a storm taking out the power supply for the collection hardware. In Florida, a forest fire burned down the tower housing some equipment; the replacement time is not instantaneous. What happens to missing data? Typically, we rely on experts from the region, from the industry, or from experienced scientists to make estimates based on previous data, related data, or inside knowledge. While every attempt is made to reduce the error involved in these estimates, it is important to keep track of how this error enters the calculations.

3.1.5 Scaling

One source of error that we do not take into account in this methodology has to do with scale and sampling. The sampling methods that go into producing the numbers in the IPCC tables are aimed at creating valid estimates on the national level. This involves a great number of samples taken over

many sites and taken over a number of years. Missing values are taken by extrapolating what takes place at nearby sites and at time where the data was collected at sites in off years.

When we move from this national level down to the activity level, the number of representative samples is reduced drastically. When we make the assumption that the averages represented in the national data are mimicked at the activity level, we are making a large assumption about the homogeneity of the data that is simply not correct. The number of samples is too small and the variability on a small scale is too great.

Unfortunately, this source of uncertainty is not well documented because it depends on individual projects and activities that are specific to given times and places. To get an estimate of corrected values and measures of the uncertainty are not within the scope of the tier 1 approach outlined here. In this document, we make the assumption that the national data *does* scale down and is relevant at the activity level; keeping the same values and the same level of uncertainty.

To improve on this assumption, more data must be collected, most likely by the individuals conducting the activity. We have to weight the cost of this increased effort and the benefit of greater accuracy in the collected data.

3.2 Implications

Having outlined some of the sources of error in the accounting for carbon emissions and sequestration, we look for the how those errors influence our accounting and our decisions. We now know that there are numerous large sources of error, many smaller sources of error, and many more potential sources of error. We also realize that there is significant uncertainty in data moving forward.

3.2.1 Proposed Methodology

The standard methods for estimating uncertainty are outlined in great and simple detail in the 2006 IPCC Guidelines, Volume 1, Chapter 3. These calculations are based on keeping track of national inventories rather than activity data. To scale down to the activity level, several of the columns in the national level calculations are not needed. For our purposes for a Approach 1 methods, we base the uncertainty calculations on the methods outlined there (pages 3.27-3.32) and convert them to basic calculations at the activity level.

The activity uncertainty and emissions factor are entered as half the 95th percent confidence interval divided by the mean and expressed as a percentage.

The combined uncertainty for multiplied independent factors can be calculated as the square root of the sum of the squares of the other two uncertainties.

If the total uncertainty is known, but not the individual factors, the combined uncertainty can be entered in one of the two categories and then again in the combined uncertainty.

For combining uncorrelated uncertainties that are added or subtracted, the formula takes the form,

If the uncertainty is correlated between years, enter the value in the Activity Uncertainty location. If there is no correlation between year, enter the value in the Emissions Factor location.

3.2.2 Reducing error and uncertainty

At this point there are two methods to reduce the uncertainty in our calculations. We can reduce the uncertainty in our activity accounting and we can find more detailed calculations on the emissions due to the products we are producing. The first is an internal accounting issue and is probably the easiest to deal with. The second moves from a Tier 1 approach to a more complex approach that requires more data and detail. Methods for higher-level approaches are outlined in the Good Practice Guidelines.

3.3 Example Calculation

Here we go through a sample calculation of the uncertainty for the example of the North American pine forest from Section 9.3. As with many of the values used to calculate the Forest Carbon Footprint, the more information that is available, the more accurate the results. Some data are more uncertain than others. In this Tier 1 approach, we will proceed with averaged uncertainty values. With more detailed knowledge, there levels of uncertainty might be found to be significantly smaller.

At the beginning of the calculation, we begin with the basic equation,

$$\textbf{Forest Carbon Footprint}_{discrete} = \sum_n L_n + \sum_p S_p - HWP - EE \qquad (1)$$

In the following calculations, the conversion factor from C to CO_2 of 3.666 is a straight conversion factor based on molecular weights and we will assume that the accuracy is without error at the resolution in which we are interested. Since the uncertainty is reported as a percentage, the uncertainty is the same for both measures.

Calculation of L

Since we have just one component, we need to incorporate the uncertainty for the volume and for the L_f, the emissions factor.

The calculation,

$$L = (H * L_f)$$

Produces uncertainty from the estimate of the volume and from the L_f value that comes from the growing stock. The uncertainty of the volume comes from errors made in calculating the volume that is an activity error. This value needs to come from the party

pursuing the activity. We will use 5% for this example. The uncertainty in growing stock is estimated at 5-8% in industrialized countries and 30% in non-industrialized countries. (IPCC GNGGI 2005, 4.2.1.5 and US NFS publication 343, page 18). Here we assume an 8% uncertainty.

Combining the two, we get

$U_L = (0.05^2+0.08^2)^{1/2} = 0.8016 = 80.16\%$

Calculation of S

Since we are assuming that $S_{mineral}$ is zero based on the Tier 1 approach, it is inappropriate to document the uncertainty in only this term as a percentage – it would be infinite.

However, we can add an uncertainty from $S_{mineral}$ to that of $L_{organic}$. The estimate of carbon in soils is ($SOC_{REFc,s,I}$ * $A_{c,s,i}$) as expressed in Appendix 2. This value, according to IPCC GNGGI 2005, Table 2.3 has an estimated error of up to 90%. Losses are difficult to document and uncertainty measures are more difficult without additional information (beyond Tier 1 calculations). As a results, we will assume that the potential error is 90% of the value of $SOC_{REFc,s,I}$ and use the previous uncertainty value for the area.

$S = S_{mineral} + L_{organic} = (SOC_{REFc,s,I} + EFc * T) * A$

In our case, $1/A*S_{mineral}$ is calculated to be (71 tonnes C/ha) and this gives an uncertainty of 0.9*71 = 63.9 tonnes carbon/ha.

$1/A*L_{organic}$ = 0.68*25 = 17 tonnes carbon /ha. We assume that error in the 25 years is taken into account elsewhere while the range of values for EFc is from 0.41 to 1.99. Assuming that this accounts for the 95 percentile range, the uncertainty is calculated as one half of this range, or 0.79.

The sum of the two terms in the calculation is 17, with an uncertainty of 63.9+19.75 = 83.65 tonnes C/ha. This gives an uncertainty of 83.65/17*100= 492%.

The uncertainty in forest area estimates is estimated at 3% for industrialized countries (A rough estimate of 30% can be used for non-industrialized countries), according to FAO, 2000 data (IPCC GNGGI 2005, 4.2.1.5). We then combine this previous uncertainty with the area uncertainty of 3%.

$U_S = (4.92^2 + 0.03^2)^{1/2} = 4.920 = 492\%$ uncertainty.

