THE COMPARATIVE VALUE OF BIOLOGICAL CARBON SEQUESTRATION

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Abstract

Carbon sequestered via forests and agricultural soils saturates over time and once saturated must be maintained to avoid atmospheric release. Consequently, sequestration credits may have a smaller value than permanent emission offsets. Net present value analysis reveals value reductions between 0 and 62 percent for soil carbon sequestration and between 1 and 49 percent for forest based carbon sequestration. Value adjustments are contingent on a multitude of factors including the dynamics of management decisions, real discount rates, and others. Agricultural sector analysis indicates little impact of value discounts on total emission abatement. However, once impermanence discounts are imposed, the economically optimal portfolio shifts away from agricultural soil and forest sequestration to sustainable biofuel strategies.

JEL Classification

C61 - Optimization Techniques; Programming Models; Dynamic Analysis

Q000 - Agricultural and Natural Resource Economics: General

Q230 - Renewable Resources and Conservation; Environmental Management: Forestry

Q250 - Renewable Resources and Conservation; Environmental Management: Water; Air; Climate

I. INTRODUCTION

Emerging policies directed toward mitigating the impacts of climate change are causing governments and industries to consider the merits of greenhouse gas emission (GHGE) reduction strategies. Land-based biological sequestration (LBS) is being evaluated as one potential option. Some have argued that LBS strategies are not only relatively inexpensive ways of lessening GHGE mitigation costs but also provide economic opportunities for farm and forest landowners (Dixon et al., 1993; Sampson and Sedjo, 1997; Marland and Schlamadinger, 1999). However, examinations of LBS characteristics have raised concerns regarding issues of permanence, leakage, monitoring, measurement and transactions costs. These concerns were recognized in the 1997 Kyoto Protocol, an international GHGE control agreement which generally approved the inclusion of LBS but did not specify implementation details. Three years later at the COP6 meetings (Sixth Conference of the Parties to the UN Framework Convention on Climate Change) in The Hague, negotiations between members of the European Union and a coalition of the United States, Canada, Japan, and Australia failed partly because of disagreement on the inclusion of LBS. Subsequent COP meetings have resolved some issues, but LBS remains a controversial element of international climate policy.

The objective of this study is to analyze how the impermanence related issues of saturation and volatility affects the market value of LBS relative to emission offsets. Some previous studies have addressed the issue of the impermanence of carbon sinks (Richards 1997, Fearnside, Lashof, and Moura-Costa 2000; Feng, Zhao, and Kling 2002). Even more studies have estimated LBS marginal abatement curves. Recent estimates of the agricultural potential include the work of Pautsch et al. (2001) and McCarl and Schneider (2001) and those presented at the 2001

Forestry and Agriculture Greenhouse Gas Modeling Forum[1]. Many forest sequestration studies are reviewed in McCarl and Schneider (2000), Sedjo et al. (1995), and Murray (2002).

This paper combines the topics of marginal abatement curve and impermanence by investigating how saturation and volatility affect the comparative value of LBS activities and the optimal portfolio of agricultural and forestry GHGE mitigation strategies. To do this, we first develop an adjustment procedure to derive payment discounts, which reflect the relative impermanence of LBS activities. Subsequently, we use a model of the US forest and agricultural sectors to simulate the effects of these discounts on the optimal level and distribution of LBS GHG mitigation activities. This simulation provides policy insight because efforts to implement LBS into any broad mitigation policy will likely involve either explicit or implicit adjustments to account for differences of LBS to sustainable emissions offsets.

II. BACKGROUND

The issue of permanence of LBS arises because of ecosystems' limited capacity for carbon uptake (saturation), and the possibility that the sequestered carbon will be released through future management reversal (volatility). LBS activities lead to carbon saturation when storage reservoirs fill up due to physical or biological capacity. Two prominent forms of LBS are reductions in agricultural soil tillage intensity and establishment of trees on currently unforested lands (afforestation). West and Post (2002) summarize the incremental carbon stock changes from 67 long-term tillage experiments involving 276 paired treatments. Based on the experimental results, they conclude that carbon sequestration rates can be expected to peak within 5-10 years with soil organic carbon reaching a new equilibrium in 10 to 15 years –

[1] See http://foragforum.rti.org/documents/Murray_presentation.ppt.

evidence of saturation. On afforested lands, data in Birdsey (1996) show carbon saturation in both forest soils and standing tree biomass although these processes take longer than in agriculture. Afforestation scenarios become even more complex when harvesting is introduced, as significant fractions of the carbon can be retained in harvested wood products for long time periods.

