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Issues related to developing monitoring and verification systems for forestry-based CO2 offset projects

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1) Background

Concern about rising atmospheric concentrations of greenhouse gases (Wigley 1993) has prompted the search for methods of sequestering carbon in plant biomass. The signing by 153 nations at the 1992 UNCED Earth Summit of the Framework Convention on Climate Change (Grubb *et al.* 1993) is evidence of intent to restrain the build-up of greenhouse gases (GHGs) in the atmosphere. The most important of these gases by weight is carbon dioxide (IPCC 1992), which is released principally by the combustion of fossil fuels, particularly coal and oil, by the burning or decay of vegetation and by flux with the oceans. Although the loss and degradation of tropical forests probably contribute only about 30% of total net CO_2 emissions (Houghton *et al.* 1992), these habitats represent one of the most productive long-term carbon sinks. The central requirement to achieve a reduction in CO_2 levels is for a reduction in fossil fuel consumption, but carbon offsets through forestry has great potential. Large expanses of under-utilised, degraded or deforested land with a low current value as carbon sinks which could be either afforested, reforested or rehabilitated are available throughout the world (Nilsson and Schopfhauser 1994).

Carbon offsets and forestry

What is carbon offset ? Here it is defined as the result of any action specifically taken to remove from and/or prevent the release of carbon dioxide into the atmosphere in order to balance emissions taking place elsewhere.

Carbon sequestration through forestry is based on two premises. First, that carbon dioxide is an atmospheric gas that circulates globally; consequently, efforts to remove greenhouse gases from the atmosphere will be equally effective whether they are based next door to the source or across the globe. Second, green plants take carbon dioxide gas out of the atmosphere in the process of photosynthesis and use it to make sugars and other organic compounds used for their growth and metabolism. Long-lived woody plants store carbon in their wood and other tissues until they die and decompose at which time the carbon in their wood may be released to the atmosphere as carbon dioxide, carbon monoxide or methane, or it may be incorporated into the soil as organic matter (Anderson and Spencer 1991).

Forestry carbon offset projects offer cost-effective methods for individuals, companies and countries to address rising atmospheric greenhouse gas concentrations. While conventional environmental policy solutions -- e.g. installing catalyst scrubbers to remove carbon gases from smokestacks --- which has been estimated to cost many hundreds of dollars per tonne, to scrub and dispose of carbon dioxide from power plant stacks (Spencer, 1992), carbon offsets through forestry can achieve the same GHG results for a fraction of the cost (Panayatou *et al.* 1994).

In carbon offset projects, the relevant output of a project is the creation of an environmental commodity. The commodity is a quantifiable volume of:

- Avoided GHG emissions or;
- Sequestered GHG in biomass and associated forms.

(see Section 3 for types of projects)

In the context of forestry and conservation practices, however, it should be recognised that not all projects which appear to have positive GHG effects are conceptually valid as carbon offsets. For example, existing national parks may not be considered to generate carbon offsets; these forests were already in existence when the concept of carbon sequestration arose. Therefore, simply renaming them as "carbon offsets" does not involve any active removal of CO_2 from the atmosphere. On the other hand, the establishment of new forests with the primary objective of carbon sequestration may then be rightly considered as an offset.

Carbon offsets are a notional commodity, based on a conceptual evaluation and scientific calculations. There is no separable entity to a tonne of carbon offset; a specific volume cannot be created in one place and materially transported to another. The commodity is derived by observing the difference between projected standard practices (known as the *project baseline* or *reference case*) and the occurring practices (known as the *project case*). That behavioural differential is translated into greenhouse gas savings, using quantitative methodologies.

By necessity, there is subjectivity in developing project baselines, because the baseline is a prediction of the future which cannot be empirically tested or directly observed. Since measurement is of relative differentials rather than of absolute quantities, it is very important that the baseline be as accurate and thorough in its assumptions as possible.

Joint Implementation (JI) and Activities Implemented Jointly (AIJ)

Joint Implementation (JI) and Activities Implemented Jointly (AIJ) are carbon offset projects in which the technological and/or financial support for the project activity originates in a different country from where the project is actually undertaken (Stuart and Jones 1995). Joint Implementation is the international diplomacy term for cooperative emission reduction ventures in which crediting occurs on a country-to-country basis. Activities Implemented Jointly are a moderated version of the same concept, in which cooperative projects are encouraged, monitored and certified, but no actual crediting between countries occurs. While GHG savings from AIJ projects are not creditable between countries, they may potentially be used by companies to meet certain national or sub-national emission goals. From a business perspective, there is very little difference between the two (Leslie 1995).

Qualitative analysis of carbon offset projects

Before a project gets to the point of creating and claiming carbon offsets, it must demonstrate that the activities are occurring -- or will occur --within the bounds of a set of subjective criteria. These criteria involve issues of project design, financing sources, secondary environmental and developmental impacts (Jones and Stuart 1994). There must be consistency with national and local objectives. While these qualitative criteria are still evolving, there is sufficient concurrence to synthesise a basic evaluation methodology. While each of the emerging bodies has unique aspects, they are all similarly concerned that four major areas be addressed within any particular project or proposal. We compartmentalise those concerns into the following categories:

- Acceptability
- Additionality
- Externalities
- Capacity

Projects must be analysed against these criteria to check if they truly qualify as valid offsets.

Quantification of carbon offsets

Carbon fixation through forestry is mainly a function of the amount of biomass and soil carbon in a given area. The amount of carbon stored in trees in a forest can be calculated by multiplying the amount of Biomass or living plant tissue in the forest by a conversion factor. Add to this the amount of carbon in the necromass and soil carbon to reach the total amount of carbon stored in a site at a point in time. Repeated measurements are required to determine the dynamic interaction between these pools throughout the life of the project. This analysis must also include the removals of carbon from the project site, such as in the case of wood products.

Plant tissues vary in their carbon content. Stems and fruits have more carbon per gram than do leaves, but because plants generally have some carbon-rich tissues and some carbon-poor tissues, an average concentration of 45-50 % carbon is generally accepted (Chan 1982). When considering carbon storage, not all forests are equal. Generally, longer-lived, higher density trees store more carbon per unit volume than short-lived, low density, fast-growing trees. This does not mean that carbon offsets which involve big, slow-growing trees are necessarily better than those involving plantations of fast-growing trees. Each forestry system is unique in the combination of its carbon pools and flows. Therefore, an analysis of the carbon sequestration capacity of a forest must take into account a variety of factors specific to that forest type such as the tree species, growth rates, rotation cycles, silvicultural regimes, harvesting rates, and fate of the wood products. This subject is discussed in more detail in Sections 3 and 4.