Calculation of HWP

The use of the 100 year time period for the HWP is wrought with error. For the total value of .318, this means that 23.33% of the original wood is now in a landfill and 9.5% is still in use. In either case, this is the quantity of wood that has not has its carbon released to the

atmosphere. This estimate is based on models that assume an exponential decay in the products and on a 100 year time horizon that may not be relevant for long-lived wood products. Neither of these assumptions are correct but at present there is no data on a more accurate model. For now we assume a 100% uncertainty, although may be higher than that in some cases. As we further investigate the time aspect of emissions and accounting, we will try to revise this figure. Therefore,

$U_{HWP} = 100\%$

Calculation of EE

From the total 5GJ of energy produced, 1GJ is sold back to the local grid. Although there is likely some uncertainty in the amount of energy produced, the amount sold back to the local grid likely has very little uncertainty. Since the amount sold back is the quantity of concern, we can ignore the total energy.

We estimate uncertainty of 2% on the energy sold back to the local grid (main activity electricity and heat production) and use an estimate of 15% for the emissions factor (industrial combustion) based on the top of the range of uncertainties in the IPCC NGGIP 2006, Table 2.15 in less developed statistical systems.

Combining the two, we obtain,

$U_{EE} = (0.02^2 + 0.15^2)^{1/2} = 0.1513 = 15.13\%$

Combined uncertainty

Combining the uncertainties, we use the summative formula for combining uncertainties,

$U_{total} = (0.8016*0.5936+4.92*0.57+1.00*0.318+0.1513*0.11399)^{1/2}$
$/(0.5936+0.57+0.318+0.11399)$

Appendix 4: Tables for calculations

4.1 General Tables

Table 4*: Average disposition patterns of carbon as fractions in industrial roundwood by region and roundwood category; factors assume no bark on industrial roundwood, which also excludes fuelwood*

	Northeast, Softwood								
	Sawlog					Pulpwood			
Year after production	In use	Landfill	Energy	Emitted without energy		In use	Landfill	Energy	Emitted without energy
0	0.569	0	0.24	0.19		0.513	0	0.306	0.181
1	0.542	0.014	0.246	0.197		0.436	0.025	0.334	0.204
2	0.517	0.027	0.252	0.203		0.372	0.046	0.359	0.223
3	0.495	0.039	0.257	0.209		0.317	0.063	0.381	0.239
4	0.474	0.05	0.262	0.214		0.271	0.077	0.399	0.253
5	0.455	0.06	0.266	0.219		0.232	0.088	0.415	0.265
6	0.438	0.069	0.27	0.223		0.197	0.098	0.429	0.276
7	0.422	0.078	0.274	0.227		0.167	0.106	0.441	0.286
8	0.406	0.085	0.277	0.231		0.139	0.113	0.452	0.296
9	0.392	0.093	0.281	0.235		0.114	0.118	0.463	0.305
10	0.379	0.099	0.284	0.238		0.093	0.123	0.472	0.313
15	0.326	0.126	0.296	0.252		0.037	0.128	0.497	0.338
20	0.288	0.144	0.304	0.264		0.021	0.122	0.505	0.352
25	0.259	0.158	0.311	0.273		0.016	0.114	0.509	0.362
30	0.234	0.168	0.316	0.281		0.014	0.107	0.51	0.369
35	0.214	0.176	0.321	0.289		0.013	0.102	0.51	0.376
40	0.197	0.183	0.324	0.296		0.012	0.098	0.51	0.381
45	0.182	0.189	0.327	0.302		0.011	0.094	0.51	0.385
50	0.169	0.194	0.33	0.307		0.01	0.092	0.51	0.388
55	0.158	0.198	0.332	0.312		0.009	0.09	0.51	0.391
60	0.148	0.202	0.333	0.317		0.009	0.088	0.51	0.393
65	0.139	0.205	0.335	0.321		0.008	0.087	0.51	0.395
70	0.131	0.208	0.336	0.325		0.008	0.086	0.51	0.396
75	0.124	0.211	0.337	0.328		0.007	0.086	0.51	0.397
80	0.117	0.214	0.337	0.332		0.007	0.085	0.51	0.398
85	0.111	0.216	0.338	0.335		0.007	0.085	0.51	0.399
90	0.106	0.219	0.338	0.338		0.006	0.085	0.51	0.399
95	0.1	0.221	0.338	0.341		0.006	0.084	0.51	0.4
100	0.095	0.223	0.338	0.344		0.006	0.084	0.51	0.4

Source: Smith, James E., Linda S. Heath, Kenneth E. Skog, and Richard A. Birdsey. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.* United States Department of Agriculture Forest Service, Northeastern Research Station. General Technical Report NE-343. April 2006.

Table 5: *Classification of Climate domains, climate regions and ecological zones*

Climate domain		Climate region	Ecological zone	
Domain	**Domain criteria**		**Zone**	**Zone criteria**
Tropical	all months without frost; in marine areas, temperature >18°C	Tropical wet	Tropical rain forest	wet: ≤3 months dry, during winter
		Tropical moist	Tropical moist deciduous forest	mainly wet: 3-5 months dry, during winter
		Tropical dry	Tropical dry forest	mainly dry: 5-8 months dry, during winter
			Tropical shrubland	semi-arid: evaporation > precipitation
			Tropical desert	arid: all months dry
		Tropical montane	Tropical mountain systems	altitudes approximately >1000 m, with local variations
Sub-tropical	≥8 months at a temperature >10°C	Warm temperate moist	Subtropical humid forest	humid: no dry season
		Warm temperate dry	Subtropical dry forest	seasonally dry: winter rains, dry summer
			Subtropical steppe	semi-arid: evaporation >precipitation
			Subtropical desert	arid: all months dry
		Warm temperate moist or dry	Subtropical mountain systems	altitudes approximately 800 m-1000 m
Temp-erate	4-8 months at a temperature >10°C	Cool temperate moist	Temperate oceanic forest	oceanic climate: coldest month >0°C
			Temperate continental forest	continental climate: coldest month <0°C
		Cool temperate dry	Temperate steppe	semi-arid: evaporation > precipitation
			Temperate desert	arid: all months dry
		Cool temperate moist or dry	Temperate mountain systems	altitudes approximately >800 m
Boreal	≤3 months at a temperature >10°C	Boreal moist	Boreal coniferous forest	coniferous dense forest dominant
		Boreal dry	Boreal tundra woodland	woodland and sparse forest dominant
		Boreal moist or dry	Boreal mountain systems	altitudes approximately >600 m
Polar	all months <10°C	Polar moist or dry	Polar	all months <10°C

Climate domain: Area of relatively homogenous temperature regime, equivalent to the Kàppen-Trewartha climate groups (Kàppen, 1931).
Climate region: Areas of similar climate defined in Chapter 3 for reporting across different carbon pools.
Ecological zone: Area with broad, yet relatively homogeneous natural vegetation formations that are similar, but not necessarily identical, in physiognomy.
Dry month: A month in which Total Precipitation (mm) ≤ 2 x Mean Temperature (ʃC).

