General Concepts and Methodology

Chapter 2

2.1 Introduction

The 'Good Practices Guidance' (GPG) developed by Intergovernmental Panel on Climate Change (IPCC) is universally accepted source book for concepts, definitions, various pools, methods, default values, various required equations etc for preparing account of forest carbon stocks (FCS). Since the subject has been developing in last two decades, many new concepts and methods have emerged but still many challenges remain. The GPG uses the term "Categories" to refer specific sources of emissions/ removals of greenhouse gases. As per the IPCC GPG 2003, the categories are: Forest land, Cropland, Grassland, Wetlands, Settlements and other lands. Each land-use category is further subdivided. The following sub-categories are considered for the sector:

Forest land remaining Forest land: An increase in the carbon stocks of Forest Land remaining Forest Land would mean improvement in canopy density and growing stock of forest. A decrease in the carbon stock of Forest Land remaining Forest Land is generally considered as degradation of forest resources.

Land converted to Forest land: Any non-forest land converted to Forest land would generally be considered as afforestation.

According to GPG, the calculation of GHG inventories require information on extent of area (in case of LULUCF) of an emission/removal category termed as 'Activity data' and emission or removal of GHG per unit of area (removal of CO_2 per ha of added forest area) termed as 'Emission factors'. The main aim is to estimate these factors for the reporting unit. Once these are estimated, the emission or removal, can be ascertained using the change in carbon stocks.

Three different approaches are given in the GPG to present the activity data (the change in area of different land categories). **Approach 1** identifies the total area for each land category; it only provides "net" area. **Approach 2** identifies the land conversions between categories by tracking and provides tabular information about land-use conversion. **Approach 3** involves, in addition, the spatial tracking of land-use conversion.

The total carbon which is stocked in the forests is divided into several pools and the emission

Table 2.1: Three IPCC tiers and data requirements

Tier	Data needs/examples of appropriate biomass data
Tier 1	IPCC default factors: Default MAI (for degradation) and/or forest biomass stock (for deforestation) values for broad continental forest types - default values given for all vegetation-based pools.
Tier 2	Country specific data for key factors: MAI and/or forest biomass values from existing forest inventories and/or ecological studies. Default values provided for all non tree pools. Newly-collected forest biomass data is required.
Tier 3	Detailed national inventory of key C stocks, repeated measurements of key stocks through time or modeling: Repeated measurement of trees from permanent plots and/or calibrated process models. Can use default data for other pools stratified by in-county regions and forest type, or estimates from process module.

factors are derived from assessments of the changes in carbon stocks in these carbon pools. These factors are developed using estimates which are used at different levels; global, national and sub-national and based on the level the 'Tier levels' (Table 2.1) are defined which are independent of the approach being followed.

In general, moving to higher tiers improves the accuracy of the inventory and reduces uncertainty, but the complexity and resources needed for conducting inventories also increases with higher tiers.

The Tier 1 approach employs the basic method and default emission factors provided in the IPCC Guidelines (Workbook). Tier 1 methodologies usually use activity data that are spatially coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics and global land cover maps.

The Tier 2 approach applies emission factors and activity data which are defined by the country. Tier 2 can also apply stock change methodologies based on country-specific data. Country-defined emission factors/activity data are more appropriate for the climatic regions and land use systems in that country.

At Tier 3, higher order methods including models and inventory measurement systems are used in which measurements are repeated over time and supported by high-resolution activity data and disaggregated at sub-national level. Such systems may use Remote Sensing and GIS tools for tracking land-use change over time.

In forest ecosystem, enormous carbon is stored which is classified in five pools by GPG. The living portion of biomass carbon is classified in two

