Critical Reviews in Environmental Science and Technology, 27(Special): S9–S21 (1997)

AN ECONOMIC APPROACH TO PLANTING TREES FOR CARBON STORAGE

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ABSTRACT: Methods are described for evaluating economic and carbon storage aspects of tree planting projects (e.g., plantations for restoration, roundwood, bioenergy, and nonwood products). Total carbon (C) stock is dynamic and comprises C in vegetation, decomposing matter, soil, products, and fuel substituted. An alternative (reference) case is essential for project evaluation.

KEY WORDS: Global change, forests, carbon, plantations, tree planting, project evaluation.

1. INTRODUCTION

Over 120 developed and developing countries met this year in Berlin[1] to discuss mitigating carbon dioxide emissions as part of their responsibilities under the Framework Convention for Climate Change.[2] The Berlin mandate obligates countries to reduce net emissions and requires policy makers and analysts to rapidly[3] become familiar with new mitigation alternatives (e.g., tree planting). Although planting trees for carbon storage appears to be a cost-effective option for many countries, consistent analytical methods are still needed to quantify costs, benefits, and carbon storage associated with planted forests.

The United Nations Food and Agricultural Organisation (FAO) (1995) estimates that 10.5 million ha of new plantations were annually established during the 1980s. The net gain in plantation area for this period was about 2 million ha per year since new plantations can *(i)* regenerate harvested plantations; *(ii)* reforest removed natural forests; or *(iii)* afforest lands previously in nonforest uses. The total area in forest plantations in 1990 was about 130 million ha (Allan and Lanly 1991), of which 14 percent was in boreal regions, 63 percent in temperate regions, and 23 percent in tropical regions (FAO 1995).

Like natural forests, planted forests take up and store carbon (C) at high rates compared to other world land covers. Storage rates commonly range from 1 to 8 MgC ha^{-1} yr^{-1} (1 Mg equals 10^6 g), and typical mean C storage over a rotation period is from 50 to 80 MgC ha^{-1}

1064-3389/97/$.50

(Winjum and Schroeder 1995). Key carbon stocks associated with planted trees may include *in situ* carbon (i.e., carbon stored at the forest location in the vegetation, decomposing matter, and soils), carbon in forest products, and carbon in substituted fuel. Two alternatives for claiming carbon storage from planting trees should be conceptually distinguished: *(i)* Carbon saved by fossil fuel substitution; *(ii)* Carbon stored *in situ* and in wood products. The duration of C storage (permanent or transitory) is of paramount importance.

In the first case, the carbon stored is the net amount of carbon saved during the tree planting project by substituting biomass fuels from the planting project for fossil fuels. This storage may be transitory if the saved fossil fuels are later used, but is otherwise permanent. In the second case, permanent carbon storage only occurs when the plantation is permanent: Storage in products is transitory (these eventually decay) and much of the *in situ* carbon stock may return to the atmosphere if the planted lands are ultimately converted to nonforest use.

Carbon storage strategies such as establishing planted trees must be considered amidst an array of emissions reduction alternatives. This paper presents an effective method for policy makers and analysts to make clear evaluations and comparisons before selecting tree planting to aid in C storage. After discussing definitions and scope, the paper describes carbon stocks, costs, and benefits associated with tree planting projects. This is followed by a discussion of project evaluation criteria, a summary, and conclusions.

2. SCOPE AND DEFINITIONS

In this discussion, forest plantations include contiguous areas of planted trees occupying areas greater than one hectare. Tree planting should be sufficient to provide stocking to at least 20 percent crown cover. This definition is consistent with FAO (1995) terminology for forest plantations and stocked forests. Planted tree areas such as in urban settings, windbreaks, or boundary strips are outside the scope of this definition. In addition, while agroforestry[4] must be acknowledged as an important class of land uses, treatment of selected agroforestry systems is beyond the scope of the present work.

Major plantation types include those planted primarily for restoration, roundwood, bioenergy, and nonwood purposes. It is clear that specific plantations may span more than one of these categories,[5] but some structure is useful for categorizing important net changes associated with components of carbon stocks (e.g., changes in fuel carbon stocks associated with bioenergy plantations).

Restoration plantations are planted primarily to obtain environmental services other than commodity products (e.g., reduced soil erosion, habitat for biologically diverse plant and animal communities). Roundwood plantations are planted primarily to obtain raw materials for timber products (e.g., pulpwood, sawnwood). Bioenergy plantations are planted primarily to obtain materials for use as energy sources (e.g., fuelwood, charcoal). Plantations for nonwood purposes are planted primarily to obtain products other than timber commodities (e.g., rubber, nuts, or fruit). Evaluations of forest plantations for C storage must consider the social and institutional settings of the land owners. In developed countries, these settings may include public, large-, and small-private classes of owners. Examples of forest plantations for these owners include government forests, industrial tree farms, and individually-owned forests, respectively. In developing countries, forests owned as commons may also be included. Examples of public, commons, and private plantations include government forests, community forests, and farm woodlots, respectively. In general, the methodology described here is applicable to all these categories, though unique consideration may be required in some cases.

3. CARBON STOCKS

A proper account of the carbon implications of a tree planting project must include the different carbon stocks that may be influenced by the project. These include carbon stored in vegetation (above and below ground), decomposing matter, soils, wood products, and the carbon substituted by burning wood for energy instead of fossil fuels. The empirically relevant stock components will vary with the type of plantation (restoration, roundwood, bioenergy, nonwood). For example, in restoration projects there may be no wood products and in bioenergy projects all biomass may be used for fuel.

