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Trade-Based Carbon Sequestration Accounting

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ABSTRACT / This article describes and illustrates an accounting method to assess and compare "early" carbon sequestration investments and trades on the basis of the number of standardized CO_2 emission offset credits they will provide. The "gold standard" for such credits is assumed to be a relatively riskless credit based on a CO_2 emission reduction that provides offsets against CO_2 emissions on a one-for-one basis. The number of credits associated with carbon sequestration needs to account for time, risk, durability, permanence, additionality, and other factors that future trade regulators will most certainly use to assign "official" credits to sequestration projects. The method that is presented here uses established principles of natural resource accounting and conventional rules of asset valuation to "score" projects. A review of 20 "early" voluntary United States based CO_2 offset trades that involve carbon sequestration reveals that the assumptions that buyers, sellers, brokers, and traders are using to characterize the economic potential of their investments and trades vary enormously. The article develops a "universal carbon sequestration credit scoring equation" and uses two of these trades to illustrate the sensitivity of trade outcomes to various assumptions about how future trade auditors are likely to "score" carbon sequestration projects in terms of their "equivalency" with CO_2 emission reductions. The article emphasizes the importance of using a standard credit scoring method that accounts for time and risk to assess and compare even unofficial prototype carbon sequestration trades. The scoring method illustrated in this article is a tool that can protect the integrity of carbon sequestration credit trading and can assist buyers and sellers in evaluating the real economic potential of prospective trades.

In the United States, official carbon emission offset credit trading is still years away, but some businesses are already involved in "early" unofficial trading. Investing in early trades is risky because the number of official offsets they may eventually be worth is still uncertain. This is especially true in the case of trades involving carbon sequestration where the criteria for "scoring" credits is bound to be fairly complicated.

This article describes the policy context and economic forces at work in early carbon sequestration credit trading and develops and illustrates a standardized accounting method that can be used to assess and compare "early" carbon sequestration trades on the basis of the number of CO_2 emission offset credits they will provide and their cost. The article is based on a review of 20 "early" voluntary United States-based CO_2 offset trades that involve carbon sequestration and an evaluation of the most likely sequestration credit scoring criteria.

The article develops a "universal carbon sequestration credit scoring equation" and uses information about two actual trades to illustrate the sensitivity of trade outcomes to various assumptions about how future trade auditors are likely to "score" credits. The scoring method that is illustrated in the article is a tool that can be used to protect the integrity of carbon sequestration credit trading until official trade rules are developed and can be used by buyers and sellers to compare the economic potential of prospective trades.

KEY WORDS: Investments; Trades; Credits; Risk; Baselines; Additionality; Leakage

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Policy Context

In the United States, "official" CO_2 emission credit offset trading is still years away (Nordhaus and others 2000). This calls into question the potential economic payoff from buying early "unofficial" CO_2 emission offset credits. The criteria that future trade regulators will use to determine the number of offset credits associated with carbon sequestration projects are far less certain than the criteria they will use to assess credits earned through CO_2 emission reductions (Marland and others 1997). As a result, early investments and trades that involve carbon sequestration projects seem to be exceptionally risky.

On the other hand, during 2002, the 107th US Congress passed several bills that offer incentives for companies to invest in CO_2 emission offsets, and most of them include incentives to invest in carbon sequestration projects. At least 20 states have statutes or regulations that encourage companies to invest in carbon credit offsets, including carbon sequestration offsets. Many states are also encouraging regional air emission

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trading programs that provide additional incentives to invest in carbon sequestration credits.

So, despite the official US position with regard to the Kyoto Protocol, the potential economic payoffs from buying "early" carbon sequestration credits are probably increasing, not decreasing. This still leaves the problem that with no official basis for "scoring" these trades, prospective buyers of carbon sequestration credits have no clear basis for assessing and comparing their options in terms of expected CO_2 emission offsets. That is the problem addressed in this article.

Accounting Context

Many monitoring and accounting methods can be used after the fact to validate the outcomes of carbon sequestration credit trades and to incorporate trade outcomes into regional, national, and global carbon accounts (Andrasko 1997; Tietenberg and others 1998). However, after-the-fact carbon trade accounting is of little use to traders who must make before-the-fact decisions about which trades to undertake. Like all investors and traders, they need "leading indicators" of expected outcomes that will result from current and future decisions more than they need verification of whether or not their previous decisions paid off. This is especially true in the case of carbon sequestration credits where leading indicators based on the outcomes of past trades may not be available for many years (Tipper and de Jong 1998). Traders are also far less interested in biophysical forecasts of potential changes in the accumulation of aboveground and belowground carbon that are expected to result from various land-use/land management changes than in forecasts of the number of valid CO_2 emission offset credits these changes are likely to be worth. Because of differences in time, risk, durability, and so on, even sequestration projects that are expected to result in the same overall level of carbon being sequestrated will not be equal in terms of their "creditworthiness" (Baumert 1999). The economic payoff from engaging in early credit trading will be based on the number of credits earned, not the amount of carbon that may be sequestered over time. Beyond conventional carbon accounting, traders need some standard basis for assessing the creditworthiness of competing projects based on the scoring criteria that are expected to be used to establish the equivalency of offsets. This means taking account of site-based and project-based differences in timing and risk.

