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Accounting for sequestered carbon: the question of permanence

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Abstract

In its attempt to provide quantitative limits on greenhouse gas emissions, the Kyoto protocol accepts the principle that sequestration of carbon in the terrestrial biosphere can be used to offset emissions of carbon from fossil-fuel combustion. Whether or not the Kyoto protocol ever comes into force, it is worthwhile to understand how carbon sequestration might be treated in any mitigation plan that provides a tax or ration on carbon emissions. Emission credits, as proposed for the energy sector, are based on the idea that a prevented emission is prevented forever, and emission credits might be traded among parties. In the event that sequestered carbon is subsequently released to the atmosphere, it would be advantageous to agree what the liability is and who assumes that liability. We describe a system whereby emissions credits could be rented, rather than sold, when carbon is sequestered but permanence of sequestration is either not certain or not desired. Our proposal is similar to that offered by the government of Colombia except that it casts these temporary emissions credits into the traditional concepts of rental agreements and it clarifies the opportunities for secondary transactions. A rental contract for emissions credits would establish continuous responsibility for sequestered carbon; credit would be assigned when carbon is sequestered and debits would accrue when carbon is emitted. © 2001 Published by Elsevier Science Ltd.

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1. Introduction

The Kyoto protocol to the United Nations Framework Convention on Climate Change (1998) has proposed a process for establishing quantitative, enforceable limits on the emission of greenhouse gases to the Earth's atmosphere. The protocol contains negotiated commitments on greenhouse gas emissions for the period 2008 through 2012 for the 38 developed countries and countries with economies in transition (plus the European Community) listed in its Annex B.

The protocol provides further that, within prescribed rules, countries can remove the greenhouse gas carbon dioxide from the atmosphere into living plants, sequester the carbon in the terrestrial biosphere, and use the sequestered carbon to offset some of their greenhouse gas emissions from other sources. Fig. 1 illustrates the concept that if we refrain from emitting a unit of CO_2 to the atmosphere, if CO_2 emissions are collected in a bottle at the point of discharge, or if emitted CO_2 is moved a short distance through the atmosphere and then taken up in vegetation; there should be no substantial difference for the atmosphere.

The concept of emissions trading has also been included in the Kyoto protocol. An Annex B country can carry out an emissions-reduction activity in another Annex B country and use the reductions as credits against its own commitments (joint implementation, described in Article 6 of the protocol), an Annex B country can carry out an emissions-reduction activity in a non-Annex B country and use the reductions against its own commitments (the clean development mechanism (CDM), described in Article 12), or an Annex B country can simply trade emissions permits

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with another Annex B country (described in Article 17). The protocol allows emissions offsets for carbon sequestration in the biosphere as part of joint implementation, but is silent on whether or not carbon sequestration can be used as part of the CDM, i.e. whether carbon sequestration in non-Annex B (developing) countries can be used to offset emissions in Annex B (developed) countries.

The Kyoto protocol is incomplete or ambiguous in several ways that need to be resolved before it, or some subsequent international accord, could be brought into force as a functioning international agreement. Notable among the issues yet to be resolved is that the protocol prescribes emissions commitments without fully laying out either the accounting rules for measuring emissions and emissions offsets or the penalties for failure to meet commitments.

The possibility of using carbon sinks in the terrestrial biosphere to offset emissions from other sources has been criticized on several grounds that need to be considered in establishing the rules for accounting (Schlamadinger and Marland, 2000). In particular, it has been suggested that sequestering carbon in the biosphere might be different from reducing greenhouse gas emissions from fossil fuels in three fundamental ways: "If activities succeed in increasing the carbon in the biosphere, will it stay there (the permanence issue)? If activities succeed in increasing the rate of carbon accumulation in the biosphere, how long will it be possible to continue at the increased rate (the saturation issue)? If activities succeed in increasing carbon stocks in the biosphere, is it possible to accurately and precisely measure and affirm that it has been done (the verifiability issue)?" (Schlamadinger and Marland, 2000). On close examination, saturation and verification raise interesting questions, but do not seem to raise compelling questions unique to land-use change and forestry activities. The fundamental issue that is unique to sequestration projects is the one of permanence, and this is the subject of the current paper. In the simple illustration of Fig. 1, we ask what has been gained if the bottle breaks or the tree burns.

Is it appropriate to treat carbon sequestration in the biosphere as the negative of emissions to the atmosphere if we cannot guarantee that carbon once sequestered will remain sequestered? In an ideal accounting system it would be possible to treat carbon flows in and out of the biosphere similarly to flows from fossil fuels: flows toward the atmosphere would be emissions and represented with a positive sign while flows from the atmosphere would be treated symmetrically and have negative sign.