Source: Table 4.13, Chp 4. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

4.2 Tables for L calculations

Table 6: *Default values for above ground biomass (tonnes of d.m./ha)*

Climate domain	Ecological zone	Forest type	Genus (as per R classification)	Above-ground biomass (tonnes d.m./ha)*
Boreal	Coniferous forest, tundra woodland, mountain system	pines		<55
		larch		
		firs and spruces		
		hardwoods		
Temperate - P	*Oceanic Forest* Asia & Europe (≤20 yr),	hardwoods	Quercus	<51
			Eucalyptus	<36
			Other broadleaf	<54
		pines	conifers	50 - 150
		other conifers		
	Oceanic Forest Asia & Europe (>20 yr),	hardwoods	Eucalyptus	>150
			Other broadleaf	>150
		pines	conifers	>150
		other conifers		
	Oceanic Forest, Continental Forest & *Mountain Systems* North & South America	hardwoods	Quercus	>51
			Eucalyptus	36-109
			Other broadleaf	54-109
		pines	conifers	36-109
		other conifers		36-109
	Continental Forest & *Mountain Systems* Asia & Europe (>20y)	hardwoods	Eucalyptus	>109
			Other broadleaf	
		pines	conifers	>109
		other conifers		
	Continental Forest & *Mountain Systems* Asia & Europe (≤20y)	hardwoods	Quercus	<51
			Eucalyptus	<36
			Other broadleaf	<54
		pines	conifers	<36
		other conifers		
Temperate - F	*Continental Forest Asia & Europe (≤20 yr) & Mountain systems North & South America (≤ 20yr)*	hardwoods	Quercus	<51
			Eucalyptus	<36
			Other broadleaf	<54
		pines	conifers	<36
		other conifers		
	Continental Forest North & South America (≤20 yr), Mountain systems Asia & Europe (≤20 yr)	hardwoods	Quercus	>51
			Eucalyptus	36-109
			Other broadleaf	54-109
		pines	conifers	36-109
		other conifers		
	Oceanic Forest (all), Continental Forest (>20yr) & *Mountain Systems* North (>20 yr)	hardwoods	Eucalyptus	>109
			Other broadleaf	
		pines	conifers	>109
		other conifers		
Mediterranean – F&P		hardwoods	NA	NA
		conifers		NA
Subtropical – F&P	*steppe*	any		any
	Humid forest	hardwoods	NA	>91

Climate domain	Ecological zone	Forest type	Genus (as per R classification)	Above-ground biomass (tonnes d.m./ha)*
	Dry forest			>15
	Humid forest	conifers		>91
	Dry forest			>15
Dry Tropical – F&P	*shrubland*	hardwoods	NA	Any
	mountain systems			
	mountain systems	conifers	NA	any
	dry forest	hardwoods	NA	>15
		conifers		
Humid tropical – F&P	*Tropical Rainforest*	conifers	NA	any
		Natural forests	NA	any
	Tropical moist deciduous forest	conifers	NA	>91
		natural forests	NA	
(*) these values are usable when specific values for wood removals are unknown. P: plantations; F: forests				
Source: Tables 4.7, 4.8 and 4.12 Chp 4. 2006 IPCC Guidelines for National Greenhouse Gas Inventories				

Table 7: *Carbon Loss Factor(L_f) for Boreal Natural Forests and Plantations (simplified)*

BOREAL NATURAL FORESTS AND PLANTATIONS					
Climate domain	**Ecological Zone**	**Forest type**	**Above-ground biomass (tonnes d.m./ha)****	**growing stock levels (m3)**	
				< 20	>21
				Lf* (tonnes C/m3)	
Boreal	**Coniferous forest, tundra woodland, mountain system**	pines	<55	0.8689	0.4203
		larch		0.8820	0.5597
		firs and spruces		0.8428	0.4268
		hardwoods		0.6533	0.4508
Boreal	**Coniferous forest, tundra woodland, mountain system**	pines	>55	0.7751	0.3749
		larch		0.7868	0.4993
		firs and spruces		0.7518	0.3808
		hardwoods		0.5828	0.4021

We assume **R=0.39 for above ground biomass <75 tonnes/ha, and **R=0.24** for above ground biomass > 75 tonnes/ha ; CF=0.47 as default value. These values apply to all forest types.*
R in root d.m./t shoot d.m.

Source: Table 4.3, 4.4 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

***Conversion above .ground .biomass. (tonnes/ha) into above ground biomass. (tonnes d.m./ha): dry weight= 72,5% of normal weight. Therefore, a.g.b <75 tonnes/ha≅ <55 tonnes d.m./ha*
According to IPCC tables 4.7, 4.8 and 4.12, above ground biomass values in natural forests and plantations are very similar.

Default Values when above ground biomass is unknown, are shaded in grey colors

Table 8: *Carbon Loss Factor(L_f) for Temperate Natural Forests (simplified)*

TEMPERATE NATURAL FORESTS								
Climate domain	**Ecological zone**	**Forest type**	**Genus (as per R classification)**	**Above-ground biomass (tonnes/ha) ***	**Above-ground biomass (tonnes d.m./ha)* ***	**growing stock levels (m3)** < 20	21 - 100	>100
						Lf* (tonnes C/m3)		
Temperate	Continental Forest Asia & Europe (≤20 yr) & Mountain systems North & South America (≤ 20yr)	hardwoods	Quercus	<70	<51	1.5651	0.8084	0.4841
			Eucalyptus	<50	<36	2.2537	1.1641	0.6971
			Other broadleaf	<75	<54	2.2850	1.1803	0.7068
		pines	conifers	<50	<36	1.4280	0.6926	0.5498
		other conifers				2.3776	0.9496	0.5712
Temperate	Continental Forest North & South America (≤20 yr), Mountain systems Asia & Europe (≤20 yr)	hardwoods	Quercus	>70	>51	2.0346	1.0509	0.6293
			Eucalyptus	50 - 150	36-109	2.0033	1.0348	0.6196
			Other broadleaf	75 – 150	54-109	1.9251	0.9943	0.5954
		pines	conifers	50 - 150	36-109	1.3158	0.6382	0.5066
		other conifers				2.1908	0.8750	0.5263
Temperate	Oceanic Forest (all), Continental Forest (>20 yr) & Mountain system (>20yr)	hardwoods	Eucalyptus	>150	>109	1.8781	0.9701	0.5809
			Other broadleaf			1.9407	1.0024	0.6003
		pines	conifers	> 150	>109	1.2240	0.5936	0.4712
		other conifers				2.0380	0.8140	0.4896

* *We assume **R=0.40** for conifers above ground biomass <50 tonnes/ha, and **R=0.29** for conifers above-ground biomass 50-150 tonnes/ha, and **R=0.20** for conifers above-ground biomass >150 tonnes/ha ; CF=0.51 as default value.*
*We assume **R=0.30** for Quercus spp above ground biomass >70 tonnes/ha, and **R=0** for Quercus spp above ground biomass <70 tonnes/ha ; CF=0.47 as default value.*
*We assume **R=0.44** for Eucalyptus above ground biomass <50 tonnes/ha, and **R=0.28** for eucalyptus above-ground biomass 50-150 tonnes/ha, and **R=0.20** for eucalyptus above-ground biomass >150 tonnes/ha ; CF=0.47 as default value.*
*We assume **R=0.46** for other broadleaf above ground biomass <75 tonnes/ha, and **R=0.23** for other broadleaf above-ground biomass 75-150 tonnes/ha, and **R=0.24** for other broadleaf above-ground biomass >150 tonnes/ha ; CF=0.47 as default value.*
t R in root d.m./t shoot d.m.