In fact, based on experience with other environmental trading systems, buyers of carbon sequestration credits, when markets actually evolve, will be most interested in the immediate (present) value of their credit purchases (Boyd and others 2001). They will want to know how many tons of current CO_2 emissions they can offset by buying credits if someone else (e.g., the seller, the trade-regulating institution, or an insurance company) accepts the risk that the sequestration project may not perform as expected. Such a question can be answered, in part, by examining site, project, and landscape conditions that affect expected changes in the accumulation of carbon. However, the answers also depend on the quality standards that trade regulators will use to determine creditworthiness (Marland and others 1997). The accounting tools needed to support carbon sequestration credit trading, in other words, are very different from those that are needed to carry out what is known as "project-level carbon accounting." They are also very different from the accounting tools that governments will need to manage regional, national, and global carbon accounts (Brown and others 1997). Accounting tools for developing uniform units of exchange (credits) and for assessing and comparing the economic outcomes of prospective trades need to be based on forecasts of credit earnings, not absolute measures of carbon.

Importance of "Unofficial" Trading

Many advocates of carbon offset credit trading argue that the best early strategy is to ignore the basis of unofficial trading. Letting buyers, sellers, verifiers, and monitors learn by doing, they suggest, will make it easier to design official trading systems that will work. Based on experiences during the early stages of other similar environmental trading systems (e.g., wetland mitigation credit trading), this is an enormously risky strategy that is likely to backfire. The first problem is that there are clear incentives for buyers, sellers, and even verifiers in these unofficial markets to engage in low-quality trades (i.e., to use overly optimistic assumptions about what projects and trades are worth). It is well known that in markets where quality standards are weak, bad quality forces good quality out of the market. The second problem is that an early track record of voluntary unofficial trades that are eventually determined not to make sense in terms of their underlying economic or carbon accounting, more than anything else, will undermine public support for official trading. There is evidence that these problems already exist. The framework and trade scoring method illustrated in this article is intended to help prevent these problems from getting worse and to improve, not limit, the potential of emerging carbon sequestration credit markets.

Extent of "Unofficial" Trading

As of December 2001, about 20 voluntary carbon offset trades have taken place that involve carbon sequestration projects undertaken on US forest and agricultural lands. Most of these trades involve energy companies paying landowners or land management companies to undertake reforestation, aforestation, and soil conservation projects in return for any future carbon emission allowance credits that result. In the largest of these trades (as of December 2001), an energy company is paying a land management company about \$11 million US dollars to reforest ~100,000 acres of publicly owned land, but most United States-based trades are much lower. Both the number and size of United States-based carbon sequestration trades are expected to grow over the next few years as new federal and state CO_2 emission offset programs begin to take shape.

To get a sense of why the standardized methods of carbon and cost accounting illustrated in this article are needed even before any "official" trading begins, consider the wide range of expected outcomes that could be attached to the large trade mentioned earlier. Press releases about that trade indicate that buyers and sellers expect to achieve carbon offsets of about 150 tons of carbon (tC) per acre over 100 years. Because the buyer is reported to be contributing about \$150 per acre to the project in return for rights to any resulting carbon credits, there are reports that the deal is based on achieving carbon emission offsets at a cost of around \$1 per ton of carbon (\$150 for 150 tC).

Properly assessing this trade, however, requires more than merely assessing the absolute amount of potential long-term carbon accumulation at the reforestation site. As a starting point, for example, it is reasonable to assume that future credit trade auditors, whoever they are and for whomever they work, will apply standard accounting methods to adjust credit earnings for all trades to account for time and risk. Based on generally accepted rules of natural resource accounting, they can also be expected to adjust credit earnings to account for criteria that are being discussed by carbon trading experts, using terms such as durability, permanence, baseline shifting, additionality, and leakage. In short, whatever institution is eventually charged with "scoring" early offset trades they will take account of quality differences and use roughly the same accounting principles that guide all other types of trade. Based on realistic assumptions about how credit markets will operate, investments in offsets that may sequester 150 tC over 100 years will not be worth 150 credits to the investor. As a practical matter, therefore, the \$1 per ton of carbon cost estimate reported for the above-mentioned trade is not providing a useful measure of performance to the traders or a meaningful market signal to other prospective buyers and sellers of carbon offset credits.

The accounting method that will be described and illustrated in the following sections is based on standard economic and natural resources accounting. It uses nine parameters to estimate the "equivalency" of credits based on expected project outcomes and various sets of assumptions about future credit scoring criteria. Using this method with a reasonable range of estimates for each of the nine parameters, the expected number of carbon offset credits associated with the above-mentioned trade could be as low as 21 tC per acre rather than 150 tC per acre.

However, making economic sense of early carbon trades requires more than applying realistic carbon credit accounting. Even using 21 tC per acre in earned offset credits, the above-mentioned trade seems to be achieving relatively low credit costs of around \$7 per ton of carbon (\$150/21). However, reports about the trade indicate that the \$150 per acre being paid by the buyer covers only the cost of project implementation (e.g., site preparation, seedlings, and tree planting). The \$7 per credit cost associated with the 21 credits is valid only if this partial investment entitles the buyer to all of the carbon offset credits. The cost of long-term site management and monitoring and credit verification can be expected to cost another \$40 per acre and the public land committed to the project is worth about \$1000 per acre. Applying full cost pricing, in other words, the overall cost per acre is roughly \$1,190, not \$150. Based on the adjusted 21 tC per acre, a full accounting of costs raises credit production costs to ~ \$57 per ton of carbon. The critical questions in evaluating this investment/trade, in other words, include not only how many "official" credits will be awarded, but how much they cost, who is paying the costs, and whether those who are paying the costs, including taxpayers in the case of investments on public lands, will claim rights to a portion of the credits.