The need for independent verification

Following the progress of carbon offset policy, it becomes apparent that there is an emerging need for independent monitoring, verification and certification of carbon sequestration claims within Activities Implemented Jointly (AIJ) and domestic programmes. As reliable third party verification is a prerequisite for any kind of national, regional or global system of GHG emissions control, we feel that this type of service will boost policy initiatives in this regard. We view independent verification as being a risk management tool for all parties in this emerging field.

Each of the bilateral relationships sketched along the outer part of the triangle (Figure 1) is enhanced through the addition of independent third party evaluation. As in any trade relationship, neutral verification of the quantity and quality of goods being promised ultimately enhances the transaction flow, by alleviating performance risk.

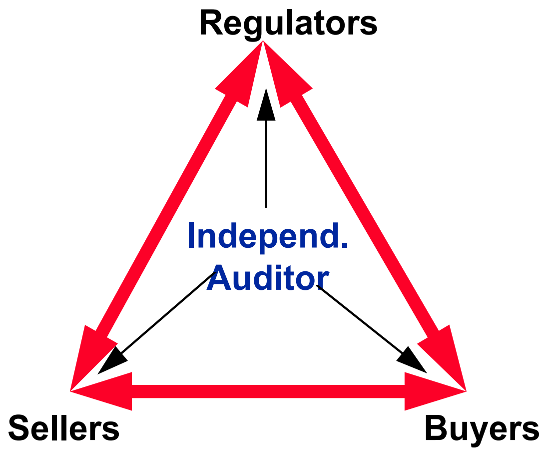


Figure 1: **Independent auditing as a trade facilitator of carbon offset transactions.**

Demonstrability

The credibility of a particular project -- as opposed to the credibility of the implementing agency -- is largely tied to the projects capacity to demonstrate its GHG-related results.

Demonstrability is, in part, a function of simplicity. If a project is so complex that it is incomprehensible to anybody outside the project management, there is little chance that the review process will be positive. It is also easy to imagine projects which clearly have GHG benefits, but are accomplishing those benefits in such a loose manner so as to be incalculable.

Finally, the project concept must allow GHG benefits to be estimated within a tolerable level of uncertainty. The degree of that tolerance is dependent upon the needs of individual participants or regulators.

2) Monitoring and verification guidelines

2.1 Terminology

It is important to define terminology, and define the roles and attributions of internal monitoring, external verification and the role of independent third party verification:

- **Internal monitoring programs**, established by projects to measure and analyse data according to the requirement of regulatory bodies

- **External verification** carried out by regulators to check on project's activities and achievements

- **Third Party monitoring services -** may be provided to projects, to assist in establishment of an internal monitoring programme of data collection and analysis.

- **Third Party auditing and verification services -** plays a wider role:

  - assists regulators in verification of compliance;

  - provides credibility to the project in the eyes of regulators, investors, sponsors and public perception;

  - provides assurance to investors and sponsors, that the project has been implemented according to the original proposal, and that it is meeting the targets set.

2.2 Internal Monitoring Program

What to measure *(Tables 1 and 2, and Section 4)*
- carbon pools
- carbon flows
- determination of significance of pools and flows
- separate measurements should be conducted for project and project baseline, to define the project's incremental carbon flows, or offsets.

How to measure *(Table 3 and Section 5)*
- methods of data collection and analysis
- lab methods
- conversion factors
- defaults

When to measure *(Section 5)*
- timing of measurements
- frequency of measurements, according to:
  - growth rates
  - associated errors
  - costs

Changes at landscape level

- changes in large areas, positive or negative
- satellite imagery
- GIS

Precision of measurements *(Section 5)*

- sampling intensity
- accuracy, SEs
- related to costs
- minimum requirements

What to claim/report

- incremental effect of the project, based on the difference between project and project baseline carbon flows (Section 6)
- maximum error or discount errors

Table 1: What to measure - carbon pools

<table>
<tr><td colspan="2">Trees
• above ground
  • stems
  • crowns
• below ground</td><td colspan="2">Other vegetation
• above ground
  • stems
  • crowns
• below ground</td><td colspan="2">Necromass
• fine litter
• coarse litter/ debris
• dead trees</td></tr>
<tr><td colspan="3">Soil
• organic carbon
• mineral carbon</td><td colspan="3">Wood products
• logs
• small wood
• NTFP</td></tr>
</table>

Table 2: What to measure - carbon flows

Trees	**Other vegetation**	**Necromass**
: tree growth : recruitment – mortality – harvesting – thinnings/pruning	: growth – weeding – thinnings	: litter fall : thinnings/prun. : tree death – decay, humidif. – removals

Soil	**Wood products**
: incorporation of organic matter – erosion (ongoing and event related)	: harvesting/thinnings : removals – decay rate – conversion rates

Table 3: How to measure - data collection methods

Trees	**Other vegetation**	**Necromass**
• PSPs, random stratified design • allometric equations for root/crowns • conversion factors for dry biomass and C • defaults, expansion factors	• stratified random samples • destructive harvesting	• PSPs or random sampling • destructive harvesting

Soil	**Wood products**
• composite samples • 0-30-50 cm • bulk density • loss on ignition	• records of timber harvested, conversion rates, final utilisation of wood products

2.2 External Verification

What to request - policy

Before any programme for internal monitoring and external verification is initiated, it is important that the regulatory body have a well defined policy establishing the regulations and requirements ruling carbon offset projects. Internal monitoring programs will aim at providing regulatory bodies the data required at the right level of precision and detail, and external verification is carried out by the regulator to check for compliance. Some of the main issues include:

- what types of projects are acceptable (Section 3)
- what pools need to be measured
- at what level of precision, which defines the frequency and intensity of measurements
- how to treat SEs
- what is the acceptable minimum time frame of a project
- how to deal with post-project effects, i.e. wood decomposition, fate of the forest area, etc. (Section 6, and discussion on carbon leasing in "Methods for quantification of offsets" in Moura-Costa 1996a)
- how to deal with leakage and slippage
- "ownership of emissions" in relation to wood products.

How to verify

Indirect methods	Direct methods
• office based • records, forms and reports • GIS and data bases • remote sensing	• emphasis on field work and field inspections • audits of companies and forests, to compare data provided with internal records, field books and data collection plots • possibly, subcontracting of specialised companies

When to verify/certify

- initial verification will focus on data provided in project proposal, analysing assumptions, accuracy of calculations, and comparing to regional defaults. Currently, most GHG regulatory bodies only conduct this initial analysis in order to approve or reject projects.