We consider possible accounting rules for carbon that is sequestered in the biosphere when the permanence of that sequestration is in doubt. In fact, we argue here that permanence of sequestration is unnecessary, that there is value in delaying emissions regardless of the long-term fate of the sequestered carbon. We propose that if emissions reductions are clearly permanent (e.g. fossil fuel is not burned), then emissions credits might be bought and sold. If emissions reductions are not clearly permanent (e.g. carbon is sequestered in a forest), then emissions credits might be rented instead. What is needed is to establish who is responsible if and when the CO_2 is released to the atmosphere. In this paper, we develop an approach for renting emissions credits and contrast this approach with the now widely discussed ton-year approach for dealing with sequestration that cannot be considered permanent. The government of Colombia Ministry of the Environment (2000) has proposed a system of expiring credits which is very similar to our approach but we broaden the ideas somewhat and cast them in more familiar economic concepts.

The Kyoto protocol has not yet been ratified by enough countries to enter into force and there is some probability that it will never enter into force in its original form. Nonetheless the protocol includes many elements that have been widely agreed to and could come into force as part of this, or some subsequent, international accord. Among these elements is trading of emissions permits where the trading partners have unequal responsibility or where one partner is unwilling or unable to accept long-term liability for managing a stored pollutant. This trading would take place in an environment where at least some parties have either a tax on emissions or a ration on emissions permits, i.e. where there is an established penalty for emissions. Rental of emissions permits provides an opportunity for reducing total emissions in this environment.

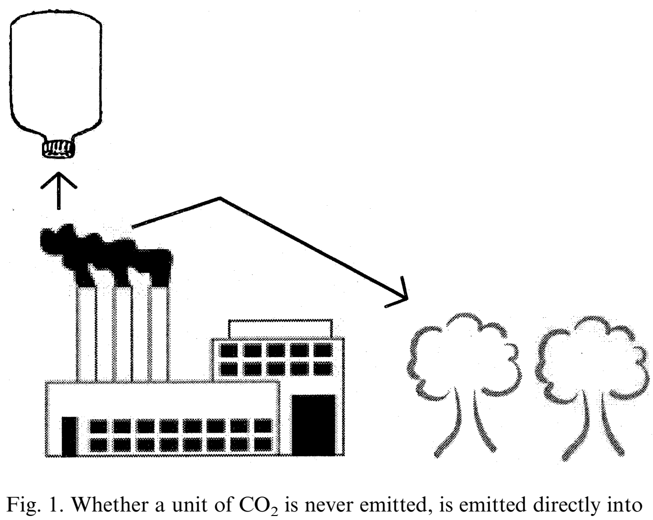

Fig. 1. Whether a unit of CO_2 is never emitted, is emitted directly into a bottle, or moves a short distance through the atmosphere before being taken up by a tree, there is no impact on the atmosphere.

2. The Kyoto context

Our basic question is whether it is appropriate to treat carbon sequestration as the negative of emissions or whether other accounting rules are necessary. Can carbon sequestration be included as a part of national commitments without compromising the objectives of the Kyoto protocol (or some successor accord)? The Kyoto protocol prescribes that net flows into or out the biosphere will be represented by the change in carbon stocks, and this simplifies the measurement and accounting somewhat (See MacLaren, 2000, for a clear discussion of measuring stocks and flows). Consistent with this, the Intergovernmental Panel on Climate Change (2000) defines sequestration as an increase in carbon stocks in some reservoir other than the atmosphere. Sequestration in a non-Annex B country would be measured against a baseline (the protocol stipulates that any CDM activity is to be measured with respect to what would have happened in its absence) and hence protection of the carbon or slowing the rate of carbon loss in a standing forest might be permitted to qualify as sequestration even if the carbon stock is not increased in absolute terms—that is, if the base case would have involved greater forest clearing and greater loss of carbon.

The accounting challenge arises partly because the Kyoto protocol does not equally count all emissions of carbon to the atmosphere or all changes in carbon stocks in the biosphere. Sequestration of carbon in an Annex B country would yield emissions credits and subsequent release of that carbon should yield corresponding emissions debits. However, since countries not listed in Annex B of the protocol do not have limits on their greenhouse gas emissions, it is possible that a project in a non-Annex B country could accrue emissions credits (called 'certified emission reductions' (CERs) in Article 12 of the protocol) during a period of carbon sequestration, but there would never be debits if the sequestered carbon was subsequently released back to the atmosphere, e.g. as the result of a fire or other disturbance, or at the end of a project. Sequestration would be used to offset emissions from an Annex B country, but there would be no guarantee of permanence for the carbon sequestered in a non-Annex B host country. In fact, one of the fundamental objections that non-Annex B countries have expressed regarding the inclusion of carbon sequestration as part of the CDM is the possibility of obligation in perpetuity, and the implications for national sovereignty.

It should be noted that the same accounting difficulties, with regard to permanence, might be encountered at the project level within Annex B countries. If a landowner sequesters carbon in forest vegetation or agricultural soil under a project contract, is it to be assumed that the landowner retains obligation in perpetuity for maintaining that carbon stock?

Other systems for emissions trading, e.g. the US system of trading sulfur emissions and the trading of CO_2 emissions from fossil-fuel combustion under the Kyoto protocol, differ in that they deal only with current year flows and do not confront the problem that decreasing emissions this year may result in increased emissions in some future year. For sulfur emissions there is no storage of sulfur with potential future release. Long-term commitment to storage is required for some other pollutants, such as radioactive wastes.