Caveats and Limitations

A few caveats are in order to put the economics of the above-mentioned trade in the proper perspective. It is the belief of the traders involved that the federal agency that manages the project land on behalf of taxpayers is donating the land to the project in order to achieve ancillary environmental benefits associated with the reforestation project (e.g., improved bird habitat or water quality). When official trading begins, therefore the public landowner may not claim rights to a share of the carbon credits that result from the project. If this is the case, the trade may actually provide the investors with more than the 13% share of credit earnings they would be due based on full cost accounting ($150/$1190). It may also be possible for some project costs to be offset by future revenues earned by selling hunting rights or residual timber or by selling credits in markets that develop for other environmental services (e.g., nutrient or biodiversity credits). Determining if these cost offsets and ancillary revenue sources are significant enough to offset the additional cost considerations mentioned earlier is beyond the scope of this article. However, the possibility that they may affect the economic outcome of this and other similar trades illustrates why there is a need for standard natural resource and cost accounting.

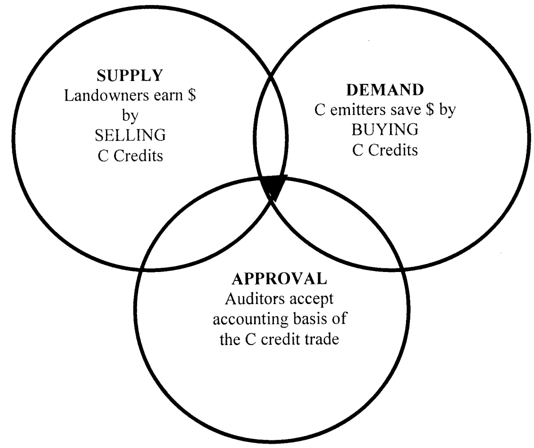


Figure 1. Necessary conditions for successful carbon sequestration credit trading.

Format of Presentation

The following sections describe and illustrate an "unofficial" method for standardizing the basis of carbon sequestration trades. The section 1 entitled Basic Concepts describes a few concepts that are essential for making economic sense of "early" carbon offset trades. The section entitled A Universal Credit Scoring Method describes an approach for comparing carbon sequestration investments and trades. The section entitled Illustrations and Applications shows results from applying the method to one reforestation project and one agricultural soil project and proposes a universal equation for scoring and comparing the credit earnings from competing carbon sequestration investments. The Conclusions section summarizes the important lessons that were learned by examining early carbon sequestration trades and attempting to develop a standard protocol for comparing them.

Basic Concepts

Carbon Markets and Risk

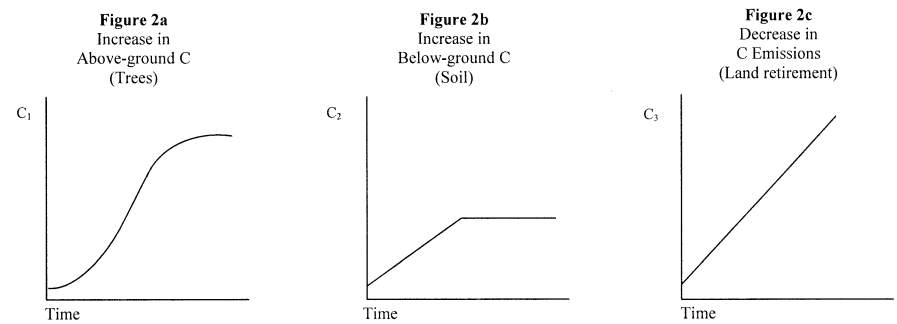
Markets deal very effectively with risk, time, and related differences in the quality or value of competing commodities. In most conventional markets, for example, buyers routinely make price/quality tradeoffs and adjust the prices they pay for competing commodities until their relative values are more or less the same. However, environmental credit markets are different. In general, buyers in these markets (credit seekers) are concerned with the price of obtaining credits; sellers (credit suppliers) are concerned primarily about the cost of producing credits; both are only as quality conscious as trade rules and trade auditors require them to be (see Figure 1). In fact, the economic returns to **both** buyers and sellers usually go up as the quality standards imposed on credits go down. The fact that environmental credit markets are not self-regulating in terms of quality/price tradeoffs is extremely important when considering "early" carbon sequestration trades that are not taking place under any official or unofficial trade rules. Buyers and sellers in these trades have economic incentives to be relatively lax about product quality standards. They also have economic incentives to use their involvement in early trading to "brand" themselves in emerging and potentially lucrative carbon offset markets.

The Trade Accounting Challenge

It is generally understood that trades based on carbon sequestration are more difficult to assess and compare than trades based on carbon emission reductions. The buyers in most of these early sequestration-based trades, for example, are investing money up front in projects that will generate carbon emission offsets that will trickle in over many years. Over time, the sequestered carbon that forms the basis of these offsets is at risk of being released into the atmosphere as a result of fire, flood, drought, wind, disease, invasive species, changes in land use, and so on. In general, time and risk have a much more important and complicated impact on the expected credit outcome of trades based on carbon sequestration than on trades based on carbon emission reductions.

Trade Accounting Versus Carbon Accounting

Carbon experts are paying a great deal of attention to how the outcomes of carbon sequestration invest-



C_1 = metric tons of Carbon (tC) above ground in tree trunks, limbs, leaves, leaf litter, dead wood, etc.
C_2 = metric tons of Carbon (tC) below ground in forest soils
C_3 = metric tons of Carbon (tC) emission reductions from reducing energy and fertilizer use
C_T = Total Reduction in Atmospheric carbon
$= C_1 + C_2 + C_3$

Note: a metric ton of Carbon (C) is equivalent to 3.67 metric tons of atmospheric carbon dioxide (tCO_2)

Figure 2. Patterns of C sequestration and emission reduction.

ments and trades can be monitored and verified (Chomitz 2000). New low-cost technologies for measuring "project-level" outcomes are being developed that include high-resolution aerial photography to measure aboveground carbon, and digital soil probes to measure belowground carbon. These tools will be indispensable to trade auditors who will be charged with monitoring and verifying the outcomes of carbon sequestration projects. However, the information that traders need to compare options requires carbon accounting tools based on "leading indicators" or forecasts of expected credit earnings. Tools for measuring aboveground and belowground carbon are not useful for this purpose. In time, they may provide a solid basis for forecasting expected rates of carbon sequestration, but for the near future, they do not. The information that is available to support the decision-making regarding early investments in carbon sequestration are associated with (1) site and project conditions that affect expected rates of carbon sequestration and (2) how future credit trade auditors will account for time and risk in the scoring of carbon credits.

