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Comparison of registry methodologies for reporting carbon benefits for afforestation projects in the United States☆

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ABSTRACT

No mandatory national program currently exists to mitigate climate change in the US Consequently, voluntary programs and mandatory state-level programs are multiplying to allow users to register emission-offset activities, creating multiple often contradictory measurement and recording standards.

For the land use sector we examined a hypothetical project: tree planting on rangelands in California. We apply four sets of protocols from the following registries – the California Climate Action Registry, the Chicago Climate Exchange (CCX), the Regional Greenhouse Gas Initiative and the USDOE 1605(b) program – and compare the results to the 'actual' net sequestration and also briefly compare them to international protocols such as the relevant Clean Development Mechanism methodology. Carbon in land use can be estimated accurately, precisely and cost-effectively, but to achieve this requires good protocols. As predicted, the consequence of applying different protocols for reportable carbon was significant. The choice of measurement pools, the handling of the baseline and the issue of uncertainty led to a baseline estimate of 0–66,690 t CO_2-e, and final sequestered carbon totals (after 60 years) that varied between 118,044 and 312,685 t CO_2-e—a factor of 2.5 difference. The amount reported under 1605(b) is the closest to "actual" with CCX entity reporting the most divergent.

1. Introduction

In 2007 for the first time the global scientific community in the 2007 IPCC report (IPCC, 2007) agreed that the warming of the climate is 'unequivocal' and that this observed increase is due to anthropogenic GHG emissions. This statement has elevated climate change mitigation to one of high importance for the countries of the world to address. There is a growing interest in the US for quantifying and reducing greenhouse gas (GHG) emissions. In 2002, the US government established a national goal of reducing GHG *emissions intensity* by 18% by 2012.[1] On a state level, targets are more ambitious. The Governors of seven Northeastern States (Regional Greenhouse Gas Initiative—RGGI) have agreed to *stabilize emissions* from power plants between 2009 and 2015, followed by a 10% reduction by 2019.[2] The state of California has committed to ambitious GHG

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[1] http://www.whitehouse.gov/ceq/global-change.html.

[2] http://www.rggi.org/docs/mou_brief_12_20_05.pdf.

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emissions reductions to 2000 levels by 2010, 1990 levels by 2020 and 80% below 1990 levels by 2050.[3]

Changes in the use and management of the land are activities available at the national and state levels that can mitigate GHG emissions by sequestering carbon in new forests or conserving existing carbon stocks under threat. Carbon dioxide in the atmosphere can be reduced by establishing forests on lands that have been used for other purposes such as agricultural production, resulting in the sequestration of carbon dioxide into biomass and in soil. Emissions from forest lands can be reduced by: protecting forests under threat for conversion to non-forest uses such as urban development; by changing forest management practices such as lengthening rotations or reducing the harvest intensity; or by reducing the incidence of uncharacteristically severe wildfires. Achieving GHG reductions on forest lands may have the additional benefits of potentially enhancing biodiversity and protecting watersheds.

The US Government's policy of an 18% reduction in GHG emissions intensity is to be achieved largely through voluntary activities and voluntary reporting by emitting entities. In contrast, California and the RGGI states have established mandatory emissions caps on emitting sectors, offsets and a trading system. Both CA and the RGGI states have developed rules that allow for forest-based carbon offsets.

Four major registries are in operation or coming into operation in the US:

- *1605(b)*: The voluntary reporting system of the US Government is known as 1605(b) after Section 1605(b) of the Energy Policy Act of 1992. The 1605(b) program is run by the US Department of Energy.
- *CCAR*: To manage registration of emissions in California, the State Government established a non-profit registry of greenhouse gas emissions known as the California Climate Action Registry (CCAR).[4] Registrants may use offset projects to help attain their emissions reduction targets.
- *RGGI*: The Regional Greenhouse Gas Initiative[5] will register emissions and reductions in emissions from power plants. Entities may use offset projects to reach their emission reduction targets.
- *CCX*: The Chicago Climate Exchange (CCX)[6] was the world's first greenhouse gas emissions registry. It is a self-regulated, rules-based registry governed by members that commit to voluntary reduction targets. Members trade 'carbon financial instrument contracts' (CFIs)—one contract being equal to 100 metric tons of carbon dioxide.

Each of CCX, CCAR, RGGI and 1605(b) have protocols for measuring, monitoring and reporting of emissions and sequestration from the land use change and forestry sector.

Given the state of the various programs within the United States – voluntary and potentially regulatory – and the different monitoring and reporting protocols available, the question arises of the comparability and interchangeability of the GHG benefits generated. The aim of this study is to examine and compare the forest protocols from the 1605(b) program (USDOE, 2006), CCX (CCX, 2008), RGGIs Model Rule (RGGI, 2007) and CCARs Forest Project Protocol (CCAR, 2004), and to apply these protocols using a hypothetical, but typical afforestation project activity.

At an international level, climate change mitigation programs exist. The most important of these programs are the flexibility mechanisms of the Kyoto Protocol (the Clean Development Mechanism [CDM] in developing countries, and Joint Implementation [JI] in developed countries). Although significant debate exists among experts over these rapidly evolving programs, the CDM in particular, sets a standard against which other programs could be compared other international mitigation reporting programs or methodologies include the WRI/WBCSD's (World Resources Institute and the World Business Council for Sustainable Development) Greenhouse Gas Protocol's *Land Use, Land-Use Change and Forestry Guidance for GHG Project Accounting* methods (WRI, 2006), and standards and methodologies under the World Bank's Carbon Funds. These other programs are not assessed here (see, e.g., Sathaye and Andrasko, 2007).

Applying the four US-based protocols to a hypothetical but yet realistic project has the purpose of demonstrating how well actual field carbon pools and project components would be represented by each of the monitoring and reporting systems. The lessons learned by this comparison will have implications for other protocols being developed.

We tested and compared the registries by applying them to a pilot project in California. California was chosen because Winrock International has done extensive analysis of the potential C supply through terrestrial carbon sequestration activities, developed statewide baselines for forestry activities and collected field data for old-growth and managed forests in both the coastal redwood area and the Sierra mixed conifers (Brown et al., 2004a,b,c). The hypothetical pilot project was afforestation of grazing lands located in Shasta County, CA—a common GHG mitigation project type, also allowable under all four of the protocols reviewed.

In the analysis we compared and contrasted the results of applying each protocol to the project with respect to each of the key project-based activity issues (the principles for assurance of project quality): additionality, baseline, leakage, permanence, carbon measuring and monitoring, and potential carbon benefits. Ultimately the protocols are judged based on how correctly greenhouse gas sequestration and emissions are accounted and on profitability for landowners in terms of the balance between protocol implementation and monitoring costs and total claimable credits. Landowners or other project developers generally get paid on actual ''delivery' of the claimable carbon credits—that is they only get paid when they can actually show, though measuring and monitoring their project, that the carbon has been sequestered.

2. Methods

2.1. *The case study*

The hypothetical afforestation project is located in Shasta County in northern California. The site totals 285 ha (704 acres)

[3] Executive Order S-3-05. http://www.dot.ca.gov/hq/energy/ExecOrderS-3-05.htm.

[4] http://climateregistry.org.

