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Technical Progress Report

"Restoring Sustainable Forests on Appalachian Mined Lands for Wood Products, Renewable Energy, Carbon Sequestration, and Other Ecosystem Services"

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ABSTRACT

The overall purpose of this project is to evaluate the biological and economic feasibility of restoring high-quality forests on mined land, and to measure carbon sequestration and wood production benefits that would be achieved from forest restoration procedures. In this segment of work, our goal was to review methods for estimating tree survival, growth, yield and value of forests growing on surface mined land in the eastern coalfields of the USA, and to determine the extent to which carbon sequestration is influenced by these factors. Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), mandates that mined land be reclaimed in a fashion that renders the land at least as productive after mining as it was before mining. In the central Appalachian region, where prime farmland and economic development opportunities for mined land are scarce, the most practical land use choices are hayland/pasture, wildlife habitat, or forest land. Since 1977, the majority of mined land has been reclaimed as hayland/pasture or wildlife habitat, which is less expensive to reclaim than forest land, since there are no tree planting costs. As a result, there are now hundreds of thousands of hectares of grasslands and scrublands in various stages of natural succession located throughout otherwise forested mountains in the U.S. A literature review was done to develop the basis for an economic feasibility study of a range of land-use conversion scenarios. Procedures were developed for both mixed hardwoods and white pine under a set of low product prices and under a set of high product prices. Economic feasibility is based on land expectation values. Further, our review shows that three types of incentive schemes might be important: (1) lump sum payment at planting (and equivalent series of annual payments); (2) revenue incentive at harvest; and (3) benefit based on carbon volume.

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INTRODUCTION

Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), has drastically altered surface mining and reclamation practices. The intent of this law is to ensure that surface mined land is reclaimed to a condition capable of supporting a productive land use. Therefore, coal companies are required to specify a post-mining land use for which the land will be reclaimed. Furthermore, productivity standards were established for various land uses, and coal companies are required to post a performance bond that will only be returned if the performance criteria for the specified land uses are achieved within five years. In the central Appalachian region, where prime farmland and economic development opportunities for mined land are scarce, the most practical land use choices are hayland/pasture, wildlife habitat, or forest land. Since 1977, the majority of mined land has been reclaimed as hayland/pasture or wildlife habitat, which is less expensive to reclaim than forest land, since there are no tree planting costs. Although an accurate measure of the total area converted from forests to grasslands is not available, it is estimated to be between 150000 and 170000 hectares in the eastern U.S alone (Burger et al., 2002). Such post-mining land uses may be useful and economically feasible on lands mined by mountaintop removal methods, if these lands will indeed be used for grazing, or growing and harvesting hay. However, in reality, lands with steep slopes that are mined by contour mining methods and reclaimed as hayland and pastureland are not ideally suited for grazing or harvesting hay, primarily due to limited accessibility by machinery and animals. Therefore, in most instances, these lands are abandoned following bond release, and slowly revert back to relatively unproductive stands of understocked and undesirable tree species. Perhaps this is why the general perception of land disturbed by strip mining for coal has historically been one of devastated, unproductive wasteland (Plass & Burton, 1967).

According to SMCRA requirements, mine operators are responsible for reclaiming mined land. Thus, landowners tend to defer post-mining land-use decisions to the coal operator. The major problem with this setup is the lack of long-term interest that the coal operators have in the land. Thus, these coal operators attempt to reclaim the land in (what they perceive to be) the cheapest and least time-consuming way possible. As a result, there are now hundreds of thousands of hectares of grasslands and scrublands in various stages of natural succession located throughout otherwise forested mountains. Most of these lands will eventually become forests by default via natural succession. However, because of existing soil and vegetation properties created by inadequate reclamation, this process will require as much as several hundred years, and the forests' potential to produce timber and to sequester carbon will remain poor due to the poor soil physical and chemical properties created during mine reclamation (Burger, 1999). From a purely economic standpoint, this time delay equals money lost. Hence, the question must be posed: Why wait several hundred years to reap the economic and ecological benefits of a mature forest, when the same results could possibly be achieved in a fraction of that time?