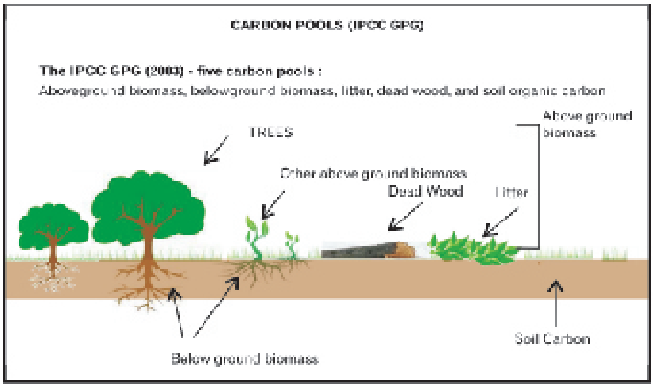


Table 2.2: Different forest carbon pools

Pools		Description
Living Biomass	Above ground biomass (AGB)	All living biomass above the soil including stem, stump, branches, bark, seeds and foliage.
	Below ground biomass (BGB)	All living biomass of live roots. Fine roots of less than 2mm diameter (country specific) are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead Organic Matter	Dead wood	Includes all non living woody biomass not contained in the litter, either standing or lying on the ground. Dead wood also includes dead roots and stumps larger than or equal to 10cm in diameter or any other diameter used by the country.
	Litter	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for FSI 5 cm), lying dead, in various states of decomposition above the mineral or organic soil.
Soil	Soil organic matter	Includes organic carbon in mineral and organic soils (including peat) to a specific depth chosen by the country (for FSI 30 cm) and applied consistently through the time series.

pools: the 'above ground biomass' (AGB) and 'below ground biomass' (BGB) and are stores of significant amount of carbon. The 'dead organic matter' (DOM) is also classified in two pools: 'dead wood' and 'litter'. The fifth pool is 'Soil organic matter' (SOM) which contains substantial amount of organic carbon.

To measure changes in carbon stocks, GPG recommends two methods: the Gain-Loss method (activity/process based approach) and the Stock-Difference method (inventory based approach). The Gain-Loss method is a process-based approach which estimates the net balance of additions to and removals from a carbon stock. The annual carbon stock change in a given pool is the difference between the annual gain and the annual loss of carbon for that pool. Not all transfers involve emissions or removals, since any transfer from one pool to another is a loss from the donor pool but a gain of equal amount for the receiving pool. The Stock-Difference method is a stock-based approach. It is used where carbon stocks in relevant pools are measured at two points of time to assess carbon stock changes.

2.2 Forest Carbon Accounting

A robust and verifiable measurement of GHG emissions is termed as Carbon accounting. The measurement of different parameters of forests is being done for ages; the carbon accounting has assumed importance in the recent past due to the role of forests in climate change. This necessitates the growing need to quantify the stocks, sources and sinks of carbon and other GHGs in the context of anthropogenic impacts on the global climate.

Historically, forest inventories are being done in the country since ages with a primary objective of assessing growing stock. Morever, the information on growing stock has become vital for calculating forest carbon stock.

Internationally, FAO provides the most comprehensive assessment of global forest cover, growing stock and carbon stock information through Forest Resources Assessment (FRA) at an interval of five to ten years.

Box 1. Obligations for forestry carbon accounting under the UNFCCC and Kyoto Protocol

Parties to the UNFCCC are required to submit national reports on the implementation of the Convention to the conference of the parties (COP). Emissions and removals of GHGs are central in these National Communications, although reporting requirements differ between Annex I and non-Annex I countries. Article 4 of the UNFCCC requires all Parties to submit national inventories of anthropogenic emissions by source and removals by sinks of GHGs to the COP. However, while Annex I countries must do this annually, there are no fixed dates for submission of the National Communications of non-Annex I Parties.

Annex I parties who have also taken on commitments to reduce emissions under the Kyoto Protocol (KP) must provide supplementary information in their National Communications. In particular, they must include calculations of emissions by sources and removals by sinks of GHGs to demonstrate KP commitment compliance. Article 3 of the KP obliges Annex I parties to include aspects of LULUCF in the calculation of these overall country carbon emissions.

Under Article 3.3 of the KP, Annex I countries are required to account for emissions from direct human induced activities of afforestation, reforestation and deforestation in forest areas not existing before 1990. The Marrakech Accords allow net emissions from afforestation, reforestation and deforestation within the commitment period (2008-2012) to be offset through forest management up to a limit of 33 mega tonnes (Mt) of CO_2 per year.

Under Article 3.4 of the KP, Annex I countries can voluntarily account for direct human- induced activities associated with forest management, cropland management, grazing land management and revegetation that have occurred after 1990. This voluntary accounting is likely to be conducted where countries believe that emissions in the commitment period will be lower than those in the base period (1990) and so the net impact of these activities is negative, a carbon sink. When this occurs, Removal Units (RMUs) of carbon can be issued up to a specified cap, helping countries to meet emission targets.

Finally, under Article 3.7 of the KP, Annex I countries with more emissions than removals from the land use change and forestry sector in 1990 are required to include the LULUCF sector in their 1990 baseline. This means LULUCF emissions are then included in the calculation of Assigned Amount Units which represent the emissions cap for a country in the commitment period.