[5] http://www.rggi.org.

[6] http://www.chicagoclimatex.com.

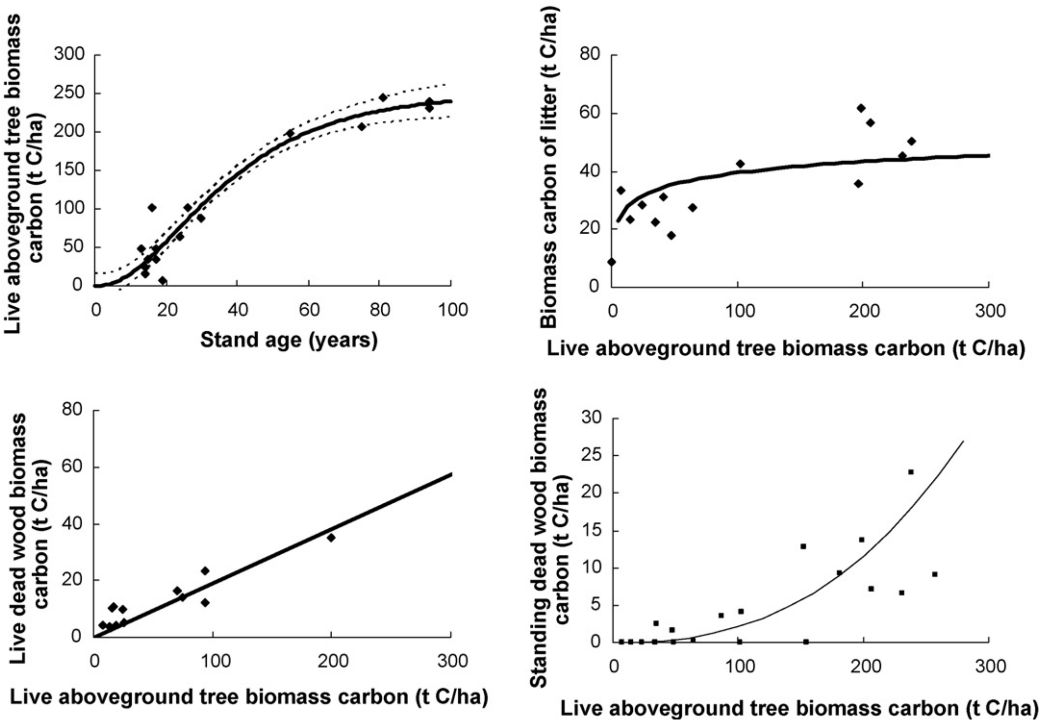

Fig. 1 – Estimates of the carbon stocks in Sierran mixed conifer forest based on field measurements (Brown et al., 2004c), which are assumed to apply to the hypothetical project.

in two neighboring parcels (41°7′–41°9′N; 121°30′–121°34′W). The parcels are surrounded by private forest lands, Department of Interior/Bureau of Land Management Lands and US National Forest Service's Shasta-Trinity National Forest. The existing land use in the project area is grazed rangeland. We concluded that the site was probably cleared of forest by fire (the perimeter of fires in 1973 and 1977 overlaps almost completely with the project locations) and that the lack of forest cover was maintained by continued grazing pressure. This project area was deemed suitable for an afforestation activity based on an analysis of the suitability of existing grazing lands in California to support forests (Brown et al., 2004a).

The hypothetical project consisted of initial site preparation to clear the existing shrub vegetation followed by planting with mixed coniferous species. A mix of ponderosa pine, sugar pine and Douglas fir was planted at a density of about 120 trees/ha. Herbicides were applied as necessary to control competing vegetation. At year 10 thinning occurred to reduce stocking to ~60 trees/ha. No subsequent management occurred.

Throughout this analysis results from application of protocols will be compared against the 'actual' sequestration or emission totals. The 'actual' totals could only ever be known with perfect monitoring systems conducting a 100% census. However, given that this is a hypothetical project it is possible for us to know the 'actual' totals and use these as the basis of comparisons.

The projected baseline is a continued use as a grazed rangeland. The carbon stock is expected to remain unchanged as a constant carbon stock in grasses and shrubs.

The rate of accumulation in each of the carbon pools is based on estimates from field measurements of chronosequences of sites in Sierra mixed conifer forest (Brown et al., 2004c; Fig. 1). Belowground biomass is added using the temperate equation of Cairns et al. (1997). From this point forward the stocks from these measurements and analyses are taken as the stocks in the hypothetical project.

2.2. *Key principles for assurance of carbon project quality*

The following represents a list and description of key principles that, when proven at the project level, act to assure carbon project quality (cf. Cathcart and Delaney, 2006).

2.2.1. *Additionality*

Additionality is the demonstration that carbon project financing has directly led to an increase in sequestration or a decrease in emissions. In the international arena, in particular under the Kyoto Protocol, additionality is the requirement that projects demonstrate their activities would not occur in the absence of the project and climate change funding. Additionality is demonstrated by meeting tests for project financial viability and/or showing the presence of barriers to implementation that will only be overcome through carbon financing. In other words, a project that is additional would not occur in the absence of GHG mitigation project finances. Within the US many refer to a different much simpler definition of additionality, which is the positive difference in carbon between the project and the baseline. Here we refer additionality as either regulatory additionality (is the activity to be undertaken already required by local, state, or federal

Table 1 – Key facets of the forestry protocols for 1605(b), the Chicago Climate Exchange, the Regional Greenhouse Gas Initiative and the California Climate Action Registry

	CCX	CCAR	RGGI	1605(b)
Admissible activities	Unlimited for reporting on own lands Limited to reforestation, 'sustainably managed forests' and conservation on ''offset'' lands	Forest-management; reforestation; conservation	Afforestation	Unlimited, except for activities that require a baseline to show benefit, such as conservation of mature forest
Measurement pools	Wood in the main stem of the tree up to the terminal bud for entity accounting For offset activities—above and belowground tree biomass and soil organic carbon	Required: live aboveground tree biomass; live belowground tree biomass; standing and down dead wood Optional: all other pools are optional and can not be certified	Required: live aboveground tree biomass; live belowground tree biomass; soil carbon; dead organic matter, coarse woody debris (optional if baseline measurement is at or near zero) Optional: live aboveground non-tree biomass; dead organic matter, forest floor	All pools included. Pools can be omitted as long as they do not lead to greater than de minimis[a] emissions
Measurement requirements	Measurement required Permanent plots allowed	Permanent plots required	Measurement required but permanent plots practically excluded	Measurement not required for registration
Baseline	Cap and trade Baseline for ''offset'' conservation activities	Required	Required	1–4 base years
Non-CO_2 gases	Non-CO_2 gases are not included	Optional	Not discussed in model rule	Required if are more than *de minimis*
Leakage[b]	All forest land inside and outside the project must be managed *sustainably*, but this does not preclude leakage	Assessment of activity shifting is required, but quantification only required if on-site Assessment of market effects, upstream and downstream effects only encouraged	Not discussed in model rule	Must certify activities do not lead to increased emissions elsewhere in entity, but no requirements for outside entity boundaries
Permanence	Indefinite reporting required on own lands Project activities require ''legal protection status''	Legal easement required	Legal easement required	Indefinite reporting required to remain in program
Additionality	No requirement for financial additionality Not applicable for entity reporting	Requirement for regulatory additionality No requirement for financial additionality Not applicable for entity reporting	Requirement for regulatory additionality No requirement for financial additionality	No requirement for financial additionality
Timing	No forward crediting allowed	No forward crediting allowed	No forward crediting allowed	A project may elect to forward register 50% of the project benefit anticipated at 50 years
Third party certification	Required	Required	Required	Not required but encouraged

[a] De minimis is defined as greater than 3% of total sequestration or emissions.
[b] Leakage refers to unintended losses of net carbon benefit as a consequence of project activities.

