Carbon accounting, trading and the temporary nature of carbon storage

By Pedro Moura Costa

Prepared for the Nature Conservancy

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EXECUTIVE SUMMARY

One of the main concerns related to the use of sinks as a greenhouse gas (GHG) mitigation option is the question of 'permanence', the length of time for which carbon will remain stored after having been fixed in vegetation, or the 'reversibility' of the benefits of storage. This paper analyses the various approaches proposed for dealing with the temporal nature of sequestration, and the financial implications of using them.

Various carbon accounting methods have been proposed to measure the greenhouse gas mitigation effectiveness of land use and forestry projects.

- **Stock change method** - the method most commonly used for expressing carbon storage, based on calculating the changes in carbon stocks of a project and its baseline during a given period of time, and measurements are usually expressed in $tCha^{-1}$. An inherent problem of the stock change method is that it involves frequent exchanges of credits and debts of carbon between project developers and buyers or regulatory bodies.
- **Average storage method** – created to account for the carbon benefits of dynamic systems, it consists of averaging the amount of carbon stored in a site over the long-term.
- **Ton year** - alternative approaches proposed to better address the temporal dimension of carbon storage, adopting a two-dimensional measurement unit that reflects storage and time, t C/yr.
- **Colombian proposal** - an application of the stock change method to CDM projects, although this concept could also be used with the average storage method. In essence it proposes that investors have to replace sequestration credits with 'emission reduction' credits at the end of a certain period or when the project ends, and has been referred to as the 'expiring credits' method.

Linked to the subject of accounting methods is that of timeframe for project analysis and project duration. After defining these parameters, it is possible to determine what would be the liability for possible reversals of benefits associated with projects which are conducted for periods of time shorted than required. The stock change and the Colombian proposal both adopt perpetuity as its implicit timeframe for analysis. The average storage method could be based on any defined timeframe. The ton year method is based on an equivalence timeframe…..

Once the minimum timeframe for project analysis has been defined, it is also important to decide how to treat projects that have a shorter duration than the minimum required timeframe. Two options can be listed: a) full liability – in the event of 'reversal' of GHG benefits, projects or

developers should return an amount of credits equal to the total amount of GHGs released, this is the approach implicitly used by the stock change method, which consists of projects receiving credits as carbon is fixed, and having to return or replace credits if stocks of carbon diminish; and b) proportional liability - projects should be debited an amount of credits proportional to the difference between the minimum required timeframe and the actual project duration (the "period of non-compliance'), this method is only applicable if a finite minimum project duration is adopted.

Academic discussions on the subject of carbon accounting often get mixed up with assumptions on the arrangements for project financing or commercialization of credits. While environmental benefits accrue depending on when a unit of carbon is removed from the atmosphere and the duration of carbon storage (factors determined according to carbon accounting methodologies), financial transactions can occur at any point in time, before, during or after the project lifetime. Various types of commercial arrangements can be used for transacting carbon, such as 'advance sales of streams of carbon credits", 'pay-on-delivery', futures contracts, call or put options, etc.

A comparison of the GHG benefits attributed to two forestry-based projects was carried out. For the example of an afforestation project, the *stock change method*, would generate 140 t C/ha for the project during the sequestration phase of each growth rotation, but the project would need to return an equivalent amount after each harvest. In the case of the *Colombian proposal*, the project would need to either replace the credits earned with 'permanent' emission reductions or with new sequestration credits at the end of the project timeframe. The *average storage* calculated for the duration of this project is 84 t C/ha, that is reached before the end of the first rotation and remains the same irrespective of the duration of the project. If the GHG benefits of the project are calculated using *ton-year accounting*, the GHG benefit attributed to the project would increase gradually as the project is conducted for a longer time frame. While the project will eventually reach a total amount of 83 t C/ha, this will only be accrued over a much longer time frame than if using the other accounting methods. Because it is assumed that the ton-year equivalence factor reflects the GHG benefit to the atmosphere derived from temporary storage, however, no loss of benefits is assumed when emissions take place. Similar results are observed for a forest conservation project.

A financial analysis was also conducted to estimate the financial impacts of using different carbon accounting methods, assuming a carbon price of U$ 10/t C, a discount rate of 10% a.a, no change in real carbon price throughout the period of analysis (54 years), and that carbon sales only occur in the year that carbon is fixed in vegetation. According to the results, the *stock change method* presents the best financial results of the four methods, providing a net present value (NPV) of U$ 674/ha for the afforestation project. This is because this method accounts for all carbon stored in a site at the time that it is fixed in vegetation (or conserved), and the liability for replacing future re-emissions are sent to the end of the project lifetime. If the *average storage* method was used, the project's NPV would be reduced to U$ 493/ha, because the method makes a 'provision' for the re-emission of carbon stocks in the future, reducing early cashflows. If the *ton-year method* is used, the NPV goes down to U$ 110/ha, because the method only credits a small fraction of the carbon stock every year (based on the assumed decay of an equivalent amount of emissions from the atmosphere).

The results above can also be expressed in terms of the price of a tonne of carbon credits accounted by different methods, and the price of a tonne of 'permanent' emission reductions ? If certain carbon accounting methods have an inherent liability attached to them, these have to be taken into consideration and the price of these credits adjusted in relation to the price of permanent credits. Assuming that permanent emission reductions generate carbon credits at U$ 10/tC, credits from sinks projects accounted using the stock change or the average storage should be worth only U$

9.88 and U$ 9.90/tC, respectively. This is because the project developer will have to set aside a certain cash amount invested for the whole period of the project, in order to buy credits at the time that it needs to replace them (i.e., in the case of this example, 54 years after initial planting, when re-emissions are expected). Of course, the shorter the project duration, the lower the value of the sinks credits in relation to the value of permanent emission reduction credits. By deferring to the future the replacement of credits, the developer is in fact reducing the value of its liability, and this serves as an incentive for the long term maintenance of the carbon stocks created by the project. In the case of credits accounted through ton year methods, they should have the same U$ 10/tC value, since this method does not attribute any liability for carbon re-emissions.