This paper addresses the design of an accounting system that accommodates the lack of permanence of sequestered carbon and yet allows inclusion of carbon sequestration projects in the CDM, within national mitigation programs, or within other carbon accounting frameworks. We believe that a system for renting emissions credits can do this. We note also that although any individual projects may be temporary, the aggregate effect of economic incentives for carbon sequestration will be to increase aggregate sequestration on a permanent basis. That is, in a world where there are incentives (payment) for carbon sequestration services we would expect more sequestration to be provided at any future time than if no payments were being made.

Related to the idea of providing incentives for delaying CO_2 emissions, ultimately, are the temporal issues of whether current emissions reductions have the same value as future emissions reductions, i.e. whether zero is the appropriate discount rate for treating emissions reductions over time or the temporary storage of carbon. Might conditions change so that emissions in the future cause more damage than the same quantity of emissions now? These temporal issues are discussed in the context of carbon sequestration by Fearnside et al. (2000), Richards (1997), Marland et al. (1997), Van Kooten et al. (1997), and Meinshausen and Hare (2000), and are not discussed further in this paper. For this paper, we assume a zero discount rate for carbon while acknowledging that any markets for trading carbon credits will adopt appropriate discount rates for the value of carbon emissions credits.

Protecting the global climate through the CDM is not the only motivation to find an accounting mechanism that encourages sequestration or protection of carbon in the forests and soils of developing countries. This inclusion could provide another incentive for activities that are generally considered desirable for other reasons: reasons such as promotion of sustainable development and protection of biodiversity, watersheds, and other environmental values (Kauppi et al., in press). The CDM was designed to provide emissions-reduction opportunities for Annex B countries but also to provide incentive for Annex B countries to promote and help finance sustainable development in non-Annex B countries.

3. Approaches that have been proposed for addressing permanence

Chomitz (2000) has suggested a useful taxonomy for approaches to deal with the issue of the permanence of carbon sequestration. He suggests that there are two primary approaches: (1) acknowledge that the sequestration is likely not permanent, assess the environmental and economic benefits of limited-term sequestration, and allot credits in proportion to the time period over which carbon is sequestered, and (2) provide reasonable assurance of indefinite sequestration. The first alternative has lead to what has been called the ton-year approach, a conceptually straightforward approach in which activities would accrue credits for each year that a ton of carbon is withheld from the atmosphere and some quantity of ton-years would be equated with a permanent ton. For the second alternative, Chomitz suggests three mechanisms for providing reasonable assurance of indefinite sequestration: (a) provide partial credits according to the perceived risk that they will be maintained for a specified time, (b) link temporary sequestration projects with obligations for later action to assure permanence of the emissions reduction, and (c) tax sequestration credits to finance research and development into emissions-saving technologies. Option 2a, providing partial credits, is essentially the creation of an insurance fund of excess credits, risk adjusted, to cover subsequent losses. Options 2b and 2c actually acknowledge the potential impermanence of sequestration but try to ensure that credits for temporary sequestration will lead to permanent emissions reductions.

The 'rental' approach suggested below is consistent with the first approach of Chomitz in that it recognizes the benefit of limited term sequestration. The rental approach differs in that it provides full credit at the time of sequestration in return for full liability if the sequestered carbon is later released. Financial markets will allot values to emissions credits according to the time over which carbon is sequestered and there is no need to define a numerical equivalence between ton-years and permanent tons.

There are a variety of reasons, both environmental and economic, that it may be advantageous for some parties to acquire temporary credits and others to provide temporary credits for carbon sequestration, even when it is understood that the sequestration is not likely to be permanent. These reasons include, but are not limited to:

1. It postpones climate change. Climate change and associated damage is lessened for every year that the carbon is sequestered.
2. It buys time for technological progress. Every year that atmospheric CO_2 is restrained provides opportunity to develop or discover alternate ways to avoid greenhouse gas emissions.
3. It buys time for capital turnover. It can be very inefficient financially to replace invested capital short of its planned lifetime.
4. It may save money for reasons not already listed. If sequestration is inexpensive and "if the marginal cost of abating industrial emissions is declining, or growing more slowly, than the discount rate, temporary sequestration may be a good bargain" (Chomitz, 2000, p. 12).
5. It allows time for learning to occur (Kolstad, 1993).
6. It may not be possible to arrange for formal insurance for perpetuity.
7. Hosts may be reluctant or unwilling to provide guarantees in perpetuity, seeing it as an unacceptable intrusion on opportunity or sovereignty.
8. And, as suggested by Chomitz (2000), some temporary sequestration may turn out to be permanent.

3.1. Ton-years

The Special Report on Land Use, Land-Use Change, and Forestry; prepared by the Intergovernmental Panel on Climate Change (2000); describes the ton-year approach for dealing with the lack of permanence of sequestered carbon. In a ton-year system, credit would be awarded for the number of tons of carbon held out of the atmosphere for a given number of years and some equivalency factor would be defined to equate a specific number of 'ton-years' with permanent sequestration.