Public Law 95-87 mandates that mined land be reclaimed in a fashion that renders the land at least as productive after mining as it was before mining (Torbert et al., 1995). Research has shown that restored forests on mined lands can be equally or more productive than the native forests removed by mining (Burger and Zipper, 2002). Given that most land surface-mined for coal in the Appalachians was originally forested, it would appear that forestry is a logical land use for most of the reclaimed mined land in the Appalachian Mountains (Torbert and Burger, 1990). However, since implementation of the SMCRA, it appears that fewer forests are being restored (Burger et al., 1998). At the same time, planting of tree seedlings is in fact one of the most commonly used methods of revegetating spoil bank areas in some states (Brown 1962), such as Virginia, where (since 1991) 86% of Virginia's mined land has been reclaimed to forested post-mining land uses. Unfortunately, the majority of mined land reclaimed as forest land is not reclaimed in a way that favors tree establishment, timber production, carbon sequestration, and (more importantly) long-term forest productivity (Torbert and Burger, 1990).

It is believed that these reclaimed mined lands are producing timber and sequestering carbon at rates far below their potential for reasons that include poor mine soil quality, inadequate stocking of trees, lack of reforestation incentives, and regulatory disincentives for planting trees on previously forested land (Boyce, 1999; Burger and Maxey, 1998). A number of these problems can be ameliorated simply through intensive silvicultural management. Through established site preparation techniques such as ripping, weed control, fertilizing and liming, the quality of a given site can be improved considerably. Other management and silvicultural techniques such as site-species matching, correct planting techniques, employing optimal planting densities, post-planting weed control, and thinning can also go a long way to ensuring improved development of forest stands, and subsequently improved timber production and carbon sequestration.

Similar to the much-debated topic of converting agricultural land to forests, the conversion of reclaimed mined lands to forests carries with it many economic implications. The primary difference between converting agricultural lands to forests and converting reclaimed mined lands to forests is the absence of any obvious extrinsic opportunity cost in the latter scenario; this, of course, only under the assumption that the reclaimed mined land has been abandoned, and is not being utilized for any economically beneficial purpose.

A fair amount of research has been conducted regarding the amounts and values of timber produced on reclaimed mined lands. The effect that a carbon market may have on decisions pertaining to the reclamation of mined lands has also been researched. According to previous research, it appears that mined lands are capable of sequestering carbon and producing harvest volumes of equal or greater magnitude to similar non-mined lands. This fact alone, however, does not render afforestation of mined lands economically profitable or feasible in all cases. There appears, at this stage, to be a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current use to forests, and the economic implications of such a land use conversion. Furthermore, the potential for an incentive scheme aimed at promoting the conversion of reclaimed mined lands to forests has yet to be explored in depth.

EXECUTIVE SUMMARY

The overall purpose of this project is to evaluate the biological and economic feasibility of restoring high-quality forests on mined land, and to measure carbon sequestration and wood production benefits that would be achieved from forest restoration procedures. In this segment of work, our goal was to develop a framework for calculating and understanding the economic implications of converting reclaimed mined lands to forests for carbon sequestration and other uses.

The cost of sequestering carbon through forestry appears to be fairly well documented in the literature. These costs range from $0/ton of carbon to $120/ton of carbon, although the majority of studies suggest a cost below $50/ ton of carbon, with van Kooten et al. (2000) suggesting a cut-off cost of $20/ton of carbon sequestered. However, the economic implications of sequestering carbon, specifically on mined lands, is not a well-researched area. Kronrad (2002) approached the carbon sequestration issue from a different angle. He assumed various values of carbon, and analyze how these various values affect the profitability of planting and managing forests on abandoned mined lands. The studies by van Kooten et al. (1995) and by Hoen and Solberg (1997) both addressed the impact of a carbon tax/subsidy scheme on the optimal forest rotation. Both studies suggested a periodic (annual) carbon subsidy payment, as a means of delaying harvest, and in so doing, extending the decay of carbon already sequestered.

Thus, there appears, at this stage, to be a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current use to forests, and the economic implications of such a land use conversion. More specifically, the only piece of literature that does address a similar topic considers only one hardwood species for reforestation, and only uses growth and yield models developed for non-mined land, and not actual data pertaining to growth on mined lands. This reforestation concept needs to be extended to other hardwood and softwood species, and needs to be based on silvicultural prescriptions that are specifically designed for mined sites. Furthermore, the potential for a variety of incentive schemes, aimed specifically at promoting the conversion of reclaimed mined lands to forests, has yet to be explored in depth. As opposed to calculating the economic feasibility of various reforestation regimes based on assumed carbon prices, it may be more useful (for policy makers) to gain an idea of what the value of carbon would need to be in order to render a given land-use conversion profitable to the landowner. Policy makers could then use these carbon values to establish real carbon subsidies.