As illustrated by the results of this simulation, the stock change requirement of replacement of carbon credits at the end of a project does not appear to create an untenable financial burden to project developers. At the same time, the method provides project developers with the flexibility to run projects for whatever timeframe as they may chose, with no negative effect on the environment. Since the full amount of carbon released will need to be offset by new credits, the changes in land use that may occur will not negatively affect the environment. Given its political acceptance, simplicity, flexibility and relatively low impact on the financial feasibility of projects, the stock change method (or the Colombian proposal) may be the most appropriate accounting methods to be adopted for forestry-based carbon offset projects. Its adoption could remove some of the uncertainties related to the use of sinks, and accelerate their acceptance in the Kyoto process and the international carbon market.

*Note on units of measure: The common unit of measure used throughout this analysis is tons of carbon or tC. To convert to tons of carbon dioxide or $tC0_2$ multiply by 44/12 or 3.667.

Carbon Accounting, Trading and the Temporary Nature of Carbon Storage

Pedro Moura Costa

1. INTRODUCTION

One of the main concerns related to the use of sinks as a greenhouse gas (GHG) mitigation option is the question of 'permanence', the length of time for which carbon will remain stored after having been fixed in vegetation. In reality, the concern is about lack of permanence, or 'reversibility' of the benefits of storage, as a result of the possible loss of carbon stocks created or conserved by a project, whether on purpose or as a result of undesirable events (e.g., natural disasters). Permanence is the main technical issue which differentiates forestry-based GHG mitigation projects from emission reduction projects.

The possible reversibility of carbon stocks, however, does not need to be seen as an insurmountable obstacle to the use of sinks as a GHG mitigation option. Carbon accounting methodologies have been devised especially for sinks projects, taking into account the technical differences in relation to emission reduction projects based on other mitigation activities. The treatment of permanence, therefore, influences and is influenced by the choice of carbon accounting methodologies, the timeframes chosen for carbon accounting, and the approach chosen for dealing with liabilities (i.e., the need to return or replace carbon credits if carbon is released to the atmosphere).

A series of papers was written during the last years dealing with these issues, including a section in the IPCC Special Report on Land Use, Land Use Change and Forestry (IPCC 2000), outlining various carbon accounting methods and their implications on dealing with permanence issues. While this report was meant to assist decision making in the context of the Climate Change convention, it is still unclear what carbon accounting method will be used for land use, land use change and forestry (LULUCF) projects under the Clean Development Mechanism (CDM) of the Kyoto Protocol. Decisions regarding accounting framework, timeframes and liability are critical to ensuring climate integrity and credibility of LULUCF projects, as well as their economic viability.

The choice of accounting methods also affects the flexibility of project developers in relation to long term land use choices. It is desirable that the method chosen does not limit the choices of the project developer and does not require that land is locked into a single land use forever. This is particularly important as many governments may not desire to commit large tracts of land to any particularly land use, and some have seen this as an 'impingement on national sovereignty'.

Another relevant question is whether the issue of permanence only relates to sink activities (i.e., those leading to the removal of carbon from the atmosphere), or whether this is also a concern to forest conservation projects. To date, most conservation projects have aimed at maintaining carbon stocks 'safe' for long periods of time and, indeed, most of the critics of forest conservation seem concerned with the maintenance of carbon stocks in perpetuity. If forest conservation projects were treated in the same way as fossil fuel emission reduction projects, however, any delay in emissions would be accounted for as having had a perpetual, irreversible effect. This discrepancy in the treatment of projects has been pointed out by some authors who suggest that the delay, rather than avoidance, of emissions from deforestation have an important effect in atmospheric systems (Fearnside et al., 2000). This paper does not suggest that this argument is right or wrong, but adopts the assumption that conservation projects need to maintain carbon stocks for long timeframes.

This paper describes the main carbon accounting methods proposed in the past, the issues of timeframes and liabilities, and their implications on carbon crediting for forestry projects.

2. CARBON ACCOUNTING METHODS

Various approaches have been used to measure the greenhouse gas mitigation effectiveness of land use and forestry projects. Some are based on absolute measurements at a point in time, while others take into account the time dimension of carbon sequestration and storage. These methods are discussed below and a comparison of results using different methods is given in Section 5.

The discussion throughout this paper will refer to two theoretical forestry-based GHG mitigation projects, as follows:

1) Project 1: a forest plantation run for three rotations of 18 years each, in a total of 54 years. It is assumed that at the end of each rotation the carbon stock in the forest reaches 140 t C/ha, that harvesting reduces carbon stocks to zero, and that the baseline is zero. At the end of the 54^{th} year, the project is discontinued and the carbon stocks reverse to zero.
2) Project 2: a forest conservation project, avoiding the release of 140 t C/ha that would have been released over a period of 18 years. The project will put in place measures to protect this forest in perpetuity, but a period of 54 years was adopted for the quantification analyses.

In the case of the plantation project, analyses were conducted assuming one single stand, in order to better illustrate the effects of the different carbon accounting methods. A carbon management strategy for plantation forests, however, would aim at creating a forest with even distribution of age classes, so that the reduction of carbon stocks generated by the harvest of one stand would be compensated by the growth taking place in other stands.

2.1 Stock change method and the 'Colombian proposal'

The method most commonly used for expressing carbon storage is based on calculating the changes in carbon stocks of a project and its baseline during a given period of time (either the duration of the project, in the case of CDM projects, or the period 2008-2012, for JI projects). This method is referred to as the *stock change method* (previously referred to as the *flow summation method*), and measurements are usually expressed in $tCha^{-1}$. It provides projects with credits as carbon is fixed (or emissions are avoided), and credits are returned when carbon is released back to the atmosphere, irrespective of the period of storage. In effect, in environmental terms the stock change method produces a 'zero-sum game' in which projects may need to return all credits earned if, for example, afforested lands are converted back to non-forest land use. For the afforestation project illustrated in Figure 1, credits will be earned during the growth phases, and returned when these forests are harvested in years 18, 36 and 54. This relates to a single forest stand. If a project involves the staggered planting of stands on a yearly basis, reaching an even age-class distribution, the debits from harvesting single stands is compensated by the credits earned in the other stands. For the forest protection project shown in Figure 2, credits are earned during the period in which it would have been lost in the absence of the project (initial 18 years), and kept by the project developer (or the investor) unless these carbon stocks are released to the atmosphere at some point in the future.

