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ORIGINAL ARTICLE

Alternative approaches for addressing non-permanence in carbon projects: an application to afforestation and reforestation under the Clean Development Mechanism

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Abstract Afforestation and reforestation (A/R) projects generate greenhouse gas (GHG) reduction credits by removing carbon dioxide from the atmosphere through biophysical processes and storing it in terrestrial carbon stocks. One feature of A/R activities is the possibility of non-permanence, in which stored carbon is lost though natural or anthropogenic disturbances. The risk of non-permanence is currently addressed in Clean Development Mechanism (CDM) A/R projects through temporary carbon credits. To evaluate other approaches to address reversals and their implications for policy and investment decisions, we assess the performance of multiple policy and accounting mechanisms using a forest ecosystem simulation model parameterized with observational data on natural disturbances (e.g., fire and wind). Our analysis finds that location, project scale, and system dynamics all affect the performance of different risk mechanisms. We also find that there is power in risk diversification. Risk management mechanisms likewise exhibit a range of features and tradeoffs among risk conservatism, economic returns, and other factors. Rather than relying on a single approach, a menu-based system could be developed to provide entities the flexibility to choose among approaches, but care must be taken to avoid issues of adverse selection.

Keywords Afforestation · Carbon · Clean Development Mechanism · Insurance · Non-permanence · Reforestation · Temporary credit

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1 Introduction: carbon sinks, permanence, and reversals

Land use, land use change, and forestry (LULUCF), which includes agriculture, account for about one-quarter of global greenhouse gas emissions (Blanco et al 2014). A substantial part of this flow is tied to the absorption, storage, and release of carbon dioxide (CO_2) in soils, biomass, and other organic pools referred to as carbon sinks. Sinks can accumulate carbon through both the maintenance of preexisting stocks (e.g., reduced deforestation, degradation, or other forms of land clearing) or through the creation of new stocks (afforestation, reforestation, improved management, and other forms of restoration). Terrestrial carbon sequestration projects are therefore part of the GHG mitigation strategy set, typically identified as a potential offset for emissions from other sources. In principle, using a metric ton of terrestrially stored carbon (or CO_2 equivalent, tCO_2e) as an offset is an equivalent credit against an emission elsewhere if it completely negates the climatic impact of that emission.

Recognizing the importance of terrestrial carbon sinks in climate mitigation, policies have been designed and implemented to expand carbon sinks. However, these terrestrial ecosystems are susceptible to disturbances that cause the stored carbon to be released back into the atmosphere (Brown et al 2000; Dale et al 2001; Galik and Jackson 2009). Problems can arise when stored carbon that has been credited as part of a climate change mitigation effort returns to the atmosphere via these disturbances, a phenomenon known as reversal. Reversals, when they occur, can nullify emissions reductions and undermine the permanence of these climate mitigation actions, and so must be otherwise addressed through policies and accounting procedures.

Under the United Nations Framework Convention on Climate Change Kyoto Protocol's Clean Development Mechanism (CDM), developing countries can host carbon sink projects that generate certified emission reduction credits. These credits can be sold to developed (Annex I) countries to help them meet their emissions reduction obligations. Currently, CDM afforestation and reforestation (A/R) projects address reversals by issuing expiring (temporary) credits. Upon expiration, these credits must be replaced. This replacement requirement raises the cost to the buyer of using them relative to a full-price permanent credit, thereby reducing the monetary value of the credit and the net revenue flow to the project (Olschewski and Benítez 2005).

As A/R projects have not been widely adopted thus far—they account for less than one percent of all CDM projects to date (United Nations Environment Programme UNEP 2012)—the question is whether other approaches for dealing with reversals are needed and how the performance of these approaches varies as applied. Here we assess non-permanence risk in A/R project-level activities under multiple policy approaches. Using the LANDCARB forest ecosystem simulation model (Harmon 2012), we investigate the influence of policy choice in the presence of random natural disturbance events on the long-term financial and environmental viability of project-based offsets. We quantify the performance of different reversal risk approaches under the threat of both wildfire and wind disturbance project on a hypothetical subtropical project representative of A/R project experience under the CDM (see, e.g., Clean Development Mechanism CDM 2012). In doing so, we provide an example of how large-scale models may be employed for evaluation of project-level accounting decisions to inform ongoing discussions of both CDM and emerging compliance and voluntary market activities.

2 Reversal risk: types and characteristics

LULUCF activities are subject to both natural and anthropogenic disturbances. Relevant natural disturbances include fire, wind, flood, drought, ice/snow, pest infestations, disease, landslides, earthquakes, and volcanic activity (see Galik and Jackson 2009 for a review).

Human-induced disturbances include the legal or illegal harvesting of trees, land clearing, and incidental mortality occurring as a result of other activities (e.g., war). The intensity and extent of disturbance can vary for both human-caused and natural events, ranging from slight damage to complete loss and from individual trees to thousands of hectares.

Risks to LULUCF activity may be classified into two types: (1) unintentional reversals due to natural disturbances outside of the project holder's control (such as wildfires, wind, and flooding) and (2) intentional risks caused by purposeful actions of the project holder (such as harvesting, land clearing, and intentionally set fires). For the purposes of the empirical analysis presented here, we consider only unintentional (natural) reversals. This is not to diminish the importance or relevance of intentional reversals, but recognizes that the suite of approaches to address intentional reversals are potentially different from those best used in unintentional reversals. Intentional reversals, for example, may be more easily traced back to responsible parties, thus facilitating repayment through contractual obligations or other legal means. Unintentional reversals, however, involve loss from stochastic, force majeure events for which there may be no responsible entity, requiring that the approaches used to ensure system integrity be evaluated and well understood.

Wildfire and wind are common causes of natural, unintentional loss, but a great deal of variation exists both within and between each with regard to disturbance frequency, intensity, and area affected (see, e.g., Dale et al 2001). Low-intensity fires may affect large areas but consume only litter and ground vegetation, resulting in negligible carbon consequences for an A/R project. Conversely, high-intensity fires can reach into the forest crown and be utterly destructive, with catastrophic results for both previously stored carbon and future sequestration potential. Wind, meanwhile, tends to affect small areas but with great intensity. While the blow-down that results from severe wind events may kill or damage individual trees, stored carbon may not be lost immediately but rather transferred from live tree to dead tree pools where it is lost slowly over time.