Source: Table 4.3 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

***Conversion above .ground .biomass. (tonnes/ha) into above ground biomass. (tonnes d.m./ha): dry weight= 72.5% of normal weight. Therefore, a.g.b <75 tonnes/ha≅ <55 tonnes d.m./ha*
According to IPCC tables 4.7, 4.8 and 4.12, above ground biomass values in natural forests and plantations are rather different.

Table 9: *Carbon Loss Factor(L_f) for Temperate Plantations (simplified)*

TEMPERATE PLANTATIONS								
Climate domain	**Ecological zone**	**Forest type**	**Genus (as per R classification)**	**Above-ground biomass (tonnes/ha) ***	**Above-ground biomass (tonnes d.m./ha)* ***	**growing stock levels (m3)** < 20	21 - 100	>100
						Lf* (tonnes C/m3)		
Temperate	*Oceanic Forest* Asia & Europe (≤20 yr),	hardwoods	Quercus	<70	<51	1.5651	0.8084	0.4841
			Eucalyptus	<50	<36	2.2537	1.1641	0.6971
			Other broadleaf	<75	<54	2.2850	1.1803	0.7068
		pines	conifers	<50	<36	1.4280	0.6926	0.5498
		other conifers				2.3776	0.9496	0.5712
Temperate	*Oceanic Forest* Asia & Europe (≤20 yr),	hardwoods	Quercus	>70	>51	2.0346	1.0509	0.6293
			Eucalyptus	50 - 150	36-109	2.0033	1.0348	0.6196
			Other broadleaf	75 – 150	54-109	1.9251	0.9943	0.5954
		pines	conifers	50 - 150	36-109	1.3158	0.6382	0.5066
		other conifers				2.1908	0.8750	0.5263
Temperate	*Oceanic Forest* Asia& Europe (>20yr), New Zealand	hardwoods	Eucalyptus	>150	>109	1.8781	0.9701	0.5809
			Other broadleaf			1.9407	1.0024	0.6003
		pines	conifers	> 150	>109	1.2240	0.5936	0.4712
		other conifers				2.0380	0.8140	0.4896
Temperate	*Oceanic Forest, Continental Forest & Mountain Systems* North & South America	hardwoods	Quercus	>70	>51	2.0346	1.0509	0.6293
			Eucalyptus	50 - 150	36-109	2.0033	1.0348	0.6196
			Other broadleaf	75 – 150	54-109	1.9251	0.9943	0.5954
		pines	conifers	50 - 150	36-109	1.3158	0.6382	0.5066
		other conifers				2.1908	0.8750	0.5263
Temperate	*Oceanic Forest, Continental Forest & Mountain*	hardwoods	Eucalyptus	>150	>109	1.8781	0.9701	0.5809
			Other broadleaf			1.9407	1.0024	0.6003

TEMPERATE PLANTATIONS								
Climate domain	**Ecological zone**	**Forest type**	**Genus (as per R classification)**	**Above-ground biomass (tonnes/ha) ***	**Above-ground biomass (tonnes d.m./ha)* ***	**growing stock levels (m3)** < 20	21 - 100	>100
						Lf* (tonnes C/m3)		
	Systems North & South America	pines	conifers	> 150	>109	1.2240	0.5936	0.4712
		other conifers				2.0380	0.8140	0.4896
Temperate	*Continental Forest* & *Mountain Systems* Asia & Europe (>20y)	hardwoods	Eucalyptus	>150	>109	1.8781	0.9701	0.5809
			Other broadleaf			1.9407	1.0024	0.6003
		pines	conifers	> 150	>109	1.2240	0.5936	0.4712
		other conifers				2.0380	0.8140	0.4896
Temperate	*Continental Forest* & *Mountain Systems* Asia & Europe (≤20y)	hardwoods	Quercus	<70	<51	1.5651	0.8084	0.4841
			Eucalyptus	<50	<36	2.2537	1.1641	0.6971
			Other broadleaf	<75	<54	2.2850	1.1803	0.7068
		pines	conifers	<50	<36	1.4280	0.6926	0.5498
		other conifers				2.3776	0.9496	0.5712

** We assume **R=0.40** for conifers above ground biomass <50 tonnes/ha, and **R=0.29** for conifers above-ground biomass 50-150 tonnes/ha, and **R=0.20** for conifers above-ground biomass >150 tonnes/ha ; CF=0.51 as default value.*
*We assume **R=0.30** for Quercus spp above ground biomass >70 tonnes/ha, and **R=0** for Quercus spp above ground biomass <70 tonnes/ha ; CF=0.47 as default value.*
*We assume **R=0.44** for Eucalyptus above ground biomass <50 tonnes/ha, and **R=0.28** for eucalyptus above-ground biomass 50-150 tonnes/ha, and **R=0.20** for eucalyptus above-ground biomass >150 tonnes/ha ; CF=0.47 as default value.*
*We assume **R=0.46** for other broadleaf above ground biomass <75 tonnes/ha, and **R=0.23** for other broadleaf above-ground biomass 75-150 tonnes/ha, and **R=0.24** for other broadleaf above-ground biomass >150 tonnes/ha ; CF=0.47 as default value.*
t R in root d.m./t shoot d.m.

Source: Table 4.3 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

***Conversion above .ground .biomass. (tonnes/ha) into above ground biomass. (tonnes d.m./ha): dry weight= 72.5% of normal weight. Therefore, a.g.b <70 tonnes/ha≅ <54 tonnes d.m./ha*
According to IPCC tables 4.7, 4.8 and 4.12, above ground biomass values in natural forests and plantations are rather different.