Stock change is the method currently adopted for carbon accounting in Annex 1 countries (IPCC 2000), given that it is consistent with the methods used for national GHG accounting (IPCC 1996). In the context of Annex 1 countries, if forestry activities are maintained forever (e.g., through harvests followed by replanting), project developers will not have to return the credits earned during the establishment phase of the forest. In the context of CDM, however, such forestry activities may be treated as 'projects' with limited timeframes, creating an inevitable liability at the end of the project. Depending on the extent of this liability, this could invalidate projects. This inconsistency suggests that different carbon accounting systems may be needed for projects in the CDM.

The Colombian proposal is essentially an application of the stock change method to CDM projects, although this concept could also be used with the average storage method. In essence it proposes that investors have to replace sequestration credits with 'emission reduction' credits at the end of a certain period or when the project ends, and has been referred to as the 'expiring credits' method (Artusio 2001; Marland et al. 2001). More recently, it has been proposed that projects should also be able to replace sequestration credits with new sequestration credits, even through an extension of the project. In this paper, we used the stock change method as the carbon accounting method to evaluate the Colombian proposal concept.

2.2 The average storage method

An inherent problem of the stock change method is that it involves frequent exchanges of credits and debts of carbon between project developers and buyers or regulatory bodies. This is particularly so in the case of dynamic systems, e.g., afforestation projects, in which planting, harvesting and replanting operations take place. In order to account for the carbon benefits of such systems, an alternative approach has been used (e.g., Dixon *et al.,* 1991; Masera, 1995) called the *average storage method* (Schroeder, 1992). This method consists of averaging the amount of carbon stored in a site over the long-term according to the following equation:

$$Average\ net\ carbon\ storage\ (tC) = \frac{\sum_{t=}^{t=n}(carbon\ stored\ in\ project - carbon\ stored\ in\ baseline), in\, tC}{n\ (years)}$$

where t is time, n is the project time frame (years), and measurements are expressed in $tC.ha^{-1}$. According to this method, the project receives credits as carbon is fixed, until it reaches the average storage calculated for the whole project timeframe. As long as the project is developed according to its original plan, there is no need to return carbon credits when carbon stocks reduce below the average, as in the case of commercial harvests (see Figure 1). In the case of conservation projects, the calculated average storage tends to equal the actual amount of carbon stored (Figure 2), so this method is not commonly used for this type of project.

The advantage of this method is that it simplifies the process of credit allocation, while still accounting for the dynamics of carbon storage over the whole project duration, not only at the times chosen for accounting. However, a weakness of this method relates to the still subjective time frame, *n*, chosen for running the analysis. In the case of Figure 1, e.g., the average net carbon storage would be equal whether the calculation was performed for one, two, or infinite rotations, as long as the denominator chosen for equation above coincided with the last year of a rotation. There is a need for determining a fixed denominator based on a stipulated period of project duration.

2.3 Ton year approaches

Alternative approaches have been proposed to better address the temporal dimension of carbon storage. Most of these are based on adopting a two-dimensional measurement unit that reflects storage and time, i.e., the ton-C year. The concept of a ton-year unit has been proposed by many authors (Moura-Costa, 1996; Fearnside, 1997; Chomitz, 1998; Tipper and de Jong, 1998; Moura-Costa and Wilson, 2000; Fearnside et al., 2000). The general concept of the ton-year approach is in the application of a factor to convert the climatic effect of temporal carbon storage to an equivalent amount of avoided emissions (this factor is referred to as the *equivalence factor*, E_f, and varies from 0.007 to 0.02) (Dobes *et al*., 1999; Tipper and de Jong, 1998; Moura-Costa and Wilson, 2000). This factor is derived from the "*equivalence time*" concept (referred to as *Te*), i.e., the length of time that CO_2 must be stored as carbon in biomass or soil for it to prevent the cumulative radiative forcing effect exerted by a similar amount of CO_2 during its residence in the atmosphere (Moura-Costa and Wilson, 2000). Different applications have been proposed for the equivalence factor (Moura-Costa and Wilson, 2000) but in this paper only the straight ton-year yearly crediting method will be used for analyses. Figures 1 and 2 illustrate the effects of ton-year accounting on crediting for the same forestry projects.

If an *equivalence factor* ton-year approach is used, carbon storage could be credited according to the time frame over which storage takes place. Such a crediting system would reduce the need for long-term guarantees and hence the risks associated with long time frames. The main disadvantage of this method is that, depending on the manner in which ton-year accounting is used, it may delay the disbursement of credits to project developers, discouraging the implementation of forestry-based GHG mitigation projects. Other applications of the ton-year method, which address this point, are discussed in Moura-Costa and Wilson (2000). One of them is to credit projects using the stock change method and the ton-year method to calculate the "loss" of benefits when emission take place.

3. PROJECT DURATION

Linked to the subject of accounting methods is that of timeframe for project analysis and project duration. After defining these parameters, it is possible to determine what would be the liability for possible reversals of benefits associated with projects which are conducted for periods of time shorted than required.

3.1 What timeframe should be used for project analysis?

A requirement of the Kyoto Protocol is that projects must result in “real, measurable and long-term benefits related to the mitigation of climate change”. The definition of “long-term”, however, varies substantially, and there is no consensus regarding how it relates to a minimum timeframe for project duration.

During the Activities Implemented Jointly (AIJ) Pilot Phase, projects have been conducted for a variety of timeframes, from 20 years (e.g., the Protected Areas Project in Costa Rica, Trines, 1998) to 99 years (e.g., the Face Foundation’s projects, Verweij and Emmer, 1998). Most projects state that their GHG benefits are expected to be maintained beyond the project timeframe (see list of AIJ projects in UNFCCC website) although their contractual arrangements are finite. This lack of definition has caused uncertainty to all parties involved, from regulatory bodies to project developers and investors.