LBS-sequestered carbon is commonly considered volatile because its storage form is subject to future release through tillage intensification, harvesting, fires, or other natural and anthropogenic disturbances. For example, cutting down a LBS-developed forest and plowing the soil up for farmland quickly releases much of the sequestered carbon. Replacing no-till agriculture with a moldboard plowing system has similar effects.

Saturation and volatility imply that additional cost terms must be considered when examining the economic value of a LBS offset. In particular, the combination of saturation and volatility for LBS strategies introduces a potential maintenance cost to keep the carbon sequestered, possibly even after saturation has been achieved.

III. GREENHOUSE GAS EMISSION OFFSET PURCHASES

Selling and purchasing of LBS emission offsets requires some type of carbon market. Why would such a market develop? One reason might be the development of a GHGE cap and trade system, as could result from implementation of the Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCCC).[2] Firms or countries, which are subjected to a cap

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[2] While the Bush Administration declared in 2001 that the US would not ratify the Kyoto Protocol, it has announced a unilateral program in 2002. Other countries agreed to the binding commitments of the Kyoto Protocol and the

and trade system, could purchase emission rights to avoid costly domestic emission reductions. Purchase opportunities may include offers from those who can (1) directly reduce emissions, (2) sequester carbon in agricultural soils, and (3) sequester carbon in forests.

Carbon transactions could also arise from “project-based” approaches to GHG mitigation, i.e. via the Kyoto Protocol’s Clean Development Mechanism (CDM). Mitigation “projects” are defined as specific transactions between a buyer and a seller, wherein the project may involve emission reductions in a country that has no mitigation policy in place.

In the context of a carbon market, our research question becomes: How do the saturation and volatility characteristics of LBS manifest themselves in the price that a buyer would be willing to pay for a unit of carbon? We argue that the amount of credit generated in an offset transaction involving LBS should, in principle, net out any differences in the duration (permanence) of GHG effects.

IV. THE RELATIVE VALUE OF LBS EMISSION OFFSETS

GHGE offsets occur over time. Offsets could involve the development of agricultural enterprises which engage in

(a) a fuel-switching project that directly offsets fossil fuel emissions for many years;

(b) adoption of reduced tillage on cropped soils that sequesters carbon in the soil but saturates after about 20 years; or

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potential application of LBS to meet those commitments at the UNFCCC 7’th Conference of Parties (COP 7) in Fal1 2001.

(c) afforestation on agricultural lands with carbon being stored in biomass and soils for 60+ years.

If the reduced tillage (case b) or forest use (case c) were eventually discontinued there would be future releases of the sequestered carbon back into the atmosphere. These dynamic considerations imply that a comparison of sequestration methods should adjust for the time value of emissions offsets as argued in Richards (1997) and Fearnside, Lashof, and Moura-Costa (2000).

Thus, we use a net present value framework, similar to that used in Feng, Zhao, and Kling (2002) and solve for the constant real emissions price (p) which equates the net present value from the emission offsets by a strategy with the net present value of the costs for strategy implementation. Mathematically, we solve for p in the following equation:

$\sum_{t=0}^{T}(1+r)^{-t}pE_t = \sum_{t=0}^{T}(1+r)^{-t}C_t$, where p is a constant real price of emission offsets, r is the real discount rate, T is the number of years in the planning horizon, E_t is the quantity of emissions offset in year t, and C_t is the cost of the emissions offset program in year t.

To proceed with the analysis, we make several initial assumptions, some of which will be relaxed later. First, to facilitate comparison across different emission offset options and without loss of generality, we assume equal rates of incremental carbon offsets and equal implementation costs. In particular, we assume carbon offsets in the amount of one unit per year at a constant price of one dollar per unit for all options. Second, we evaluate the incremental costs and returns caused by use of each offset option over a time period of 100 years. Third, we use a 4 percent real discount rate. Fourth, we employ linear approximations for the annual sequestration rates to keep the mathematics more straightforward. For example, we will have a one-unit offset for every year until the point of saturation, and zero offset thereafter. Carbon dioxide emissions released after the saturation point (e.g., from harvest or reversion to conventional tillage) also are approximated linearly.