Although non-Annex I countries are not obliged to annually account and present GHG emissions to the COP, they are not without forest carbon accounting experience. A small number of forest carbon projects have necessitated accounting for tradable emission reductions, either via the Clean Development Mechanism of the KP or through voluntary carbon markets.

2.3 Good Practice for Forest Carbon Accounting

Accurate and Precise

Accuracy is how close estimates are to the true value; accurate measurements lack bias and systematic error. Precision is the level of agreement between repeated measurements; precise measurements have lower random error. To give confidence in the estimate, both accuracy and precision are desirable and can be increased through removal of bias and reduction in uncertainty as far as possible.

Comparable

The data, methods and assumptions applied in the accounting process should conform international standard and should allow meaningful and valid comparisons between areas

Complete

Accounting should be inclusive of all relevant categories of sources and sinks and gases, as limited accounting may lead to misleading results. All carbon pools should be measured as precisely as possible.

Conservative

Where accounting relies on assumptions, values and procedures with high uncertainty, the most conservative option in the biological range should be chosen so as not overestimate sinks or underestimate sources of GHGs. Conservative carbon estimates can also be achieved through the omission of carbon pools

Consistent

Accounting estimates for different years, gases and categories should reflect real differences in carbon rather than differences in methods

Relevance

Recognising that trade-offs must be made in accounting as a result of time and resource constraints, the data, methods and assumptions must be appropriate to the intended use of the information

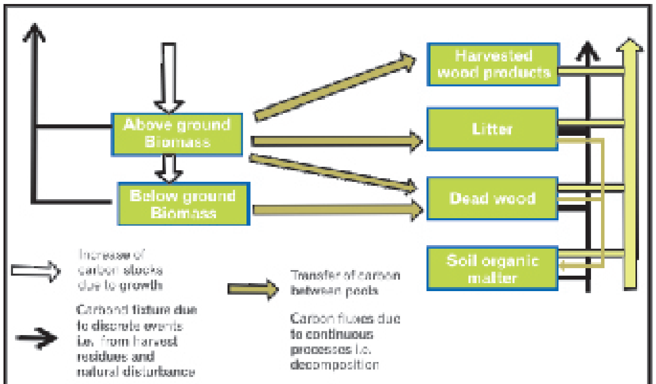
Transparent

The integrity of the reported results should be varifiable by a third party or external actor. This requires sufficient and clear documentation of the accounting process to be available so that credibility and reliability of estimates can be assessed.

2.4 Biomass, Carbon Pools and Stock Accounting

Forest biomass is organic matter resulting from primary production through photosynthesis minus consumption through respiration and harvest. Assessment of biomass provides information on the structure and functional attributes of a forest and is used to estimate the quantity of timber, fuel and fodder components (Brown S. 1997). With approximately 50% of dry forest biomass comprised of carbon (Westlake, 1966), biomass assessments also illustrate the amount of carbon that may be lost or sequestered under different forest management regimes. Carbon is lost to the atmosphere as CO_2. To convert carbon in biomass to CO_2, the tonnes of carbon are multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12). Estimating the biomass density of forest components is, therefore, the first step in forest carbon accounting.

A carbon source is a carbon pool from which more carbon flows out than flows in: forests can also represent a net source (rather than sink) of carbon due to the processes of decay, combustion and respiration. A carbon sink is a carbon pool from which more carbon flows in than out: forests can act as sink through the process of tree growth and resultant biological carbon sequestration (Brown, 2002). Forests can switch between being a source and a sink of carbon over time, with the stock of the forest referring to the absolute quantity of carbon held within a forest component at a specified time. The transfer of carbon between carbon pools is represented in Figure 2.



Generalized flow of carbon between pools

Stock accounting sums carbon pools at a single point of time. Decisions on which carbon pools should be included are largely dependent on the availability of existing data, costs of measurement and the level of conservativeness required (MacDicken, 1997). Trees often represent the greatest fraction of total biomass of a forested area, with other carbon pools only a fraction of the total tree biomass. The understorey is estimated to be equivalent to 3% of above-ground tree biomass, dead wood 5-40%, and fine litter only 5% of that in the above-ground tree biomass. BGB is more variable, ranging between 4-230% and can be more than two times greater than that in the above-ground tree biomass (Brown, 1997). AGB in trees also responds more rapidly and significantly as a result of landuse change than other carbon pools. As a consequence, the majority of carbon accounting efforts are focussed on tree AGB.