Default Values when above ground biomass is unknown, are shaded in grey color

Table 10: *Carbon Loss Factor(Lf) for Mediterranean Natural Forests and Plantations. Default Values (simplified)*

MEDITERRANEAN NATURAL FORESTS AND PLANTATIONS				
Climate domain	**Forest type**	**growing stock levels (m3)**		
		< 20	21 - 40	>40
		Lf* (tonnes C/m3)		
Mediterranean	hardwoods	2.6085	0.9917	0.3807
	conifers	3.4017	0.6783	0.3264

We assume ***R=0*** *because there is NO other R value given at the IPCC methodology;*
CF=0.47 as default value and 0.51 for conifers

Source: Table 4.3 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 11: *Carbon Loss Factor(Lf) for Subtropical Natural Forests and Plantations (simplified)*

SUBTROPICAL NATURAL FORESTS AND PLANTATIONS							
Climate domain	**Ecological Zone (as per R classification)**	**Forest type**	**Above-ground biomass* (tonnes/ha)**	**Above-ground biomass** (tonnes d.m./ha)**	**growing stock levels (m3)**		
					< 20	21 - 40	>40
					Lf* (tonnes C/m3)		
subtropical	Humid forest	hardwoods	<125	<91	3.1302	1.1900	0.4568
	Dry forest	hardwoods	<20	<15	4.0693	1.5471	0.5939
	Mountain Systems ^	hardwoods	NA	NA	No estimate available		
	Humid forest	conifers	<125	<91	3.7619	0.7501	0.3610
	Dry forest	conifers	<20	<15	4.8904	0.9752	0.4692
	Mountain Systems ^	conifers	NA	NA	No estimate available		
	Steppe	ANY	any	Any	0.8347	0.3173	0.1218
subtropical	Humid forest	hardwoods	>125	>91	3.2345	1.2297	0.5187
	Dry forest	hardwoods	>20	>15	3.3389	1.2694	0.5354
	Humid forest	conifers	>125	>91	3.8873	0.7751	0.3905
	Dry forest	conifers	>20	>15	4.0127	0.8001	0.4031

We assume* ***R=0.56* *for subtropical dry forest above ground biomass <20 tonnes/ha, and* ***R=0.28*** *for subtropical dry forest above ground biomass > 20 tonnes/ha ;*
We assume ***R=0.2*** *for subtropical humid forest above ground biomass <125 tonnes/ha, and* ***R=0.24*** *for subtropical humid forest above ground biomass > 125 tonnes/ha ;*
We assume ***R=0.32*** *for subtropical steppe. These values apply both to hardwoods and conifers. CF=0.47 as default value.*
^No R estimate available.

***Conversion above .ground .biomass. (tonnes/ha) into above ground biomass. (tonnes d.m./ha): dry weight= 72.5% of normal weight. Therefore, a.g.b <125 tonnes/ha≅ <91 tonnes d.m./ha*
According to IPCC tables 4.7, 4.8 and 4.12, above ground biomass values in natural forests and plantations are comparable.

Default Values when above ground biomass is unknown, are shaded in grey colors

Table 12: *Carbon Loss Factor (Lf) for Dry Tropical Natural Forests and Plantations (simplified)*

DRY TROPICAL NATURAL FORESTS AND PLANTATIONS							
Climate domain	**Forest type**	**Ecological Zone (as per R classification)**	**Above-ground biomass* (tonnes/ha)**	**Above-ground biomass**(tonnes d.m./ha)**	**growing stock levels (m3)** < 20	21 - 40	>40
					Lf* (tonnes C/m3)		
Dry Tropical	hardwoods	dry forest	<20	<15	4.0693	1.5471	0.5939
		shrubland	Any	Any	1.0434	0.3967	0.1523
		mountain systems	any	Any	0.7043	0.2678	0.1028
	conifers	dry forest	<20	<15	5.3067	1.0581	0.5092
		mountain systems	any	Any	0.9185	0.1831	0.0881
Dry Tropical	hardwoods	dry forest	>20	>15	3.3389	1.2694	0.4873
	conifers				4.3542	0.8682	0.4178

We assume* ***R=0.56* *for tropical dry forest above ground biomass <20 tonnes/ha, and* ***R=0.28*** *for tropical dry forest above ground biomass > 20 tonnes/ha ;*
We assume ***R=0.4*** *for tropical shrubland, and* ***R=0.27*** *for tropical mountain system. These values apply both to hardwoods and conifers. CF=0.47 as default value.*
R in root d.m./t shoot d.m.

Source: Table 4.3, 4.4 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

***Conversion above .ground .biomass. (tonnes/ha) into above ground biomass. (tonnes d.m./ha): dry weight= 72.5% of normal weight. Therefore, a.g.b <20 tonnes/ha≅ <15 tonnes d.m./ha*
According to IPCC tables 4.7, 4.8 and 4.12, above ground biomass values in natural forests and plantations are comparable.

Default Values when above ground biomass is unknown, are shaded in grey colors

Table 13: *Carbon Loss Factor(Lf) for Humid Tropical Natural Forests and Plantations (simplified)*

HUMID TROPICAL NATURAL FORESTS AND PLANTATIONS								
Climate domain	**Forest type**	**Ecological Zone (as per R classification)**	**Above-ground biomass* (tonnes/ha)**	**Above-ground biomass** (tonnes d.m./ha)**	**growing stock levels (m3)** < 10	11 - 30	30-80	>80
					Lf* (tonnes C/m3)			
Humid tropical	conifers	Tropical Rainforest	any	Any	0.8378	0.3142	0.2132	0.1497

HUMID TROPICAL NATURAL FORESTS AND PLANTATIONS								
Climate domain	Forest type	Ecological Zone (as per R classification)	Above-ground biomass* (tonnes/ha)	Above-ground biomass** (tonnes d.m./ha)	growing stock levels (m3) < 10	11 - 30	30-80	>80
					Lf* (tonnes C/m3)			
		Tropical moist deciduous forest	<125	<91	2.7173	1.019	0.69156	0.4855
	natural forests	Tropical Rainforest	Any	Any	1.739	0.6565	0.4220	0.2411
	natural forests	Tropical moist deciduous forest	<125	<91	5.6400	2.1291	1.3686	0.7821
Humid tropical	conifers	Tropical moist deciduous forest	>125	>91[a]	2.8079	1.0529	0.7146	0.5017
Humid tropical	natural forests	Tropical moist deciduous forest	>125	>91[a]	5.8280	2.2001	1.4143	0.8081

We assume **R=0.20 for tropical moist deciduous forest above ground biomass <125 tonnes/ha, and **R=0.24** for tropical moist deciduous forest above ground biomass > 125 tonnes/ha ;*
*We assume **R=0.37** for tropical rainforest . These values apply both to hardwoods and conifers. CF=0.47 as default value.*
R in root d.m./t shoot d.m.
Source: Table 4.3, 4.4 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

***Conversion above .ground .biomass. (tonnes/ha) into above ground biomass. (tonnes d.m./ha): dry weight= 72.5% of normal weight. Therefore, a.g.b <125 tonnes/ha≅ <91 tonnes d.m./ha*
According to IPCC tables 4.7, 4.8 and 4.12, above ground biomass values in natural forests and plantations are comparable..

a : *Plantations of Africa broadleaf and Pinus sp. (≤20y) have an A.g.b. <91 tonnes d.m./ha*

4.3 Tables for S calculations

Table 14: *Soil Organic Carbon stock reference factors (SOC); default values*

Soil Organic Carbon stocks= SOC_{REF} (in tonnes of C/ha in 0-30 cm depth)						
Climate region	HAC[1]	LAC[2]	Sandy[3]	Spodic[4]	Volcanic[5]	Wetland[6]
Boreal	68	NA	10[#]	117	20[#]	146
Cold temperate, dry	50	33	34	NA	20[#]	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70[#]	88