Based on this review, our approach is as follows:

1. Develop a framework for calculating/understanding:
   - the economic implications of converting reclaimed mined lands to forests under various: silvicultural regimes, alternative rates of return and timber prices.
   - incentive schemes required to render regimes profitable for landowners.
2. Evaluate the economic feasibility of converting mined land, reclaimed since the implementation of SMCRA in 1978, from grasslands to high-quality white pine and mixed hardwood forests through the:

- estimation of market benefits and costs of conversion, for various silvicultural regimes , alternative rates of return and timber prices.
- estimation of the present value of net benefits for the private landowner that follow from market activities over a range of scenarios (by varying: site preparation costs, timber prices and alternative rate of return).

3. Calculate incentive levels required to render regimes profitable for landowners. This will entail the evaluation of three different incentive schemes:

   - Lump sum benefit, paid at the time of planting – this benefit will equate to a once-off payment made at the time of planting, in order to render the given scenario economically feasible. This benefit, paid at the time of planting, will also be translated into an annual payment.
   - Benefit based on revenue received at harvest – this benefit will equate to the increase in revenue at harvest required to render the given regime economically feasible.
   - Benefit based on carbon volume – this benefit will equate to an annual payment per unit carbon volume, required to render the given scenario economically feasible. In other words, we will calculate the value of carbon necessary to render a given scenario economically feasible.

EXPERIMENTAL

The following report consists of a literature review.

RESULTS AND DISCUSSION

Introduction

Literature pertaining to the reclamation of mines in general is in abundance. Much of the literature describes mine reclamation techniques and the advantages and disadvantages of mine reclamation. Relatively few studies have been conducted researching the economic feasibility of mine reclamation through forestry. This literature review is divided into four primary subsections: (1) economic analyses; (2) taxes, subsidies and policy design; (3) survival rates of planted trees; and (4) growth and yield on reclaimed mined lands. In reviewing the literature on mine reclamation and carbon sequestration, I focused primarily on studies that dealt with mining-, carbon sequestration-, and forestry-related economic analyses. Secondly, I reviewed studies that dealt with taxes and subsidy design. Lastly, in order to obtain data for use and comparison in my study, I reviewed studies that dealt with the survival rates of planted hardwood and pine plantation trees, and the growth and yield of various tree species on reclaimed mined lands.

Economic Analyses

The financial feasibility of converting reclaimed mined lands to forests is not well-researched. In fact, only one such study was found. However, the concept of, and methods used in, analyzing the financial feasibility of a land-use conversion is by no means unique to reclaimed mined lands. Therefore, the search for literature was extended to a variety of forestry-related economic studies, with a concentration on carbon sequestration-related studies.

Mined Land Study

Kronrad (2002) conducted an economic feasibility study on abandoned mine lands in Pennsylvania, Ohio, West Virginia, Kentucky, Tennessee, Virginia, Maryland and North Carolina. The purposes of this study were to (1) calculate the profitability of planting and managing forests on abandoned mine lands for the dual products of timber and carbon storage, (2) calculate the total amount of carbon that can be stored, and (3) determine the average cost of sequestering carbon. He considered only pure red oak (*Quercus rubra*) stands in his study. Variables used in the study include a range of site indices, rates of return, costs of site preparation, and values for each ton of carbon stored. Five site indices, 40, 50, 69, 70 and 80 (base age 50), were used, and six alternative rates of return (ARR), 3.5, 5.5, 7.5, 10, 12.5, and 15% were considered. Site preparation costs ranged from $300/acre (low site preparation cost) to $1325/acre (high site preparation cost), and sawtimber and pulpwood prices were adjusted according to the state. Five thinning intensities were employed: 20, 25, 30, 35 or 40% of basal area removal. For the analyses, the price of carbon was assumed to be $10, $50, or $100 for each additional ton of carbon that is sequestered. He evaluated several thinning and harvesting schedules in order to determine optimal thinning and harvesting schedules. For this part of the study, the Forest Vegetation Simulator (FVS) was used to simulate growth and yield of red oak in the Appalachian region. For each thinning and harvesting schedule combination, economic analyses were performed to determine net present value and soil expectation value. Results were then used to determine how profitable red oak management is on abandoned mine land, how profitable it is to sell timber and carbon credits on these sites, how much carbon can be stored on an acre of abandoned mine land, and the cost of sequestering carbon on these lands. The results of Kronrad's study suggest that as site quality increases and real rate of return decreases, the average cost of sequestering carbon decreases. The profitability of forest management increases as the assumed market price of carbon increases. Hence, as soil quality increases, profitability increases, but as the rate of return increases, forest investment becomes less appealing. He concluded by suggesting that investments should be made on the highest quality sites first and in projects that require the lowest site preparation costs.