The Purchase Value of Emission Offsets

First, we compute the purchase value of direct GHGE offsets arising from permanently available options such as replacing fossil fuels with renewable biofuels. We assume that these opportunities can be continued over the whole 100-year period. Application of the net present value framework from above leads to a break-even real carbon price (p) of 1.00 for this type of emission offsets.

Next, we analyze agricultural-soil-based offsets arising from the adoption of a reduced tillage system. We assume that carbon saturation occurs in year 20 and that the implementation cost is an incentive paid to the sequestration producer[3] for as long as specified in the program contract. We consider three different agricultural scenarios (A-I to A-III) regarding practice continuation and program payments beyond year 20. Namely, farmers are paid to adopt reduced tillage for 20 years, and then one of the following sequences occurs:

(A-I) At the end of the 20 years the payment ceases. In turn, farmers acting in their own best interest revert back to conventional tillage. Subsequently, we assume that the sequestered carbon volatizes and is released over three years in equal increments of 6.67 units per year.

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[3] This payment does not equal the cost of the practice but rather the incentive that needs to be paid to the farmer to make him adopt the practice. Thus, it includes all lost income from practice switching, extra costs of sequestration practices, incentives to bear additional risk, learning costs etc.

(A-II) Farmers are paid for the full 100 years to continue the practice and maintain the sequestered carbon even though carbon accumulation ceases at year 20.

(A-III) At the end of the 20 years the payment ceases. However, farmers acting in their own best interest[4] maintain the practice, thereby maintaining the carbon.

The carbon and cost profiles differ across the scenarios. The cumulative amount of carbon offsets rises up to year 20, then either remains the same (scenarios A-II and A-III) or drops to zero over the next three years (scenario A-III). The total program cost rises until year 20 then stays the same under scenarios A-I and A-III or continues to rise for the entire 100 years (scenario A-II).

Solving our net present value equation, we obtain p=2.64 for scenario A-I where the carbon is released, p=1.80 for scenario A-II where the farmer is paid well past the saturation point, and p=1.00 for scenario A-III where the practice continues without subsidy. Inverting these prices reveals the relative value of tillage based carbon sequestration. In particular, if a subsidy is required for the reduced tillage system to be continued, agricultural soil carbon is worth only 38 percent (scenario A-I) and 56 percent (scenario A-II) relative to direct emission offsets. Generally, the saturation and volatility characteristics of agricultural soil sequestration will result in a discount if either the carbon is released or the cost continues beyond the saturation point and the free lunch of scenario A-III does not occur.

Forestry based offsets materialize from afforestation, lengthening timber harvest rotation, ceasing harvest, or improving forest management. These offsets entail four types of net carbon emission reductions. First, forest soils store more carbon than agricultural soils because trees

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[4] By "own best interest" we mean that farmers may find it profitable to maintain this tillage practice even without carbon incentives, as some agronomic research suggests.

have larger root systems, forest soils are disturbed less frequently, and forests deposit and retain more surface matter litter. Second, standing trees store carbon in their leaves, limbs, and trunk. Third, harvested timber products are substantially made up of carbon and may be placed in long-term storage through their use in buildings, furniture, and other products. Fourth, a sizeable portion of harvested forest carbon offsets GHGE as it replaces fossil fuel based energy and accompanying emissions. This occurs both through the trees used as fuel wood and through the use of milling residues for co-generation.

A forest's saturation age and post-harvest forest carbon profiles were determined based on Birdsey 's (1996) data for southeastern US pine plantations. Birdsey's data for onsite forest carbon from the FORCARB model (Plantinga and Birdsey 1993) is supplemented with data on the amount of carbon removed from the site at harvest, decay rates for the logging debris, and the carbon disposition by pool (product, landfill, energy use, and emissions) over time (Row and Phelps, 1991). These data reveal that, left-alone, planted forests in this region saturate about 80 years after establishment.

We set up several forestry scenarios (FI to FVIII, Table 1) to evaluate various dimensions of the problem, including

- timing of forest harvest (if it occurs at all);
- whether reforestation occurs after harvest;
- the period of time over which payments occur; and
- the use of harvested products for pulpwood or saw timber, which influences residency time for harvested carbon as well as for biofuels.

The first two scenarios represent two simple cases.