Soil Organic Carbon stocks= SOC_{REF} (in tonnes of C/ha in 0-30 cm depth)						
Climate region	**HAC**[1]	**LAC**[2]	**Sandy**[3]	**Spodic**[4]	**Volcanic**[5]	**Wetland**[6]
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	
Tropical montane	88*	63*	34*	NA	80*	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown.
A nominal error estimate of ±90% (expressed as 2x standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.
# Indicates where no data were available and default values from *1996 IPCC Guidelines* were retained.
* Data were not available to directly estimate reference C stocks for these soil types in the tropical montane climate so the stocks were based on estimates derived for the warm temperate, moist region, which has similar mean annual temperatures and precipitation.
1 Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).
2 Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).
3 Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).
4 Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)
5 Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)
6 Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

Table 15: *Emission factors for drained organic soils in managed forests (default values).*

Climate domain	Emission factors (tonnes C/ha yr)	
	Values	Ranges
Tropical	1.36	0.82-3.82
Temperate	0.68	0.41-1.91
Boreal	0.16	0.08-1.09

Source: GPG-LULUCF, Table 3.2.3

4.4 Tables for more accurate calculations

Table 16: *Above-ground biomass in forests.*

Domain Ecological zone Continent	Above-ground	Biomass	Above-ground biomass (tonnes d.m. ha-1)
Tropical	Tropical rain forest	Africa	310 (130-510)
		North and South America	300 (120-400)
		Asia (continental)	280 (120-680)
		Asia (insular)	350 (280-520)
	Tropical moist deciduous forest	Africa	260 (160-430)
		North and South America	220 (210-280)
		Asia (continental)	180 (10-560)
		Asia (insular)	290
	Tropical dry forest	Africa	120 (120-130)
		North and South America	210 (200-410)
		Asia (continental)	130 (100-160)
		Asia (insular)	160
	Tropical shrubland	Africa	70 (20-200)
		North and South America	80 (40-90)
		Asia (continental)	60
		Asia (insular)	70
	Tropical mountain systems	Africa	40-190
		North and South America	60-230
		Asia (continental)	50-220
		Asia (insular)	50-360
Subtropical	Subtropical humid forest	North and South America	220 (210-280)
		Asia (continental)	180 (10-560)
		Asia (insular)	290
	Subtropical dry forest	Africa	140
		North and South America	210 (200-410)
		Asia (continental)	130 (100-160)
		Asia (insular)	160
	Subtropical steppe	Africa	70 (20-200)
		North and South America	80 (40-90)
		Asia (continental)	60
		Asia (insular)	70
	Subtropical mountain systems	Africa	50
		North and South America	60-230
		Asia (continental)	50-220
		Asia (insular)	50-360
Temperate	Temperate oceanic forest	Europe	120
		North America	660 (80-1200)
		New Zealand	360 (210-430)
		South America	180 (90-310)
	Temperate continental forest	Asia, Europe (≤20 y)	20
		Asia, Europe (>20 y)	120 (20-320)
		North and South America (≤20 y)	60 (10-130)
		North and South America(>20 y)	130 (50-200)
	Temperate mountain	Asia, Europe (≤20 y)	100 (20-180)

Domain Ecological zone Continent	Above-ground	Biomass	Above-ground biomass (tonnes d.m. ha-1)
	systems	Asia, Europe (>20 y)	130 (20-600)
		North and South America(≤20 y)	50 (20-110)
		North and South America(>20 y)	130 (40-280)
Boreal	Boreal coniferous forest	Asia, Europe, North America	10-90
	Boreal tundra woodland	Asia, Europe, North America(≤20 y)	3-4
		Asia, Europe, North America(>20 y)	15-20
	Boreal mountain systems	Asia, Europe, North America(≤20 y)	12-15
		Asia, Europe, North America(>20 y)	40-50
References: *IPCC, 2003; Gower et al., 2001; Battles et al., 2002; Gayoso and Schlegel, 2003; Hall et al., 2001; Smithwick et al., 2002; Hessl et al., 2004; Montès et al., 2002; Sebei et al., 2001; Hughes et al., 1999; Baker et al., 2004a*			
Source: adapted from Table 4.7, 'Above-ground biomass in forests,			

Table 17: *Above-ground biomass in plantations.*

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha-1)
Tropical	Tropical rain forest	Africa broadleaf > 20 y	300
		Africa broadleaf ≤ 20 y	100
		Africa Pinus sp. > 20 y	200
		Africa Pinus sp. ≤ 20 y	60
		Americas Eucalyptus sp.	200
		Americas Pinus sp.	300
		Americas Tectona grandis	240
		Americas other broadleaf	150
		Asia broadleaf	220
		Asia other	130
	Tropical moist deciduous forests	Africa broadleaf > 20 y	150
		Africa broadleaf ≤ 20 y	80
		Africa Pinus sp. > 20 y	120
		Africa Pinus sp. ≤ 20 y	40
		Americas Eucalyptus sp.	90
		Americas Pinus sp.	270
		Americas Tectona grandis	120
		Americas other broadleaf	100
		Asia broadleaf	180
		Asia other	100
	Tropical dry forest	Africa broadleaf > 20 y	70
		Africa broadleaf ≤ 20 y	30
		Africa Pinus sp. > 20 y	60

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha-1)
		Africa Pinus sp. ≤ 20 y	20
		Americas Eucalyptus sp.	90
		Americas Pinus sp.	110
		Americas Tectona grandis	90
		Americas other broadleaf	60
		Asia broadleaf	90
		Asia other	60
	Tropical shrubland	Africa broadleaf	20
		Africa Pinus sp. > 20 y	20
		Africa Pinus sp. ≤ 20 y	15
		Americas Eucalyptus sp.	60
		Americas Pinus sp.	60
		Americas Tectona grandis	50
		Americas other broadleaf	30
		Asia broadleaf	40
		Asia other	30
	Tropical mountain systems	Africa broadleaf > 20 y	60-150
		Africa broadleaf ≤ 20 y	40-100
		Africa Pinus sp. > 20 y	30-100
		Africa Pinus sp. ≤ 20 y	10-40
		Americas Eucalyptus sp.	30-120
		Americas Pinus sp.	60-170
		Americas Tectona grandis	30-130
		Americas other broadleaf	30-80
		Asia broadleaf	40-150
		Asia other	25-80
Subtropical	Subtropical humid forest	Americas Eucalyptus sp.	140
		Americas Pinus sp.	270
		Americas Tectona grandis	120
		Americas other broadleaf	100
		Asia broadleaf	180
		Asia other	100
	Subtropical dry forest	Africa broadleaf > 20 y	70
		Africa broadleaf ≤ 20 y	30
		Africa Pinus sp. > 20 y	60
		Africa Pinus sp. ≤ 20 y	20
		Americas Eucalyptus sp.	110
		Americas Pinus sp.	110
		Americas Tectona grandis	90
		Americas other broadleaf	60
		Asia broadleaf	90
		Asia other	60
	Subtropical steppe	Africa broadleaf	20
		Africa Pinus sp. > 20 y	20
		Africa Pinus sp. ≤ 20 y	15