3 Risk management approaches: concepts and criteria

Selection of a reversal risk management approach requires multiple determinations. Each stage of the approach selection process likewise involves multiple considerations. Beginning with a determination of who is ultimately liable for reversals should they occur, decisions also need to be made on whether awarded credits are temporary or permanent, and whether full credits are issued or whether they are awarded incrementally over time.

3.1 Liability determination and assignment

A necessary first step is to assign liability for reversals. From an accounting perspective, a reversal occurs once it is detected, quantified, and reported. Standard practice would cancel credits equivalent to the size of the reversal. Since canceled credits mean that the use of the credits for offsetting emissions has been compromised, some replacement of the canceled credits with valid credits would be necessary to restore balance to the system. The issue comes down to who is liable for replacing the credits. Although largely a policy determination, the assignment of liability can itself determine the incentives to manage for the reduction in non-permanence risk.

3.2 Accounting mechanisms for addressing reversals as they occur

The incidence of reversal can be automatically incorporated into the crediting system in a number of ways. Historically, many of the considerations for addressing reversals have evolved from a project-level perspective and emerged from the modalities and procedures developed for A/R under the CDM and from the voluntary market. Although often lumped together as ways to collectively address non-permanence, the following approaches are fundamentally different in the questions they seek to answer and the function they seek to provide.

3.2.1 Incremental crediting over time

One could assign more permanent credits for projects that store carbon for longer periods of time. One such approach is the tonne year approach (Moura-Costa and Wilson 2000; Noble et al 2000), which is similar in some ways to the rental approach described by Sohngen (2003) in which credits accrue the longer the carbon is stored. In this approach, tonnes stored early on in a project receive small payments that progressively accumulate as the project continues and achieves storage over a longer period. Because payments are based on achieved permanence, there is no up-front payment for permanent credits once initial storage is verified and no liability to replace the credit if reversal occurs. Rather, a reversal simply reduces the basis for subsequent payments.

3.2.2 Full crediting upon verification

Rather than awarding credits incrementally, credits could be fully awarded upon verification. Doing so, however, requires that mechanisms be in place to ensure that any carbon that is subsequently lost to reversal is somehow accounted for or replaced. Under the temporary certified emission reduction (tCER) approach of the CDM, all credits that were issued for a project expire at the end of the (Kyoto Protocol) commitment period after they were issued. The tCERs can however be reissued upon subsequent verification. Crediting periods can be much longer for long-term certified emission reductions (lCERs), which are valid for 20 years, renewable twice (for up to 60 years) or for a single, 30-year crediting period. Simple economics suggests that the difference in credit life will translate into a difference in price between the two types of credits. Under a system that mandates replacement at the end of the contracts, short contracts will have heavily discounted credits, since the replacement requirement will be near at hand (Kim et al 2008; Murray et al 2007). lCERs would therefore command a higher price than tCERs due to the greater amount of time before replacement is required, while themselves trading for less than a comparable permanent credit. While longer contracts should have lower discounts, there is no transaction data upon which to confirm this.

An alternative is to issue fungible permanent credits once carbon storage is verified, typically requiring replacement of credits previously issued for carbon that has been deemed to have been reversed before the end of the period stipulated to fulfill a permanence obligation. These credits can be sold as soon as the carbon is sequestered and credits are issued. But as the credit is issued prior to fully serving its offsetting function, and with no preset expectation of expiration as in the case of temporary credits, legal obligations to replace lost storage and/or specific accounting procedures to facilitate such replacement are typically put in place to ensure that system integrity is not affected by a reversal.

One mechanism to ensure replacement of lost storage is to require the creation of a buffer or set-aside. The buffer concept is common in the voluntary market. It has also caught hold in the UNFCCC process, as evidenced by CMP7 approved modalities and procedures for geological carbon capture and storage (CCS) projects under the CDM (UNFCCC 2011b). A buffer approach requires that some portion of earned credits be set aside or held in escrow to address non-permanence. If a reversal occurs under the buffer approach, credits from the buffer are used to compensate for the carbon storage lost. The size of the set aside may vary depending on the inherent riskiness of the activity and the length of time over which the risk is evaluated (Verified Carbon Standard VCS 2012).

Another way to address the potential loss of permanent credits is through commercial insurance. Private insurance for carbon markets and policy regimes functions much the same as it does in personal service and commodity markets. Regular payments, or premiums, are paid to some insuring entity, which in turn guarantees the permanence of credits generated by the covered activity (e.g., by replacing reversed credits). In the event of loss, the project will likely be required to first pay a deductible. As opposed to buffers, which require that some number of credits be set aside up front, the deductible is an “if and when” call that is only required upon reversal. Although carbon insurance products are rare now, analogs exist in other forest and agriculture applications. When it is available, a primary benefit of insurance is that it is simple and straightforward to implement so long as the insuring entity is appropriately capitalized to withstand catastrophic loss.

A project’s host country could agree to replace any credits lost to reversal. Such a guarantee would allow projects to be marketed at lower risk to the buyer, thereby increasing credit demand. The host country guarantee approach builds off recent proposals to address residual liability for carbon, capture and storage (CCS) activities under the CDM (UNFCCC 2011b), in which the host country acts as a fiduciary backstop to address reversals from physical leakage of CO_2 from the storage reservoir unresolved at the project or sub-national level. Precedent also exists under the Joint Implementation (JI) mechanism of the Kyoto Protocol, in which project losses must be balanced against a given country’s national account. Under this model, a given country or their designated third party can choose to assume liability for any losses over and above the provisions made for covering losses (such as a buffer) at the project or sub-national program levels. The economic viability of such an approach depends on the relationship between the monetary value of expected losses and host country or third-party willingness and ability to devote the necessary resources to cover them.