- on-going verification will certify real achievements.

3) Types of forestry-based carbon offset projects

Carbon fixation through forestry is mainly a function of the amount of biomass and soil carbon in a given area. Therefore, any activity or management practice that changes the amount of biomass in an area has an effect on its capacity to store or sequester carbon.

Forest management practices can be used to reduce the accumulation of greenhouse gases in the atmosphere through two different approaches. One is by actively increasing the amount or rate of accumulation of carbon in a given area (i.e., sink creation or enhancement). The second is by preventing or reducing the rate of release of carbon already fixed in an existing carbon pool.

3.1 Forestry approaches for promoting carbon accumulation

The most obvious approach to promote carbon fixation is by planting trees. Although carbon sequestration is often discussed in the context of the establishment of new forests, carbon fixation can also be achieved by improving the growth rates of existing forests. A variety of possibilities can be listed:

- *afforestation, reforestation, forest rehabilitation* - considering that most carbon in a forest is stored in tree stems, any activity that involves tree planting results in carbon fixation during tree growth;

- *enrichment planting* - the underplanting of existing degraded forest with long-lived trees is a promising approach for sink enhancement. This was the approach of one of the first carbon offset projects in the world, the Innoprise-Face Foundation Project in Sabah, Malaysia (Moura Costa *et al.* 1993, 1994a and b);

- *agroforestry* - in areas where land use is primarily allocated to agriculture or grazing, the introduction of agroforestry practices could be a good way to promote carbon sequestration (Dixon *et al.* 1993b). The introduction of trees in agricultural or pasture lands often has a series of beneficial effects such as crop diversification, risk reduction, better use of existing resources, erosion control, water catchment protection and fire-wood production (Lamprecht 1989);

- *silvicultural treatments* such as thinning, liberation treatments, weeding or fertilisation can greatly increase the growth rates of the forest stand (e.g. Korsgaard 1992, de Graaf 1986), improving their rate of carbon fixation. For estimates on the effects on carbon sequestration of a series of management practices and silvicultural treatments in temperate forests see the study by Hoen and Solberg (1994);

- *soil amelioration practices* - since most of the soil carbon is in the form of organic matter, management practices that promote an increase in soil organic matter can have a positive carbon sequestration effect (Dixon *et al.* 1994a, Johnson 1992, Lugo and Brown 1993).

The effectiveness and feasibility of carbon sequestration through forestry varies widely depending on a variety of factors such as:

- *Species* - The choice of species has direct implications on its potential for carbon sequestration. Fast growing species accumulate higher amounts of biomass than slow growers during the same time period. However, their wood density tends to be lower, and therefore contains less carbon than slow growing hardwood trees. Due to this difference in growth rates, wood quality and growth requirements, different species require different management systems and have different end uses. These factors are directly linked to the rate of carbon accumulation of the forest.

- *The growth cycle or length of the rotation* determines how long carbon will be stored in standing trees. Slow growing trees retain carbon for a long time during one growth cycle, while repeated cycles of fast growing trees are required to maintain levels of stored carbon for an equivalent length of time. For this reason, it is particularly important to consider the post-harvest management of the forest: whether it will be replanted, managed for natural regeneration, or converted to other land uses.

- *The final use of the timber* defines for how long carbon will remain stored in the form of wood products. Construction materials and furniture potentially retain carbon for a long period (Elliot 1985); carbon in paper or fire-wood have a shorter post-harvest life (Dewar 1990).

3.2 Forestry approaches for preventing or reducing release of carbon

The most obvious option for preventing the release of carbon fixed in vegetation is the direct conservation of forests. A large proportion of land under forest cover is threatened with conversion into other forms of land use which have lower value as carbon sinks (Dixon *et al.* 1994b). Some of the main pressures are conversion to agriculture and pasture, logging operations, and urbanisation (World Resources Institute 1990). Conservation of forests plays a double role in relation to carbon sinks. Firstly, it prevents the emission of carbon which would be caused by decomposition of the forest biomass. It has been estimated that deforestation contributes to 30% of the current global CO_2 emissions (Houghton *et al.* 1992). Secondly, conservation prevents the reduction in areas with potential for active carbon sequestration. There are many positive effects of using conservation as a means to preserve carbon pools, such as maintenance of unique ecosystems and wildlife, and protection of biodiversity. It also allows a further income from recreation and the ecotourism industry. It is estimated that conservation can promote a substantial increase in the global carbon pools (Brown et al. 1995).

Activities that reduce the rates of carbon emissions include:

- *reduction in rates of deforestation* - considering the current high deforestation rates world wide, any scheme or program that effectively reduces this rate has a positive effect on reducing the ongoing rates of GHG emissions. This is one of the main approaches utilised by the Costa Rican Joint Implementation Office programme (Tattenbach 1996);

- *introduction of techniques for controlled logging* - It is estimated that 15 million hectares of tropical forests are logged yearly throughout the world (Singh 1993), and the majority of logging operations in tropical countries are considered unsustainable and damaging (Poore 1989). The implementation of techniques for reducing the impact of logging, thus avoiding unnecessary destruction of biomass and release of carbon, has great potential (Pinard and Putz 1995; Putz and Pinard 1993; Moura-Costa and Tay 1996). Further reductions in damage (and therefore C emissions) may be achieved if less destructive methods for timber hauling are adopted. The use of helicopters (Arentz 1992, Blakeney 1992), balloons (Dykstra 1994), or skyline systems (Bruijnzeel and Critchley 1994, Sarre 1992) have great potential for reduction of logging damage;

- *fire prevention* - in the last decade fire outbreaks destroyed millions of hectares of rainforests, and it is expected that the incidence of forest fires will tend to increase in the next decade (ITTO 1994). A combination of ground-based practices of fire prevention and control, and available remote sensing monitoring systems (Malingreau *et al.* 1989, DSE 1991) has great potential for reducing the frequency and extent of forest fires;

- *fuel switching* - may also play an important role in reducing the release of GHGs to the atmosphere. Forests can be created with the sole objective of fire-wood production, reducing the use of fossil-fuels. Because fuel switching is a fully sustainable cyclic system, it is thought to be the most promising option for carbon sequestration in the long term (Grainger 1990);

- *soil erosion control* - The introduction of any technique that prevents or reduces soil loss has impacts on carbon sinks. This includes rationalisation of the use of heavy machinery, preferential use of selective felling as opposed to clear felling harvesting systems, the adoption of slope limits for plantations or logging operations, and the implementation of erosion-control techniques. This is particularly important considering that twice as much carbon is stored in soils as in vegetation, globally (Dixon *et al.* 1994a). According to the study of Nabuurs and Mohren (1993), tropical rainforests have up to 90 t C ha^{-1} (30 % of total carbon in this eco-system) and the humus-rich soils of boreal forests can have up to 150 t C ha^{-1} (60 % of total).