There is a need, therefore, to agree on what timeframe should be used as the basis for quantification of the GHG benefits of a project. Different timeframes or approaches have been proposed:

a) Perpetuity - the environmental benefits of projects have to be maintained forever. This argument is based on the assumption that the “reversal” of GHG benefits of a project at any point in time would totally invalidate a project (Maclaren, 1999), and that only maintenance of carbon stocks in perpetuity could counter the environmental effects of GHG emissions from fossil fuel sources.

b) 100 years – the GHG benefits of a project have to be maintained for a period of 100 years to be consistent with the Kyoto Protocol’s adoption of the IPCC’s GWPs (Article 5.3) and of a 100-year reference timeframe (Addendum to the Protocol, Decision 2/CP.3, para. 3) for calculation of the Absolute Global Warming Potential (AGWP) for CO_2. While this concept has limitations, it has been adopted for use in the Kyoto Protocol to account for total emissions of the greenhouse gases on a CO_2-equivalent basis.

c) Equivalence based - the GHG benefits of land use projects have to be maintained until they counteract the effect of an equivalent amount of GHGs emitted to the atmosphere, estimated based on the cumulative radiative forcing effect of a pulse emission of CO_2 during its residence in the atmosphere (its AGWP; IPCC, 1992). Variations of this concept have been developed, proposing minimum timeframes of 55 years (Moura-Costa and Wilson, 2000) or 100 years (Fearnside et al., 2000). If the ton-year method is to be used, this equivalence timeframe must be defined.

d) Variable - acknowledging that different projects may have different operational timeframes. Given the wide range of timeframes of projects carried out to, it can be implied that this has been the approach adopted during the AIJ Pilot Phase.

The stock change and the Colombian proposal both adopt perpetuity as its implicit timeframe for analysis. The average storage method could be based on any defined timeframe. If this method is to be used, however, it is important that a standard timeframe is defined to be used for the analysis of al projects, in order to avoid the problems raised in Section 2. The ton year method is based on an equivalence timeframe, as determined in option (c) above.

The adoption of a standard definition of the minimum required timeframe for project duration would greatly facilitate consistency in accounting for GHG benefits of different projects. It would also reduce the uncertainty of all parties involved in project development (project developers, investors, certifiers, regulatory bodies, and the general public).

3.2 How should projects with shorter timeframes be treated?

Once the minimum timeframe for project analysis has been defined, it is also important to decide how to treat projects that have a shorter duration than the minimum required timeframe. Two options can be listed:

a) Full liability **–** in the event of 'reversal' of GHG benefits, projects or developers should return an amount of credits equal to the total amount of GHGs released. This is the approach implicitly used by the stock change method, which consists of projects receiving credits as carbon is fixed, and having to return or replace credits if stocks of carbon diminish.

b) Proportional liability - projects should be debited an amount of credits proportional to the difference between the minimum required timeframe and the actual project duration (the "period of non-compliance'). This method is only applicable if a finite minimum project duration is adopted, as could be the case if the average storage method were chosen for carbon accounting. If, for instance, a minimum timeframe of 100 years is adopted, a plantation project which is harvested without replanting at 60 years (assuming that all carbon is released to the atmosphere), would be liable for not maintaining carbon stocks for the last 40 years of the required timeframe.

The ton-year approach does not lead to any environmental liability, given that credits are only earned after they fulfill their environmental 'role' (countering the effect of an equivalent amount of emissions), similarly to the reduction of emissions from fossil fuel sources.

Irrespective of the method used for quantifying the extent of liabilities (as discussed above), it is also important that projects aim to prevent liabilities from accruing, and/or prepare themselves to face these liabilities as and when they occur. A series of methods for preventing liabilities exist, such as portfolio diversification, external or internal insurances (such as the creation of an internal 'buffer reserves') or the maintenance of cash reserves. Sections 5 and 6 below deal with the inevitable replacement of credits required by some carbon accounting methods, and assume that a cash reserve will need to be kept in order to replace credits when required.

3.3 For how long do projects have to be run?

Depending on the regulatory choices of carbon accounting method, timeframe for analysis and liabilities, project developers can make their choices in relation to the actual duration of their forestry projects.

- In the case of the ton-year method, it doesn't require projects to be run for any determined period of time, allowing forestry activities to be discontinued at any time.

- If a minimum timeframe is adopted for use with the average storage method, a developer has the choice to interrupt the project at any given time, claiming only the amount of credits relative to the duration of the project;

- In the case of the stock change method, while perpetuity is the implicit timeframe for analysis, it can also be implied that this is not necessarily the timeframe for project duration. In fact, the stock change provides projects with the flexibility to run for whatever timeframe they chose, given that at any point in time a reversal of carbon benefits will have to be fully compensated for with a replacement of credits.

This flexibility helps to counter some of the criticism of the requirement for perpetual projects, which include: 1) it is impossible to guarantee that a project will be run in perpetuity; 2) maintenance of projects in perpetuity may create conflicts with other land uses in the long term; 3) because of the decay pattern of GHGs in the atmosphere, there may be no need for mitigation effects to be perpetual.

4. COMMERCIALIZING CARBON CREDITS

Academic discussions on the subject of carbon accounting often get mixed up with assumptions on the arrangements for project financing or commercialization of credits. It is important, however, to distinguish between these two issues.

The objective of "carbon accounting" is to determine the environmental (i.e. atmospheric) value of GHG mitigation projects. Given that LULUCF projects are based on both the amount of carbon stored or sequestered (i.e., taken out of the atmosphere) and the duration of storage, accounting systems try to reflect the temporal nature of this type of project (as opposed to emission reduction projects, where accounting is based only on the amount of carbon emissions avoided), as discussed in Sections 2 and 3 above.

While environmental benefits accrue depending on when a unit of carbon is removed from the atmosphere and the duration of carbon storage, financial transactions can occur at any point in time, before, during or after the project lifetime. In order to maintain the environmental integrity of the carbon trading system, however, it must be ensured that:

- Only after carbon has been fixed (or its emission avoided) credits can be used for the purposes of compensating for emissions taking place elsewhere, never before.