Table 2 – Baseline components and estimation for the hypothetical afforestation project

	Actual	CCAR	1605(b)	RGGI	CCX
Baseline or base year(s)	Baseline	Baseline	Base years	Baseline	Base year
Estimation	66,690 t CO_2-e	0	54,758 t CO_2-e	51,015 t CO_2-e	0
Pools included in estimation	Non-tree vegetation and soil organic carbon	None	Non-tree vegetation and soil organic carbon	Soil organic carbon	None

law?) or financial additionality (is it likely that for financial motivations the activity would have been undertaken regardless of carbon financing?). Additionality is clearly only relevant for project reporting of offsets, it is not applicable where an entity is reporting its stocks and changes in stocks under a cap-and-trade system.

2.2.2. *Baseline*

The baseline is the emissions or removals of greenhouse gases that would occur without the project. In the case of this hypothetical project it is the continued carbon stocks present under the shrub and grass land cover.

2.2.3. *Permanence*

Permanence is a measure of the anticipated longevity of carbon sequestered as part of the carbon project activity. For tree planting projects, credits are issued for carbon sequestered from the atmosphere and stored in the trees and associated carbon pools. Without guarantees that the carbon is permanently sequestered then there are arguments that the offset credits are not genuine.

2.2.4. *Leakage*

Leakage is the loss of carbon outside the boundaries of the project as a result of project activities. So in this case if the project site was used for grazing land, the displaced rancher may cut down trees elsewhere to create replacement grazing land.

2.2.5. *Co-benefits*

Co-benefits are the project benefits arising from the project that are not directly related to greenhouse gases. Examples are social benefits, improvements in water quality or quantity or benefits to biodiversity.

2.2.6. *Timing*

Accrual of carbon benefits, for tree planting projects in particular, occur over many years, and a project developer generally gets paid when the credits are actually produced. Project protocols must define whether crediting is only possible subsequent to proof of sequestration or whether some forward crediting at a discounted rate is permissible.

Table 3 – Carbon stock in baseline (year 0) and after 60 years for the afforestation project as calculated under each of the protocols and as compared to "actual" stocks

Carbon pool	Carbon stock or emission					
	Actual	CCAR	1605(b)	RGGI	CCX project	CCX entity
Year 0						
Trees—aboveground	0	0	0	0	0	0
Trees—belowground	0	0	0	0	0	–
Standing dead	0	0	0	–	–	–
Down dead	0	0	0	–	–	–
Understory	15,675	–	15,675	–	–	–
Litter	0	–	0	–	–	–
Soil	50,091	–	39,083	51,015	–	–
Total	65,766	0	54,758	51,015	0	0
Year 60						
Trees—aboveground	202,730	209,000	209,000	209,000	209,000	118,044
Trees—belowground	50,423	51,983	51,983	51,983	51,983	–
Standing dead	11,892	12,135	5,748	–	–	–
Down dead	13,888	14,933	5,748	–	–	–
Understory	627	–	2,613	–	–	–
Litter	50,308	–	31,350	–	–	–
Soil	50,225	–	48,175	–	–	–
Total	380,093	288,050	354,615	311,998	260,983	118,044
Non-CO_2	−1,105	–	–	–	–	–
Project emissions	−448	–	–	–	–	–
Leakage	−49	–	–	–	–	–
Net total	312,685	288,050	299,857	260,983	260,983	118,044

Plus project emissions and leakage. All units are in thousand t CO_2-e.

Table 4 – Net GHG benefits of the afforestation project as calculated under each of the protocols and as compared to "actual" change

Year	Net project gain					
	Actual[a]	CCAR	1605(b)	RGGI[b]	CCX project	CCX entity
0	−16.8	0	−15.7	0	0	0
10	15.4	24.1	21.9	21.8	21.8	0
30	173.0	134.2	157.2	138.3	138.3	49.5
60	312.7	259.2	299.9	261.0	261.0	118.0
100	373.0	314.9	376.5	0	311.8	151.9

All units are in thousand t CO_2-e.
[a] Includes non-CO_2 emissions from site clearance and project emissions from vehicle-use and machinery use.
[b] No reporting beyond 60 years under RGGI.

2.3. *The protocols*

Some of the important similarities and differences between how the four protocols address the terms of project definition and the key principles for assurance of project quality given in Section 2.2 are listed in Table 1. For CCX different protocols exist depending on whether the activity is on the member's own lands (under the cap and trade system—termed entity accounting protocol here) or are to be counted as ''Exchange Offsets'' (i.e., GHG mitigation occurring outside one's own lands or facilities—termed project protocol here). Some of the differences for offset activities are highlighted in Table 1, but here both protocols are considered.

The four protocols vary with respect to how they address the key principles discussed above (Section 2.2). For example, for additionality, none of the protocols require a project developer to show financial additionality and only RGGI and CCAR require projects to show regulatory additionality (Table 1). Permanence is well addressed by all protocols, either through legal easements or indefinite reporting to remain registered. All protocols require a baseline except the 1605(b), which requires a base period of 1–4 years. Leakage is the most poorly addressed in all four protocols, ranging from a statement under the CCX that forest land inside and outside the project must be managed sustainably (this does not necessarily mean leakage is tracked or quantified) to no mention of it at all under RGGI.

2.3.1. *Uncertainty in quantifying the carbon credits*

Under its Forest Project Protocol, CCAR handles the issue of uncertainty in measuring, monitoring and the carbon credits by determining deductions that are scaled proportional to the uncertainty in the results from sampling and field measurements. CCAR selects the 90% confidence interval (as opposed to the more commonly applied 95% CI), and requires projects to calculate the half-width of the confidence interval as a percentage of the sampled mean. This is a representation of precision. A proportional deduction is then applied based on the half-width of the confidence interval, from zero deduction for a confidence interval within 5% of the sampled mean, a 10% deduction for 1/2 confidence interval equal to 10% of the sampled mean to a 100% deduction if the 1/2 confidence interval equals or exceeds 20% of the sampled mean. For reporting of forest lands within a CCAR-registered entity, the lower precision requirement of a standard error being within 20% of the sampled mean is required, this is comparable to a 1/2 95% confidence interval equal to approximately 40% of the sampled mean (given samples sizes of greater than 30).