The Gold Standard for a Carbon Credit

To make sense of any particular carbon offset credit trade, it is necessary to view a credit as a right to release one ton of CO_2 into the atmosphere. In order to compare trades that involve different patterns of credit earnings, it is useful to put a time reference on this credit standard such that a standard credit is a right to release 1 ton of CO_2 into the atmosphere at a particular point in time. The "gold standard" for a CO_2 emission allowance credit defined in this way is a voluntary reduction of 1 ton in CO_2 emissions that takes place near the same time as the 1-ton increase in CO_2 emissions it is providing the offset against. In terms of strict carbon accounting, this provides a relatively riskless one-for-one offset and makes the role of any credit trade regulator relatively simple.

However, based on this credit standard, how many credits is an investment in a carbon sequestration project worth? These projects generate carbon offsets that trickle in over time, if they succeed. For a carbon credit associated with sequestration to be viewed as being in the same risk category as a credit earned via CO_2 emission reductions, it also requires commitments to long-term land-use restrictions to keep sequestered carbon from being released into the atmosphere.

Trade Assessment Criteria

The three general criteria that investors should use to assess and compare investments in carbon sequestration are *performance, risks,* and *costs.* These criteria and the measures that can be used to distinguish between projects are as follows.

Performance. The amount of carbon sequestered over time as a result of a project can be measured in each of the following three categories:

1 *Increases in aboveground sequestration* (e.g., trunks, limbs, leaves, leaf litter, dead trees) The accumulation of C in aboveground biomass generally follows an S-shaped (logistic) curve (see Figure 2a). Annual accumulation rates peak about midway through the tree growth cycle (e.g., 40 years) and decline to very low rates as the tree stand matures. These low rates may continue for long periods, with new trees replacing standing or down-dead material that may take decades to decompose. The result is a slow, but

Table 1. Categories of carbon sequestration credit production costs

Category	Description of costs
Conversion costs	Cost of planning, site preparation, planting, and other tasks during year 1 (amortized)
Treatment and maintenance costs	Annual site maintenance costs, including watering, weeding, fire control, and other tasks (but not including C monitoring or verification)
Verification costs	Annualized cost of providing acceptable verification of baseline conditions, site suitability, C sequestration rates, and so on
Opportunity costs	Lost annual income from changing land use (based on existing land use)
Option costs	Loss of speculative value of land associated with restricting future land uses and forfeiting options to profit from potential new technologies and markets

Note: Opportunity costs are associated with foregone income that results from restricting land use in order to produce carbon credits. Option costs are associated with the decline in the speculative value of land that results from restricting future land uses in order to produce carbon credits. Both opportunity costs and option costs are usually reflected in the price landowners will accept to sell or lease land or to allow restrictive easements to be placed on land. The difference between the speculative value of land with and without land-use restrictions (option costs) is more difficult to measure than opportunity costs, but is extremely important. It explains why many landowners will not "sign up" to produce carbon credits at credit prices that seem to cover their production costs.

continuing increase in C accumulation for many years.

2 *Increases in belowground C sequestration* (e.g., soils). The accumulation of C below ground is relatively constant (linear) from year to year until the soil carbon reaches a steady state (about 25–50 years), where annual accumulation is offset by annual decomposition so that there is little or no measurable annual increase in soil C (see Figure 2b).

3 *Emission reductions* (e.g., less energy, fertilizer use). Carbon emission reductions result from land-use/land management changes that reduce energy/fertilizer use. These accumulate in a relatively constant (linear) pattern over time (see Figure 2c).

Costs. For purposes of most comparisons, it is appropriate to follow rules of full cost accounting, which means accounting for all costs regardless of who is paying them or why. Buyers and sellers in land-based carbon trades often measure project costs and benefits in different ways. Costs and benefits that accrue to parties other than those involved in the trade, for example, may not be considered at all by the trading partners. The opportunity cost of restricting the use of public land, for example, or the environmental benefits of reforesting public land may not be important considerations to trading partners. Measuring the potential ancillary benefits of sequestration projects and determining how the overall costs of a project should be allocated to carbon sequestration and to other potential benefits is beyond the scope of this study. For purposes of comparing investment options, we organize project costs into the five categories listed in Table 1.

Caveats Regarding Costs. The analysis presented here is based on a full accounting of project costs, but it addresses only the production of potential carbon credits. Not considering other factors that may affect the economic payoff from engaging in some trades may, in some cases, provide an unbalanced basis for comparing alternative sequestration projects and trades. Landowners who commit land to reforestation to produce carbon credits, for example, may maintain ownership of the land and may keep rights to timber stands that result from reforestation, which will have a market value at the end of the carbon trade accounting period. In times of increasing land and timber prices, this may make the economic payoff from reforestation high enough to justify projects even though the costs per credit appear to be relatively high.

Risks. Trade risks are associated with factors that influence the rate of increase in carbon sequestration that will result from a project (performance risk) and the likelihood that whatever level of carbon is sequestered as a result of the project will be released after the project (durability risk). Table 2 lists the most common types of risk associated with carbon sequestration projects and the most common sources of trade risks.