(F-I) Payments cease upon saturation and the stand is harvested with land reverting back to agriculture. Solving our net present value equation, we obtain p=1.07 or a relative value of 93 percent if the forest products used as fuel are treated as additional carbon offset. This value falls to 91 percent (p=1.09) without consideration of the fuel offset.

(F-II) Payments continue until year 100 and the stand remains in its saturated state after year 80. We find a 98 percent value (p = 1.02) relative to the value of direct emissions offsets.

Next, we analyze managed forests, which are harvested for products with part of the sequestered carbon volatilizing upon harvest. First, we consider short rotation strategies, primarily managed for pulpwood, which are harvested after 20 years. If such lands revert back to agriculture after harvest, we obtain a relative purchasing value of 65 percent with fuel offsets considered, and 51 percent without (Scenario F-III). If the land is reforested after harvest, landowners may need to be subsidized only for the first rotation (analogous to the agricultural scenario A-III); then the "discount" factor with timber biofuel residuals treated as an offset actually rises to 125%. This indicates a potential willingness to pay a premium for the carbon from a 20-year pulp rotation that once begun would stay in forestry, because it generates higher net discounted benefits than an emission-reduction program alone.

Finally, we consider longer, 50-year rotations, which are primarily saw timber (lumber and plywood) management regimes (scenarios F-VI, F-VII and F-VIII). In those cases we find higher relative values because the carbon accumulates in the forest longer and because the products have longer shelf lives than those made with pulpwood (paper and paperboard).

The Offset Value under Leasing

Some policymakers and researchers are advocating leasing rather than buying GHGE offsets. With leasing the carbon storage is only guaranteed during the lease period after which the lessor must either renew the contract or find other sources to replace the offsets that were generated throughout the lease period. Colombia advanced such a proposal in the Kyoto Protocol negotiations (United Nations, 2000). Similarly, Marland, Fruit, and Sedjo (2001) and Bennett and Mitchell (2001) each extol the attractiveness of potential leasing.

To investigate the implications of leasing, we examined a 20-year case for which both payments and carbon values immediately drop to zero at the end of the lease. Under these circumstances we find leased carbon to be worth 36 percent relative to direct emission offsets. Therefore, it appears that leased carbon does have value, but would trade at a substantial discount relative to verified emissions reduction offsets.

In addition to the leasing scenario just described, many other variants of project terms could be examined. For example longer lease terms would cause less of a discount while shorter terms would increase it. However, a full assessment of leasing options is beyond the scope of the present paper.

V. STRATEGY POTENTIAL WITH IMPERMANENCE DISCOUNTS

Agricultural and forestry (AF) activities may contribute to net GHGE reduction efforts more broadly than through LBS activities alone. Following McCarl and Schneider (2000), non-LBS contributions from agriculture can be grouped into the following categories.

1. *Direct emissions reductions.* Agriculture's global share of anthropogenic GHGE has been estimated to be 23 percent of carbon dioxide, 74 percent of methane, and about 70 percent of nitrous oxide (IPCC, 2001). The carbon dioxide emissions come from

deforestation, tillage intensification, and fossil fuel use. Rice, livestock and termites are major sources of agricultural methane emissions. The nitrous oxide emissions largely arise from manure and fertilization. Changes in management practices can reduce contributions from these sources.

2. *Provision of emissions saving product substitutes.* AF can produce commodities, which substitute for GHGE-intensive products and thereby displace emissions. This principally involves biofuels or substitute building products.

Agriculture and forestry based mitigation strategies are not only numerous and diverse but also interrelated. The nature of these interrelationships can be competitive or complementary. For example, a shift towards no-till agriculture may not only sequester soil carbon, but also affect the use of emission intensive production inputs such as diesel, fertilizer, and pesticides. Because crop yields and input requirements tend to be different under no-till management, this system may indirectly promote crops, which are well suited for reduced tillage. The resulting change in crop mix may increase or decrease overall levels of greenhouse gas emissions. Crop mix adjustments and yield changes are also likely to affect levels of crop production and prices, which in turn affect livestock production. Alternative livestock diets, herd size, and manure characteristics may again increase or decrease overall emissions.

Given these diverse interrelated options the question arises: What are the implications of impermanence discounts for the absolute desirability of agricultural offsets to potential buyers and the relative desirability of LBS activities compared to other agricultural possibilities? We now investigate this question.