Different forest management practices sequester or prevent the release of different amounts of carbon from a given area over different time frames. Table 4 provides some examples and order of magnitude of the potential of carbon sequestration of different forestry activities.

Table 4: **Estimated masses of carbon sequestered over different time periods for different forest activities in the tropics.** Positive values reflect active carbon sequestration derived from a forestry option; negative values (between brackets) represent the potential emission of carbon which was prevented from the adoption of a forestry practice. References are listed for further reading and do not necessarily reflect the source of data given in table.

Approach	**Carbon sequestration or conservation[1] (t ha^{-1} during the time frame given)**	**Time frame (years)**	**References**
Plantations of fast growing species	100 - 200	10 - 20	Freedman *et al.* (1992) Dixon *et al.* (1991)
Enrichment planting with hardwoods	150 - 280	50 - 70	Moura-Costa *et al.* (1994a, b)
Agroforestry	90 - 150	20	Faeth *et al.* (1994)
Silvicultural treatments	90 - 150	30	Hoen and Solberg (1994)
Rainforest conservation (against total deforestation)	(300 - 400)	?	Faeth *et al.* (1994) IPCC (1992)
RIL[2] with tractors[3]	(35)/(80)	2/10	Putz and Pinard (1993) Pinard and Putz (1995)
RIL with helicopters[3]	(70)/(140)	2/10	-
Fuel switching to biomass fuel	(100 - 200)	10	IPCC (1992)
Fire protection	(250 - 350)	?	IPCC (1992)
Soil protection	(20 -30)	1	IPCC (1992) Faeth *et al.* (1994)
Soil improvement	1 - 2	1	Dixon *et al.* 1994a

1. *Figures derived from straight summation of carbon flow (see Richards and Stokes 1994).*
2. *RIL = Reduced impact logging techniques.*
3. *First and second carbon figures refer to volumes estimated for 2 and 10 year time frames, respectively.*

4) Carbon pools and flows

In order to quantify the carbon impacts of a forestry project, it is necessary to identify and analyse all the carbon stores (carbon pools) and their rates of change (carbon flows) during the life time of the project. The objective of the following section is to clarify what variables are important to monitor and to present guidelines for data collection and monitoring. The discussion is intended for verifying activities of forestry-based offset projects, such as plantations, agroforestry projects, natural forest management or conservation, and afforestation. The approach recommended for monitoring focuses on the stand, where carbon benefits are based on a composite of the various stands (or land uses) within the project area.

4.1 Main Carbon Pools

The carbon stores in forests that are likely to be relevant to carbon offset projects are plant biomass (trees and other vegetation, above- and below-ground), necromass (woody debris, standing dead trees, litter), and soil carbon (organic and mineral). For some projects, carbon stored in forest products (timber and/or non timber products), and energy resources are also likely to be relevant. Project monitoring efforts should focus on changes in the carbon stores that are directly related to project activities, but changes in all potentially important carbon pools need to be evaluated for their significance and vulnerability to change.

4.1.1 Biomass - trees and other vegetation

In a forest, carbon is found in plant biomass, both above and below-ground, in woody tissues, bark, leaves, and fruits and flowers. Carbon is also found in animals (macro- and micro-organisms) but the relative importance in terms of mass is generally small in forests. Carbon content varies for different plant tissues, usually within the range of 35-65% carbon. In a forest, because woody tissues dominate in terms of biomass, often the carbon content of wood (about 50%, IPCC 1995) is applied to the entire biomass pool.

Above-ground biomass is largely determined by the volume of stem wood occupying a site, although wood density is also important. Generally, as trees get larger, the relative proportion of their biomass in the stem rather than in the crown and root biomass increases. In uneven-aged stands, much of the biomass may be in the few very large trees. In many tree species the bark contains an insignificant proportion of the total tree carbon. In non-forested, terrestrial environments, shrubs and herbs may provide the only biomass and the below-ground component may be as significant as the above-ground.

Below-ground biomass (i.e., woody roots, fine roots, rhizomes, soil fauna) can represent between 10-60% of the total biomass on a site. Typically, spatial variability is high, both horizontally and with depth. But even with the heterogeneous distribution, the ratios between above- and below-ground biomass that have been published for forests fall within a fairly narrow range. Fine root production and turnover rates may be high but probably do not contribute to a large change in carbon stored. Fine root mass increases after clearing or harvests and generally is thought to reach an asymptote within 10 yrs after disturbance. Alternately, coarse root biomass will gradually and continuously increase with stand maturation.

4.1.2 Necromass and Soil Carbon

Necromass includes all of the pools of dead plant material on the forest floor and above, and generally includes soil carbon. In forests, aboveground necromass includes coarse woody debris (i.e., fallen logs, branches, stumps), standing dead trees, small woody debris, and leaf litter. Below-ground necromass includes dead roots, buried stems and branches, and other plant residues in varying stages of decomposition, and soil organic matter and inorganic carbon.

It is useful to divide the necromass pool into components based on decomposition rates. Aboveground necromass divisions are generally defined by size but these divisions are correlated with persistence. Soil organic matter also can be divided into fractions based on the rate of decomposition (Coleman et al. 1989). The labile constituents are more likely to be affected by forestry activities than are the stable organic fraction and the inorganic or mineral fractions.

The relative importance of the carbon in necromass for total forest carbon is likely to be positively associated with the maturity of the stand. For projects involving preservation of mature forest or natural forest management, the necromass pool is likely to be significant. For plantations, a fluctuation in levels of necromass is observed, depending on the timing of the thinnings, prunings and removals of fuel wood.

4.1.3 Forest Products

For projects that involve harvesting, and the conversion of trees felled at the end of rotations or as part of thinnings to wood products, carbon stored in the wood products may constitute an important carbon pool. This will be particularly true if the lifetime of the wood products exceeds the rotation length, allowing a successive build-up of carbon storage. Generally, the lifetime of wood products is poorly known. Products from thinnings or harvests where the wood is converted to veneer or paper or packaging would have a much shorter lifetime, maybe in the order of 5 yrs (Dewar & Cannell 1992). An assumption used for products from temperate forests is that wood product lifetimes equal rotation lengths (Thompson & Mathews 1989).