- If financial transactions take place before the full environmental benefit of the carbon credits is accomplished there must be contractual obligations to ensure that storage will take place for a sufficient period of time, or determining responsibility for the liability associated with storage periods shorter than contracted.

Depending on regulatory requirements and market preferences, a variety of options exist for commercializing carbon credits of sinks projects:

- Advance sales of "streams of carbon credits" – to date, most projects have been developed in partnership with parties interested in the rights to the carbon credits that the project will generate during its lifetime, effectively assuming the position of "equity investors" in the carbon component of the project. In many cases, such payments occur at the onset of the project, to be used for project establishment. Only the credits actually generated may be used for the purposes of compliance to emission reduction targets.

- 'On delivery' – Buyers may only be interested in acquiring credits for which carbon has already been fixed in vegetation (or its emissions avoided). Indeed, this has been the market preference in the recent years. In this case, there must be an associated contractual arrangement establishing an obligation to store this amount of carbon for an agreed timeframe and/or allocating a liability for the emissions associated with its release before the end of the established project duration. In this case, a policy decision has to be made to determine how to calculate the magnitude of this liability, as discussed in Section 3.2 above.

- Futures contracts, call or put options (options to buy or sell), are types of derivatives that are already being sold by specialized environmental brokers, enabling project developers to sell credits before they are actually generated. Similarly to the sale of 'carbon streams', for the purposes of compliance to emission reduction targets buyers will only be able to use credits after they are fixed, and associated contractual arrangements for allocation of liability have to be in place.

5. COMPARISON OF METHODS

Table 1 shows a comparison of the GHG benefits attributed to the two forestry-based GHG mitigation projects described in Section 2 above. In the case of the 'Colombian proposal', it was assumed that the credits would 'expire' at the end of 54 years (at the end of the projects described in Section 2), when they will need to be replaced.

It is clear from these examples that depending on the accounting method used different amounts of carbon benefits accrue to the project, as is shown by the following results:

1. According to the ***stock change method***, the forest plantation project (Figure 1) would receive 140 t C/ha during the sequestration phase of each rotation, and would need to return an equivalent amount after each harvest. In the case of the conservation project (Figure 2), the developer would receive a total of 140 tC by year 18, and keep them forever, unless an inadvertent loss of carbon stocks happened. In this case, the project would loose an amount of credits equivalent to the reduction in carbon stock.

2. In the case of the ***Colombian proposal***, the projects would need to either replace the credits earned with 'permanent' emission reductions or with new sequestration credits (which could come from an extension of the project), at the end of the 54-year timeframe.

3. The ***average storage*** calculated for the duration of the plantation project is 84 t C/ha, that is reached before the end of the first rotation and remains the same irrespective of the duration of the project. If a set timeframe is adopted for the calculation of the average storage (i.e., with a pre-determined denominator in the average storage equation), the GHG benefits of a project would increase proportionally to the time frame under which the project is conducted. For instance, if a minimum project duration of 100 years was required, and the project was run for 54 years, the average storage of this project would be only 45 t C/ha. In the case of the conservation project, the average storage of 125 tC/ha would be reached in year 17, at which time the developer would stop receiving credits.

4. If the GHG benefits of the project are calculated using ***ton-year accounting***, the GHG benefit attributed to the project would increase gradually as the project is conducted for a longer time frame. Because it is assumed that the ton-year equivalence factor reflects the GHG benefit to the atmosphere derived from temporary storage, no loss of benefits is assumed when emissions take place.

Table 1. Comparison of GHG benefits (t C/ha) attributed to two forestry projects at different points in time, according to different carbon accounting methodologies. Positive values denote GHG benefits (crediting), and negative values denote "reversal" of benefits (removal of credits). Project 1 is an afforestation project conducted for three rotations of 18 years each. It is assumed that at the end of each rotation, the carbon stock in the forest reaches 140 t C/ha, and that harvesting reduces carbon stocks to zero. For simplicity, it also assumed that the baseline is zero. Project 2 is based on the conservation of forests with a stock of 140 tC/ha, which would be lost in 18 years in the absence of the project. The values reflect the amount of credits accumulated until the year shown, since the previous point in time.

Method	Year 18	Year 18 after harvest[b]	Year 54	Year 54 after harvest/credit replacement	Balance
Project 1: Forest plantations					
Stock change/Colombian proposal	140	-140	140	-140	0
Average storage	84	0	0	0	84
Ton-year crediting[a]	28	28	83	83	83
Project 2: Forest conservation					
Stock change	140	na	140	na	140
Colombian proposal	140	na	140	-140	0
Average storage	125	na	125	na	125
Ton-year crediting[a]	24	na	123	na	123

a. The parameters used for calculation of ton-years are: Time for equivalence of 55 years ($Te = 55$) and Equivalence factor (E_f) = 0.0182; **b.** Harvests only in the case of Project 1; **na** = not applicable

The financial results associated with these projects will also be affected depending on the carbon accounting method adopted. An estimate of carbon gains was calculated for these projects using the following assumptions:

- Discount rate of 10% a.a;
- Today's carbon price of U$ 10/tC;
- No change in real carbon price throughout the 54 years;
- Sales only occur in the year that carbon is fixed in vegetation.

The present value of sales was calculated discounting the incremental carbon stream on a yearly basis. The results are shown in Table 2, and discussed below. For Project 1, for both the stock change and the average storage cases, it was assumed that the project will only have to replace the credits 're-emitted' at the end of the 54 years, when it will stop replanting its forests after the last harvest ("liabilities at the end" approach). In the case of the stock change method, it was also calculated the effect of having to replace credits at every harvesting year ("ongoing liabilities" approach). In the case of Project 1, at every harvest the developer will have to return 140 t C/ha, and then be allowed to claim any carbon that is again fixed in the site. In the case of Project 2, two scenarios were assumed: a) that no liability would accrue to the project if at the end of the 54 years the carbon stock was still intact (the 'standard' stock change method); and b) that the carbon stocks at the end of the year 54 would have to be replaced with new credits (either 'permanent', new sequestration credits, or an extension of the project), as suggested in the Colombian proposal.