Methodology

To address the question just raised, the analytical framework used must not only depict simultaneous implementation of all interrelated AF mitigation strategies but also portray implications for traditional agricultural production. Econometric estimation of abatement curves based on observed landowner responsiveness to carbon prices is not possible because carbon has not been priced to date. Consequently, we use a mathematical-programming-based model of the agricultural and forestry sector, hereafter called ASMGHG. We introduce hypothetical carbon prices and estimate the amount of emission reductions in total and by each individual mitigation strategy.

The model is an extension of earlier versions as documented in Baumes (1978), Chang et al. (1992), and McCarl et al. (2001). Schneider (2000) incorporated GHG features for the agricultural sector by linking ASMGHG to several biophysical models. For example, soil carbon sequestration estimates for a complete and consistent set of crop management options across all model regions were simulated using the Environmental Policy Integrated Climate (EPIC[5], Williams et al., 1989) model. To include forest sector responses, ASMGHG employs a forestry response curve generated using the Forest and Agricultural Sector Optimization Model (FASOM, Adams et al., 1996).

ASMGHG solves for prices, production, consumption, and international trade in 63 US regions for 22 traditional and 3 biofuel crops, 29 animal products, and more than 60 processed agricultural products. Trade relationships are integrated between the US and 28 major foreign trading partners (Chen, 1999). The model incorporates domestic and foreign supply and demand

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[5] For this study, we used EPIC version 8120. Details about this version are available from the EPIC team or the related web page at: http://www.brc.tamus.edu/blackland/.

conditions and is constrained by resource endowments. The market equilibrium reveals commodity and factor prices, levels of domestic production, export and import quantities, management adoption, resource usage and environmental impact indicators. These indicators include levels of GHG emission or absorption, water pollution, and soil erosion.

ASMGHG incorporates a relatively complete inventory of possible US-based AF responses to a net greenhouse gas mitigation effort. The strategies considered are briefly identified in Table 2. Details on data sources and implementation are documented in Schneider (2000) and Schneider and McCarl (2002a, 2002b). Additional information is available from the authors.

Incorporating Impermanence and Generating Marginal Abatement Curves

To simulate the impact of impermanence discounts on the attractiveness and viability of LBS strategies, we solved ASMGHG for a wide range of carbon prices first without and then with impermanence discounts. In the case of discounting, we multiplied the hypothetical carbon price times 0.50 for carbon sequestered on agricultural soils and times 0.75 for emission offsets from afforested lands. These adjustments are representative of the magnitude of the impermanence discount factors estimated in the first part of the paper. The carbon price applied to all sustainable GHGE mitigation options such as displacement of coal by biofuel was not discounted.

Simulation Results

The marginal abatement cost curves derived from ASMGHG using carbon prices from \$0 per ton to \$500 per ton of carbon equivalent (tce) are given in Figure 1. These curves reveal the GHGE offset quantities generated by the model at each carbon price with and without impermanence discounting of LBS carbon.[6] The results in Panel A suggest that discounting causes only a modest upward shift in the cost of achieving any given volume of GHGE offsets from the total AF portfolio. However, the presence of impermanence discounts causes the optimal portfolio of AF options to shift away from LBS strategies towards other options. Namely, the shares of carbon emission abatement through agricultural soils (Panel B) and afforested cropland (Panel C) decline whereas the share of sustainable biofuel carbon offsets rises (Panel D).

Interestingly, the magnitude of the impermanence discount is not a good predictor for the magnitude of the abatement cost curve shift. For example, the peak contribution of agricultural soil carbon, subject to a 50 percent impermanence discount, falls only by about 10 percent. Afforestation offsets, on the other hand, are discounted much less (25 percent); yet the competitive abatement share for this LBS option drops by about one-third. These outcomes reflect the complex nature of strategy interactions and the relative costs across the LBS and other mitigation options. Agricultural soil carbon offsets are attractive at relatively low carbon prices and have no competing AF mitigation activity. Thus, although soil carbon may incur relatively high impermanence discounts, it still remains the best agricultural option at low carbon prices. Afforestation, which in ASMGHG context includes the establishment of traditional long rotation

[6] For instance, at a price of $150/ton, the AF activities included in this analysis could generate roughly 300 mmtce per year, which offsets just less than one-fifth of total GHG emissions for the United States in 1990. However, it seems likely that an actual near term carbon price would be less than $150/ton. The Council of Economic Advisors (1998) estimates of the US cost of compliance with the Kyoto Protocol (1997) would be roughly $23/ton of carbon. If the carbon market price were in this range, LBS offsets from AF would be more modest – less than 100 mmtce/year.