Finally, it is possible to have a replacement obligation in the absence of any formal mechanism (i.e., no buffer contribution/commercial insurance coverage requirement). With no mechanism facilitating credit payback, however, protections must be put into place to ensure that affected projects have the financial resources to compensate for lost storage. One way to do this is to require a project to establish a performance bond or some other form of collateral in advance.

4 Quantitative analysis of risk management approaches

4.1 Simulation of growth and disturbance

We simulated forest growth using a significantly updated version of the ecosystem simulation model LANDCARB (Harmon 2012). LANDCARB is a landscape-level ecosystem process model. LANDCARB integrates climate-driven growth and decomposition processes with species-specific rates of senescence and mortality, while incorporating the dynamics of inter- and intra-specific competition that characterize forest gap dynamics. Inter- and intra-specific competition dynamics are accounted for by modeling species-specific responses to solar radiation as a function of each species’ light compensation point and assuming light is delineated through foliage following a Beer-Lambert function. By incorporating these dynamics, the model simulates successional changes as one life-form replaces another, thereby representing the associated changes in ecosystem processes that result from species-specific rates of growth, senescence, mortality, and decomposition. LANDCARB represents stands on a cell-by-cell basis, with the aggregated matrix of stand cells representing an entire landscape. Each cell in LANDCARB simulates a number of cohorts that represent different episodes of disturbance and colonization within a stand. Each cohort contains up to four layers of vegetation (upper tree layer, lower tree layer, shrub, and herb).

To generate a distribution of results for each risk management approach, we re-run the model 50 times under the threat of random fire and wind disturbance. For each of the 50 runs performed for each scenario, we assessed a 45×45 matrix of 10 hectare cells, for a total project area of 20,250 ha. To assess forest growth and disturbance on the performance of smaller projects, we randomly selected a starting cell from each run of 45×45 cells and chose the adjacent 10 rows and columns, yielding a smaller project area of 1,000 ha. For all projects, we assume that lands are afforested in the first year of the project. No harvests are conducted during the project, meaning that we do not track harvested wood products (HWP) nor do we assess potential long-term carbon storage in the HWP pool.

Forest growth in our model runs is based on growth-yield curves established for high management, high productivity softwood plantation species (*Pinus taeda-P. echinata*) stands as described in Smith et al (2006). These and other similar softwood species are featured in existing A/R projects. The sequestration profile of *P. taeda* also lies between faster growing shorter rotation species and slower growing longer rotation species used in A/R projects (Fig. 1), thus providing for a rough mid-point analysis.

Our analysis incorporates wildfires in all simulations. In the LANDCARB model, fire severity controls the amount of live vegetation killed and the amount of combustion from the various C pools, and is influenced by the amount and type of fuel present. Fires can increase (or decrease) in severity depending on how much the weighted fuel index of a given cell exceeds (or falls short of) the fuel level thresholds for each fire severity class (T_{light}, T_{medium},

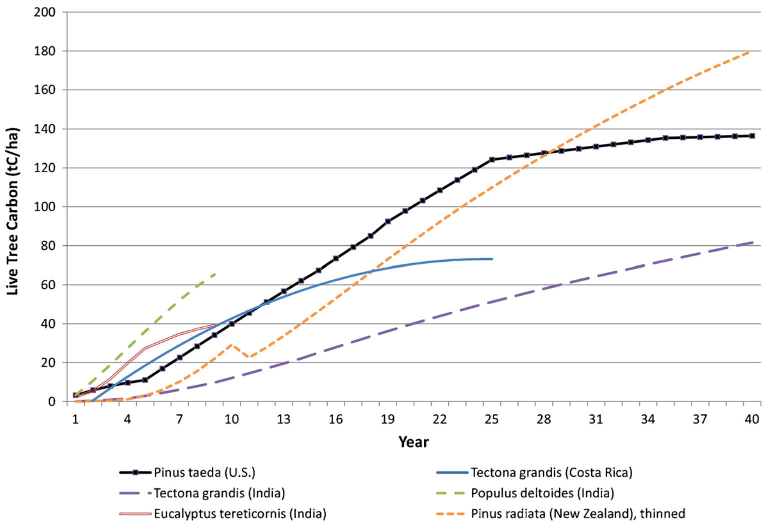

Fig. 1 Sequestration profile for species used (or equivalent) in CDM A/R projects. *Pinus taeda* (U.S.) shows the sequestration profile of the forest type assumed in the quantitative analysis performed in this paper. Source: Costa Rica *Tectona grandis* – Bermejo et al (2004), site index 23, fit using simple polynomial trendline; *T.grandis*, *Eucalyptus tereticornis*, and *Populus deltoids* (India) – Kaul et al (2010); *P. taeda* (U.S.) – adapted from Smith et al (2006); *P. radiata* – Paul et al (2008)

T_{high}, and T_{max}) and the probability values for the increase or decrease in fire severity (P_i and P_d). For example, a low-severity fire may increase to a medium-severity fire if the fuel index sufficiently exceeds the threshold for a medium-severity fire. Fuel-level thresholds were set by monitoring fuel levels in a large series of simulation runs where fires were set at very short intervals to see how low fuel levels needed to be to create a significant decrease in expected fire severity.

The modeled fire regime is intended to replicate fire behavior in subtropical loblolly pine stands. Not only does this fire regime conform to our choice of species to use in the A/R project, but it may also be representative of other subtropical locations that are home to a sizable portion of current A/R projects. Although data on low-frequency, high-severity fires is generally unavailable in the Southeastern U.S. due to a lack of primary forest on which fire reconstruction studies could be performed, we can nonetheless estimate reasonable fire return intervals through comparison with other forested systems. For example, longleaf pine stands are adapted to a low-severity, high-frequency (3–7 years) fire regime; loblolly pine stands burn with less frequency than longleaf pine stands, but this is, in part, due to fire suppression. Based on the observed frequencies in other systems, we thus estimate a reasonable mean fire return interval (MFRI) in the system modeled here to be 16 years for a low-severity burn, a 100-year MFRI for a medium-severity fire, and a 300-year MFRI for a high-severity fire. From these, we generated exponential random variables to assign the years of fire occurrence (Van Wagner 1978). Fire severities in each year generated by this function are cell-specific, as each cell is assigned a weighted fuel index calculated from fuel accumulation within that cell and the respective flammability of each fuel component, the latter of which is derived from estimates of wildfire-caused biomass consumption.