Several approaches have been suggested for defining the equivalency factor, i.e. the number of ton-years that is to be equated with permanence (Intergovernmental Panel on Climate Change, 2000; Fearnside et al., 2000; Moura Costa and Wilson, 2000). Basically one would integrate over time the number of tons sequestered and convert this to tons of carbon emissions offset by dividing by the equivalency factor, i.e. ton-years/f = permanent tons, where f is the equivalency factor. If, for example, the equivalency factor were chosen to be 50, sequestering 1 ton of carbon for 50 years or sequestering 50 tons of carbon for 1 year would both entitle the land owner (or the purchaser of the permit) to offset 1 ton of C emissions from fossil fuels during 1 year. The accounting rules would have to establish both the equivalency factor and when, over the period of sequestration, the credit might be used (see below). Nonetheless, a ton-year accounting system recognizes that delaying the release of carbon to the atmosphere deserves some credit regardless of the long-term fate of the carbon.

Values proposed in the literature for the equivalency factor range from 42 to 150 and are based on a variety of reasoning (Table 1). Although the logic and the mathematics differ, most values are based on the princi-

Table 1
A variety of values have been suggested for the conversion rate between ton-years of carbon sequestration and permanent tons of carbon emissions reductions

Author	Ton-years equal to 1 permanent ton
Tipper and de Jong (1998)	42–50
Fearnside et al. (2000)	46
Chomitz (1998)	50
Moura Costa and Wilson (2000)	55
Bird (1997)	60
Fearnside (1997)	100
Dobes et al. (1998)	150

ple that carbon storage should have the same net effect on climate as does reducing carbon emissions and call on the concept of the global warming potential, as already accepted and endorsed in the Kyoto protocol to define equivalence between emissions of different greenhouse gases. A ton of carbon emitted to the atmosphere does not result in a permanent 1-ton increase in the atmosphere. Rather the increase in atmospheric concentration decays with time as some of the carbon mixes into the ocean and the biosphere. If we envision the emission of one ton of carbon to the atmosphere and integrate out to 100 years the number of ton-years of atmospheric increase in carbon, we can find the ton-years of atmospheric carbon increase that result from the pulse emission (Fig. 2). Moura Costa and Wilson, for example, write, "as understood by the protocol, carbon sequestered at $t = 0$ and stored until $t = 55$ is directly equivalent to an avoided emission at $t = 0$ and could be credited accordingly." Using different mathematical models for the behavior of the global carbon cycle yields slightly different values for the equivalence factor (Fearnside et al., 2000). Some of the analyses recognize that a 'pulse' removal of 1 ton of carbon from the atmosphere would also be compensated over time by a change in the fluxes among the other reservoirs. A common practice with ton-year proposals is to integrate out to 100 years, with the result that all things that happen within the first 100 years are equal and all things that happen after 100 years do not count at all.

As seen in Fig. 2 and Table 1, the equivalence between ton-years and permanent tons will depend on the logic assumed, the scenario chosen, and on the carbon cycle model selected. Chomitz (2000) summarizes that there is no unique way to determine a conversion rate between ton-years and permanent tons and that the choice among a number of justifiable possibilities is thus a policy decision.

We agree with Chomitz (2000) view that there is no unique way to determine a conversion rate between ton-years and permanent tons. We suggest, however, that it is unnecessary to do so. From a financial perspective it is easy to shift between the value of an asset, e.g., the value of permanent credits, and the annual value (rental) of the services provided by that asset. Furthermore, in a world where carbon credits are traded, the market would provide the value of a permanent carbon credit (the asset value). This would provide a base price from which annual rental values for carbon sequestration services could be determined. Additionally, the market would consider the additional costs associated with any extra monitoring (some monitoring would need to take place for sequestration projections whether temporary or permanent). Thus, rental contracts could be arranged using information on the price of permanent carbon credits, the discount rate, and costs unique to quasi-temporary projects. In many respects this market could be thought of like a used car market with similar but not homogeneous goods.

Two principal objections to the ton-year approach are (1) ton-year credits accumulate very slowly, and (2) there is a lack of symmetry in credits and debits. On the first objection, many participants in sequestration activities are likely to be motivated by immediate need for offset credits and many of the activities contemplated have large up-front costs. In a straight credit–debit system any credit would be available at the time carbon is sequestered, but a strict ton-year system would require 42–150 years before the equivalent of a perma-