forests, is impacted differently. Long rotation forest strategies compete closely for cropland with other more sustainable AF strategies such as short rotation based biofuel generation. With no impermanence discounts in place, afforestation has a slight cost advantage over sustainable energy crop plantations in several US regions at several carbon price levels. This slight advantage, however, can turn into a slight disadvantage when impermanence discounts are introduced because these discounts would affect afforestation but not energy crop plantations. Consequently, a relatively small discount on offsets from afforested croplands can cause substantial shifts in total long rotation based afforestation acreage.

VI. CONCLUSIONS

The impermanence of land-based biologically sequestered carbon has several implications. First, because carbon sinks saturate, sequestration offsets will only be generated until saturation occurs. Thus, the payment offer from potential buyers will fall if the contract helps to defer the maintenance costs beyond the point of saturation. Second, additional discounts are likely if the sequestered carbon remains volatile, i.e. if the purchaser has no control over land management decisions beyond the end of the contracted period but must incur liability for any releases. Third, the negotiated discount for sequestration offsets may not reflect their true value because of uncertainty about whether landowners will continue the practice or revert to a carbon releasing practice at the end of the contract period.

Explicit computations for a variety of scenarios reveal discounts between 0 and 62 percent for agricultural soil carbon and reductions between 1 and 49 percent for carbon sequestered through afforestation. Driving variables behind these computations include program payment design features, the time to saturation (carbon capacity), and a variety of future land management decisions, which may lead to partial or full atmospheric release of the sequestered carbon.

The discounts for LBS activities cause realignment of the emission reduction portfolio in a multi-strategy setting. Simulated results reveal a modest shift in the aggregate marginal abatement curve but proportionately large adjustments in the composition of the economically optimal strategies. The level of adjustment depends critically on the competitiveness of sustainable biofuel mitigation options at a given carbon price. While energy crop plantations displace afforestation at carbon prices above 50 dollars per ton of carbon equivalent, agricultural soil carbon sequestration is impacted relatively little due to its low costs but forestry is impacted substantially more at higher carbon equivalent prices.

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FOOTNOTES AND ABBREVIATIONS

AF = agricultural and forestry,

ASM = Agricultural Sector Model,

ASMGHG = Agricultural Sector Model accounting for Greenhouse Gases,

CASMGS = Consortium for Agricultural Soil Mitigation of Greenhouse Gases,

CSITE = Carbon Sequestration in Terrestrial Ecosystems,

C_t = cost of the emissions offset program in year t,

EPA = Environmental Protection Agency,

E_t = quantity of emissions offset in year t,

FASOM = Forest and Agricultural Sector Optimization Model,

FORCARB = Forest Carbon Model,

GHG = greenhouse gas,

GHGE = greenhouse gas emission,

GWP = global warming potential,

IPCC = International Panel on Climate Change,

LBS = land-based biological sequestration,

tce = metric tons of carbon equivalents,

mmt = million metric tons,

mmtce = million metric tons of carbon equivalents,

p = constant real price of emission offsets,

r = discount rate,

t = year index, and

T = number of years in the planning horizon.

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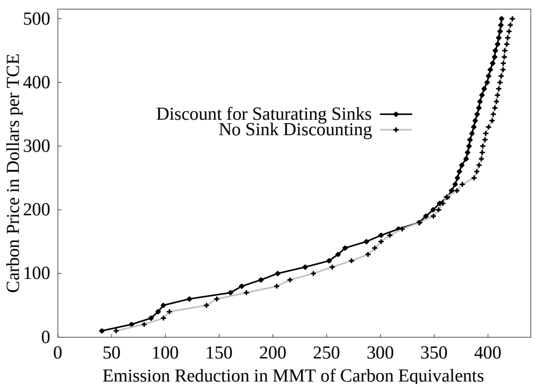
Table 1 Scenario Descriptions and Terms of Trade for Forest Carbon Offsets[7]