1605(b) operates a grading system for monitoring activities. The project as a whole must achieve a 'B' grade. Typically

Table 5 – Baseline, net sequestration and carbon pool exclusions for each of the four protocols for the hypothetical afforestation project

	Actual	CCAR	1605(b)	RGGI	CCX project	CCX entity
Baseline	66,690	0	54,758	51,015[c]	0	0
Net carbon gain (after 60 years)	312,685	259,254[a]	299,857[b]	260,983	260,983	118,044
Excluded pools	None	Understory vegetation, forest floor, soil organic matter	None	Understory vegetation, coarse woody debris, forest floor	Branches, roots, understory vegetation, forest floor, soil organic matter	Roots, understory vegetation, forest floor, soil organic matter
Carbon benefit missed due to excluded pools	0	53,223	0	78,932	130,915	221,871

All units in t CO_2-e after 60 years.
[a] After uncertainty deduction.
[b] Only trees measured, dead wood, understory and forest floor added from 1605(b) look up tables for mixed conifer stands with afforestation of land in the Pacific Southwest.
[c] Soil organic matter.

Table 6 – Selected program incentives and disincentives to improve measurement and monitoring (MM) of project activities, and cost implications

	CCAR	1605(b)	RGGI	CCX
Incentives to improve MM	Precision less than 5% of the mean with 90% confidence requires a C discount, thus incentive to improve precision CCAR, CCX and 1605(b) have no time limit on C benefits	Can include or exclude carbon pools based on cost and expected sequestration, but must measure all pools that could emit carbon dioxide over the analysis period	Must achieve a precision equal to 10% of the mean with 95% confidence	Deduction for uncertainty required, but not yet defined
Disincentives to improve MM	Only required pools will be certified, so no incentive to include optional pools	The rating system requires only an average of a B which can be achieved through models so there is no requirement for field measurements	All carbon pools must be separately measured to 95% confidence. Acts as a disincentive to include optional pools. Soil carbon must be measured to this high precision level even if no accumulation is expected Permanent plots excluded. C benefits limited to 60 years	For projects, only tree stem biomass considered. No incentive to include other pools For entity measurements only aboveground tree biomass considered
Cost implications	Allows pools to be combined to determine 95% confidence, dominated by high-C tree stems, which reduces costs of sampling low-C pools	Lookup tables and online calculators (e.g., COLE, COMET-VCR) reduce sampling costs	High confidence for low-C pools never cost effective	Stem biomass only approach for entity reporting can be measured inexpensively but halves C benefits, raising cost

on-the-ground measurements give an A-grade, a locally parameterized model gives a B-grade and ‘‘default look-up tables’’ (based on Forest Inventory and analysis data base given in Smith et al., 2006) give a C-grade, but in cases where measurement knowledge is limited then higher grades will result from using models or look up tables. Equally, validating data will raise the grade, so that a model incorporating local ground data or a look-up table validated with local data can receive an A-grade. For the portion of the assessment that is physically sampled a precision equal to 10% of the mean with 95% confidence is required with no deduction. The logic behind this approach is to minimize costs to land-owners wishing to participate in greenhouse gas programs. 1605(b) is a voluntary program and for any program forming a part of a trading system field measurement is invariably expected.

RGGI requires that each pool must separately achieve a high precision rather than the pools combined together—in this case each pool must be measured to a precision whereby the 95% confidence interval is within 10% of the sampled mean. Effectively, this means it will not be cost effective to track the stocks in dead organic matter or non-tree vegetation because these pools tend to be very variable and would need a high number of sample plots to achieve the required precision.

CCX requires a ‘‘discount’’ to account for the ‘‘statistical variance’’ associated with the methods used. The rulebook states that methods for calculating uncertainty including confidence levels must be approved by the Forestry Committee. No published detailed guidance is currently given.

2.4. ‘‘Actual’’ stocks and changes in stocks

2.4.1. Baseline

The baseline for this afforestation project is shrubs and grasses on a grazed rangeland. No trees are present. The carbon stocks that are in existence include non-tree vegetation and those present in soil. As the site has been used as grazing land for many years we assume the soil is neither gaining nor losing carbon. Site preparation results in the emission of the stocks present in the shrubs and grasses with an assumption of no additional emissions from the soil (soil disturbance was minimal). The constant baseline stocks in shrubs and grasses on the project site are equal to 55 t CO_2-e/ha (all values are in metric tons) or 15,675 t CO_2-e over the 285 project hectares. The constant baseline soil carbon stocks are equal to 179 t CO_2-e/ha or 51,015 t CO_2-e over the 285 project hectares (Table 2).

2.4.2. Activity

The ‘actual’ data for the project area include the time zero ‘site preparation’ emissions including the CO_2 and non-CO_2 emissions from cutting and burning the shrubs and grasses, and the transport and machinery necessary for the site preparation to occur. The volatilized shrubs and grasses over the 285 ha are equivalent to 15,675 t CO_2 plus 1105 t CO_2-e in non-CO_2 gases. The total time zero emissions are equal to 16,789 t CO_2-e.

Over 60 years, the project sequestration totals 330,000 t of CO_2 with 61% in aboveground tree biomass, 15% in belowground tree biomass, 0.2% in understory vegetation, 4% in down dead wood, 4% in standing dead wood, 15% in litter and 0.04% in soil organic carbon accumulation. After 100 years the sequestered total rises to 391,000 t CO_2-e. Net of project emissions, the sequestered total is 313,000 t CO_2-e after 60 years and 373,000 t CO_2-e after 100 years (Tables 3–5).

2.4.3. Non-CO_2 gases

Fire was used to clear the existing vegetation (70% of the pre-fire biomass was volatilized), using Intergovernmental Panel on Climate Change (IPCC) Tier 1 methods (IPCC, 2006), we would predict an emission of: 1005 t CO_2-e in the form of methane and 102 t CO_2-e as nitrous oxide. Vehicle and machinery use totals 8.8 t CO_2-e annually.

3. Results

3.1. Application of protocols

3.1.1. Baseline

CCAR: CCAR requires project developers to quantify the existing stocks and forecast the stock over time. CCAR only certifies the required measurement pools—living tree biomass and standing and lying dead wood. There is therefore little value in including the optional pools in the inventory and accounting under the CCAR program.

The baseline stocks are in shrubs and grasses and soil organic carbon on the grazed rangeland. These are optional pools, cannot be registered and we argue would not be measured and accounted for by a landowner to minimize their cost. Therefore under CCAR the baseline carbon stock is zero (Table 2).

1605(b): 1605(b) uses a base year or up to 4 base years. The base year stocks over the 4 years prior to the start of project activities would be the constant baseline stocks in shrubs and grasses on the project site of 55 t CO_2-e/ha or 15,675 t CO_2-e over the 285 project hectares.

Baseline stocks will also exist in soil carbon. However, sampling of soil carbon stocks through a project is likely to have significant associated costs. Under the 1605(b) rating system, sampling of all pools would achieve an A rating. As stated in the section on uncertainty under 1605(b), only a B rating is required across the project. So that a lower precision in for example the soil carbon pool from using look up tables could be balanced by a higher precisions/grade in other pools. Soil carbon values are therefore used here from the default look-up table for afforestation of mixed conifer in the Pacific Southwest (Table B27, in Smith et al., 2006). Using this look-up table, the soil carbon baseline value is 137 t CO_2-e/ha or 39,083 t CO_2-e over the 285 project hectares. Giving a combined stock of 54,758 t CO_2-e (Table 2).