Table 2. Comparison of financial results (U$/ha) attributed to two forestry projects at different points in time, according to different carbon accounting methodologies, for the projects described in Table 1.

Method	PV of sales	PV of liability at yr 55	NPV
Project 1: Plantations			
Stock change with liability at the end (Colombian proposal)	682	8.1	674
Stock change with ongoing liabilities	827	305	522
Average storage	498	4.8	493
Ton-year crediting	110	0	110
Project 2: Conservation			
Stock change with no liability	637	0	637
Colombian proposal (Stock change with liability at the end)	637	8.1	629
Average storage	624	4.8	619
Ton-year crediting	126	0	126

PV = present value; NPV = net present value.

According to these results, the stock change method presents the best financial results of the three methods. This is because this method accounts for all carbon stored in a site at the time that it is fixed in vegetation (or conserved), unlike the other two methods. In the case of the average storage, the method makes a 'provision' for the re-emission of carbon stocks in the future, and the ton-year method only credits a small fraction of the carbon stock every year (based on the assumed decay of an equivalent amount of emissions from the atmosphere).

While the stock change method does not value the temporal nature of carbon, it is interesting to notice that it is the temporal value of money that makes this method feasible. By deferring to the future the replacement of credits, the developer is in fact reducing the value of its liability. Indeed it provides an incentive to keep postponing even further the end of the project. These results are based on the assumption that the project developer will have to set aside a certain cash amount, invested at the same interest rate (i.e. 10%) for the whole period of the project, in order to buy credits at the time that it needs to replace them. Alternatively, the developer may buy carbon credits from another developer, to be delivered at a future point in the time (in this case 54 years). In this case, the value of these 'future credits' needs to be much discounted, and if the same discount rate of 10% is used, this developer will pay approximately U$0.06/tC today for credits to be delivered in 54 years from now.

It is interesting to note that the plantations project shows slightly higher values than the conservation project, even though the total amounts conserved/fixed are the same. This is because of the growth pattern of the forest, which follows a sigmoid curve, while the conservation pattern was assumed to be linear. If the average storage method is used, however, the conservation projects scores much higher, given that it does not involve any reduction of carbon stocks from harvests.

This analysis assumes that the real price of carbon will remain the same throughout the period of the analysis. These results could substantially change if supply and demand forces alter carbon prices in the future.

6. EFFECTS ON VALUE OF CARBON CREDITS

What should be the price of carbon credits generated by sinks projects compared to the price of 'permanent' emission reductions ? If certain carbon accounting methods have an inherent liability attached to them, these have to be taken into consideration and the price of these credits adjusted in relation to the price of permanent credits. Table 3 shows the results of this analysis.

Table 3. Comparison of the relative value of carbon credits (U$/tC) depending on the different carbon accounting methodologies adopted, assuming that the replacement value of carbon credits (i.e. 'permanent' emission reductions) is U$ 10/tC. Figures calculated using example from the Plantations Project 1.

Source of credit or carbon accounting method used for sink credits	Price before adjustments	PV of liability at yr 55	Adjusted price
Permanent emission reductions	10	0.00	10.00
Stock change with liability at the end (Colombian proposal)	10	0.12	9.88
Stock change with ongoing liabilities	10	3.69	6.31
Average storage	10	0.10	9.90

Ton-year crediting	10	0.00	10.00

7. BUT, ARE FORESTRY PROJECTS MORE EXPENSIVE?

A different way to analyze the value of acquiring carbon through emission reductions or sinks, is to estimate the net present value (NPV) of the carbon credit streams generated by projects that deliver a similar amount of carbon. Table 4 shows a comparison between the LULUCF projects described above and an emission reductions project that delivers 7.777 tC per year for 18 years (in a total of 140 t C during the period). Using the same assumptions of carbon price and discount rate, Table 4 shows that the net present value of the carbon credit stream generated by the emission reductions project is U$ 638. If we use the current carbon price of U$ 10,00 for both projects, it can be seen that the value the carbon stream generated by the plantations project can be higher than that of the emission reductions project, even taking into account the liability issues. This is because of the schedule of disbursement of credits of a plantation project, which is based on the delivery of a higher amount of carbon credits in the initial years, reducing at the end of a rotation (see Figure1) while the energy project used for the comparison is based on the delivery of similar amounts of carbon credits every year. This 'front loading' of credits generated by forestry projects may benefit them in relation to other mitigation options, even with all the liability issues associated with permanence. Undoubtedly, the rate of accumulation of credits is an important component of these comparisons, and if changed would affect the results described here.

The forest conservation project, on the other hand, if accounted using the stock change method, shows the same value as of the emission reduction project. This is because, for the example used, they are effectively the same in terms of the delivery of emission reductions. If the Colombian proposal method is used, it reduces this value slightly, given that the project will need to replace the 'expiring credits' at the end of the 54-year period.

Table 4. Comparison of the net present value of different projects depending on the different carbon accounting methodologies adopted, assuming that the value of carbon credits is U$ 10/tC.

Source of credit or carbon accounting method used for sink credits	NPV of the project (U$)	Tons of C generated for use (tC)
Permanent emission reduction	638	140
Project 1: Plantations		
Stock change with liability at the end (Colombian proposal)	674	140
Stock change with ongoing liabilities	522	140
Average storage	493	84
Ton-year crediting	110	83
Project 2: Conservation		
Stock change with no liability at the end	638	140
Colombian proposal (Stock change with liability at the end)	630	140
Average storage	619	126
Ton-year crediting	126	123

8. CONCLUSIONS

Much discussion has surrounded the topic of a choice of carbon accounting method for forestry projects. It has often been assumed that methods that require replacement of carbon credits at the end of a project's lifetime would render such projects unfeasible. The comparison of the financial impacts of different carbon accounting methods provides us with interesting results, however. Given the long term nature of forestry projects, the effects of discounting 'erode' the financial burden of having to replace carbon credits at a future point in time, making some of these methods less unattractive than initially expected.