Wind loss is represented in the LANDCARB model as a harvest in which no timber is removed (i.e., all downed timber is left onsite). Lacking adequate data on the distribution of wind disturbance frequency and intensity in any of the countries currently hosting A/R projects, we used U.S. data as a proxy. The incidence and intensity of wind disturbance events were derived from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center Storm Events Database,[1] using the state of Georgia, USA, as a reference point. Area affected is not consistently included in the events database, so we instead used U.S. census data on housing density and housing value along with expected levels of damage at varying wind intensities as reported in the Fujita tornado damage scale, to generate estimates of windstorm area.[2] Next, we estimated likely loss to a forested stand and assumed that all events of a particular intensity resulted in a particular loss of forest overstory. Events above 45 meters per second (m/s, or approximately 100 mph) resulted in 100-percent loss, 35–45 m/s (approximately 78–100 mph) resulted in 75-percent loss, and 25–35 m/s (approximately 56–78 mph) result in 50-percent loss.[3] When this exercise was conducted for Clayton County, Georgia, an area slightly larger (37,037 ha) than our modeled landscape area (20,250 ha), we estimated that the average annual percent area affected is 0.3 %, with an average weighted intensity of 50 % loss. This average annual loss was applied to the modeled scenario each year, but its spatial occurrence was randomized (i.e., 0.3 % of the area will be affected each year, but where it occurs will be randomly assigned by the model).

[1] http://www.ncdc.noaa.gov/stormevents/ftp.jsp Cited 6 August 6 2012.

[2] http://www.spc.noaa.gov/faq/tornado/f-scale.html Cited 6 August 2012.

[3] Thresholds are based on categories and descriptions of loss detailed on pp 350–1 in Mason (2002), though the assignment of loss percentages to each threshold is ours alone. Assessing the risk of wind damage is a complicated undertaking, and we acknowledge this treatment vastly oversimplifies the effect of wind disturbance on forest stands. See, e.g., Quine (1995), Moore and Quine (2000), and Mason (2002) for more information.

Our model results provide an indication of possible losses under a specific set of parameters and assumptions, but use of a different forest type or different disturbance regime is likely to generate different output data on both carbon storage and the susceptibility of that storage to subsequent loss. Slow-growing hardwoods in fire-prone tropical and subtropical broadleaf forest ecosystems would encounter wildfire and be affected by fire differently than, say, a temperate softwood plantation. Nonetheless, the analysis presented here is broadly informative in comparing different approaches to addressing non-permanence under representative circumstances. This can provide a platform for future work that encompasses more geographic and risk conditions.

4.2 Modeling of risk management approaches

Having first generated raw output data on forest condition under the threat of wind and fire, we then employ a modified forest offset accounting framework (e.g., Galik and Cooley 2012) to track the environmental and financial performance of the hypothetical project under several risk management approaches. For each LANDCARB run and risk management approach, we track the costs associated with A/R project establishment and implementation, the revenues generated by the sale of stored carbon, and the carbon consequences of reversal events. Project assumptions and cost data used for all policy scenarios are included in Table 1. For tonne year scenarios, we further assumed a 40 year permanence period. The permanence period defines the fraction of the credit earned in each year. The 40-year permanence period assumed here means that 2.5 % (100 %/40) of a credit will be earned in any given year, which is then sold at the estimated carbon price for that year. For buffer scenarios, 10 % of net additional carbon storage in a given year is placed into a set-aside pool; the remaining carbon generated in that year is then sold at the estimated carbon price.

The calculation of tCER pricing is more complicated, as the value of a temporary credit stems from the deferred compliance the credit generates. An entity that purchases a tCER offsets full compliance by the number of years the tCER stands viable. Short contracts will have heavily discounted credits, since the replacement requirement will be near at hand (Kim et al 2008; Murray et al 2007). Longer contracts should have lower discounts, but this depends on the expectation of future prices for replacement credits; if the price of replacement credits is expected to be much higher in the future than it is today, then temporary credits may have little value. For tCECRs to maintain any value, prices of permanent credit must grow at a rate lower than the discount rate (Olschewski and Benítez 2005; Maréchal and Hecq 2006; Bird et al 2004; Subak 2003). If the rate of growth of permanent credits is equal to or greater than the discount rate, however, the value of a temporary credit becomes zero or negative.

At assumed carbon price increase rates and global discount rates (assumed in this analysis to both be 6 %), the theoretical price of tCERs goes to \$0. There is no market transaction history, however, to confirm the relevance of the theoretical value of tCERs to actual trades. The only trades in tCERs of which we are aware are recent purchases by the BioCarbon Fund for approximately \$4–5/tCO_2e.[4] As these purchases are better viewed as an attempt to seed a nascent market, the question remains as to the true value of a tCER. A price \$0 is obviously too low a price to fairly assess the net present value (NPV) of a tCER approach—but \$4 is likely too high. Accordingly, we instead rely on general relationships noted in Bird et al (2004). In situations where the discount rate and "inflation rate" (assumed to be the rate of carbon price increase) are similar in value, 5-year tCERs will trade at approximately 10 % of the price of

[4] See the following CDM project descriptions: http://cdm.unfccc.int/Projects/DB/JACO1260322827.04/view and http://cdm.unfccc.int/Projects/DB/JACO1245724331.7/view Cited 15 February 2012.