In some mills, waste wood is used as an energy source and thus replaces alternatives such as fossil fuels. The carbon saved related to the fuel replacement may represent another significant carbon pool for a project. In this case it is necessary to analyse the energy content of biomass and its equivalence in terms of the fuels replaced.

4.2 Main Carbon Flows

The primary aim of a monitoring program is to estimate carbon gains and losses from the system defined by the project. This can be done by measuring the pools at intervals and calculating net change or it can be done by directly measuring transfers between pools or carbon flows. In many forest projects, the parameters that are likely to be relevant to carbon flows include the following rates:

- tree growth or biomass accumulation;
- plant recruitment;

- plant mortality;
- litterfall;
- necromass decay;
- harvest, thinnings and any removals from the forest;
- conversion to wood products.

Other variables that may be important when soil conservation is an important component of the project are soil erosion and transfers of carbon between soil organic matter fractions.

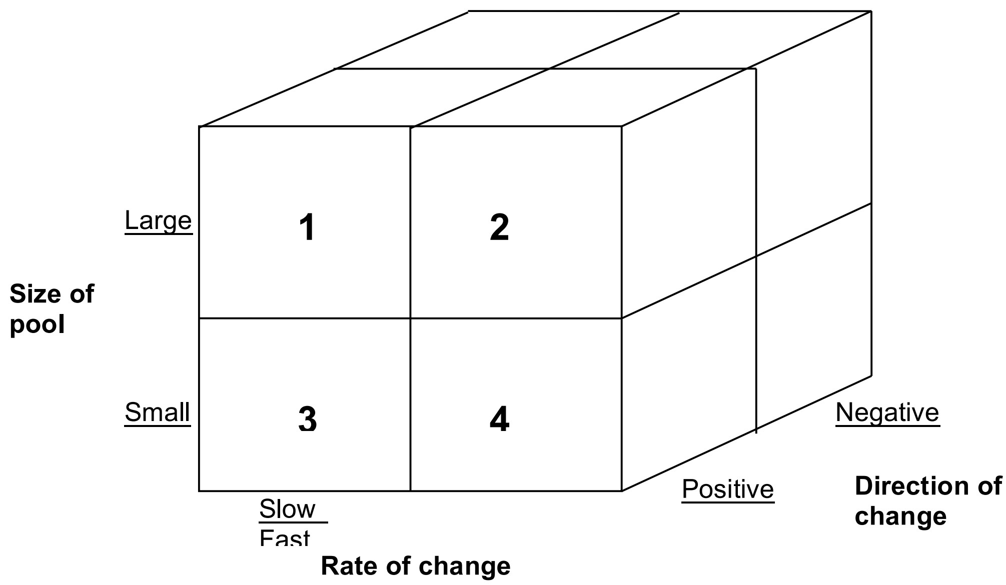
4.3 Significance of Carbon Pools

Part of the project development process involves defining which of the carbon pools are significant and which are likely to change. The significance of a pool may be defined by its relative size and speed of change. For example, in a forest preservation project, the carbon stored in the trees may represent 70-80% of the total carbon stored on site, and consequently is a relatively significant pool. Leaf litter contains only 1% of the carbon contained in the trees, therefore, does not represent a significant pool in terms of relative size. Changes in pools that are directly attributed to project activities should be the focus of the monitoring program but changes in all pools need to be evaluated for their relative significance to the project's carbon balance.

It may be useful to rank the carbon pools according to their significance (relative size), vulnerability (rate of change), and direction of change (positive or negative; Figure 1). Pools that are relatively large, and that are likely to change rapidly are very important to monitor (square 2). However, pools that are relatively small and unlikely to change are not so important to monitor (square 3). For pools that are potentially important (e.g., large pools that change slowly or small pools that change rapidly, squares 1 and 4), it will be important to determine the direction of change. A monitoring program should adopt a conservative approach when deciding upon which pools to monitor. Only pools that are monitored should be considered as part of the carbon sequestration benefit. Some small pools may not justify the expense required to acquire reasonably reliable estimates of carbon contents (e.g., fine roots or fine litter).

Figure 1. A matrix for identifying the carbon pools that are important to monitor in forestry carbon offset projects. Pools that are important to monitor, or not important to monitor, can be identified based on their significance (size of pool) and vulnerability (rate of change). Pools that are possibly important to monitor, based on significance and vulnerability, can be further evaluated based on the anticipated direction of change in the carbon pool. If, based on credible evidence, the pool is expected to gain carbon over time (+), monitoring would be considered discretionary. If the pool is

expected to lose carbon over time (-), monitoring is important (Figure adapted from Hamburg *et al.* 1996).



5) Data collection and analysis

This section provides a general overview of methods of data collection for carbon offset projects. It is not meant to be an extensive instructions guide. For detailed information on carbon inventory methods, please refer to A Guide to Monitoring Carbon Sequestration in Forestry and Agroforestry Projects (Winrock 1996) or the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1995).

5.1 Biomass and Necromass

The most common approach to monitoring the carbon sequestration benefits associated with a forestry project is through permanent sampling plots, in which biomass and necromass are measured at regular intervals. Specific methodologies exist for measuring the distinct pools and flows but the general approach of permanently identifying plots, trees, or sites and re-measuring specific variables associated with these plots, trees, or sites will often be appropriate. The advantage of permanent plots over random samples is that the relevant variables (e.g., diameter, biomass, soil organic matter content), and changes in these variables between time *i* and time *i+1*, can be estimated with more precision. The frequency at which measurements are repeated should reflect the rate of change in the variables being measured. It is not worth re-measuring trees too frequently because the error is often as great or greater than the diameter increment.

Standard protocols used for the establishment of forest growth and yield plots are applicable to monitoring carbon in trees. Plots are located in a stratified random design with the strata defined to incorporate the range of variability that exists within the site. In each plot, trees above a minimum dbh are tagged and identified. At intervals of 2-5 years, the diameter at breast height (1.3 m, hereafter dbh) is measured, as is height. Tree deaths are recorded and any trees that have grown above the minimum are tagged and recorded. This standard methodology provides an estimate of growth (i.e., diameter and volume increment), mortality, and recruitment.