Timing

The method described in the next section takes account of time by allowing (but not requiring) the discounting of carbon credits that accrue in future years to their "present value." Using a nonzero discount factor reflects the generally held belief that benefits that accrue earlier (e.g., near-term reductions in atmospheric carbon) are worth more than benefits that accrue later. Discounting for time is not based on a scientific assessment of carbon emission impacts at different points in time. As applied here,

Table 2. Types and sources of risk

Types of Risk
Performance risk—the likelihood that the project will not achieve the expected rates of carbon sequestration
Durability risk—the likelihood that the carbon sequestered through successful projects will be released into the atmosphere before the end of the contract or trade accounting period
Baseline risk—the likelihood that some of the carbon gains at the project site would have resulted without the project
Displacement risk—the likelihood that the project will displace activities and associated carbon impacts to other sites, resulting in "leakage"
Sources of Risk
Project risks are associated with the following project stages:
Planning
Design
Implementation
Management
Contract risks are the following provisions of the trade:
Assignment of performance risk (e.g., to the buyer or seller or both)
Monitoring/verification of results (e.g., to validate/modify terms of trade)
Enforcement of trade obligations (e.g., liability in terms of money and/or carbon credits)
Physical risks are associated with largely uncontrollable natural events including the following:
Weather or climate events (e.g., windstorms, flooding, drought, fire, ice damage)
Disease
Insect infestation
Invasive species (noninsect)

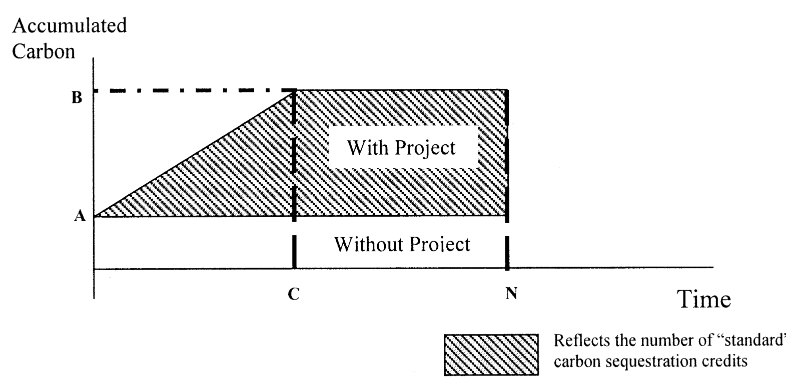


Figure 3. Accumulation of offset credits over time.

however, it does allow the scoring of credits to reflect the fact that the criteria adopted by future trade auditors are unlikely to score a ton of carbon sequestered in year 50 or 100 as "equivalent" to a ton of carbon sequestered in year 5 or 10. As applied here, the discount factor only accounts for differences in the timing of gains and losses in atmospheric carbon. It does not reflect risk or potential changes in the market price of credits over time.

A Universal Credit Scoring Method

The A, B, C's of Credit Scoring

The graph in Figure 3 illustrates how the expected accumulation of carbon above and below ground at a sequestration site can be expected to provide a basis for scoring credit earnings. It shows the level of carbon sequestered at the site, measured in metric tons of carbon (tC) per acre, increasing from level A, without the project, to a maximum level B after the project has had its full effect. This maximum level is shown to be achieved C years after initiation of the project.

The first step in assessing the credit basis of the project, therefore, is to estimate parameter values for A, B, and C. For example, if the level of carbon sequestered at the site prior to the project is 20 tons, and the project is expected to result in 120 tons being sequestered at the site after 50 years, then $A = 20$, $B = 120$, and $C = 50$. The total increase in carbon sequestered at the site as a result of the project, therefore, would be 100 tons $(B - A)$, and the average annual rate of carbon sequestration would be 2 tons $[(B - A)/C]$. Do

Table 3. List of credit scoring variables

Basic project parameters	
	(A) Level of carbon sequestered at the project site prior to the project
	(B) Level of carbon sequestered at the site after the project has had full effect
	(C) Number of years until the project will have full effect
Risk adjustment parameters	
	(a) Baseline risk—probability of changes in level of carbon at the site without the project
	(b) Project risk—probability that the project will not succeed, such that exp $B = B(1 - b)$
	(d) Durability risk—probability of postproject carbon release within the trading period
	(l) Leakage risk—percent of direct carbon gains offset by indirect carbon losses
Time adjustment parameters	
	(i) Time discount factor—used to adjust future gains and losses to "present value"
	(N) Length of the trade accounting period (may be greater or less than C)

not be bothered that this assumes a linear accumulation of carbon. That does not matter as much as one might think in terms of credit earnings, and it is far less important than adjusting expected outcomes for risk and time.

Adjusting for Risk and Time

The above-described approach employs basic project/site characteristics to estimate A, B, and C, but ignores time, risk, and other factors, such as the length of the trade accounting period, which might be 1, 10, 50, or 100 years. Table 3 lists and defines six parameters in addition to A, B, and C that can be used to take account of these factors. To appreciate the potential effects of each of these parameters on the number of credits associated with a project, consider the six credit scoring methods listed in Table 4 Scoring Method #1 ignores time and risk altogether ($a, b, d, l, i = 0$). Subsequent methods consider an increasing number of factors, ending with Scoring Method #6, which considers time and all types of risk ($a, b, d, l, i > 0$).

A Three-Step Method for "Scoring" Trades

Applying the above-illustrated method to evaluate specific carbon sequestration investments and trades in terms of expected CO_2 emission offsets is a three-step process.