RGGI: For RGGI, non-tree vegetation is an optional pool and so the baseline shrubs and grasses would not be accounted. Therefore, the only baseline pool accounted will be soil carbon that, in contrast to the other protocols, is required under RGGI. The time zero carbon stock in soil for the rangelands was measured to a mean of 179 t CO_2-e/ha or 51,015 t CO_2-e over the 285 project hectares (Table 2).

CCX: For CCX, the baseline stocks are in non-tree vegetation, which is a non-eligible CCX pool. In addition, for the entity protocol all lands are under cap-and-trade so no baseline will exist. Effectively cap-and-trade means that any gains in carbon are relative to the stocks when the activity starts. As only the biomass of trees are considered, any new growth of trees will represent additional carbon stocks (Table 2). For the project protocol, soil carbon could be included but preliminary analyses justifying little change but high costs to measure any change would justify exclusion.

3.1.2. *Activity*

CCAR: As only required pools will be certified by CCAR, it would only be cost-effective to invest in monitoring these pools. After 60 years the difference in stocks between recording just the required pools versus including the optional pools is 53,000 t CO_2-e (Table 3).

Carbon accumulation is net of baseline carbon stocks. As detailed above, the baseline under CCAR is zero. This contrasts with an estimated stock, if shrubs and grasses were included, of 55 t CO_2-e/ha or 15,625 t CO_2-e over the project area.*1605(b)*: The following pools are considered to increase as a result of activities and will be included here: trees above and belowground, standing and downed dead wood, forest floor and soil organic carbon.

As already stated a mean of only a B rating is required across the project, so costs could be saved by selectively using look up tables. In Fig. 2 it is apparent that differences between values from the look-up tables and from sampling are only large for the live tree pools. Values are based on Winrock sampling in the California Sierras in 2003 (Brown et al., 2004a,b,c), and the default look-up table for afforestation of mixed conifer in the Pacific Southwest (Smith et al., 2006).

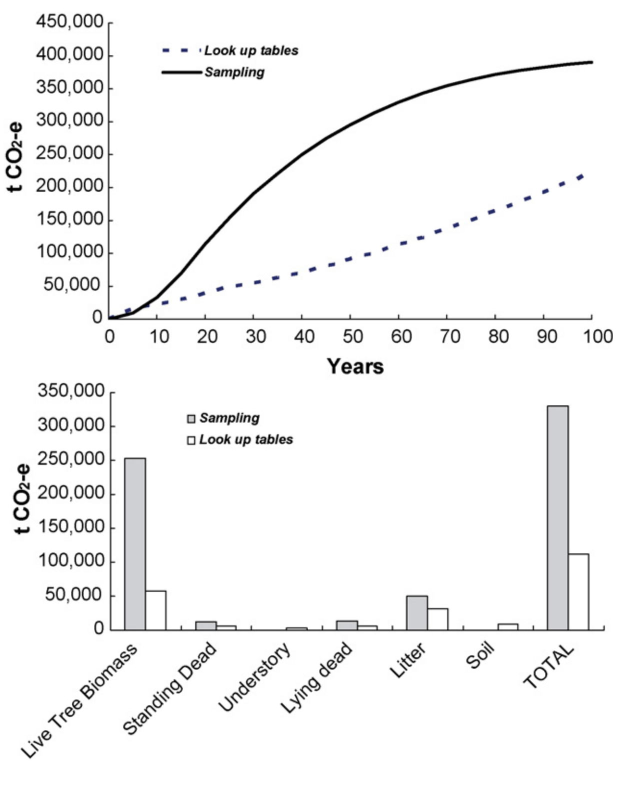

Fig. 2 – A comparison between values anticipated from sampling and values taken from the 1605(b) look-up tables for the afforestation case study. The lower figure illustrates the anticipated totals from the two methods after 60 years.

Consequently, a project would be advised to sample the above and belowground tree biomass (maximizing the reported results), but to reduce costs by not sampling the additional pools and instead using the look-up tables (in this case from soil organic carbon, understory vegetation, dead wood and litter).

The mean grade across the project is determined through multiplying those pools sampled (A) by a factor of 4 and those from look up tables (C) by a factor of 2, then dividing by the sum of the stock in all pools.

At 60 years:

Trees:

$$260\,983\,\text{t}\,CO_2\text{-e} \times 4\,(\text{A}) = 1\,043\,932$$

Understory, soil carbon, standing and down dead wood and litter[7]:

$$2613\,\text{t}\,CO_2\text{-e} + 9823\,\text{t}\,CO_2\text{-e} + 5748\,\text{t}\,CO_2\text{-e} + 5748\,\text{t}\,CO_2\text{-e} + 31\,350\,\text{t}\,CO_2\text{-e} \times 2(\text{C}) = 110\,561$$

$$\frac{1\,154\,493}{316\,265} = 3.7(\text{B}+)$$

Following this approach the project achieves an overall grade of B+, which is more than sufficient to meet the reporting criteria of the 1605(b) program.

The difference in reportable carbon stocks between using the look up tables and field measurement for understory, dead wood, litter and soil carbon and field measurement is an under-reporting of sequestered carbon of 21,569 t CO_2-e or 76 t CO_2-e/ha compared to the 'actual' sequestration (less than 7% of sequestered total after 60 years) (Table 3). This under reporting is likely to be beneficial when the avoided measurement costs are considered.

RGGI: The required RGGI pools are living trees above and belowground, and soil carbon. Even though there will be no change in soil carbon it must be measured, and must be measured to a 95% confidence interval that is within 10% of the sampled mean. Soil carbon is a variable pool and consequently will likely require in excess of 100 measurements at each monitoring interval to achieve this precision.

As coarse woody debris is minimal or absent in the baseline it is an optional pool. The requirement to achieve the high precision level of each pool individually instead of for the combined pools means that it will never be cost effective to track the stocks in dead organic matter or non-tree vegetation.

Because the cost of monitoring carbon is highly related to the number of plots needed to achieve a given precision level (more plots are needed to achieve a smaller confidence interval, all other conditions equal), monitoring of the living tree carbon pool is also likely to be more expensive under RGGI than under the other protocols. Why is this the case? Under RGGI, permanent monitoring plots, although required in the protocol, are practically excluded, on statistical grounds, given the method required to report the amount of carbon sequestered. The RGGI requires that reported sequestered carbon should be equal to the total stock of all pools at time

[7] 316,265 = sum of all pools.

$t = 2$ minus all pools at time $t = 1$ (RGGI, 2007). When permanent plots are used, trees have to be permanently tagged and the increment of carbon accumulation by growth in trees is tracked so that the growth of individual trees between two time periods is recorded rather than the total stock at time 1 and time 2 (Brown and Masera, 2003; Pearson et al., 2005, 2007). However, to meet the RGGI requirement of subtracting total stocks, statistically the estimates at time 1 and time 2 must be based on independent measurements. Thus the measurements cannot be taken from permanent plots, but rather a new set of plots must be established at each monitoring interval (to satisfy the statistical condition of independence of the sample). Permanent plots reduce measurement costs because fewer plots are needed overall by reducing one aspect of variation.