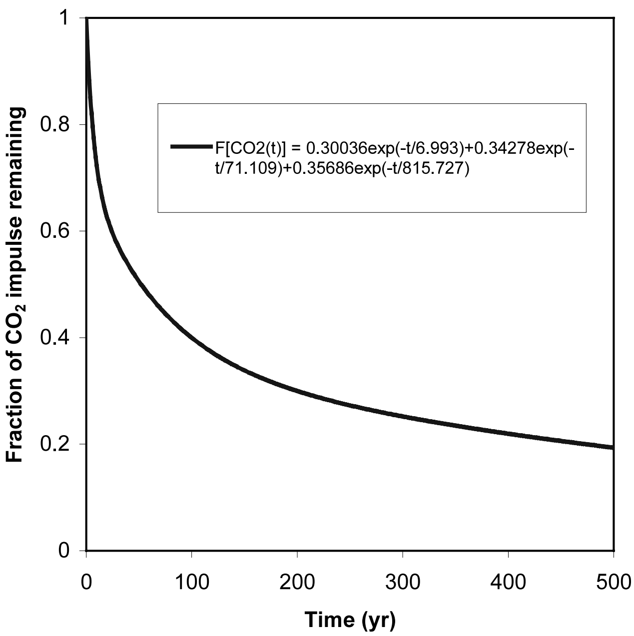

Fig. 2. The response of the atmosphere to an impulse emission of CO_2. The curve shows the response for current atmospheric CO_2 and for the model adopted by the IPCC 1990 and 1992 reports. For an increasing baseline of CO_2 concentration or for a different model of the global carbon cycle, the curve will be similar in concept but different in detail (from Intergovernmental Panel on Climate Change (1995)).

nent ton of offset credit was available. In the simple illustration of Fig. 1, the release of 1 unit of C from the power plant might be compensated by 1 unit of carbon sequestered but only $1/f$ ton-years of credit in the year of emission, and then $1/f$ ton-years of credit per year until the full 1 permanent ton of credit was achieved. Like other investments, one would not expect full payment before the services were rendered. Contracts could be made for full payment of credits in the initial year, but in this evaluation the future values would be discounted. Most of the advantages of temporary credits (e.g. credit for delaying emissions), as listed above, rely on the credits being available early in the project life, i.e. at the time of actual sequestration.

It is, of course, possible to devise ton-year systems where the credits: (a) are available from the beginning, (b) are not available until the project conclusion, or (c) accumulate in a pay-as-you go type accounting (Moura Costa and Wilson, 2000). When the credits are available at the time of sequestration, the gradual accumulation of ton-years would gradually decrease the liability for subsequent release. After 50 years, e.g. 50 ton-years of credit would have been accumulated, the full permanent ton of offset credit would have been satisfied, and there would be no debits if the carbon was then released.

Regarding the second objection, a rental system would provide the symmetry. Debits and credits would both be accounted on a periodic (perhaps annual) basis and would be counted in the time interval that the loss or gain of carbon occurred. No one has yet proposed a ton-year-like approach for dealing with 'temporary' debits.

Fearnside et al. (2000), conclude that "Mg-year (i.e. ton-year) equivalence provides a needed mechanism for comparing the global warming impacts of different activities and the benefits of different mitigation projects. It allows temporary sequestration to be compared on an equitable and consistent basis with permanent C sequestration or fossil fuel emission avoidance." We suggest that a rental system achieves the same objectives in a more attractive way.

3.2. Insurance

There are a variety of ways that insurance programs might be used to provide reasonable expectation of permanent sequestration. Chomitz (2000), however, believes it is likely not feasible to find commercial insurers for these long-term commitments and suggests a mutual insurance program. Chomitz (2000) suggests adjusting credits downward according to the magnitude of the risk of premature release, thus spreading the risk across a portfolio of projects and creating a reserve of credits held as a buffer to cover any premature losses. However, with the rental system suggested here, the role of insurance would be substantially less critical and investors would have incentives to pay market rates for credits to protect their flow of future annual payments. Any insurance would be for defined contract periods and with better definition of risk.

3.3. Other possibilities

Even if permanent sequestration is not certain, it is possible to devise approaches to try to assure that impermanent sequestration is linked to a permanent net reduction in emissions. This can be accomplished by continuing payments for carbon sequestered earlier, perhaps by renewal of rental agreements. Continuing payments provide continuing financial incentive. Thus, while there is not initial commitment that the project is permanent, the investor has reasons to try to extend the period of sequestration. Permanence in a forest, for example, might be accomplished by establishing a steady-state forest on a previously unforested site. Once the steady state biomass (and carbon) is attained, the investor has a financial incentive to try to maintain the steady-state function. Permanence might also be accomplished through a reserve of extra credits or through an obligation to replace temporary credits with permanent credits over time. As noted above, either third party or self insurance programs or performance bonds could be used to support these objectives (see below and e.g. Chomitz, 2000).

And, as suggested earlier, even if individual sequestration projects are temporary, economic incentives for carbon sequestration can be expected to result in permanent sequestration in the aggregate, as more sequestration is provided over the long term.