1 Step 1: Estimate the unadjusted (nominal) carbon credit basis using specific site/project values for A, B, and C.
2 Step 2: Adjust the nominal carbon credit basis estimated using A, B, and C to account for risk and the possibility of a shifting baseline using b, d, and a to arrive at a number of "standard" credits.
3 Step 3: Discount the number of "nominal" credits to account for time using i and for the possibility of leakage using l to determine the number of "standard" (time and risk adjusted) credits over an assumed trading period of N years.

Sensitivity Analysis

Table 4 lists six alternative credit scoring "Methods" that reflect how time and risk will affect project outcomes. Figure 4 graphically depicts how credit earnings accrue using each method. The initial scoring method (Method #1), for example, is based on gross levels of carbon sequestration alone, taking no account of time or risk. Subsequent methods incrementally consider risk factors and the effects of time such that Method #6 accounts for all risks and time. For each project under consideration, it makes sense to estimate or assume project-specific/site-specific values for each of the parameters listed in Table 3 and use each of the scoring methods listed in Table 4 to determine two outcomes: the number of credits earned per acre and the expected cost per credit. It is reasonable to expect that future credit trading standards and guidance will resemble Method #6 because it captures all of the trade scoring issues that are being discussed nationally and internationally. However, we make *no value judgments about which factors or scoring method future trade auditors should use to assign credits to projects.* For example, if investors choose to ignore the effects of time and risk on the scoring of credit earnings, they can base their investment decisions on Method #1.

A Universal Scoring Equation

Figure 5 presents a general equation that can be used to score carbon sequestration investments using any or all of the methods depicted in Figures 7 and 8. Users can ignore time and risk, set all the parameters other than A, B, and C equal to zero, and use Method #1 to establish the number of offset credits associated with an investment or trade, or they can use what they know about the project site and land-use/land management changes to specify nonzero values for the other parameters and generate a fully adjusted estimate of "standard" project credits using Method #6. Note that because project costs will be the same regardless of which scoring method is chosen, the selection of scoring method, because it determines the number of credits, has an enormous effect on the estimated cost/price of a "standard" credit.

Table 4. Scoring methods (from no adjustments to full adjustments for risks and time)

Method	Description
Method #1	Nominal scoring, no adjustments ($a, b, d, l, i = 0$)
Method #2	Adjusted for project risk ($b > 0$; $a, d, l, i = 0$)
Method #3	Adjusted for project risk and durability risk ($b, d > 0$; $a, l, i = 0$)
Method #4	Adjusted for project and durability, risk, and time discounting ($b, d, i > 0$; $a, l = 0$)
Method #5	Adjusted for project, durability, baseline risk, and time discounting ($a, b, d, i > 0$; $l = 0$)
Method #6	Adjusted for all risk, including leakage risk and time discounting ($a, b, d, i, l > 0$)

Note: Reduced forms of the universal carbon credit scoring equation presented in Figure 5 can be used to calculate credit earnings using Method #1 through Method #6.

The formula presented in Figure 5 can be used to score any type of carbon sequestration project using whatever credit scoring method the user chooses. Although it may appear formidable, it is actually a simple linear equation that employs the fewest possible number of parameters to take account of time and various types of risk when considering the credit outcomes of carbon sequestration investments and trades. Future trade regulators, in fact, may use far more complicated methods to score trades. Until these methods are developed, however, it makes sense to follow the three-step process outlined earlier to characterize projects and use the equation presented in Figure 5 as a basis for estimating credit costs.

Illustrations and Applications

Tables 5 and 6 show the results of applying the standard carbon sequestration credit scoring equation presented in Figure 5 to two typical United States-based trades. The first is a trade based on reforesting undeveloped land to achieve a 150-tC increase in carbon over 100 years (as described in the section entitled Basic Concepts). The second trade is based on an agricultural soil conservation project (e.g., shift from till to no till) that is expected to result in a net annual increase in soil carbon of 0.2 tC until the soil becomes carbon saturated after 30 years. The nine parameters used to score trades based on each project are listed in Table 5 Each trade is scored on the basis of a 50-year trade accounting period. Describing the technical basis for establishing the parameter values in each trade is beyond the scope of this article. However, an examination of the values assigned to the nine project performance and credit scoring parameters, and the cost estimates for each illustration will reveal that they are reasonable.

Results shown in Table 6 illustrate the sensitivity of credit earnings and credit costs to alternative assumptions about trade scoring. For example, for Illustration #1, the reforestation project, results show that the number of "standard" credits per acre over the life of the project could be as high as 86 tC and the cost per offset credit could be as low as $1.74 per ton of carbon. These are the figures cited in press releases about actual trades that are similar to the one depicted in Illustration #1. However, these are the results only if trade auditors are assumed to ignore time and risk when scoring project performance and if land costs are ignored. Accounting for time and risk (using preliminary but very reasonable parameter values for *a, b, c, d, i,* and *l*), the number of "standard" credits earned per acre is 21; accounting for the full cost of the project, including land costs, the cost per ton of carbon is approximately $56.67, or 39 times higher than the unadjusted cost estimate.

The results summarized in Table 6 illustrate the enormous effects of "scoring" assumptions on the economics of carbon sequestration trading. However, they actually include only some of these effects. Sensitivity tests using ranges of plausible values for key scoring parameters (e.g., annual baseline shifts of 0.5% or 1.0%, project failure rates of 0.5%, 1%, or 1.5%, and discount rates of 3%, 5%, and 7%) reveal even wider ranges of outcomes than those shown in Table 6.