Soil carbon measurements revealed, as expected, no change in the baseline stock of 51,015 t CO_2-e (179 t CO_2-e/ha ± 16 [mean ± 95% confidence interval] in the baseline and 181 t CO_2-e/ha ±18 after 60 years). Therefore the total stock after 60 years was 311,998 t CO_2-e, which is a net gain over the baseline of 260,983 t CO_2-e (Tables 3–5 and Fig. 3). The maximum project duration under RGGI is 60 years so no additional accumulation can be accounted beyond this date.

CCX: In the entity protocols only the stem biomass of the trees is considered under CCX. After 60 years this will give 118,044 t CO_2-e (Tables 3–5 and Fig. 3). In the project protocols, the total biomass of trees above and belowground is considered giving a total of 260,983 t CO_2-e (the higher number represents the inclusion of the branches and the non-commercial portion of the stem as well as the roots). Soil carbon is not included as the measurement costs would not be justified through the minimal accumulation. The accumulations numbers compare to 339,915 t CO_2-e with the additional inclusion of litter and dead wood. Continuing the project activities through to 100 years would result in the additional reportable sequestration of 33.9 thousand t CO_2-e under the entity protocols and 50.8 thousand t CO_2-e under the project protocols.

3.1.3. *Uncertainty*

CCAR: The estimates presented here are largely based on measurements taken in Sierran mixed conifer forests in California in 2003 (Brown et al., 2004c) and we use them here to represent the expected likely carbon stock and variability. From 75 measurement plots of trees between 75 and 98 years of age, the mean stock was 748 t CO_2-e/ha with a standard deviation equal to 323 t CO_2-e/ha. This standard deviation gives a 1/2 95% confidence interval equal to 10% of the mean (74 t CO_2-e/ha) and a 1/2 90% confidence interval equal to 8% of the mean. Referencing the CCAR rules (CCAR, 2004), this would

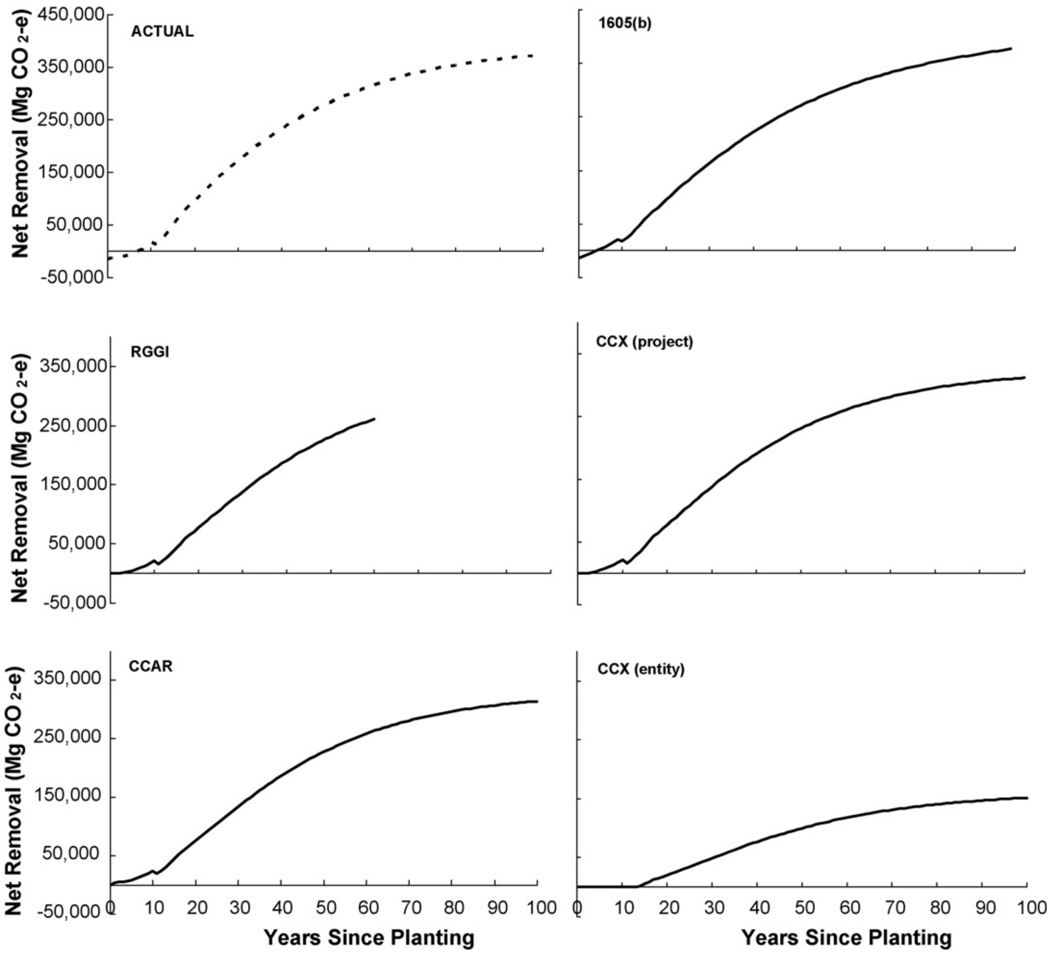

Fig. 3 – Illustration of net carbon dioxide equivalent accumulation across the four protocols and compared to the 'actual' scenario.

initiate a 10% deduction in the certifiable carbon sequestration.

Higher uncertainty would be expected in the standing and lying dead wood stocks. For example, measurements in Sierran mixed conifer forest aged >75 years (Brown et al., 2004c) resulted in the following:

Standing dead wood—measurements in *36 plots*: 90% CI = 30% of sample mean;
Lying dead wood—measurements in *46 plots*: 90% CI = 43% of sample mean;

If reported separately this would require a 100% deduction in the registered sequestration. However, combining all the pools, and considering the dominance of the tree pool reduces the significance of the high variation in the dead wood pools. Using a propagation of errors approach (square root of the sum of squared individual errors) produces a summed error equal to just 8% of the mean, which would require a 10% deduction.

1605(b): As stated above the project achieves the minimum grade needed for reporting (B). The sampled pool (trees) is sampled to within 10% of the mean with 95% confidence, which is the required level of precision.

RGGI: RGGI requires measurement of all pools to a precision equal to 95% confidence intervals within 10% of the mean. The measurements of the tree biomass met this precision level, but the measurement of the individual pools of dead wood did not. No deductions are required for uncertainty.

CCX: CCX requires a deduction for uncertainty but it is currently undefined.

3.1.4. Non-CO_2 gases

CCAR, RGGI and CCX do not require accounting of non-CO_2 gases. As stated above in the 'actual' case non-CO_2 gases would be derived through biomass burning (for site preparation), and through the use of fossil fuels for project management and maintenance.

Fire, vehicle and machinery use emissions are each less than 3% of the total sequestration and so would not have to be reported under the 1605(b) criteria (considered *de minimis*).

3.2. Comparison of results

None of the protocols would include deductions due to additionality, leakage or non-CO_2 gases. The most significant differences, however, arise through:

- the inclusion or exclusion of measurement pools and hence the exclusion of the shrub and grass biomass under all the protocols except 1605(b);
- the use of default look-up tables and the inclusion of the forest floor/litter pool under 1605(b);
- the limitation to the stem of the tree for within entity calculations under CCX;
- the required deduction for uncertainty under CCAR.