Carbon Economics Studies

Ravindranath and Somashekhar (1995) conducted a study to analyze the potential and economics of various forestry options for carbon sequestration in India. Although not on mined lands, one of these options was the revegetation of degraded lands, under various management regimes. The "Soft Wood Forestry" (SFW) option (6-year rotation) yielded a NPV of $122/ha at a commercial interest rate of 12%, and a NPV of -$226/ha at an interest rate of 17.25%. The "Timber Forestry" (TF) option (hardwoods – rotation length not specified) yielded a NPV of $67 at an interest rate of 12% and a NPV of -$186 at an interest rate of 17.25% (1994 prices and exchange rate). Benefits considered included the value of biomass extracted per hectare of different options, namely firewood, timber, and some non-timber products. Establishment costs comprised expenditures in the initial two or three years for the establishment of the tree plantations. Ravindranath and Somashekhar reported carbon sequestration rates of 80 tonnes/ha and 120 tonnes/ha for the SFW and TF options, respectively. The NPV/tonne of carbon sequestered were reported as $1.5 and $0.5 for the SFW and TF options, respectively. The sequestered carbon values are net values after deducting the carbon emissions from clearfelling and end use. According to Ravindranath and Somashekhar, the two major sources of carbon emissions in India are energy and forestry. They reported that the investment cost per tonne of carbon benefit was lower for all forestry options compared to energy options.

In a study similar to that of Ravindranath and Somashekhar, Ismail (1995) evaluated the economics of various forestry options in Malaysia that contribute to the reduction of carbon dioxide in the atmosphere. Three types of forest management regimes were examined: (1) protective forestry; (2) production forestry; and (3) plantation forestry. Ismail used three criteria to evaluate the effectiveness in carbon sequestration: (1) Net Present Value (NPV) – derived from cash flow (discount rate = 8%), (2) – Net Present Value of Carbon (NPVC) – derived from carbon flow table using discount rates of 0%, 1% and 3%, and (3) Benefit of Reducing Atmospheric Carbon (CRAC) – ratio of NPV divided by NPVC, multiplied by the sum of the discount rate and decay rate of atmospheric carbon. The role of protective forests is simply to sequester carbon dioxide until the climax stage, where the net carbon sequestered is zero. Due to the loss in potential timber revenue, this management regime yielded negative NPVs for all variations. The production forest management regime is aimed at a sustainable supply of timber through selective logging. Results indicated that the production forests returned a relatively higher NPV compared to the protective forests, primarily due to revenue generated from old growth (virgin) forests. The plantation option yielded between 5 and 50 times the carbon sequestering capacity over the productive and protective forests. Results for plantation forests are presented in Table 1.

Table 1. Carbon flow analysis for plantation forest areas (Ismail, 1995).

	CRAC	NPVC ($/ha)	NPV ($/ha)
Quality timber (30 yrs):			
0%	0.12	300.3	-410
1%	0.16	230.175	-410
3%	0.25	146.675	-410
Fast-growing species (3 x 10 yrs):			
0%	-2.68	585.9	17455
1%	-3.31	475	17455
3%	-4.73	332.225	17455

The negative NPVs for quality timber management are attributed to the long rotation and the high initial establishment costs incurred. Ismail concluded that, although forest plantations could sequester the highest amounts of carbon per unit area, natural forests which are managed for sustainable timber production are the cheapest option for per-unit area carbon sequestered.