Table 1 Cost data and assumptions used in the analysis of project financial viability

Parameter	Value	Comments
Site preparation	\$50 ha^{-1}	Costs will be highly variable. This is a moderate to low estimate, assuming some vegetation control or soil preparation using power equipment (power equipment cost is estimated at U.S. rates), and developing country wage rates.
Inventory	\$30,000 project^{-1}	Assumes developing country field technician costs of \$15/day, and limited road access (e.g., relatively high amounts of time to travel to plots). Assumes enough plots to achieve +/- 10-percent confidence interval at 95 % statistical confidence. Assumes experienced staff compile inventory at developed country wage rates. Does not include major equipment purchases, such as multiple electronic data recorders. Occurs at project inception and again at 5-year intervals.
Management plan preparation	\$30,000 project^{-1}	Assumes a basic management plan with maps, inventory, prescriptions, and general harvest and road plans. Does not include detailed surveys of sensitive species. Occurs at project inception and again at 10-year intervals.
Regeneration	\$500 ha^{-1}	Assumed to be half of the cost of commercial forest regeneration in the U.S.
Project Development	\$30,000 project^{-1}	A low-end estimate based on observation of about 20 projects. This cost covers some map development and writing a project document. It does not include methodology development or significant payments to consultants for modeling.
Pre-project calculations	\$10,000 project^{-1}	Assumes experienced staff who can quickly make calculations from inventory data.
Field verification	\$35,000 project^{-1}	Slightly higher than a mid-range estimate to allow extra travel costs to remote sites. Based on observation of verification contracts of the past few years. Occurs at project inception and again at 5-year intervals.
Validation	\$40,000 project^{-1}	Cost is slightly higher than a mid-range estimate, based on observed validation contracts of the past few years.
Site maintenance	\$1 ha^{-1}	A low "placeholder" rate. Actual costs could be lower or much higher. If higher costs occur, the higher costs should only be for the first 1-3 years after planting. Higher costs could be needed for control of competing vegetation or protection of plantings from herbivory.
Field sampling and monitoring	\$40,000 project^{-1}	Includes the cost of an inventory, plus a modest amount for staff to prepare offset reports for verification. Occurs at project inception and again at 5-year intervals.

Table 1 (continued)

Parameter	Value	Comments
Annual verification report	\$1,000 project^{-1}	A desk review performed in years when field verification is not performed. Although the time involved is low, and some registries cap fees for desk reviews, transaction costs of contracting and liability costs of verifiers will likely cause these fees to increase.
Registry maintenance fee	\$500 project^{-1} year^{-1}	Estimated from the APX fee schedule for a VCS account. Offset issuance and transfers are sometimes denominated in U.S. dollars and sometimes denominated in Euros.
Issuance/registration fee	\$0.15 credit^{-1}	Estimated from current registry fees.
Insurance premium/ deductible	Varies	Premiums and deductibles for project full value and buffer insurance are estimated from the mean annual loss for each of the 40 years across the 50 reiterations of the 20,000 ha project example. In this respect, the data and assumptions represent a simplified midpoint analysis.
Initial carbon price	\$7 tCO_2e^{-1}	Approximates prevailing carbon price reported in Diaz et al (2011).
Carbon price increase	6 %	Increases at the discount rate, consistent with recent analysis of comprehensive climate policy initiatives (e.g., U.S. Environmental Protection Agency, 2009).
Discount rate	10 % for in-country project development expenses; 6 % for international capital.	

full permanent credits, the relationship assumed here. At the end of every 5-year project period, total project carbon storage is therefore sold at this carbon price.

Finally, we explore three private insurance options: project full value replacement, catastrophic loss limit, and buffer insurance. Project full value guarantees replacement of all losses from a project due to a variety of disturbances. Catastrophic loss limit covers up to the amount expected to be lost in a rare, catastrophic disturbance event (e.g., a 1-in-250 year event). Buffer insurance, meanwhile, guarantees capitalization up to a certain threshold of a given buffer (e.g., 85 % of initial buffer volume), providing a commercial insurance backstop against excessive buffer depletion.

Insurance premiums are assessed annually while deductibles are assessed only in years of recorded loss. Premiums and deductibles for all products are calculated as functions of the risk of loss and the total sum insured, itself a function of forest carbon stock and assumed carbon price. Premiums and deductibles for project full value and buffer insurance are estimated from the mean annual loss for each of the 40 years across the 50 reiterations of the 20,000 ha project example. In this respect, the data and assumptions represent a simplified midpoint analysis. There is a strong likelihood that single policies would not be written for the duration of a project. Rather, policies would likely be written for much shorter durations (e.g., annually), with new premiums and deductibles estimated upon renewal. Buffer insurance models the effect of a 10-percent buffer supplemented by an insurance product which prevents the buffer from falling below 85 % of its starting value in any given year. In this case, insurance would seek only to address the incremental natural disturbance events that would otherwise deplete the buffer over time. Our modeling resulted in so few years of buffer failure that pricing a product that simply insures against collapse was not possible using standard techniques. In situations of low probability loss, we instead priced premiums on a rate on line (ROL) basis, or the percentage that the premium bears to the insurers' totally liability (typically 3 to 4 %).

4.3 Results

It is difficult to directly compare the various approaches on their ability to ensure unintentional reversals do not undermine the system's environmental integrity because each approach is employing a different mechanism and acting upon the system in a different manner. It is somewhat easier, however, to compare approaches from a financial perspective (Fig. 2). For example, our analysis shows that tCERs perform poorly relative to other approaches, but tend to improve performance over longer periods of time. Buffer and insurance are comparable for both project lengths, whereas tonne year performs substantially better in the longer project. Further discussion of each approach is provided below.

4.3.1 Tonne year accounting

Project length has a strong influence on the number of credits earned, which translates directly into project financial performance (Fig. 2). The reason for this is twofold. The first is simply that a growing forest will generate a larger number of credits over time. The second has to do with the nature of the tonne year approach. Since only a fraction of credits are earned in each year, more credits are accumulated as time goes on.

4.3.2 Temporary crediting (tCERS)

We specifically consider the example of repeatedly verified tCERs issued every five years for projects that are 20 and 40 years long. Our analysis of tCER NPV, especially for the 40-year projects, is largely driven by carbon price assumptions (Fig. 2). Regardless of the pricing assumed here, tCERs could prove to be attractive in the presence of a higher carbon price and positive carbon price growth rate. This is due to the rolling nature of tCERs, in which carbon storage may be repeatedly credited in subsequent verification periods, yielding large pools of potential credits in the later, higher-carbon-price years of the project.