2.5 Approaches to Emission Accounting

Although many natural processes lead to emissions and removals of GHGs for example, fires, insect attacks and local climate variability. Anthropogenic activities such as slash and burn, fire management and harvesting have accelerated the release of GHGs from forests (Canadell, J.et.al., 2007). These forest management practices affect the balance of emissions into the atmosphere through biomass fluctuation, soil and litter disturbance (Sajwaj et al., 2008) and so have differing impacts on the various carbon pools.

The purpose of emissions accounting is to quantify the exchange of GHGs between the atmosphere, terrestrial vegetation and soils through photosynthesis, respiration, decom-position and combustion. There are two main approaches to emissions accounting: the inventory approach and the activity based approach, which are outlined below. Both approaches are supported under IPCC guidance (IPCC, 2003) and are based on the underlying assumption that the flows of GHGs to or from the atmosphere are equal to changes in carbon stocks in the biomass and soils.

The inventory approach measures the difference in carbon stocks averaged between two points of time. Also called periodic accounting or the stock-difference approach, measurement of stock change in this way can cover large areas and a variety of species and site conditions. The inventory-based system also captures non-linear changes in carbon stocks, for example biomass accumulation through growth. However, relying on the addition of carbon pools and assessments conducted in this way often leaves out smaller biomass components such as leaf biomass, ground vegetation and litter, which needs to be measured separetly.

In contrast, the activity-based approach estimates the net balance of additions to and removals from a carbon pool. The activity-based approach, also called the gain-loss or flux approach, estimates changes in carbon stocks by first establishing the rate of area change in land use and multiplying this by the response of carbon stocks under a particular land use. This biological response of a given land use is based indirectly on rates of carbon losses and gains by an area or it is directly measured with the aid of technology (for an example see Baldocchi, 2003). The activity-based approach is useful where individual carbon pools are difficult to measure and is less susceptible to short-term variation in carbon stocks. However, emission factors require non-linear carbon stock changes to be time-averaged and assumptions must be made explicit.

In general, the accounting approach chosen must reflect both purpose and acceptability to policy-makers, with decisions also likely to rely on the availability and form of existing forest data within a territory.

2.6 Data Acquisition for Forest Carbon Accounting

2.6.1 Collating existing forest data

Forest carbon accounting can make use of existing national, regional or global data. Sources will vary between territories, as will the reliability and uncertainty of the source. However, good quality secondary data reduces both time and cost requirements for accounting.

At a national level, forest inventories, woody biomass assessments, agricultural surveys, land registry information and scientific research can prove useful for land classification and model parameters. Data on temperature, rainfall, soil type and topography should also be sourced at smaller scales. In particular, data sources will include national statistical agencies, sectoral experts and universities.

Global and regional level data is also valuable for forest carbon accounting. International land-use and land cover datasets exist, largely from remote sensing imagery, although image resolution and the accuracy of ground-referenced data are generally limited. Sources of data include international experts, international organisations publishing statistics, such as the United Nations and OECD, and international scientific journals. In particular, the FAO Forest Resources Assessment (FAO, 2010), the IPCC Agriculture, Forestry and Other Land Use (AFOLU) inventory guidance volume (IPCC, 2006), and FAO's primer for estimating biomass (Brown, 1997) all provide parameter information that can be used in carbon accounting.

It is important to ensure that data sets are harmonised for example, in terms of consistency of definition for land classifications and forests and that the trade-offs between the use of secondary data and accuracy of accounting are acknowledged. The IPCC recognises that tradeoffs exist and so presents a multi-tiered approach to emissions accounting. Three levels of detail with differing mathematical specification of methods, information requirements and sources of activity data are offered to estimate net emissions.

Generally, Tier 1 reporting requires very little primary data collection to generate estimates of forest biomass. IPCC guidance reports a number of parameters and emission factors that can be applied, based on region-specific climate and vegetation data. IPCC has given estimated forest biomass values and annual growth increment in biomass by region and forest type. With the use of such default parameters, the uncertainty in accuracy is inevitably large; furthermore, not all carbon pools and GHGs are accounted for. Tier 2 also utilises default forest biomass information, but in combination with country-specific data. Tier 3 uses highly detailed localised data, often with repeated measures of permanent forest sample plots.

With increasing data requirements and analytical complexity from Tier 1 to Tier 3, the accuracy and precision of the carbon estimate also increases. In order to verify or improve the quality of carbon accounting estimates, and for project-level accounting, remote sensing data and field measurements tend to be required.