Xu (1995) calculated the amount of carbon sequestered through large-scale afforestation in China, and calculated related costs and benefits, assuming that the forests are managed in perpetual rotations. Similar to the carbon sequestration rates reported by Ravindranath and Somashekhar (1995), amounts of carbon sequestered varied, over a range of management scenarios, between 6.3 tons/ha and 146.4 tons/ha. NPVs calculated for the various management regimes ranged between -$39.80/ha and $1176.95/ha. Xu concluded that, given the results of this study, the least expensive way of developing forests for the purpose of sequestering carbon emissions is through the planting of *Pinus massoniana* from the initial investment point of view, followed by spruce.

Sedjo et al. (1995) conducted an assessment of existing studies regarding the economics of managing carbon via forestry. They report that a host of early studies have suggested relatively low carbon sequestration costs through tree planting; in many cases, under $10 per ton and rarely over $50 per ton. These, however, are only point estimates, and do not represent the problem of rising costs that are associated with involving large land areas. According to Sedjo et al., a number of more recent studies have overcome some of the limitations of the earlier analyses by:

- developing a cost function that estimates the rise in costs of capturing carbon associated with large-scale tree planting
- recognizing that land has opportunity costs
- refining the tree plantation establishment cost estimates
- utilizing discounting procedures

Results from three such studies are presented in Table 2.

Table 2. Estimates of marginal cost of carbon sequestered by tree planting (marginal costs $/ton) (Sedjo, et al., 1995).

Study	Total Carbon Sequestered (million tons per year)				
	45	**120-140**	**280**	**420**	**700**
Moulton/Richards (1990)	9	16.57	20.69	23.24	34.73
Adams et al. (1993)	n.a.	18.5	25.11	37.21	95.06
Parks/Hardie (1995)	10.14	82.49	n.a.	n.a.	n.a.

According to Sedjo et al., there has been relatively little work done on the cost of sequestering carbon by simply using various forest management practices. The study by Hoen and Solberg (1994) suggests that thinning is not a cost-effective means of sequestering carbon, while the carbon sequestration returns to forest fertilization generates marginal carbon sequestration costs of approximately $71 per incremental ton of carbon captured. Turner et al. (1993) summarized the findings of a number of studies by suggesting that the least promising silvicultural practices, from a direct carbon storage point of view, are those such as thinning, fertilization, and other stand improvement treatments.

In a seminal work on the effect of non-timber benefits on optimal timber rotations, Hartman (1976) has shown that rotations may be extended if there is some non-timber value associated with the forest. Unlike the Hartman rotation, where externality benefits are a function of the volume of timber growing on a site at any time, carbon benefits are a function of the change in biomass and the amount of carbon per cubic meter of biomass (van Kooten et al., 1995). In a study by van Kooten et al. (1992), the authors concluded that, under what they viewed as the most likely parameters, rotation ages increased by approximately 20% over the optimal financial rotation age, when no carbon costs or benefits were considered. Further research by van Kooten et al. (2000) focused on the economics of afforestation in western Canada. The purpose of the study was to examine the potential for planting trees on marginal agricultural land as one method for Canada to achieve its CO_2 emissions reduction commitments. Forests store carbon by photosynthesis. Van Kooten et al. reported that for every tonne (t) of carbon sequestered in forest biomass, 3.667 t of CO_2 is removed from the atmosphere. Carbon is stored, not only in above-ground biomass, but also in decaying material on the forest floor, in the soil and in products produced from harvested timber. Through a series of expansion factors, van Kooten et al. calculated total carbon content in hardwood and softwood timber for the given study region. They reported average costs of sequestering carbon through planting hybrid poplar ranging from $18.82 per tonne, if the value of carbon is not discounted, to $32.97 per tonne, if the value of carbon is discounted at 4%. If a mix of species is planted, average cost per tonne of carbon was reported as $26.87 and $57.78 at 0% and 4% discount rates, respectively. Van Kooten et al. suggested that a cost of $20/tonne of carbon sequestered is a reasonable cutoff for socially desirable investment in afforestation. The authors concluded that the potential of tree plantations as an economically viable carbon sink is not clear for the case of one-time planting.