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha-1)
		Americas Eucalyptus sp.	60
		Americas Pinus sp.	60
		Americas Tectona grandis	50
		Americas other broadleaf	30
		Asia broadleaf > 20 y	80
		Asia broadleaf ≤ 20 y	10
		Asia coniferous > 20 y	20
		Asia coniferous ≤ 20 y	100-120
	Subtropical mountain system	Africa broadleaf > 20 y	60-150
		Africa broadleaf ≤ 20 y	40-100
		Africa Pinus sp. > 20 y	30-100
		Africa Pinus sp. ≤ 20 y	10-40
		Americas Eucalyptus sp.	30-120
		Americas Pinus sp.	60-170
		Americas Tectona grandis	30-130
		Americas other broadleaf	30-80
		Asia broadleaf	40-150
		Asia other	25-80
Temperate	Temperate oceanic forest	Asia, Europe, broadleaf > 20 y	200
		Asia, Europe, broadleaf ≤ 20 y	30
		Asia, Europe, coniferous > 20 y	150-250
		Asia, Europe, coniferous ≤ 20 y	40
		North America	50-300
		New Zealand	150-350
		South America	90-120
	Temperate continental forest and mountain systems	Asia, Europe, broadleaf > 20 y	200
		Asia, Europe, broadleaf ≤ 20 y	15
		Asia, Europe, coniferous > 20 y	150-200
		Asia, Europe, coniferous ≤ 20 y	25-30
		North America	50-300
		South America	90-120
Boreal	Boreal coniferous forest and mountain systems	Asia, Europe > 20 y	40
		Asia, Europe ≤ 20 y	5
		North America	40-50
	Boreal tundra woodland	Asia, Europe > 20 y	25
		Asia, Europe ≤ 20 y	5
		North America	25
References: IPCC, 2003; Kraenzel et al., 2003; Stape et al., 2004; Hinds and Reid, 1957; Hall and Hollinger, 1997;			

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha-1)
Hall,,2001			
Source: adapted from Table 4.7, 'Above-ground biomass in forests,			

Table 18: *Carbon Loss Factor(L_f) for Boreal Climates*

BOREAL						
			growing stock levels (m3)			
Climate domain	Forest type	Above-ground biomass (tonnes/ha)*	< 20	21 - 50	51 - 100	100+
			Lf* (tonnes C/m3)			
Boreal	pines	<75	0.8689	0.4900	0.4116	0.3593
	larch		0.8820	0.5684	0.5553	0.5553
	firs and spruces		0.8428	0.4769	0.4181	0.3854
	hardwoods		0.6533	0.5030	0.4508	0.3985
Boreal	pines	>75	0.7751	0.4371	0.3672	0.3205
	larch		0.7868	0.5070	0.4954	0.4954
	firs and spruces		0.7518	0.4254	0.3730	0.3439
	hardwoods		0.5828	0.4488	0.4021	0.3555

We assume **R=0.39 for above ground biomass <75 tonnes/ha, and **R=0.24** for above ground biomass > 75 tonnes/ha ; CF=0.47 as default value. These values apply to all forest types.*
R in root d.m./t shoot d.m.

Source: Table 4.3, 4.4 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 19: *Carbon Loss Factor(L_f) for Temperate Climates*

TEMPERATE								
				growing stock levels (m3)				
Climate domain	Forest type	Genus (as per R classification)	Above-ground biomass (tonnes/ha)*	< 20	21 - 40	41 - 100	100-200	200+
				Lf* (tonnes C/m3)				
Temperate	hardwoods	Quercus	<70	1.5651	0.8883	0.7285	0.5499	0.4183
		Eucalyptus	<50	2.2537	1.2792	1.0490	0.7919	0.6024
		Other broadleaf	<75	2.2850	1.2969	1.0636	0.8029	0.6107

	pines	conifers	<50	1.4280	0.7925	0.5926	0.5498	0.5498
	other conifers			2.3776	1.1067	0.7925	0.5926	0.5498
Temperate	hardwoods	Quercus	>70	2.0346	1.1548	0.9471	0.7149	0.5438
		Eucalyptus	50 - 150	2.0033	1.1370	0.9325	0.7039	0.5354
		Other broadleaf	75 – 150	1.9251	1.0926	0.8961	0.6764	0.5145
	pines	conifers	50 - 150	1.3158	0.7303	0.5461	0.5066	0.5066
	other conifers			2.1908	1.0197	0.7303	0.5461	0.5066
Temperate	hardwoods	Eucalyptus	>150	1.8781	1.0660	0.8742	0.6599	0.5020
		Other broadleaf		1.9407	1.1015	0.9033	0.6819	0.5187
	pines	conifers	> 150	1.2240	0.6793	0.5080	0.4712	0.4712
	other conifers			2.0380	0.9486	0.6793	0.5080	0.4712

* *We assume* ***R=0.40*** *for conifers above ground biomass <50 tonnes/ha, and* ***R=0.29*** *for conifers above-ground biomass 50-150 tonnes/ha, and* ***R=0.20*** *for conifers above-ground biomass >150 tonnes/ha ; CF=0.51 as default value.*
We assume ***R=0.30*** *for Quercus spp above ground biomass >70 tonnes/ha, and* ***R=0*** *for Quercus spp above ground biomass <70 tonnes/ha ; CF=0.47 as default value.*
We assume ***R=0.44*** *for Eucalyptus above ground biomass <50 tonnes/ha, and* ***R=0.28*** *for Eucalyptus above-ground biomass 50-150 tonnes/ha, and* ***R=0.20*** *for Eucalyptus above-ground biomass >150 tonnes/ha ; CF=0.47 as default value.*
We assume ***R=0.46*** *for other broadleaf above ground biomass <75 tonnes/ha, and* ***R=0.23*** *for other broadleaf above-ground biomass 75-150 tonnes/ha, and* ***R=0.24*** *for other broadleaf above-ground biomass >150 tonnes/ha ; CF=0.47 as default value.*
t R in root d.m./t shoot d.m.