Plot data on stand structure (number of individuals per ha by diameter class) can be used to calculate stem volume or biomass using a variety of methods which vary in terms of cost, precision, and training required. Destructive harvesting for direct measurements of biomass are likely to be appropriate for mixed species shrub and herbaceous vegetation, understorey or early successional vegetation. For vegetation that is dominated by trees, the use of allometric equations applied to stand data from permanent plots is generally recommended.

Allometric equations are linear regressions that relate biomass or stem volume to one or more independent variables, usually diameter at breast height (dbh) and height (to first branch). The equations are developed from destructive sampling of 100-1000 trees and are a standard component in the development of stand volume tables used for predicting yield. Relationships between stem volume and dbh (or diameter and height) are species- and region-specific but generic equations for tropical trees by climatic region have been produced (Brown 1997) and provide average figures for species and sites that are not well known. For species with established stem volume equations, conversion from stem volume to biomass can be achieved by the application of a Biomass Expansion Factor (IPCC 1995).

Below-ground biomass, as with aboveground biomass, can be measured directly by coring of fine roots and pit sampling and excavations of coarse roots, or indirectly with allometric equations or conversion factors that estimate below-ground biomass from aboveground biomass. For the purposes of monitoring carbon offset projects in natural forest, direct sampling of coarse roots may not be cost-effective as variability in root biomass is likely to be high, sampling is time-consuming and labour intensive, and below-ground biomass is unlikely to be a major contributor to the carbon benefit. For sites and forest types where the relationship between above- and below-ground biomass has been estimated from empirical data, the use of this simple factor adjustment to convert aboveground biomass to total biomass may be a reasonable approach.

To measure necromass and monitor changes in the pool, it is useful to divide the necromass pool into components based on decomposition rates. Aboveground necromass divisions are generally divided by size but these divisions are correlated with persistence. The distribution of coarse woody debris has been found to be highly clumped and correlated with slope, consequently, a stratified random design, with strata defined by position on slope, may be a suitable design.

5.2 Soil Carbon

Soils are often large storage pools for carbon, both organic and inorganic. It is possible to effectively determine the soil carbon content by taking composite samples from multiple plots. Soil can contain two types of carbon: organic and inorganic (carbonates). Not all soils contain inorganic carbon and most changes in soil carbon due to project activities are assumed to be in organic matter, and not in inorganic carbonate.

Soil samples should be taken when the permanent plots are established in the forest. They should be taken from the 0-30 cm horizon using either a soil corer or hand-dug pits. All vegetation and litter should be cleared from the soil surface and after sampling coarse fragments should be removed using a 5 mm screen. If the site has been burned it is important to remove any charcoal from the sample because of its high carbon content.

The size of the sample will depend on the needs of the laboratory and this should be discussed thoroughly before collection. The must commonly used lab method for the quantification of soil carbon is “loss on ignition” (Anderson and Ingram 1989). The bulk density of soils is required to convert total or organic carbon concentrations (expressed as a percentage of the sample) into total quantities. Bulk density is considered to have relatively low spatial variability with coefficients of variability of less than 10%. For a uniform soil type, four samples should be sufficient to estimate bulk density to within 10% of the true value 95% of the time. It is then possible to calculate the tonnes of soil carbon per hectare for the 0-30 cm soil depth.

5.3 Forest Products

Projects that include the conversion of trees to wood products must address the fate of the carbon that leaves the project area as wood products. Given the inherent difficulty in determining the exact fate of wood products after they leave the forest or project area, a reasonable approach may be to determine the proportion of timber that is converted into different products, and use general defaults to estimate its average life time and decay rates.

In the case of the use of biomass for the replacement of other sources of fuel, it is necessary to determine how much fuel was displaced by combining the energy potential of the different fuels and the amount of biomass utilised.

5.4 Sampling Intensity and Precision of Estimates

A universally accepted level of precision for estimates of carbon benefits does not currently exist. As a general rule, the cost of a monitoring program is negatively related to the precision of the estimate of the carbon benefit. To a certain extent, the market value of carbon sequestered in offset projects will determine the level of precision that is cost-effective. We suggest that a reasonable target for the precision of a project's carbon benefit is a standard error of the mean of 20-30% of the mean. In certain cases, a cheaper solution to increasing the level of accuracy of measurements is to adjust the carbon claims discounting the standard error of measurements.

In developing an internal monitoring program for an individual project, it is unlikely that a common level of precision will be desired for each of the significant pools and flows. For example, there is little cause to be very precise in a small flow if the large flow can't be estimated with similar level of precision.

Sample size determination, based on a desired precision in the estimate, is described in standard statistical method books such as Zar (1984), Steel and Torrie (1960), or Winrock (1996).

6) Determination of carbon offsets and typical curves

As discussed in the previous sections, the GHG effect of a project is the difference between the carbon flows generated by the implementation of the project and the assumed carbon flows that are likely to take place in the same site in the absence of the project.

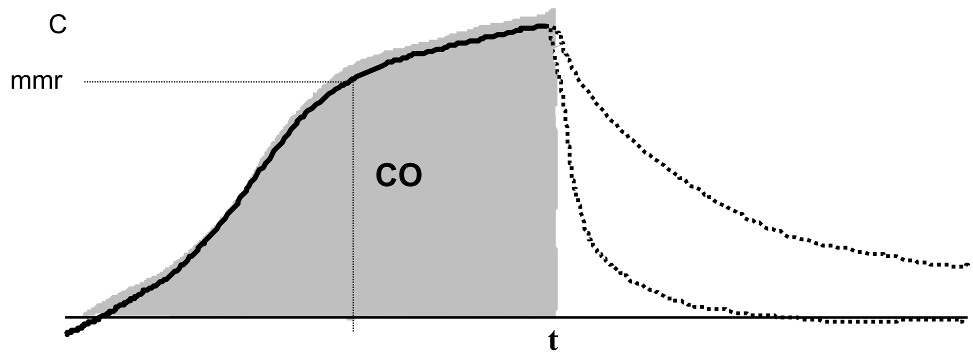
Quantification of offsets, therefore, involves the following steps:

- estimation of baseline carbon flows;
- quantification of carbon flows generated by the project;
- calculation of the difference between the two, to find out the incremental effect of project.

In this section these concepts are discussed in relation to different forestry practices. The exact shape of the curves depend on technical parameters such as growth rates and biomass accumulation of a particular combination of site and species, and will not be discussed here.