2.6.2 Using remote sensing

Remote sensing is useful in forest carbon accounting for measurement of total forest area, forest types and canopy cover. There are two categories of sensors, passive and active: the first measures the reflectance of naturally occurring solar radiation as in photography and the second measures radiation that is transmitted and reflected from the earth's surface (radar, for example). Aircraft sensors principally involve aerial photos linked to a geographical reference system, or Light Detection and Ranging (LIDAR) imagery giving image resolutions of up to 1m or less. Satellite-based sensors acquire mosaics of images covering large geographical areas and have variable resolution from very high to coarse. Once imagery has been acquired, expertise is required to classify remotely sensed data to different land cover. These land cover categories then require field data, from either existing or newly acquired studies, to estimate carbon stocks for each category.

2.6.3 Data from field sampling

Actual field data is preferable to default data for forest carbon accounting and is required to verify remotely sensed information and generalised data sets. Gathering field measurements for forest carbon accounting requires sampling as complete enumerations are neither practical nor efficient. By definition, sampling infers information about an entire population by observing only a fraction of it. In order to confidently scale up this data to the required geographical level, proper sampling design is vital.

Stratified random sampling is generally used for forest/carbon inventory as mostly forest areas are heterogeneous. Under stratified sampling, forest areas are stratified into homogenous strata and samples are selected from each strata randomly. This provides precise estimates for different strata and also for population. Once sample sites have been selected, established methods of biomass inventory are employed for different pools.

2.7 Accounting for Forest Carbon Stocks

2.7.1 Above-Ground Biomass (AGB)

The AGB carbon pool consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. For accounting purposes, it can be broadly divided into two parts viz. trees and understory. The most comprehensive method to establish the biomass of this carbon pool is destructive sampling, whereby vegetation is harvested, dried to a constant mass and the dry to-wet biomass ratio established. Destructive sampling of trees, however, is both expensive and somewhat counter-productive in the context of promoting carbon sequestration. Two further approaches for estimating the biomass density of tree biomass exist and are more commonly applied. The first directly estimates biomass density through biomass regression equations. The second converts wood volume estimates to biomass density using biomass expansion factors (Brown, 1997).

The biomass per average tree of each diameter class of the stand table can be estimated through biomass regression equations, also called allometric equations where stand tables showing the tally of all trees in a particular diameter class are available. Alternatively, the results of direct sampling of tree diameter in the area of interest can be used in these regression equations. The total biomass of the forest stand is then derived from the average tree biomass multiplied by the number of trees in the class, summed across all classes. In both tropical and temperate forests, such diameter measurements explain more than 95% of the variation in tree biomass (Brown, 2002).

There are a number of databases and publications that present default regression equations, stratified by rainfall regime and region (Appendix IV; Brown, 1997; IPCC, 2003). These default equations, based on a large sample of trees, are commonly applied as the generation of local allometric equations is often not feasible. However, the application of default equations will tend to reduce the accuracy of the biomass estimate.

Box 2. Two approaches to carbon accounting

Equation 1: Inventory/Periodic Accounting

$\Delta C = \sum (C_{t2}\ C_{t1}) / (t2\ \ t1)$

ΔC = carbon stock change, tonnes C per year
C_{t1} = carbon stock at time t1, tonnes C
C_{t2} = carbon stock at time t2, tonnes C

Equation 2: Activity-based/Flux Accounting

$\Delta C = \sum [A \bullet (C_I\ C_L)]$

A = area of land, ha

C_I = rate of gain of carbon, tonnes C per ha per year

Where information on the volume of wood stock exists, through traditional inventories, biomass density can be estimated by expanding the merchantable volume of stock, net annual increment or wood removals, to account for biomass of the other above-ground components. To do this, either Biomass Expansion Factors (BEFs) or Biomass Conversion and Expansion Factors (BCEFs) are applied. BEFs expand dry wood stock volume to account for other, non-merchantable, components of the tree. To establish biomass, the volume must also be converted to a weight by multiplication of the wood density as well as the BEF. In contrast, BCEFs use only a single multiplication to transform volume into biomass; this is useful where wood densities are not available. Default BEFs and BCEFs reported in the literature can be applied in forest carbon accounting. However, unless locally-specific equations exist to convert direct measurements of tree height and diameter to volume, regression equations to directly estimate biomass from tree diameter are preferable (IPCC, 2003). The Biomass data of herbs, shrubs and climbers are also collected during the forest inventory and estimated accordingly.