In another carbon-related study, Plantinga et al. (1999) implemented econometric land use models to estimate the marginal costs of carbon sequestration in Maine, South Carolina, and Wisconsin. Scenarios with and without timber harvesting are examined. Plantinga et al. expressed carbon flows over the course of the various scenarios in terms of present value. For the sake of the study, a present value of 30.3 (short) tons per acre was assumed as the carbon flow in a southern pine stand in the southeastern United States, assuming a 60-year time horizon, no harvesting, and a 5% discount rate. A present value of flows of 23.7 tons per acre was assumed if the forest was assumed to be harvested and replanted in year 30. Plantinga et al. found that marginal costs per metric ton of carbon sequestered ranged between $0 and $120, and concluded that afforestation is indeed a cost-effective strategy for offsetting CO_2 emissions.

Other Forestry-Related Study

Amacher et al. (1997) conducted an economic feasibility study on the reforesting of frequently flooded agricultural lands in the Mississippi Delta. The four primary objectives of this study were:

- To estimate the net present value (NPV) of returns for alternative Delta reforestation strategies on flood-prone farmlands under representative soybean farming situations (e.g., hydrology, soils, prices and costs), and to determine whether reforesting is an economically feasible wetlands restoration option.

- To discuss how considerations other than NPV can influence landowner decisions to reforest, and landowner responses to alternative public policy designs.
- To describe policies and programs that can be developed for encouraging landowner adoption of reforestation on wetland soils as a restoration measure.
- To describe the effects of reforestation on the regional economy.

Seven possible bottomland hardwood reforestation scenarios were proposed and analyzed. The scenarios differed according to the silvicultural/planting regime appropriate for each species, differences in growth and yield, differences in soil type, and differences in rotation age. In order to compare the simulated NPVs, a common time horizon of 60 years (longest rotation) was implemented for all reforestation regimes. The NPV of reforestation for each soil type was computed using state-specific cost and return information. Estimates of the expected future prices for forest products and cost estimates for the various regimes were made. For computing NPV of forestry returns, the proportions of sawtimber to pulpwood, on various site qualities, implemented in this study are presented in Table 3.

Table 3. Proportions of sawtimber and pulpwood by species and site class (Amacher et al., 1997).

Site Quality	Sawtimber	Pulpwood
	-------------- %	--------------
High (all species)	75	25
Low (oak)	66.7	33.4
Low (other species)	50	50

Thinning was not included in any of the silvicultural regimes. Reforestation costs incorporated some or all of the following: site preparation (mechanical & labor), chemical treatment, disking (labor & mechanical), cultivation (labor & mechanical), seedling costs, and planting costs. The estimated total reforestation costs per acre for the various regimes ranged from $199.54/acre to $ 234.24/acre. In the NPV calculation for reforestation, returns, costs, and applicable cost sharing payments were included. A real interest rate of 5% was implemented in this study. Results yielded a range of net economic returns to reforestation from $139.44/acre to -$176.00/acre.

Taxes, Subsidies and Policy Design

It is important to recognize that private actions are likely to be affected by public policies that have actual or potential market implications (Sedjo et al., 1995). And so, carbon taxes and subsidies will affect the optimal forest rotation and, consequently, the carbon stored in forests (van Kooten et al., 1995).

Parks and Hardie (1995) calculated total discounted costs and employed current total carbon ratios to evaluate a specific carbon sequestration program similar to other successful environmentally motivated programs designed to change land use. They derived a supply schedule for carbon sequestered in trees planted on marginal agricultural lands in the U.S. This schedule was then used to develop criteria for enrolling lands in a national carbon sequestration program modeled after the Conservation Reserve Program. They concluded that a cost-effective program should focus on establishing softwood forests on pastureland, and selected lands by minimizing cost per ton of carbon sequestered. They estimated that such a program would sequester approximately 48.6 million tons of carbon per year (3.5 % of U.S. emissions) on 22.2 million acres. Costs would include $3.7 billion in land rental costs and forest establishment costs. Minimizing cost per acre would increase enrollment to 23.1 million acres, and would sequester 45 million tons per year, based on their analysis.