4.3.3 Buffer set aside

The buffer approach performs well, financially, as compared to other mechanisms (Fig. 2). The ability of a buffer system to perform effectively depends on its ability to be appropriately capitalized to cover potential liability from replacing reversed credits (Cooley et al 2012). Our analysis of unintentional reversals from fire and wind shows that 20-year projects tend to achieve this coverage using a 10 % credit withholding rate, yielding positive buffer balances at the conclusion of the project (Fig. 3). Over 40 years, the buffer is positive in most model iterations but occasionally ends in deficit. We attribute this to two general causes, both stemming from our choice of forest system modeled here. The first is that forest growth in these modeled forest stands begins to slow over time. In the early years of the project, forest growth is quite aggressive and losses encountered on one part of the project are typically compensated for or even outpaced by continued growth elsewhere. A second cause pertains to

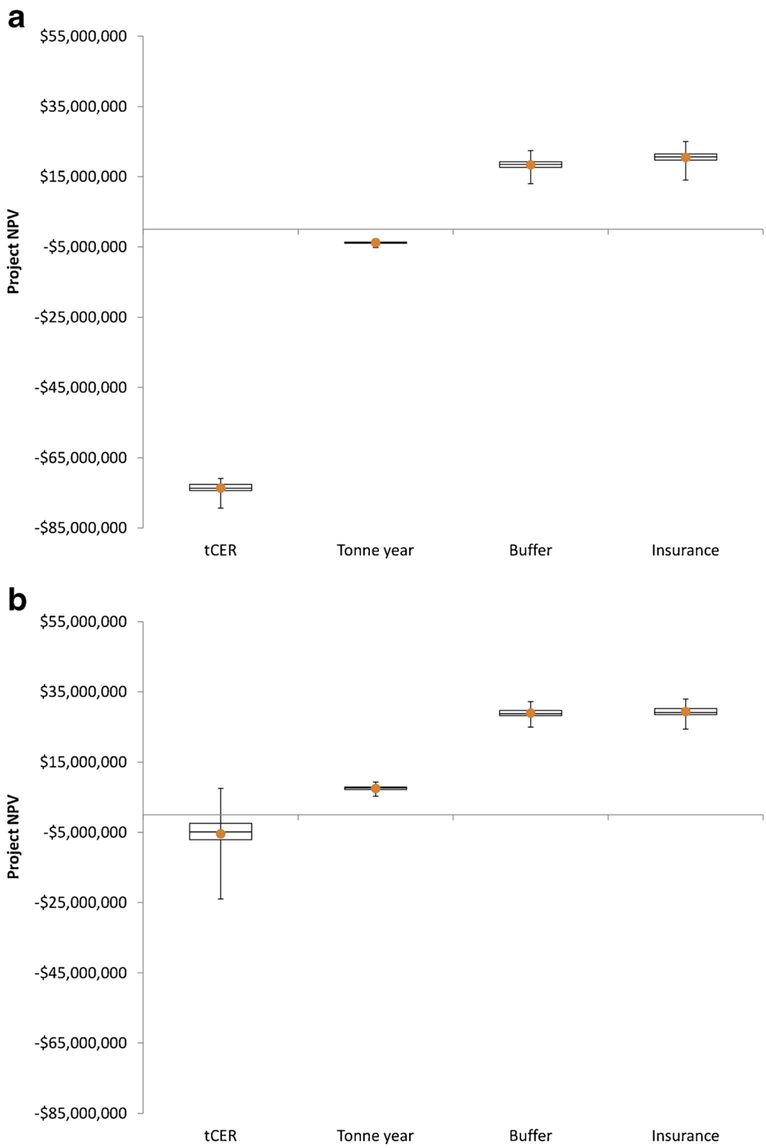

Fig. 2 Comparison of financial performance of four permanence approaches, tCER, Tonne Year, Buffer, and Commercial Insurance for (**a**) 20-year and (**b**) 40-year projects. tCER assumes that tCERs trade at 10 % of the value of a full permanent credit. Tonne year assumes a 40 year permanence period, Buffer assumes a 10 % buffer, and Insurance assumes full value coverage. Error bars represent the minimum and maximum value recorded across 50 model iterations. The box plot indicates 3rd quartile, median, and 1st quartile values, while the orange circle represents the mean

fuel buildup in forested stands over time. As fuel accumulates on the stand in the form of downed material and dead wood, there is a larger risk of more intense events occurring.

Owing to these two contributing factors, longer project periods tend to have more scenarios end in negative buffer balances, even though the mean buffer balance across project lengths is roughly the same. This means that there is a greater spread between the best and worst

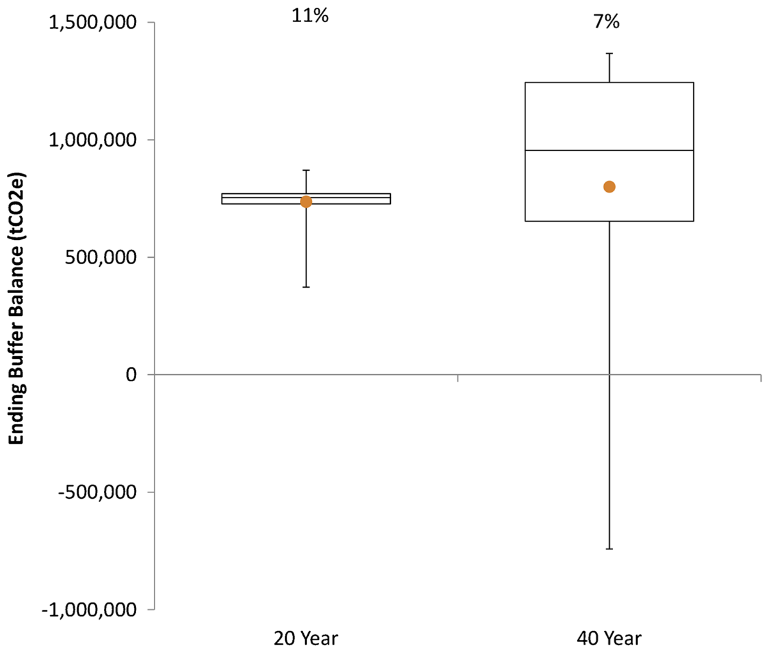

Fig. 3 Ending buffer balance, assuming a 10 % withholding rate in 20,000 ha projects at the conclusion of 20-year and 40-year projects. Mean buffer balance as a percentage of total credits earned is indicated above each example. Error bars represent the minimum and maximum value recorded across 50 model iterations. The box plot indicates 3rd quartile, median, and 1st quartile values, while the orange circle represents the mean