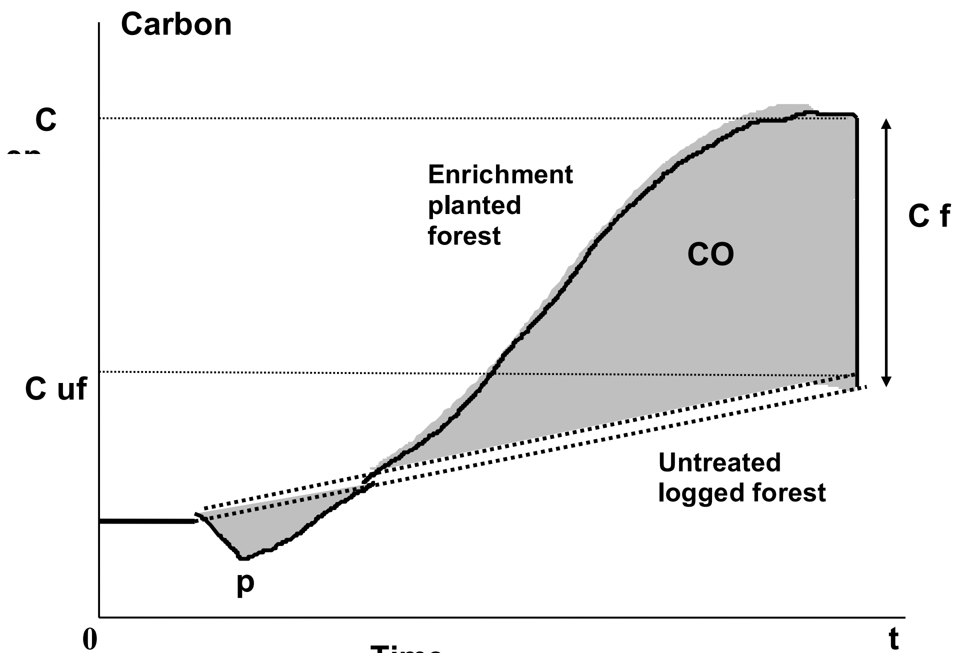
The model of carbon sequestration for plantations and afforestation is given in Figure 2. Carbon fixed (**Cf**) until a given point in time (**t**) can be directly calculated by multiplying the biomass of planted trees by a conversion factor, which depends on the wood density of the species planted. If the baseline for the project is a clear field (with low or negligible amounts of carbon), than the amount of carbon offset is illustrated by the shaded area **CO**. If the existing carbon pool in the site is considered significant, then the carbon emissions incurred during site clearing must be computed. It is also necessary to look at what happens to the planted forest after the end of the growth cycle, determining the slope of the post-harvest decay rates of the different wood products harvested. These are typically fast in the case of pulp and paper production (**p**, Fig.2) and slower in the case of conversion to furniture (**f** in Fig.2). Alternatively, a different carbon profile would take place if the trees are not harvested (**nh** in Fig.2).

Figure 2: CO_2 offset by plantation forestry and post-harvest decomposition curves for pulp (p), furniture (f), or non-harvested options (nh).



In the case of enrichment planting (Fig.3), the offset (**CO**) is the difference between the carbon accumulated in the planted forest (**C ep**) and the carbon in the untreated forest (the baseline, **C uf**). A reduction in carbon is observed during site preparation, when planting lines are cleared of vegetation, but this is compensated by the higher biomass increment of planted trees as compared to the untreated logged forest. **Silvicultural treatments** would have a similar trend of increasing biomass of a site compared to untreated. **Cf** = Carbon fixed at the end of the project cycle, **p** = time of planting

Figure 3: Carbon offset by enrichment planting



Carbon offset by the use of reduced-impact logging (RIL) techniques (**Fig.4**), can be quantified as the difference between carbon stored in a forest logged conventionally (the baseline) and one logged according to RIL guidelines at some point in the post-logging (**t**). Immediately following logging no difference should exist between carbon stored in the two forests, if equivalent volumes of timber are removed from the two sites. However, more vegetation is damaged, and subsequently dies, in conventional logging. Therefore, as the logging debris decomposes, the carbon stored in a conventionally logged forest will decrease more quickly and to a lower level than will a forest logged with minimal damage to the residual stand. In addition, approximately 10 years following logging (**t1**), the logged forests should become sinks for carbon and the residual stand in a RIL forest will be healthier, consist of more higher density woods and will therefore sequester more carbon per ha than will a conventionally logged forest. These advantages are even greater in the case of less destructive aerial hauling methods are used.

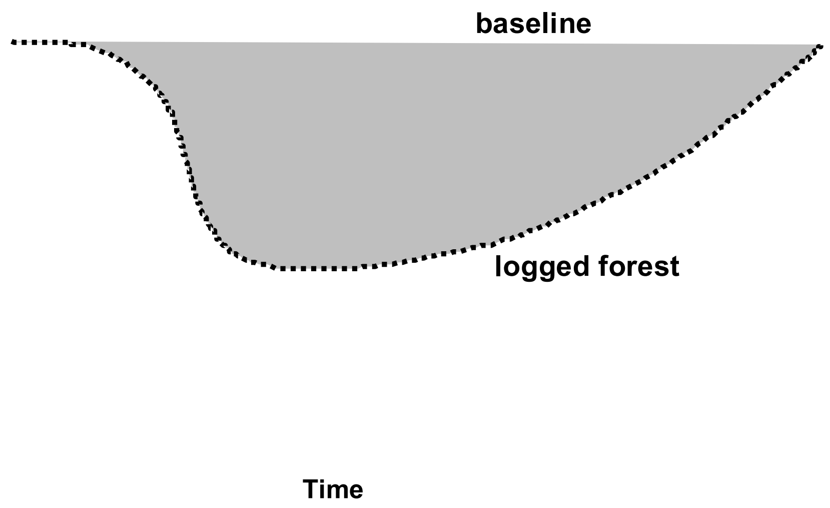
CO

Conventionally logged forest

Figure 4: Carbon offset by the use of reduced-impact logging (RIL) techniques.
C pf = Carbon stored in the primary forest

Carbon offset by **forest conservation** can be quantified as the difference between the carbon stored in the existing forest and the potential reduction caused by logging (Fig.5). In this case no net carbon sequestration occurs; the offset is based on avoided emissions that would happen if the forest was logged.

Figure 5: Carbon offset by conservation of an area originally designated to be logged
CO = Carbon offset



Although soil was not mentioned in these examples, it is implicit that the use of good soil management techniques would improve the capacity of carbon sequestration of any forestry practice chosen.

Carbon fixed or carbon leased ?