2.7.2 Below-Ground Biomass (BGB)

The BGB carbon pool consists of the biomass contained within live roots. As with AGB, although less data exists, regression equations from root biomass data have been formulated which predict root biomass based on above-ground biomass carbon (Brown, 2002; Cairns et al., 1997). Cairns et al. (1997) review 160 studies covering tropical, temperate and boreal forests and find a mean root-to-shoot (RS) ratio of 0.26, ranging between 0.18 and 0.30. Although roots are believed to depend on climate and soil characteristics

(Brown & Lugo, 1982), Cairns et al. found that RS ratios were constant between latitude (tropical, temperate and boreal), soil texture (fine, medium and coarse) and treetype (angiosperm and gymnosperm) (Cairns et al., 1997).

As with AGB, the application of default RS ratios represents a trade-off between costs of time, resources and accuracy. BGB can also be assessed locally by taking soil cores from which roots are extracted; the oven dry weight of these roots can be related to the cross-sectional area of the sample, and so to the BGB on a per area basis (MacDicken 1997)

2.7.3 Dead Organic Matter (Wood)

The DOM wood carbon pool includes all non-living woody biomass and includes standing and fallen trees, roots and stumps with diameter over 10cm. Often ignored, or assumed in equilibrium, this carbon pool can contain 10-20% of that in the AGB pool in mature forest (Delaney et al., 1998). However, in immature forests and plantations with long rotation both standing and fallen dead wood are likely to be insignificant in the first 30-60 years of establishment.

The primary method for assessing the carbon stock in the DOM wood pool is to sample and assess the wet-to-dry weight ratio, with large pieces of DOM measured volumetrically as cylinders and converted to biomass on the basis of wood density, and standing trees measured as live trees but adjusted for losses in branches (less 20%) and leaves (less 2-3%) (MacDicken, 1997). Methods to establish the ratio of living to dead biomass are under investigation, but data is limited on the decline of wood density as a result of decay (Brown, 2002).

2.7.4 Dead Organic Matter (Litter)

The DOM litter carbon pool includes all non-living biomass with a size greater than the limit for soil organic matter (SOM), commonly 2mm, and smaller than that of DOM wood, 10cm diameter. This pool comprises biomass in various states of decomposition prior to complete fragmentation and decomposition where it is transformed to SOM. Local estimation of the DOM litter pool again relies on the establishment of the wet-to-dry mass ratio. Where this is not possible, default values are available by forest type and climate regime from IPCC ranging from 2.1 tonnes of carbon per hectare in tropical forests to 39 tonnes of carbon per hectare in moist boreal broadleaf forest (Volume 4, Chapter 2, IPCC, 2006).

2.7.5 Soil Organic Matter (SOM)

SOM includes carbon in both mineral and organic soils and is a major reserve of terrestrial carbon (Lal et al., 2001). Inorganic forms of carbon are also found in soil; however, forest management has greater impact on organic carbon and so inorganic carbon impact is largely unaccounted. SOM is influenced through land use and management activities that affect the litter input. In SOM accounting, factors affecting the estimates include the depth to which carbon is accounted, commonly 30cm, and the time lag until the equilibrium stock is reached after a land use change, commonly 20 years.

Although reference SOM data exists (Section 7.4. Appendix IV; IPCC, 2006; Houghton et al., 1997; and the online ISRIC World Inventory of Soil Emission (WISE) Potential Database, ISRIC, 2009), research findings to date on the forest management impacts on soil carbon are highly variable. This is due to large differences in carbon impact, dependent on the site-specific ratio of mineral to organic soil types, uncertain carbon impacts of soil erosion and long time periods of adjustment after land use changes.

Accounting for SOM can also be more costly as local estimation of the carbon contained in this pool commonly relies on laboratory analysis of field samples. At sample sites, the bulk density of the soil and wet weight of the sample must also be recorded so that laboratory results can be translated into per area carbon stock.

2.8 Accounting for Carbon stored in Harvested Wood Products (HWPs)

The IPCC currently presents four approaches to HWP accounting (IPCC, 2006). However, no single method is promoted and member states are allowed to report zero contribution of HWPs to emissions inventories if they are deemed insignificant. Where HWPs are accounted for, memberstates can utilise basic FAO data (FAO, 2005) in combination with national trade statistics. At their simplest, HWPs estimates can be derived from changes in the 'in use' HWP pool, entry from domestic sources, HWP imports and exports, and HWPs in solid waste disposal sites. This Tier 1 approach assumes a constant fraction of the stock lost annually and IPCC guidance presents a number of default decay factors. Where more detailed historical and country-specific data is available for woodproduct stocks and flows, a Tier 3 method is presented.