An intriguing alternative approach for treating a stock pollutant that society would like to retain from release into the environment is a deposit-return system. In a typical deposit-return system the holder of a beverage container, for example, pays a fee upon acceptance of a 'pollutant' and is ultimately compensated for control and return of the 'pollutant'. The deposit and return provide incentive for stewardship of the pollutant. Stewardship in perpetuity, however, lacks an endpoint for return of the deposit and we have not been able to envision a workable model for a deposit-return system in perpetuity. On the other hand, a system could be devised to reward stewardship over an extended period, a period that is similar to the equivalency time discussed under the ton-year approach above. If registration of sequestered carbon was accompanied by deposit into an escrow account with a third party, return of the escrow (plus accumulated interest less account management costs) could take place at the end of the agreed equivalence time. While this might be well short of 'permanence' it could establish minimum standards for sequestration and motivate long-term stewardship. See also (Schwarze and Niles, 2000).

4. The fundamental issue-liability

The essential issue for permanence is liability. The Kyoto protocol envisions a system whereby credits against emissions commitments can be achieved by sequestering carbon in the terrestrial biosphere. Carbon sequestration is a reversible process, however, and the Kyoto protocol does not fully prescribe who is responsible if the sequestered carbon is subsequently released and the basis for the credits thereby lost.

The system of credits and debits created by the protocol does suggest that carbon sequestration in Annex B countries will create credits while subsequent loss of sequestered carbon will create debits. However, since developing countries (non-Annex B countries) do not have emissions commitments under the protocol, it is necessary to have an alternate description of the commitment to retain carbon sequestered in non Annex B countries. If credit is given when carbon is sequestered, who then assumes the liability if the sequestered carbon is lost? The discussion above suggests four alternatives for who bears the liability for lost carbon, i.e. who will be assigned responsibility for the carbon emissions if sequestered carbon is released to the atmosphere, against whose ration the emission will be changed: (1) the host party that holds the carbon, (2) the purchasing party that has paid for and used the carbon credits, (3) a third party, such as an insurer or the holder of a performance bond, (4) a collective of purchasers, who maintain a risk-adjusted reserve of credits to compensate for premature losses. Variations include systems where liability declines to zero over time (e.g. the ton-year system) and systems where liability is transferred from one party to another over time. The rental system described below is such a transfer system, liability would reside with the activity host so long as a rental contract was in place but would revert to the buyer/renter of credits when the rental contract expired. With the proposed carbon rental system commitments would be made one contract period at a time.

5. Renting credits

A traditional system for limited-term use of a capital asset involves a rental contract, and rental contracts seem ideally suited to transfer of emissions credits for carbon sequestration where permanence is either not guaranteed and/or not desired. A rental contract can allow the 'buyer/renter' to enjoy the limited term benefits of the asset while the 'seller/host' retains long-term discretion. We consider how an accounting system might work if credits for carbon sequestration in non-Annex B countries were rented, rather than sold, to Annex B countries to meet the Annex B countries' emissions commitments. We envision a regulatory environment, similar to that described by the Kyoto protocol, where emissions are rationed or taxed, creating what is essentially a termination penalty on sequestered carbon.

A principal feature of a rental system is that it behaves like a direct credit/debit system for the renter of credits, i.e. the Annex B participant. Credit is assigned when carbon is sequestered and debits accrue when carbon is emitted. The credits and debits are symmetric and instantaneous. The difference is that credit is leased for a finite term, during which someone else accepts responsibility for emissions, and at the end of that term the renter will incur a debit unless the carbon remains sequestered AND the lease is renewed.

At the end of the rental period the renter will have received some of the benefits listed above (in the section on 'Approaches that have been proposed for addressing permanence') and can either renew the lease or incur the emissions debit and replace the credit with one from another activity. We would argue as an analogy that a party renting a garage to park his car can, at the end of the lease contract, either renew the release or find another place to park his car. The car driver might have used the rental term to either find a better lease agreement elsewhere, build his own garage, or make the decision to park his car on the street and suffer the damages. The car driver might have found another mode of transport and no longer need a garage.

At the end of the rental agreement the renter would incur an emissions debit and the host would be released from further liability. If the carbon remained sequestered the host could: (a) renew the lease, at newly re-negotiated terms, (b) lease the credit to another Annex B Party, (c) retain the credit for its own use, or (d) set free the sequestered carbon if it had a higher use for the committed land. The emissions credit would in fact be used only one time, but it could be transferred among parties at any later time (so long as the carbon remained sequestered) if the first party incurred a current year debit and the new renter received a current year credit. To continue the metaphor, our car driver above would be looking for a new place to park his car but the garage would be available for another driver. And if the garage owner had become wealthy enough to purchase a new car, he could decline to renew the lease and use the garage for his own car.

A rental contract for emissions credits would establish continuous responsibility for sequestered carbon. The host country would have to accept short-term liability, over the duration of the rental contract (although the liability could be transferred to an insurance or bonding agent). The renter would need to have legal and financial recourse for provision of the contracted service, i.e. carbon sequestered. In fact, it is likely that the renter would ultimately absorb the cost associated with the risk of premature carbon loss. Presumably the

Table 2
The flow of credits and debits for two different accounting alternatives when 1 unit of carbon is sequestered in year 1 and subsequently released in year 11

Year	1	2	3	4	5	6	7	8	9	10	11
Carbon sequestered	1										
Carbon released											1
(1) Ton-years earned											
Credits	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Debits											
(2) Rental											
Credits	1										
Debits											1

value of rented credits would vary with the credibility and responsibility of the host.