performing projects over time. Increasing buffer withholding rates can reduce or eliminate instances of negative buffers in the scenarios modeled here, but this comes at a financial cost to the project and fails to address the increasing spread between project outcomes.

A buffer requirement can also be imposed on multiple projects and the retained credits deposited in a master buffer account pooled across all projects. This is shown in Fig. 4, which shows the ending buffer balance for a 10 % buffer after 40 years for both 50 model iterations of a 20,000 ha project and 50 different portfolio configurations made up of 20 randomly selected 1,000 ha projects. While the individual projects sometimes experience negative buffers, no portfolios do. The key to making such a system work is ensuring that the collective buffer withholdings are sufficient in size and diversity to cover the aggregate risk of the pool. This is more likely to occur if the pooled buffer system is large relative to the individual projects within and is geographically diversified to minimize common risks across the pool (e.g., extremely widespread wildfires, wind damage, or pest outbreaks).

4.3.4 Private insurance

Our analysis of a hypothetical A/R project under risk of disturbance suggests that full value insurance could be financially competitive with other mechanisms (Fig. 2). In comparing different insurance options, however, we see a great deal of variation in both project financial performance and net GHG reduction (Fig. 5). Buffer insurance is shown on the far left, and demonstrates the effect of a 10 % buffer supplemented by an insurance product which prevents the buffer from falling below 85 % of its starting value in any given year. Full value insurance,

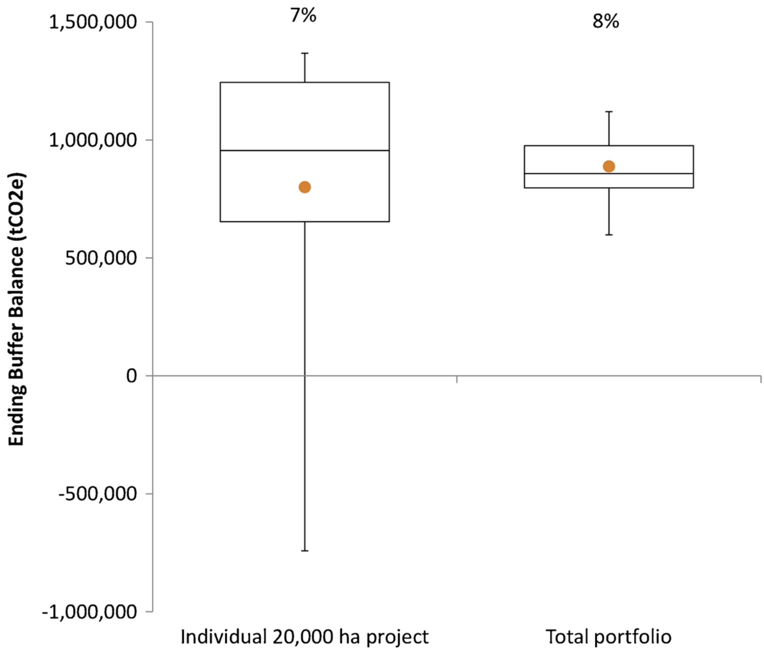

Fig. 4 Buffer balance for single 20,000 ha projects and the 20,000 ha portfolio comprising 20 1,000 ha projects. Percentage above figure indicates the mean loss as compared to total credits earned by the project. Error bars represent the minimum and maximum value recorded across 50 model iterations. The box plot indicates 3rd quartile, median, and 1st quartile values, while the orange circle represents the mean

which guarantees replacement of all losses from a project due to a variety of disturbances, performs somewhat better financially than the buffer + insurance approach. As all losses are covered by the insurer as they occur, there is no residual storage or loss to the project associated with this approach. Compare this to the catastrophic loss limit (cat loss) example on the right, in which a handful of disturbance events exceeded the mean calculated loss limit. We modeled these as losses recorded by the system (i.e., no one is responsible for picking up the residual loss). In reality, it is likely that some individual or entity would be responsible for backstopping the loss (e.g., a host country). But as the catastrophic loss product covers fewer losses, it is a less-expensive product than the full value option and therefore results in a marginally higher project NPV.

5 Discussion and conclusions

Use of an ecosystem simulation model allows for the effect of random natural disturbance events on offset integrity to be observed over time. This in turn allows for different risk management approaches to ensuring offset integrity to be evaluated against one another under different economic and project design considerations. The importance of this contribution is that losses due to non-permanence need not be observed on the ground before decision-makers are motivated to consider alternative approaches. Similarly, projects need not be disadvantaged by overly conservative risk management approaches if others exist that are equally effective but more conducive to project development and implementation.