A study by van Kooten et al. (1995) examined the question of lengthening the rotation through the effect of carbon taxes and subsidies on the forest rotation when the carbon sequestered was explicitly valued. The study, which looked at forests in coastal British Columbia and northern Alberta, suggested that under some sets of timber prices, carbon values and tax/subsidy regimes, it is economically efficient never to harvest the forest, since the value of the sequestered carbon overwhelms the timber values. The proportion of carbon in biomass varies with species, although they estimated that it is in the range of 200 kilograms per m^3. Van Kooten et al. suggested that in order for forest companies to correctly take into account the external benefits and costs of their decisions, they should receive a yearly subsidy of P_cX for each m^3 of timber added to the growing stock (where: P_c = "price" or implicit social value of carbon that is removed from the atmosphere; X = (metric) tons of carbon per m^3 of timber biomass). Thus, this subsidy would be an annual subsidy equal to the total value of the carbon sequestered that year. Van Kooten et al. suggested that forest companies should face a tax levied at harvest time that equals the external cost of the carbon released to the atmosphere. The tax would be equal to $P_cX(1-B)$ per m^3 of timber harvested (where: B = fraction of timber that is harvested, but goes into long-term storage in structures and landfills).

Hoen and Solberg (1997) proposed a carbon tax/subsidy scheme, and analyzed how such a scheme would impact forest rotation ages. For the sake of their study, Hoen and Solberg assumed that subsidies are paid at the time of carbon sequestration and that taxes are imposed at the time of decay. The authors suggested that, if the subsidy/tax regime is connected to the stock, it would not be proper to use a once-and-for-all payment (lump sum) at the time of harvest, but rather to pay a smaller amount on a per-period basis. This would create (correct) incentives for promoting actions that extend/delay the decay of the carbon already sequestered. A lump sum payment, on the other hand, similar to the way timber is valued at harvesting, would generate counterproductive incentives, as it, at the margin, would represent a substantial cost to increase the rotation age and postpone the payment related to the carbon sequestered. Hoen and Solberg presented results from a numerical simulation, in which both timber and CO_2 benefits and costs are valued for a timber rotation of spruce. The results suggest that the optimal rotation age increases with increasing CO_2 price. The results further indicate that, under moderate CO_2 prices, the optimal rotation age decreases when the real rate of return increases.

Sullivan and Amacher (1999) developed a framework that links landowner and regional impacts of land use shifts from agriculture to forestry in the Mississippi Delta, in order to compare economic impacts of land use changes at landowner and regional levels and to investigate the self-financing potential of subsidies. They concluded that, for limited combinations of tree species and soil type (better soils), landowner subsidies could be self-financing, providing tax revenues that could offset government outlays. Furthermore, if subsidies were adopted, they should target specific species and site conditions.

CONCLUSION

The economic feasibility study by Kronrad (2002) appears, at this stage, to be the only study that directly considers the economic implications of planting and managing forests on abandoned mined lands. His study, however, focused on establishing forests on abandoned mined lands, and not on converting reclaimed mined lands to forests. His study also considered only one hardwood species for reforestation.

The cost of sequestering carbon through forestry appears to be fairly well documented in the literature. These costs range from $0/ton of carbon to $120/ton of carbon, although the majority of studies suggest a cost below $50/ ton of carbon, with van Kooten et al. (2000) suggesting a cut-off cost of $20/ton of carbon sequestered. However, the economic implications of sequestering carbon, specifically on mined lands, are not well-researched. Kronrad (2002) approached the carbon sequestration issue from a different angle. He assumed various values of carbon, and analyzed how these various values affected the profitability of planting and managing forests on abandoned mined lands. The studies by van Kooten et al. (1995) and by Hoen and Solberg (1997) both addressed the impact of a carbon tax/subsidy scheme on the optimal forest rotation. Both studies suggested a periodic (annual) carbon subsidy payment as a means of delaying harvest, and in so doing, extending the decay of carbon already sequestered.

Thus, there appears at this stage to be a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current use to forests, and the economic implications of such a land use conversion. More specifically, the only piece of literature that does address a similar topic considered only one hardwood species for reforestation, and only used growth and yield models developed for non-mined land, and not actual data pertaining to growth on mined lands. This reforestation concept needs to be extended to other hardwood and softwood species, and needs to be based on silvicultural prescriptions that are specifically designed for mined sites. Furthermore, the potential for a variety of incentive schemes, aimed specifically at promoting the conversion of reclaimed mined lands to forests, has yet to be explored in depth. As opposed to calculating the economic feasibility of various reforestation regimes based on assumed carbon prices, it may be more useful (for policy makers) to gain an idea of what the value of carbon would need to be in order to render a given land-use conversion profitable to the landowner. Policy makers could then use these carbon values to establish real carbon subsidies.

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