Overall, results show that the number of "standard" credits and the cost of producing "standard" credits vary by several orders of magnitude depending on assumptions about the treatment of issues that are being discussed by carbon sequestration trading experts under terms such as time, risk, durability, permanence, additionality, leakage, and baseline shifting. Results also show how near-term market signals provided by "early" trades (e.g., published prices and costs) may not be providing the proper market signals or incentives to potential carbon traders. Proponents of market-based climate change solutions, and carbon sequestration credit trading in particular, should not wait for international government organizations to remedy this situation. If energy companies want to use early trading to learn by doing, voluntary carbon and cost accounting standards should be established to be sure they learn

Figure 4a
Scoring Method #1
Nominal Scoring
(no adjustments)
(**a**, **b**, **d**, **i**, **l** = 0)

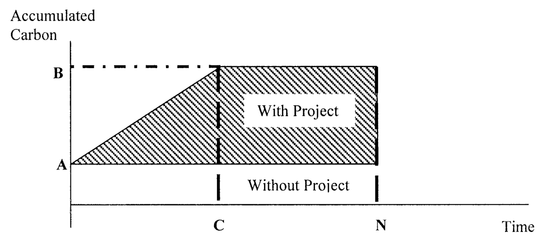


Figure 4b
Scoring Method #2
Adjusted for:
- Project Risk

(**b** > 0; but **a**, **d**, **i**, **l** = 0)

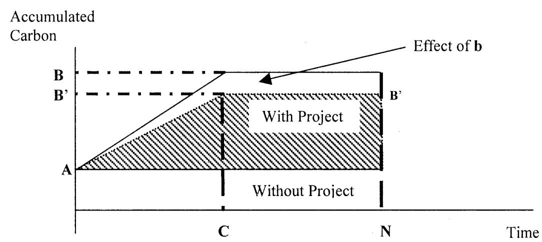


Figure 4c
Scoring Method #3
Adjusted for:
- Project Risk
- Durability Risk

(**b** > 0, **d** > 0; but **a**, **i**, **l** = 0)

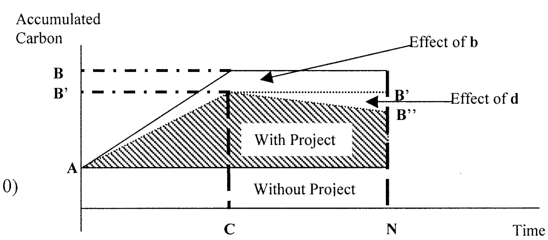


Figure 4d
Scoring Method #4
Adjusted for:
- Project Risk
- Durability Risk
- Time discounting

(**b** > 0, **d** > 0, **i** > 0; but **a**, **l** = 0)

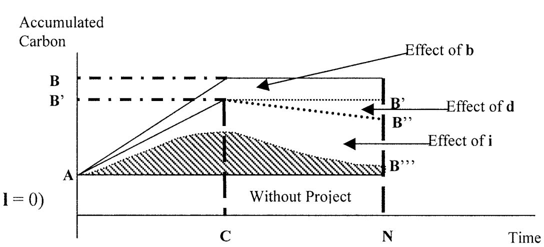


Figure 4e
Scoring Method #5
Adjusted for:
- Project Risk
- Durability Risk
- Time discounting
- Shifting Baseline

(**a**, **b**, **d**, **i**, > 0; but **l** = 0)

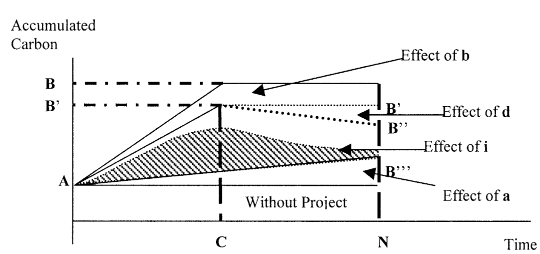


Figure 4f
Scoring Method #6
Adjusted for:
- Project Risk
- Durability Risk
- Time discounting
- Shifting Baseline
- Leakage

(**a**, **b**, **d**, **i**, **l** > 0)

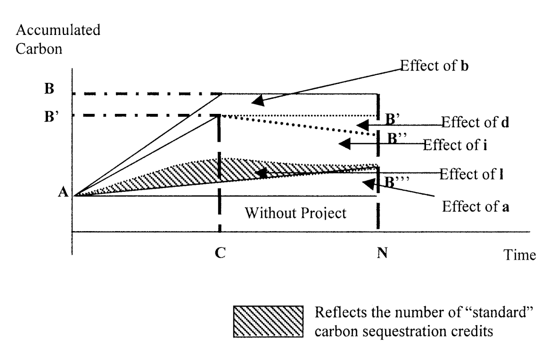


Figure 4. Graphical depictions of credit accrual under various scoring methods.

Overview

- Standardizes project-level accounting and provides a basis for assessing the equivalency of carbon credit trades.
- Parameters can be set to reflect: 1) site/project characteristics, 2) project and post-project risks, and 3) alternative trade scoring criteria.
- Uses the same nine parameters to estimate number of standard credits (**K**) generated by all kinds of sequestration projects.

The Equation

$$K = \left[\sum_{t=1}^{t=C} \frac{[(B(1-b)/C)(1-d) - A(1+a)/C}{(1+i)^t} \right] * \left[1 - \sum_{t=C+1}^{t=N} \frac{d}{(1+i)^t} \right] * [1-l]$$

Where:

K = Cumulative number of "standard" carbon sequestration credits earned over the life of a project undertaken at the beginning of year **t**=1, where each unit of **K** reflects project outcomes sufficient to offset a (standard) one-ton increase in C emissions in year **t** = **1**, resulting in no net change in atmospheric carbon during a defined trade accounting period **N.**

A = Level of carbon sequestered at the site at the start of the project (e.g., 40 tC per acre).

a = Annual % change in **A** without the project. **a** < 0 implies an expected loss (e.g., logging) and **a** > 0 implies an expected gain (e.g., natural growth).