Source: Table 4.3 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 20: *Carbon Loss Factor(L_f) for Mediterranean Climates*

MEDITERRANEAN					
Climate domain	Forest type	growing stock levels (m3)			
		< 20	21 - 40	41 - 80	80+
		Lf* (tonnes C/m3)			
Mediterranean	hardwoods	2.6085	0.9917	0.4183	0.3431

	conifers	3.4017	0.6783	0.3417	0.3111

*We assume **R=0** because there is other R value given at the IPCC methodology;*
CF=0.47 as default value and 0.51 for conifers

Source: Table 4.3 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 21: *Carbon Loss Factor(L_f) for Subtropical Climates*

SUBTROPICAL							
Climate domain	Forest type	Ecological Zone (as per R classification)	Above-ground biomass (tonnes/ha)	growing stock levels (m3) < 20	21 - 40	41 - 80	80+
				Lf* (tonnes C/m3)			
subtropical	hardwoods	Humid forest	<125	3.1302	1.1900	0.5020	0.4117
		Dry forest	<20	4.0693	1.5471	0.6525	0.5352
		Steppe	any	0.83472	0.317344	0.133856	0.109792
		Mountain Systems ^	NA	No estimate available			
	conifers	Humid forest	<125	3.7619	0.7501	0.3779	0.3440
		Dry forest	<20	4.8904	0.9752	0.4912	0.4473
		Mountain Systems ^	NA	No estimate available			
subtropical	hardwoods	Humid forest	>125	3.2345	1.2297	0.5187	0.4254
		Dry forest	>20	3.3389	1.2694	0.5354	0.4392
	conifers	Humid forest	>125	3.8873	0.7751	0.3905	0.3555
		Dry forest	>20	4.0127	0.8001	0.4031	0.3670

We assume **R=0.56 for subtropical dry forest above ground biomass <20 tonnes/ha, and **R=0.28** for subtropical dry forest above ground biomass > 20 tonnes/ha ;*
*We assume **R=0.2** for subtropical humid forest above ground biomass <125 tonnes/ha, and **R=0.24** for subtropical humid forest above ground biomass > 125 tonnes/ha ;*
*We assume **R=0.32** for subtropical steppe. These values apply both to hardwoods and conifers. CF=0.47 as default value.*
^No R estimate available.

Table 22: *Carbon Loss Factor(L_f) for Dry Tropical Climates*

DRY TROPICAL				
Climate	Forest type	Ecological Zone	Above-ground	growing stock levels (m3)

domain		(as per R classification)	biomass (tonnes/ha)	< 20	21 - 40	41 - 80	80+
					Lf* (tonnes C/m3)		
Dry Tropical	hardwoods	dry forest	<20	4.0693	1.5471	0.6525	0.5352
		shrubland	Any	1.0434	0.39668	0.16732	0.13724
		mountain systems	any	0.704295	0.267759	0.112941	0.092637
	conifers	dry forest	<20	5.3067	1.0581	0.5331	0.4853
		mountain systems	any	0.918459	0.183141	0.092259	0.083997
Dry Tropical	hardwoods	dry forest	>20	3.3389	1.2694	0.5354	0.4392
	conifers			4.3542	0.8682	0.4374	0.3982

We assume **R=0.56 for tropical dry forest above ground biomass <20 tonnes/ha, and **R=0.28** for tropical dry forest above ground biomass > 20 tonnes/ha ;*
*We assume **R=0.4** for tropical shrubland, and **R=0.27** for tropical mountain system. These values apply both to hardwoods and conifers.*
CF=0.47 as default value.
R in root d.m./t shoot d.m.

Source: Table 4.3, 4.4 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 23: *Carbon Loss Factor(L_f) for Humid Tropical Climates*

Lf= Carbon Loss Factor= BCEFr*CF*(1+R) (in tones of C/m3)											
Climate domain	**Forest type**	**Ecological Zone (as per R classification)**	**Above-ground biomass (tonnes/ha)**	**growing stock levels (m3)**							
				< 10	11 - 20	21- 40	41- 60	61- 80	80-120	120-200	200+
				Lf* (tones C/m3)							
Humid tropical	conifers	Tropical Rainforest	any	0.837828	0.366078	0.262293	0.209457	0.167943	0.158508	0.145299	0.145299
Humid tropical	conifers	Tropical moist deciduous forest	<125	2.7173	1.1873	0.8507	0.6793	0.5447	0.5141	0.4712	0.4712
Humid tropical	natural forests	Tropical Rainforest	Any	1.739	0.772116	0.540829	0.396492	0.328671	0.290413	0.250416	0.182595
Humid tropical	natural forests	Tropical moist deciduous forest	<125	5.6400	2.5042	1.7540	1.2859	1.0660	0.9419	0.8122	0.5922
Humid tropical	conifers	Tropical moist deciduous forest	>125	2.8079	1.2269	0.8790	0.7020	0.5628	0.5312	0.4869	0.4869
Humid tropical	natural forests	Tropical moist deciduous forest	>125	5.8280	2.5876	1.8125	1.3288	1.1015	0.9733	0.8392	0.6119

We assume* ***R=0.20* *for tropical moist deciduous forest above ground biomass <125 tonnes/ha, and* ***R=0.24*** *for tropical moist deciduous forest above ground biomass > 125 tonnes/ha ;*
We assume ***R=0.37*** *for tropical rainforest . These values apply both to hardwoods and conifers. CF=0.47 as default value.*
R in root d.m./t shoot d.m.

Source: Table 4.3, 4.4 and 4.5 Chp 4, Forest Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Appendix 5: Emission factors

Table 24: *Emission factors for stationary combustion fuels.*

Fuel	Applicable category	Emission factor (t CO_2eq/GJ) ($CO_2 + 25*CH_4 + 310*N_2O$)	Source
Sulphur Lies (Black liquor)	Any Fuel Combustion Activities	0.095995	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
Wood/ wood Waste	Fuel Combustion Activities of: -> Energy Industries; Manufacturing Industries and Construction	0.11399	IPCC emission factors tool (http://www.carbonmetrics.com/ipcc-emission-factors-tool) and IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
	Fuel Combustion Activities of: -> Commercial/Institutional ; Agriculture/Forestry/Fishing	0.12074	IPCC emission factors tool (http://www.carbonmetrics.com/ipcc-emission-factors-tool) and IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
Primary solid biomass*	Fuel Combustion Activities of: -> Energy Industries; Manufacturing Industries and Construction	0.10199	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
	Fuel Combustion Activities of: -> Commercial/Institutional ; Agriculture/Forestry/Fishing	0.10874	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
Natural Gas**	Fuel Combustion Activities of: -> Energy Industries; Manufacturing Industries and Construction	0.056156	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
	Fuel Combustion Activities of: -> Commercial/Institutional ; Agriculture/Forestry/Fishing	0.056256	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
Bitaminous coal***	Fuel Combustion Activities of: -> Energy Industries	0.095090	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)

	Fuel Combustion Activities of: -> Manufacturing Industries and Construction ; Commercial/Institutional	0.0995315	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)
	Fuel Combustion Activities of: -> Agriculture/Forestry/Fishing	0.102565	IPCC Search page (http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php)

* This includes dung and agricultural, municipal and indusrial wastes. These factors are considered the best available global default factors to date.
** Suggested default emission factor should include a 0.5% correction (natural gas) for unoxidized carbon.
*** these factors assume no unoxidized carbon; to account for unoxidized carbon, IPCC suggests multiplying by these default factors: coal = 0.98, oil = 0.99, and gas = 0.995 (factors presented in the table are rounded to three significant figures)
NOTE: IPCC contains specific information on stationary combustion emission factors for Finland.