Scenario Description		Defining Assumptions			Computed Results			
					With Consideration of Fuel Offset		Without Consideration of Fuel Offset	
Broad Scenario Class	Scenario	Harvest Age	Reforest After Harvest	Years of Payments	Equivalent price	Value Relative to Emission Offset	Equivalent price	Value Relative to Emission Offset
Forest kept to Saturation	F-I	80	No	80	1.07	93%	1.10	91%
	F-II	Never		100			1.02	98%
Shorter rotation forestry (primarily pulpwood)	F-III	20	No	20	1.54	65%	1.95	51%
	F-IV	20	Yes	100	1.44	69%	1.78	56%
	F-V	20	Yes	20	0.80	125%	0.99	101%
Longer rotation forestry (primarily saw timber)	F-VI	50	No	50	1.18	85%	1.26	79%
	F-VII	50	Yes	100	1.15	87%	1.22	82%
	F-VIII	50	Yes	50	1.01	99%	1.07	93%

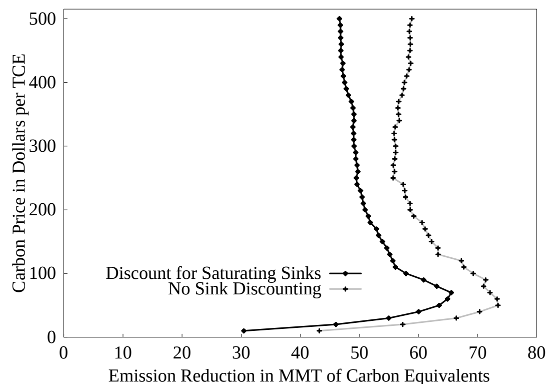
[7] Discount rate equals 4 percent.

Table 2 Mitigation Strategies Included in the Analysis

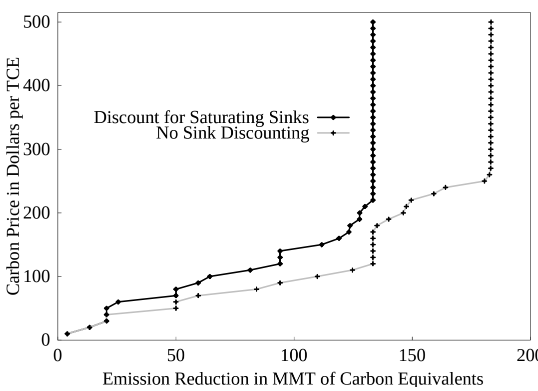
Agricultural or Forest Strategy	Abatement Effect	Greenhouse Gas Affected		
		CO2	CH4	N2O
Afforestation / Timberland Management	Sequestration	X		
Energy Crop Plantations (Switchgrass, Willow, or Poplar)	Offset	X	X	X
Ethanol via Cornstarch	Offset	X	X	X
Crop Mix Alteration	Emission, Sequestration	X		X
Rice Acreage	Emission		X	
Crop Fertilization Alteration	Emission, Sequestration	X		X
Crop Input Alteration	Emission	X		X
Crop Tillage Alteration	Emission	X		X
Grassland Conversion	Sequestration	X		
Irrigated /Dry land Conversion	Emission	X		X
Livestock Management	Emission		X	
Livestock Herd Size Alteration	Emission		X	X
Livestock Production System Substitution	Emission		X	X
Manure Management	Emission		X	



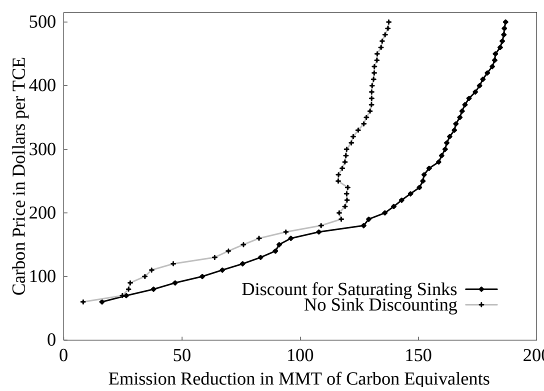
Panel A – Total Emissions Offsets from Agriculture and Forestry



Panel B - Emissions Offsets from on Agricultural Soil Carbon Sequestration



Panel B – Emission Offsets from Afforestation of Cropland



Panel B – Emission Offsets from Sustainable Energy Crop Plantations

Figure 1 Annual Net Abatement of GHG from US Agriculture and Forestry (Impermanence Discount equals 25% for Afforestation and 50% Agricultural Soil Carbon)