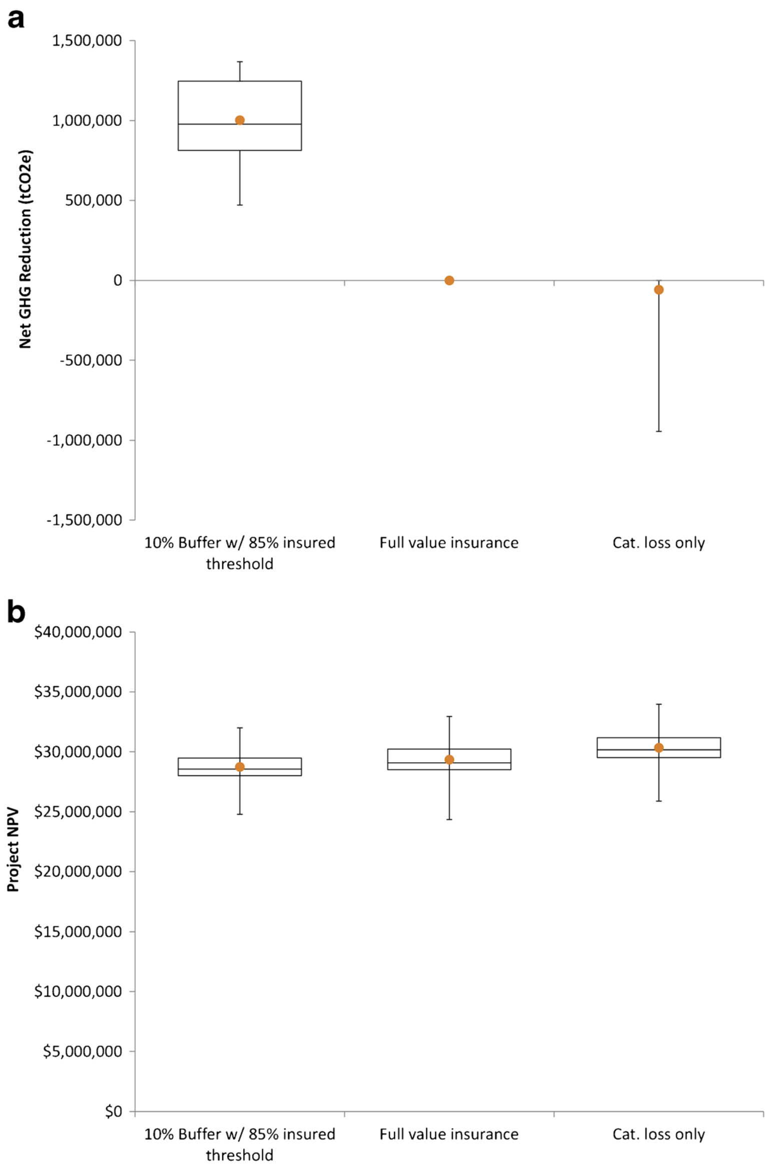

Fig. 5 Comparison of multiple insurance product effects on (**a**) net GHG reduction and atmospheric integrity and (**b**) project financial performance. All projects are 40 years in length and 20,000 ha in size. Error bars represent the minimum and maximum value recorded across 50 model iterations. The box plot indicates 3rd quartile, median, and 1st quartile values, while the orange circle represents the mean

The analysis in this report highlights a number of policy issues for consideration. Credits can be issued in full once the carbon storage has been quantified (i.e., at the end of the verification period), or they can be issued incrementally using a tonne year approach, in which permanent credits are issued over time as storage is demonstrated. To assess the proportion of annual credits to be issued under the tonne year approach, a permanence period must be adopted that takes into account scientific and policy aspects of mitigation. If credits are issued in full at the time of verification, this leads to the issue of whether those credits are temporary credits with an expiry date, as is currently the case with CDM A/R credits, or whether they are permanent credits on par with credits from other sectors under the CDM and other compliance and voluntary markets.

If temporary crediting is pursued, subsequent decisions are necessary to determine whether to continue with existing practices—tCERS and lCERs with full replacement required at defined points in time—or to modify the approach slightly, perhaps altering length of commitment or credit periods. For permanent credits issued upon verification, there are requirements to both identify the reversal management approach to be used (buffer/insurance/host country guarantee) and to clarify contingent liability for credit replacement upon reversal (project/seller or buyer). The point in time at which point storage has reached an acceptable level of permanence must also be clarified in order to assess replacement liability, particularly in the case of a tonne year approach. The choice of approach is therefore not the only consideration that must be weighed; the assignment of liability and the permanence period likewise have implications for the environmental integrity and financial viability of A/R projects.

Focusing on the selection of reversal risk approaches, our analysis presents the various accounting approaches as being separate and apart from one another, but program rules could be set up in to combine features of the different accounting approaches discussed above into one system. For example, one could have temporary crediting with only partial replacement at expiry, based on interim permanence achieved via the tonne year principles or a programmatic buffer backed by commercial insurance or host country guarantee in the event of buffer failure. Alternatively, a menu-based system could be set up to allow entities the flexibility to choose among approaches; the menu-based approach could also be useful given different countries' capacities for guarantees. Some options have lower initial financial returns, but they reduce obligations for long-term commitment and thus might suit some project participants better as such provisions would allow them to more easily opt out should circumstances warrant. Other parties may be more willing to commit to longer time periods and opt to generate permanent credits upon verification, but also accept the responsibilities associated with replacement under different options presented to them – system buffer or commercial insurance (if available), possibly backed up by a financial guarantee on the part of the project participants or some other third party.

In establishing options, particularly if allowing entities to choose their preferred approach, care must be taken to avoid issues of adverse selection. This could occur, for example, if high-risk projects, unable to secure coverage or competitive rates for private insurance, turn instead to a managed buffer system. In such a case, the composition of the resulting buffer would be skewed by contributions from these higher-risk projects, making it more likely to be drawn upon and, therefore, more prone to failure.

Although this analysis was initially motivated by discussions under the UNFCCC to consider alternative approaches for addressing the risk of non-permanence under the CDM (UNFCCC 2011a), it presents information relevant to existing voluntary markets and emerging country- or state- level compliance markets. It presents an approach for evaluating the effects of stochastic disturbance events on the financial and environmental viability of biological offset projects under different policy approaches. It likewise outlines a template for the comparison of these different approaches. Apart from the choice of mechanism itself, operational decisions such as the length of assumed permanence period and the size of a required buffer are shown to be important considerations. Given the variety of possible approaches, a one-size-fits-all approach may be less efficient than a menu-based approach, one that allows for risk management to be tailored to each particular situation.

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