The omission of the baseline stocks in shrubs and grasses credits the CCX, CCAR and RGGI analyses with 15,675 t CO_2-e after 60 years. The use of look-up tables both saves the 1605(b) analysis field measurement costs but also over-reports the stocks in dead wood, litter, soil and understory relative to the actual case by 21,569 t CO_2-e. The limitation to the stem of the tree reduces the CCX entity-level total by 90,956 t CO_2-e relative to total aboveground tree biomass or 221,871 t CO_2-e relative to biomass in all pools. The uncertainty deduction reduces the CCAR total by 27,238 t CO_2-e after 60 years.

The end consequence is a net total after 60 years of 312,978 t CO_2-e are sequestered in the 'actual' case, with all the protocols reporting less. The amount reportable under the 1605(b) is the closest to the actual (299,857 t CO_2-e), with CCAR, RGGI and CCX project reporting coming in at values similar to each other at about 260,000 t CO_2-e, and CCX entity reporting having the least quantity (118,044 t CO_2-e) (Table 4 and Fig. 3).

4. Discussion

Each of the protocols considered accounts for the carbon stock changes due to land use activities. However, inclusions and exclusions from the protocols lead to significant departures between the range of 'offsets' generated after 60 years—ranges from the 'actual' 312,685–118,044 t CO_2-e under CCX entity accounting. These departures while generally conservative with respect to the atmosphere have significant impacts on resulting project profitability for a land owner.

It is understandable and laudable to seek to increase simplicity and utility of methodologies and protocols to minimize the cost to landowners to implement such projects. If perfect measurement and monitoring were required then profitability for landowners could never be possible because of high costs, with a resulting lack of interest in implementing projects. However, none of the protocols potentially issuing project offsets adequately accounts for additionality or leakage. These are policy and technical issues for project-based activities that have been widely debated (e.g., Brown et al., 2002; Brown and Masera, 2003; Cathcart and Delaney, 2006), but for which programmatic solutions seldom have been implemented. Without consideration of these quality assurance principles the chances are greatly raised of non-genuine project impacts on atmospheric GHG concentrations.

CCAR, RGGI and CCX each take the approach of prescribing measurement pools. This has the effect of increasing costs for landowners through requiring measurement even if the anticipated change in stocks does not warrant inclusion of the pool. On the opposite side, there is no requirement for measurement if the result is an artificial inflation of the reported values (as is the case if the optional pool exists in the baseline and will be destroyed as part of the project).

1605(b) in this case most accurately accounts for carbon stocks, and the use of look-up tables will greatly decrease measurement costs. However, the agreement with reality may not always be the case when alternative methods to field measurement are used. The methods are open to interpretation and exploitation; with potential for methods being specifically chosen to maximize reportable sequestration or avoided emissions. For example, look-up-table use is allowed, which in this case does not artificially inflate the estimated sequestered carbon but scenarios could be envisaged where they might. The 1605(b) protocols also do not include a baseline but instead employ base year values. This is adequate if the baseline is constant through time, but where the baseline is anticipated to change, then base years will not account for changes in carbon stocks. Finally, 1605(b) does not adequately include uncertainty. Steps are involved to ensure that, across the project, on average at least a model has been used, but this does not guarantee precision.

The RGGI protocol requires all selected pools to be measured to a high level of precision (95% confidence intervals equal to 10% of the mean or less). This creates a disincentive to measure optional pools and greatly increases the costs of required pools. International measurement protocols (cf. Pearson et al., 2005) typically require the total carbon stock or carbon stock change to have a high precision but this ''total'' precision can be derived from precision in the dominant live tree carbon pools. This approach allows lower levels of precision in the highly variable pools such as dead organic matter and soil carbon, which contribute relatively little to the total carbon stock change in an afforestation project.

The RGGI protocol is the only one to limit the duration of projects. RGGI afforestation projects consist of up to three 20-year periods. This mirrors the system under the Clean Development Mechanism of the Kyoto Protocol (see Pearson et al., 2006). However, clearly sequestration does not stop at 60 years and unlike the CDM, RGGI requires a permanent easement that will prevent landowners from cutting down trees and choosing alternative land uses after 60 years. The CCAR, CCX and 1605(b) protocols can therefore potentially claim large additional sequestration beyond what is possible under RGGI by continuing to report on sequestration beyond 60 years. After 40 additional years this would be equal to 60,292 t CO_2-e in the actual case, 55,653 t CO_2-e under CCAR, 76,664 t CO_2-e under 1605(b), 50,800 t CO_2-e under the CCX project protocols and 33,829 t CO_2-e under the CCX entity accounting protocols over the 285 ha of the hypothetical project. These extra years potentially represent great actual benefit to the atmosphere but under RGGI the landowner would receive no credit.

The differences in the baseline and protocol estimates are significant for the single, small case study assessed, as shown in Table 3. However, these registry programs are being developed in expectation that large portfolios of such projects will emerge in response to programmatic, policy or market pressures in the years ahead, as US national and state climate change policies evolve. To consider the large-scale effect of these differences across protocols in the magnitude of C benefits eligible for reporting, we estimated carbon benefits from a portfolio of 1000 projects equivalent to the afforestation case study for each program. A large program could record 2.5 times as many metric tons under the 1605(b) protocol guidelines as under the more conservative CCX guidance, a difference of 182 Mt CO_2-e above the CCX entity accounting estimate. A program under CCAR or RGGI would record 2.2 times the number of credits as under the CCX entity accounting protocols.

4.1. *Comparison with CDM*

To compare our results of the four domestic US program reporting methods to the evolving guidance in use by a major international GHG reporting program, we use the guidance provided by the CDM afforestation/reforestation accepted methodology number AR-AM0007 ''Afforestation and Reforestation of Land Currently under Agricultural or Pastoral Use''. This methodology is broadly applicable to our afforestation case. This is purely a hypothetical comparison exercise because US projects would not be eligible for the CDM and the US government has not ratified the Kyoto Protocol.

The AR-AM0007 is a protocol/methodology that includes all measurement pools except for soil carbon, but under the CDM, pools can be excluded if it can be shown that this is conservative. To use AR-AM0007 a project would have to show that it is financially additional, any leakage caused by the project through displacement of people or activities would have to be accounted for, and emissions through vehicle use, fertilizer or biomass burning would also have to be estimated. The baseline under AR-AM0007 would be the shrub and grass vegetation and the assumption that this would be burned would lead to an additional emissions of methane and nitrous oxide. The results obtained would therefore mirror the results under the 'actual' scenario presented in this paper. The only departures would be due to the small sequestration in soil carbon and differences that would emerge through sampling errors and sampling uncertainty. A CDM methodology approach would be precise and accurate with regard to atmospheric impact but the benefits to landowners would be more equivocal. Although the result from applying the CDM methodology to the hypothetical project would be higher than any of the four protocols compared here, the CDM methodology with its enhanced requirements and high level of regulatory oversight would be significantly more expensive to implement.