Table 2 illustrates the flow of carbon and carbon credits for two potential accounting approaches (ton-years, and carbon rental) for a simple scenario. We consider that one ton of carbon is sequestered in the first year and that it remains in the terrestrial biosphere until being released in the eleventh year. We assume that sequestration occurs in a non-Annex B country and 50 ton-years are taken to be equivalent to one permanent ton.

A system that has been described with different words but is essentially identical to our concept of renting carbon credits has been introduced to the Kyoto negotiations by the government of Colombia Ministry of the Environment (2000) and elaborated by Blanco and Forner (2000). The Colombia proposal introduces ‘expiring CERs’, i.e. emissions reduction credits that expire after some negotiated period. Colombia envisions their proposal as a ‘simple liability scheme’ that addresses the concerns of countries ‘preoccupied about the sovereignty issue’. Colombia proposes placing an expiration data on emissions credits from sequestration activities so that emissions credits would eventually have to be replaced by permanent credits or additional expiring credits. Lands on which carbon is sequestered would be released from any further obligation when the credits expired. Colombia recognizes that the owner of a project might choose to extend the lifetime of a project and thus the lifetime of expiring credits.

Our proposal is similar to that of Colombia except that we establish no expiration date. Expiration occurs when it occurs, and the implication is that the rent payments cease. The duration of rental contracts could be left to the discretion of the contracting parties. Thinking in terms of rental contracts also tends to make clear the opportunities for secondary transactions, a concept not addressed by the Colombia proposal. Describing the approach in terms of rentals helps bring the proposal into familiar financial terms and concepts. In the words of traditional property transactions it might also be appropriate to think in terms of easements.

One question posed with regard to rental credits involves the long term commitments of corporations or other non-governmental organizations that engage in rental agreements for carbon emissions credits. These entities would essentially accept long-term, unsecured obligations for carbon releases potentially many years after the use of the credits, and there is no assurance of their existence and responsibility by the time that the rental contracts expire. In fact, it is governments that will likely be bound by international obligations, whether they be taxes or rations on emissions, and that must ultimately determine the extent to which they will choose to include rented credits as part of their reporting and long-term obligations. We cite student loans as an example where the US government backs long-term, unsecured obligations by students seeking to finance their educations. The US government ultimately backs these loans but imposes limits on the magnitude of individual obligations. Similarly, individual countries may chose to provide limits on the extent to which individual investors can use rented credits to contribute to meeting the national commitment.

Finally, we point out another interesting dilemma that could arise under a ton-year accounting system but is avoided under a rental system. Consider carbon that is sequestered in growing biomass and later harvested for use as a fuel. Under a ton-year accounting system this circumstance could produce multiple credits. The sequestered carbon would accumulate ton-year credits (convertible to permanent tons) during the period of sequestration and then permit an additional credit as it was burned to avoid an equivalent amount of fossil-fuel use. Under a rental system there would be 1 unit of credit at the time of sequestration. At the time of harvest and burning there would be 1 unit of debit for the lost sequestration plus 1 unit of credit for the fossil fuel avoidance, essentially the transfer of one temporary credit to a permanent credit.

Rental of carbon emissions credits should ideally bring benefits to both the renter and host. The attraction of rented credits for the renter would presumably be financial. Those in need of credits could either buy permanent credits, rent temporary credits, or borrow money to purchase permanent credits as in taking a mortgage on the garage. Rented credits would provide revenue to the host. They would also, presumably, bring a flow of development and environmental values to the host. They would not, however, obligate the host beyond the negotiated rental contract, a matter that has been of considerable concern to potential host countries.

6. Summation

The initial premise of the Kyoto protocol is based on a real-time accounting of greenhouse gas emissions to the atmosphere, with corresponding offset credits if carbon is removed from the atmosphere and sequestered. The protocol specifies integration over a 5-year commitment period and we assume that integration over some significant spatial scale might also be used to even out small-scale variability and to minimize the burden of monitoring and verification. Real time accounting of credits and debits encounters problems, however, if sequestration can occur where there is no legal responsibility for subsequent loss of the sequestered carbon, and this would arise if carbon sequestration were permitted in non Annex B countries under the CDM. Despite this concern over the permanence of sequestered carbon, there are many reasons to want to include carbon sequestration in non Annex B countries within the formality of the Kyoto protocol (or any subsequent international agreement on greenhouse gas emissions).

The challenge is to design an accounting system that provides appropriate incentives for carbon sequestration while preserving the integrity of the objectives of the protocol. Ton-year accounting systems can provide credits for temporary sequestration of carbon if we define a time interval for sequestration that is considered to be equivalent to permanent sequestration. Although ton-year systems do not reflect the reality of changes in carbon stocks, they can be designed to provide incentives for storing carbon in the terrestrial biosphere. However, ton-year accounting does not treat emissions to and removals from the atmosphere similarly and it introduces unnecessary complexity in defining a numerical equivalence between permanent and temporary sequestration. These problems can be avoided if we accept that transactions involving emissions permits could involve either their sale or rental. The financial markets will establish their relative value.