Because carbon offset is becoming an activity of increasing importance, there is a need to develop acceptable means of quantification of the sequestration capacity of different projects. Different methods are used by different authors, making it difficult to allow comparison between mitigation options. Furthermore, some of the methods currently in use are over-simplistic and do not fully account for the sequestration capacity of mitigation activities. Therefore, there is a need to describe and discuss the validity of the different methods in use, and suggest alternatives that can improve the deficiencies of such methods.

Determination of the amount of carbon stored in a site at a point in time is based on summing the amount of carbon in biomass, necromass and soil. Repeated measurements are carried out to determine how the carbon pools change through time to calculate the sequestration potential of a particular forest type or management system.

Debate has arisen over how to quantify a carbon offset over a period of time. Different methods have been proposed. The most common is based on the amount of carbon fixed in biomass at a certain point in time, usually the end of a rotation period. This will be called "carbon fixed" and it can be exemplified as the amount of carbon stored in planted trees at a certain time **t** after planting (Fig. 3). Many estimates for carbon sequestration found in the existing scientific literature use this concept (*e.g.,* Putz and Pinard 1993; Freedman et al. 1992; van Kooten et al. 1992). Using this procedure, quantification of carbon sequestration over time is done by measuring trees on a frequent basis, calculating their growth increment, and calculating the amount of carbon fixed during that period.

One limitation of this approach is that it does not fully account for the cumulative sequestration over time. For example, a possible offset approach could involve postponing the release of carbon stored in plant biomass to the atmosphere. In forestry terms this might involve the adoption of longer rotation periods, or delaying the inevitable post-harvest decomposition of timber products. On purely commercial grounds, harvest would take place as soon as the point of maximum marginal return of carbon accumulation is achieved (**mmr** in Fig 2). Since this often does not coincide with the maximum carbon "storage" capacity of the tree stand, a postponed harvest generates an offset. Furthermore, determination of the amount of carbon fixed at the end of the project cycle assumes a condition of stability, *i.e*. that a given forest area will continue to store carbon at the maximum level in perpetuity. In reality, however, forests are kept for a finite period. In this situation, the slope of the post-harvest decomposition rate would determine the carbon sequestration efficiency of the forest type analysed, *i.e.* low in the case of pulp and paper production (**p**, Fig.2) or high in the case of conversion to furniture (**f** in Fig.2). Similarly, if the trees are not harvested, there must be a time-dimension for the remuneration of this foregone benefit (**nh** in Fig.2).

An alternative approach for quantification is to use the concept of "carbon leasing". The quantification of carbon leasing is slightly different, because the time factor is brought in, and the unit used should be Mg C ha^{-1} $year^{-1}$, instead of Mg C ha^{-1}. While for carbon fixed only the incremental carbon fixed during a certain period of time is accounted (**y** in Fig. 3), in the case of leasing, the cumulative amount of carbon sequestered is leased at each period, as shown by the grey area in Figure 3.

An advantage of the concept of carbon leasing is that it allows carbon sequestration to be treated as a service that can be stopped at any time, therefore requiring less long-term guarantees between the contracting parties. This is important since governments are often reluctant to make commitments for an indefinite future. An example would be to halt the logging of a given area for a certain period of time, "leasing" the forest in this area as a repository of carbon, without any assumption that this forest will not be logged after the period agreed. Another advantage is that this concept allows the comparison of forestry options with different time frames.

A comparison of the amounts of carbon fixed versus carbon leased for the same area suggests that one unit of carbon leased should be worth much less than one unit of carbon fixed: one is a permanent asset while the other represents a service rate.

Methods for calculating the costs of carbon fixation of different projects

The use of different methods of carbon quantification creates difficulty in comparing projects. Among the approaches suggested, the most simplistic is called the *flow summation method* (Richards and Stokes 1994) and is based on the direct division of the total cost of the project by the amount of carbon fixed at a point in time. Its main weakness is that it does not takes into consideration time, both for quantification and for remuneration of carbon sequestration. Furthermore, it provides a "snap shot" of the carbon fixed at a certain point in time, and therefore the values derived from this method vary depending on the often arbitrary decision of when to quantify.

To reward projects that promote carbon fixation over a shorter period of time, the *discounting method* has been suggested (Richards and Stokes 1994). It consists of discounting the incremental carbon fixed on a yearly basis using a social discount rate (about 5% per year). Then the present value of the project's costs is divided by the discounted carbon figure. This approach, however, tends to bias towards activities which prevent the release of carbon, such as conservation or reduced impact logging, instead of activities which actively remove carbon from the atmosphere over a longer period (*e.g.,* forest establishment). This is because conservation activities internalise large amounts of carbon at the beginning of the project cycle, therefore suffering less from the effects of discounting. There remains the question of whether or not to use discounting techniques for environmental issues, as questioned by Price and Willis (1993).

An alternative non-time-biased approach is the leasing concept. It consists of dividing the costs by the total amount of carbon leased during a project's life. Carbon lease can be calculated by using the integral of the of the carbon fixation curve for the project (for example, the shaded areas in Figures 2, 3, 4, and 5). A similar approach called the *average storage method* has been used (Dixon et al. 1991 and 1993a). It consists of dividing the project's costs by the sum of the total carbon sequestered in an area on a yearly basis, averaged over one full rotation.

Finite environmental services versus long term consequences

As mentioned before, forests only actively sequester CO_2 during the growing phase, after which carbon is stored in trees for as long as they are kept as living trees or as forest products (timber, paper, etc.). The decomposition of forest products eventually releases the carbon back to the atmosphere. However, this may occur decades, or even centuries, after the forests were initially established. However limited, this period during which carbon is retained in plant biomass could play a very important role in reducing the overall concentration of greenhouse gases (GHGs) in the atmosphere. For this reason, even though carbon offset through forestry does not provide a solution for eternity, it can be seen as an important interim environmental service of atmospheric cleansing while alternative sources of energy that do not entail CO_2 release are developed.

The following theoretical example illustrates this concept. Figure 2 shows the accumulation of carbon fixed by trees planted in an area which was initially bare. Assume that at the end of the growth cycle, this forest was burned, immediately releasing the whole amount of carbon fixed in planted trees. Therefore the amount of carbon fixed at the end of this exercise is the same as the beginning, *i.e.* zero. At first impression, one might assume that it was not worth planting trees at all. However, during the period of time **t** a total amount of carbon dioxide **C** was kept out of circulation, reducing the total concentration of GHGs in the atmosphere during that period. An analogy would be the cooling effect that an air-conditioner has on its surrounding environment during the period that it is kept functioning.

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