B = Level of carbon that will be sequestered at the site after a successful project has had its full effect (e.g., 100 tC per acre).

b = *performance risk* associated with the likelihood that the project will fail to achieve the expected level of carbon sequestration **B.** The level of carbon expected at year **C**, after accounting for this risk, is **B** (1 - **b**), and the expected annual increase in carbon sequestration during the project period is **B** (1 - **b**)/**C**.

C = Number of years before a successful project achieves full effect (e.g., 25 years to achieve **B**), based on biophysical characteristics, not trade accounting.

M = Length of the trade contract period that limits the number of "standard" credits **K** associated with the trade.
{Note: **M** is assumed here to be equal to **C**, such that the buyer in a trade contracts with the seller for all the credits **K** generated by a project.}

N = Number of years in the trade accounting period used to score gains and losses in atmospheric carbon (e.g., 50-year carbon trading horizon).

d = *durability risk*associated with the likelihood that carbon sequestered as a result of a successful project will be released into the atmosphere due to uncontrollable natural events. Up to year **C** positive values of **d** result in downward adjustments to the annual accrual of credits. During year **C** + 1 to year **N** positive values of **d** result in a decline in the number of credits earned through year **C**. In the above formulation, **d** is constant for all years before and after **C** through year **N**. *{Note that project performance risks reflected in **b** exist from year 1 through year C, while durability risks reflected in **d** exist from year 1 through year N.}*

i = % discount rate used to adjust gains and losses in different time periods to their present value in year **t** = 0 (e.g., **i** = 0% or **i** = 5 or 7%).

l = % of net carbon gains from the project that will be offset by carbon losses resulting from displaced activity.

Figure 5. General approach to standardizing carbon sequestration credits using a carbon sequestration credit (CSC) equation.

Table 5. Sensitivity of credit earnings and credit costs to alternative credit scoring methods; Project-specific credit scoring parameters (based on typical project characteristics)

	A	*B*	*C*	*a*	*b*	*d*	*i*	*l*	*N*
Illustration #1									
Reforestation project	40	160	70	0.01	0.005	0.005	0.05	0	50
Illustration #2									
Shift from till to no-till farming	10	16	30	0.005	0.005	0.005	0.05	0	50

Table 6. Sensitivity of credit earnings and costs to alternative credit scoring methods; Effects of scoring on case studies (credits and cost per credit)

	Illustration #1: Reforestation			Illustration #2: Conservation tillage			
		Cost per credit			Cost Per Credit		
Scoring method	Credit/acre	at $150/acre	at $1,190/acre	Credit/Acre	at $25/acre	at $50/acre	at $100/acre
Method #1	86	$1.74	$13.84	6	$4.22	$8.45	$16.89
Method #2	85	$1.76	$14.00	6	$4.28	$8.56	$17.12
Method #3	66	$2.27	$18.03	5	$5.06	$10.12	$20.24
Method #4	23	$6.52	$51.74	3	$9.19	$18.38	$36.76
Method #5	21	$7.14	$56.67	2	$10.25	$20.49	$40.98
Method #6	21	$7.14	$56.67	2	$10.25	$20.49	$40.98

the right lessons. One lesson is that using early trades to achieve short-term public relations benefits, if those trades do not address essential trade accounting issues, is very likely to backfire. By undermining public support for "official" trading, these early trades could cost the companies involved, and everyone else, in terms of lost opportunities to use market-based solutions and reduce the cost of achieving GHG reduction targets.

Conclusions

With "official" carbon sequestration credit trading still years away, and no standard basis for "scoring" early carbon sequestration trades, those who stand to gain from having others invest in carbon sequestration offset projects can base their claims about potential payoffs on whatever assumptions they choose. Strong economic and political incentives exist for sellers and buyers involved in these trades to overstate the number of carbon emission offsets they will be worth once "official" trading begins. This "quality uncertainty," in addition to resulting in some bad investments for individual firms, is costly to everyone else in at least three ways. First, bad trades, and the improper price signals associated with them, will force good trades out of emerging carbon offset markets. Second, a track record of bad early "unofficial" trades will undermine public support for "official" trading. Third, ignoring the inherent riskiness of these trades, one typical way that expectations about trade outcomes are inflated, will prevent the development of market-based solutions for managing trade risks (e.g., weather insurance).

From a credit trading perspective, the important focus is not carbon accounting, but accounting based on expected numbers of valid carbon emission offsets. The review of early carbon sequestration trades discussed in this article indicates that buyers, sellers, trade auditors and verifiers, and others involved in early carbon sequestration trades are basing their expectations on widely varying assumptions about how future trade regulators will deal with time and risk and matters being discussed using terms like baseline setting, leakage, additionality, and durability. Some traders simply choose to assume that these matters will be ignored and that a ton of carbon sequestered will always offset a ton of carbon emitted. This is not a realistic assumption on which to base investment or credit pricing decisions.

The standardized carbon sequestration credit scoring equation that is developed and illustrated in this article provides a realistic basis for assessing and comparing the expected economic payoff from carbon sequestration investments and trades. Users can make whatever assumptions they choose about which factors will be used to determine the "creditworthiness" of their investments and trades. They can then examine the sensitivity of their credit earnings to these assumptions. Individual firms can use the equation to evaluate early investments and trades and to avoid costly and embarrassing mistakes, especially during the years leading up to official trading. Trading advocates can use the equation to protect the integrity of emerging carbon credit markets by using it to call attention to exaggerated claims by credit buyers and sellers. Third-party entrepreneurs, such as credit consolidators and insurers, can use the equation to evaluate risks and design portfolios of projects that diversify risks and reduce uncertainty.

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