This is clearly true in the case of the stock change method, or Colombian proposal. Depending on the proposed duration of the project, the impact of this credit replacement could be reasonably low, e.g., about 1% of the value of the carbon credits at present. This would enable project developers to make a small financial provision to be able to replace these credits at the end of the project, without affecting much the financial feasibility of the project. As seen in Tables 2, 3 and 4, however, it would be beneficial if regulatory bodies took into consideration the full planned duration of a project (adopting the 'liability at the end' approach), and not the fluctuations that may take place during the development of the project, such as in the case of harvests followed by replanting (as illustrated by the 'ongoing liabilities' approach in Tables 2, 3 and 4).

In the case of conservation projects, it would be beneficial if the projects could just 'roll on' the crediting arrangements, as long as the carbon stocks are still intact, without having to replace them with emission reduction credits from energy sources. This is the concept behind the Colombian proposal, or the carbon rental concept proposed by different authors (Moura-Costa, 1996, Marland et al. 2001).

Because the present value of this liability reduces as the timing of replacement is delayed into the future, this approach provides project developers with an incentive to ensure permanence of carbon stocks for a long period of time.

At the same time, the stock change requirement of replacement of carbon credits at the end of a project, provides project developers with the flexibility to run projects for whatever timeframe as they may chose, with no negative effect on the environment. Since the full amount of carbon released will need to be offset by new credits, the changes in land use that may occur will not negatively affect the environment, while at the same time being a simpler approach than calculating the relative environmental value of projects with different durations.

Given their level of political acceptance, their simplicity, flexibility and relatively low impact on the financial feasibility of projects, the stock change method and the Colombian proposal may, after all, be the most appropriate accounting methods to be adopted for forestry-based carbon offset projects at this stage of the negotiating process. Their adoption could remove some of the uncertainties related to the use of sinks, and accelerate their acceptance in the Kyoto process and the international carbon market.

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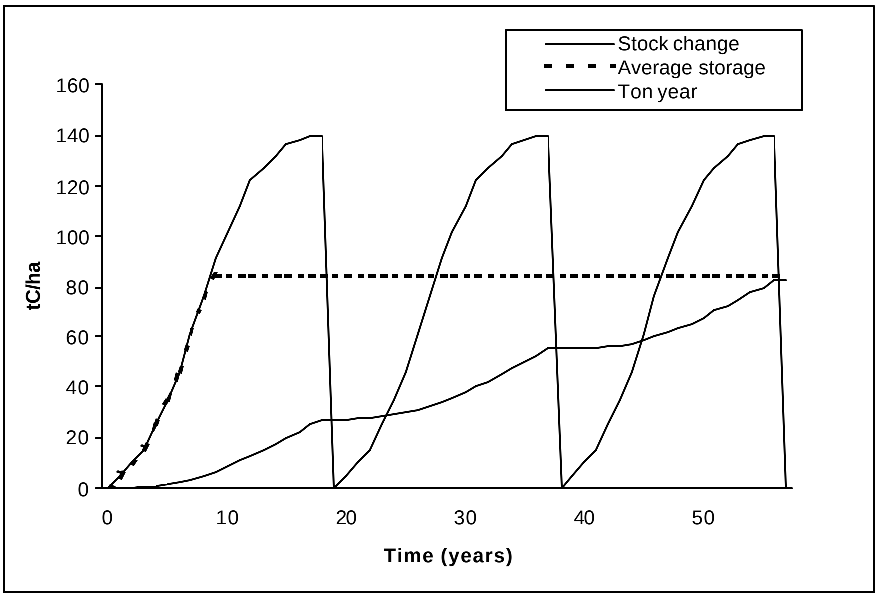
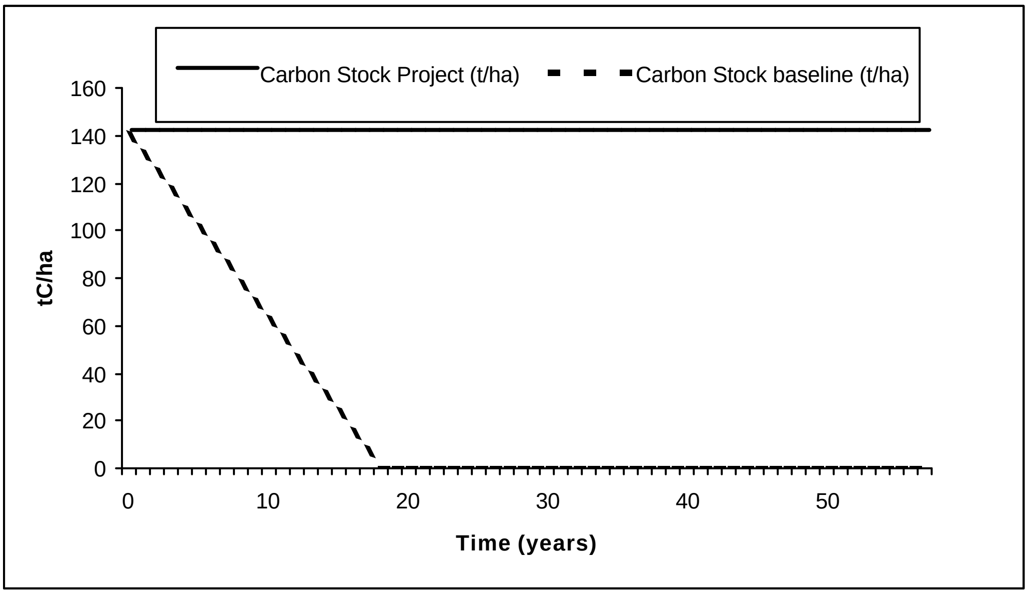


Figure 1. Projection of cumulative carbon credits generated by a plantation project over three rotations. For simplicity, it is assumed that the baseline is zero, that harvesting leads to an immediate release of all carbon stored, and that equilibrium of carbon pools is reached in the first rotation cycle. The effects of the different carbon accounting methods is shown.