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References

Bird, N., 1997. Greenhouse Challenge Carbon Sinks Workbook: A Discussion Paper. Greenhouse Challenge Office, Canberra, Australia as cited in IPCC, 2000.

Blanco, J., Forner, C., 2000. Special Considerations Regarding the 'Expiring CERs' Proposal; paper prepared for presentation at the International Forum on Enhancement of Japan's Private Sector's Overseas Re-afforestation Cooperation, fall, 2000, The Ministry of the Environment, Colombia, p. 17.

Chomitz, K.M., 1998. Baselines for Greenhouse Gas Reductions: Problems, Precedents, Solutions. Development research Group, World Bank, Washington, DC, USA as cited in IPCC, 2000, p. 62.

Chomitz, K.M., 2000. Evaluating Carbon Offsets from Forestry and Energy Projects: How do they Compare? World Bank Policy Research Working Paper 2357, New York, p. 25, see http://wbln0018.worldbank.org/research/workpapers.nsf/5ade973899c86086852567310068 34d5/d92de72e3c60be77852568f9004b40e3?opendocument

Colombia Ministry of the Environment, 2000. Expiring CERs, A Proposal to Addressing the Permanence Issue, pp. 23–26 in United Nations Framework Convention on Climate Change, UNFCCC/SBSTA/2000/MISC.8, available at www.unfccc.de.

Dobes, L., Enting, I., Mitchell, C., 1998. Accounting for carbon sinks: the problem of time. In: Dobes, L. (Ed.), Trading Greenhouse Gas Emissions: Some Australian Perspectives, Occasional Papers no. 115. Bureau of Transport Economics, Canberra, Australia, pp. 1–15 as cited in IPCC, 2000.

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

Fearnside, P.M., Lashof, D.A., Moura-Costa, P., 2000. Accounting for time in mitigating global warming through land-use change and forestry. Mitigation and Adaptation Strategies for Global Change 5, 239–270.

Intergovernmental Panel on Climate Change, 1995. Climate Change 1994: Radiative Forcing of Climate Change. Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change, 2000. Land Use, Land-Use Change, and Forestry: A Special Report of the IPCC, Cambridge University Press, Cambridge, UK.

Kauppi, P., Sedjo, R., Apps, M., Cerri, C., Fujimori, T., Janzen, H., Krankina, O., Makundi, W., Marland, G., Masera, O., Nabuurs, G.-J., Razali, W., Ravindranath, N.H. Chapter 4. Technical and Economic Potential of Options to Enhance, Maintain, and Manage Biological Carbon Reservoirs and Geo-engineering. In: Metz, B., Davidson, O., Swart, R., Pan, J., (Eds.), Climate Change 2001: Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge (pp. 301–343).

Kolstad, C.D., 1993. Looking vs. leaping: the timing of CO_2 control in the face of uncertainty and learning. In: Kaya, Y., Nakicenovic, N., Nordhaus, W.D., Toth, F.L. (Eds.), Costs, Impacts, and Benefits of CO_2 Mitigation. International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 63–82.

MacLaren, J.P., 2000. Trees in the Greenhouse: The Role of Forestry in Mitigating the Enhanced Greenhouse Effect. Forest Research Bulletin No. 219. Forest Research, Rotorua, New Zealand, p. 72.

Marland, G., Schlamadinger, B., Leiby, P., 1997. Forest/biomass mitigation strategies: does the timing of carbon reductions matter? Critical Reviews in Environmental Science and Technology 27, S213–S226.

Meinshausen, M., Hare, B., 2000. Temporary Sinks do not Cause Permanent Climatic Benefits. Manuscript distributed at the sixth meeting of the Congress of Parties to the UN Framework Convention on Climate Change, The Hague, The Netherlands, see www.carbonsinks.de.

Moura Costa, P., Wilson, C., 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.

Richards, K.R., 1997. The time value of carbon in bottom-up studies. Critical Reviews in Environmental Science and Technology 27, S279–S292.

Schwarze, R., Niles, J.-O., 2000. The long-term requirement for CDM forestry and economic liability. Journal of Environment and Development 9 (4), 384–404.

Schlamadinger, B., Marland, G., 2000. Land Use & Global Climate Change: Forests, Land Management, and the Kyoto Protocol. Pew Center on Global Climate Change, Arlington, VA, USA, p. 54, available at www.pewclimate.org.

Tipper, R., de Jong, B.H., 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 as cited in IPCC, 2000.

United Nations Framework Convention on Climate Change, 1998. The Kyoto Protocol to the United Nations Framework Convention on Climate Change, document FCCC/CP/1997/7/Add.1, available at www.unfccc.de.

Van Kooten, G.C., Grainger, A., Ley, E., Marland, G., Solberg, B., 1997. Conceptual issues related to carbon sequestration: uncertainty and time. Critical Reviews in Environmental Science and Technology 27, S65–S82.