4.2. *Other land use activity types*

Forest management is an eligible activity under CCAR, CCX and 1605(b). It is not eligible under RGGI. Comparing the three protocols for a hypothetical riparian extension project on commercial forest lands, also in Shasta County California (Brown et al., 2004c), using similar methods to those used here, the analysis revealed values of carbon credits that ranged by a factor of 2.8 with 1605(b) again providing the high estimate and CCX entity accounting the low estimate. Forest management introduces an additional pool—wood products. Harvested wood is not automatically emitted to the atmosphere; instead it forms a sequestered pool in products such as paper, building materials and furniture. Wood products are an optional pool under CCAR. In 'change in forest management' projects, where harvest is reduced, then the project benefit is artificially inflated if a moving baseline of wood products is not included. However, the base year under 1605(b) precludes this, and the optional nature of the pool under CCAR makes it unlikely that a project would choose to include this deficit voluntarily. For CCAR this artificially inflates the numbers in the hypothetical case study by 9% after 100 years, and the base year inflates the 1605(b) total by 3%.

Beyond forestation and forest management, the most significant difference between the protocols comes in forest conservation. With the exception of the RGGI, all protocols allow forest conservation projects. CCAR allows the calculation of a site-specific anticipated baseline deforestation rate, or else gives conservative California County-average rates to apply to the project site. In contrast, under 1605(b) and CCX for entity accounting, managers would actually or effectively take a base year value (which is likely to be the stock of carbon in mature forest) and the benefit is equal to any additional sequestration above this value. In other words 1605(b) and CCX entity level accounting do not consider whether deforestation would or could have occurred in the absence of the conservation activity. CCX does allow forest conservation offset activities in Brazil. In this case the baseline is set as the statewide average deforestation rate that is provided in the rulebook (CCX, 2008).

4.3. Costs and profitability

Regarding cost of carbon monitoring, total project sample costs are dependent on a number of fixed and variable costs. Fixed costs do not vary with the number of samples taken and include the cost for such activities as planning and organization and transportation for the project field crew (to/from the base location to the project location). Variable cost are directly related to the: precision level that is targeted; number of pools that need to be monitored; travel distance to reach measurement plots that is related to the spatial configuration of the project site (e.g., one contiguous parcel of land or multiple parcels of land); frequency of monitoring; complexity of monitoring methods (Brown and Masera, 2003). In general, the more carbon pools included, the more variable the carbon-stock changes within the project boundary, with the boundary spread over multiple parcels of land, the higher the cost to sample to achieve a desired precision level. In practical terms, if monitoring costs are high relative to the expected increase in carbon stocks – which might be the case, for example, with understory herbaceous vegetation in an afforestation project (small pool of carbon) – then it would make sense not to include these pools.

Mooney et al. (2004) provide an estimate of the costs (both fixed and variable) for one monitoring event of 1000 ha parcel of land under afforestation, assuming a fixed cost of $1000, a desired precision level of ±10% of the sample mean with 95% confidence, and a coefficient of variation of the carbon stock changes of 30% (a measure of the variability that determines the number of plots needed to attain the given precision level) for both aboveground and soil carbon stocks. For one contiguous parcel, the cost was $5.54 ha^{-1} for aboveground carbon only and $7.02 ha^{-1} for both aboveground and soil carbon. For non-contiguous parcels, the cost increased to $9.8 ha^{-1} for aboveground carbon and to $11.3 ha^{-1} for both pools. These costs per ha would increase for smaller project areas and higher precision levels and decrease for larger areas and lower precision levels. The effect of changing any of the parameters as well as including multiple monitoring events can be investigated by use of calculator tool available at: http://www.winrock.org/Ecosystems/files/Winrock_Sampling_Calculator.xls.

As each of the protocols is being applied to the same site the fixed costs, the coefficient of variation, and area of the parcel are kept constant. The four protocols, however, differ in their variable costs because of the required number of pools and the required precision level.

Most inexpensive to measure will be the CCX entity protocols where a standard inventory of forest volume, as is typically done in a ‘‘timber cruise’’, is the only requirement. However, this low measurement cost is balanced by low reportable carbon stocks decreasing the profitability of applying this protocol.

Most expensive will be the RGGI protocols that contain the requirement to meet the precision target of a 95% confidence interval within ±10% of the sampled mean for each of the measured pools, including soil and the CCAR protocols that require a precision of ±5% of the sampled mean with 90% confidence. For example, from the above discussion on cost, including soil carbon increases the cost of monitoring per ha by 15–26% over including aboveground carbon only; and requiring the CCAR precision increases the cost per ha by 20% compared to the cost to attain a precision of ±10% of the sample mean with 95% confidence. The profitability of the RGGI protocol is further decreased by the inability to include the forest floor carbon pool and the inability to consider sequestration occurring beyond the 60-year project limit.

Most profitable will be the 1605(b) program. Under 1605(b) the project could elect to track increments in soil carbon, understory vegetation, standing and down dead wood and the forest floor through default look up tables. This would greatly reduce measurement costs while only marginally impacting reportable carbon stocks. The 1605(b) protocols also allow the discounted registration of future accruals (see Table 1). This is very favorable to landowners and investors but is not part of any protocol under a mandatory system due to the risks associated with forward crediting.

4.4. Conclusions

Taking the viewpoint of the landowner looking to maximize profits, the choice of protocol would remain the 1605(b) protocol. As a B grade is the maximum that is required, it would be possible to run models of anticipated carbon sequestration and conduct few field measurements with their associated costs or, as demonstrated here, pair limited measurements with default look-up table values. The 1605(b) protocol also does a good job of tracking actual carbon sequestration. However, 1605(b) is the US Government's voluntary reporting program and as such is not tied to a carbon market and so achieving project financing may be complicated through this protocol. From the perspective of accuracy and precision in accounting and the consequences for the atmosphere, the 1605(b) protocols do not require third party auditing which opens the possibility of gaming.

The CCX entity results, while simple to measure and report have an increased cost per unit area because of the greatly reduced reportable carbon credits due to the limitation to just the stem of the tree. In addition, CCX requires independent 3rd party validation of reported results before registration, which is beneficial in terms of guaranteeing an atmospheric benefit but detrimental in terms of additional costs to landowners.

The greatest cost is likely to be incurred through using the CCAR Protocol or RGGI Protocol as field measurements are mandatory and independent 3rd party validation of reported results are required. However, the greater requirements of CCAR and RGGI give a greater credibility to projects registered there. This will be important for investors and for any potential trading of accumulated benefits.

Ideally, GHG mitigation registries and programs should provide incentives to improve the data and methods of GHG benefit estimation over time, so the system evolves and more GHG pools or fluxes are included more accurately and precisely. Table 6 provides an overview of selected incentives and disincentives of the four programs to the improvement of measurement and monitoring of project activities, and their cost implications. Significant disincentives exist in the current programs, and offer the potential for evolution of methods and reduced transaction costs if such barriers are addressed.

An ideal protocol would require proof of financial and legal additionality, and would fully consider leakage and all project emissions. However, an ideal protocol would also seek to minimize project implementation costs for landowners while maintaining accurate and precise estimates of GHG impacts. To do so, an ideal protocol would allow projects to achieve the given precision standard across all pools and would allow pools to be included or excluded at the projects choice as long as doing so did not artificially inflate the reported impacts.

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