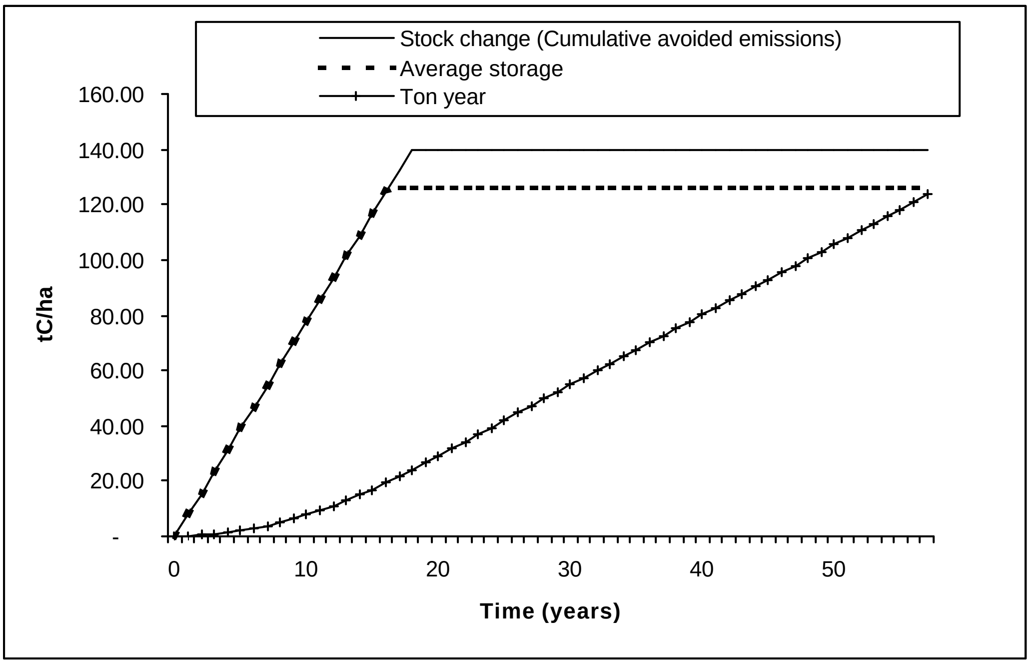


Figure 2 (a and b). Above**:** Projection of carbon stocks in a conservation project and its deforestation baseline. Below: Cumulative amount of credits earned by this project, calculated using the different carbon accounting methods.

REFERENCES

Artusio, C. 2001. *Carbon for Rent: An Analysis of Expiring Credits in the Clean Development Mechanism*. Harvard University, unpublished.

Chomitz, K. 1998. *Baselines for greenhouse gas reductions: problems, precedents, solutions*. Draft paper, Carbon Offsets Unit, World Bank.

Dobes, L., I. Enting and C. Mitchell. 1998. Accounting for carbon sinks: the problem of time. In: Dobes, L. (ed.) *Trading Greenhouse emissions: some Australian perspectives.* Occasional papers No 115. Bureau of Transport Economics, Australia.

Dixon, R.K., P.E. Schroeder and J. Winjun (eds). 1991. *Assessment of promising forest management practices and technologies for enhancing the conservation and sequestration of atmospheric carbon and their costs at the site level*. Report of the US Environmental Protection Agency No. EPA/600/3-91/067. Environmental Research Laboratory, Corvallis, Oregon.

Fearnside, P. 1997. Monitoring needs to transform Amazonian forest maintenance into a global warming-mitigation option. *Mitigation and Adaptation Strategies for Global Change* **2**: 285-302.

Fearnside, P.M., D.A. Lashof and P. Moura-Costa. 2000. Accounting for time in mitigating global warming. *Mitigation and Adaptation Strategies for Global Change* (in press).

IPCC. 1996. *Revised 1996 Guidelines for National Greenhouse Gas Inventories.* Houghton, J.T., L.G. Meira Filho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D.J. Griggs and B.A. Callander, (Eds.). IPCC/OECD/IEA.

IPCC. 1992. *Climate Change 1992: The supplementary report to the IPCC scientific assessment*. Cambridge University Press.

IPCC. 2000. *Intergovernmental Panel on Climate Change Special Report on Land Use, Land Use Change and Forestry*. Cambridge University Press.

MACLAREN, P. 1999. *CARBON ACCOUNTING METHODOLOGIES - A COMPARISON OF REAL-TIME, TONNE-YEARS, AND ONE-OFF STOCK CHANGE APPROACHES*. UNPUBLISHED MANUSCRIPT.

Marland, G., Fruit, K. and Sedjo, R. 2001. *Accounting for sequestered carbon: the question of permanence.* Resources for the Future, Washington DC.

Masera, O.R. 1995. Carbon Mitigation Scenarios for Mexican Forests: Methodological Considerations and Results. *Interciencia* **20**: 388-395.

Moura-Costa, P.H. 1996. Tropical forestry practices for carbon sequestration. In: A. Schulte and D. Schone (eds.) *Dipterocarp Forest Ecosystems - Towards sustainable management*, pp 308-334. World Scientific, Singapore.

Moura-Costa, P.H. and C. Wilson. 2000. An equivalence factor between CO_2 avoided emissions and sequestration – description and applications in forestry. *Mitigation and Adaptation Strategies for Global Change* **5**: 51-60.

Schroeder, P. 1992. Carbon storage potential of short rotation tropical tree plantations. *Forest Ecology and Management* **50**: 31-41.

Tipper, R. and B.H. de Jong. 1998. Quantification and regulation of carbon offsets from forestry: comparison of alternative methodologies, with special reference to Chiapas, Mexico. *Commonwealth Forestry Review* **77**: 219-228.

Trines, E. 1998. Assessing and monitoring carbon offset projects: the Costa Rican case. *Commonwealth Forestry Review* **77**: 214-218.

Verweij, H.J.A. and I.M. Emmer. 1998. Implementing carbon sequestration projects in two contrasting areas: the Czech Republic and Uganda. *The Commonwealth Forestry Review* **77(3):** 203-208.