The total MgC ha^{-1} stock of carbon stored at time t (C_t) is the sum of *(i)* carbon stored in living vegetation above and below ground (C_{vt}), *(ii)* carbon stored in decomposing matter (e.g., litter and coarse woody debris, including dead trees, dead branches, and dead leaves) (C_{dt}), *(iii)* carbon stored in soils (including humus and soil organic matter) (C_{st}), *(iv)* carbon stored in wood products[6] (e.g., furniture, lumber, paper and paperboard products) (C_{pt}), and *(v)* cumulative carbon substituted by the replacement of fossil fuels with biomass fuel from the project (C_{ft}),

$$C_t \; C_{vt} + C_{dt} + C_{st} + C_{pt} + C_{ft} \, .$$

Similarly, the rate of change in total carbon stock (c_t) is comprised of rates of change in carbon stored in vegetation, decomposing matter, soils, products, and substituted fuel (i.e., $c_t \; c_{vt} + c_{dt} + c_{st} + c_{pt} + c_{ft}$). (These rates of change will subsequently be referred to as carbon flows.)

For ease of exposition, consider a project planning horizon where time is measured in discrete units (e.g., years). The total carbon flow c_t is defined as $C_{t+1} - C_t$; carbon flows for each component of carbon stock are similarly defined. These flows are useful in analysing carbon stored during finite periods. For example, the total carbon stored during the life of a tree planting project over T years is

$$C_T = \sum_{t=0}^{T} c_{vt} + c_{dt} + c_{st} + c_{pt} + c_{ft}$$

Each flow may be positive or negative, and may be influenced by management activity pursued during the planning horizon. Consequently, empirical studies frequently calculate carbon stocks for finite periods by multiplying an average flow by the length of the planning horizon. Ideally, the planning horizon should be long enough to assure that the carbon stock has reached a steady (equilibrium) state (i.e., $c_T = 0$).

Tree planting projects are often evaluated using mean carbon storage over the life of the project. Collapsing the dynamic stream of carbon storage into a single statistic will obscure the timing of carbon storage benefits; however, defining this statistic is often unavoidable when tree planting projects must be compared to other emissions reduction projects (e.g., source reduction) of different lengths. Mean carbon storage (MCS) for a plantation of T years is $1/T \; \_ \; \Sigma_{t=1,T} C_t$. When T coincides with the length of a rotation (e.g., for roundwood, bioenergy, and nonwood product plantations) and soil carbon reaches equilibrium within T years,[7] then MCS for a perpetual series of identical rotations is equivalent to MCS for a single rotation. When the life of the project is finite, specific assumptions are required about which components of MCS legitimately may be claimed as permanent (see above).

Defining MCS for restoration plantations (that once established may never be harvested) is not simple. For example, if the restoration plantation reaches a steady state stock of carbon C_T after some finite time T (i.e., $c_T = 0$ " $t > T$), then an infinite number of observations of the stock C_T will be made following time T. Under this interpretation, MCS for the restoration plantation is equivalent to the steady state carbon stock C_T.[8]

Not all authors use the carbon stock categories described above (cf. Dewar 1990). Depending on the approach and the type of information available, authors may collapse vegetation and decomposing matter in one pool (Swisher 1991) or may use a component of C_{vt} (e.g., merchantable wood) to estimate total carbon (Moulton and Richards 1990). Carbon stocks of substituted fuel and products are central to an ongoing debate about the magnitude of carbon storage associated with fuel and materials substitution. The latter is attributed to the substitution of wood products from the tree planting project for energy intensive products (e.g., cement, steel). The net carbon storage gain associated with these stocks clearly depends on the alternative (i.e., reference case) to which the planting project is compared (see below).

4. COSTS

Depending on the type of plantation being considered, the direct cost of a tree planting project may include the value of resources (e.g., land, labour, materials) needed to establish, maintain, manage, monitor, and produce energy from the project. Project funding must cover the project's development and the expenses and incentives for its on-going operation, including maintenance, management and monitoring (see Table I).

The cost of establishing a plantation may include, for example, the costs of seeds or seedlings and other materials; labour costs for site preparation, planting, and building access roads; and materials and labour for replanting trees that do not survive the first year (Sedjo 1983). In developing countries, the value of labour inputs may be difficult to assess, especially when alternative uses of workers' time are in unpaid household production activities. Establishment costs are highest for restoration projects and biomass energy projects and tend to be lower for production of non-wood products.

Management costs include the cost of overall administration and technical supervision, and the costs of training, technical assistance and extension services to provide for a sufficient level of technical competence on the part of the participants. These costs tend to be relatively high for small-holder plantations, such as for production of non-wood products, and lower for roundwood plantations.

Maintenance costs may include weeding and thinning, road maintenance, and fire protection, as well as production costs including harvesting and transport. These costs tend to be higher for roundwood plantations and lower for restoration projects. The costs for biomass energy projects may also include the capital and operating costs of bioenergy production. The cost for biomass energy production is often expressed net of the value of

TABLE I
Relative Magnitudes for Selected Components of Cost for Restoration, roundwood, Bioenergy, and Non-Wood Product Plantations.

Establishment	Management Maintenance Energy[a]
Restoration	++ [b]
	+
	0
	0
Roundwood	+
	0
	++
	0
Bioenergy	++
	+
	+
	+
Non-wood	+
	++
	+
	0

[a] Refers to net costs of producing biomass energy (see text). [b] '++' indicates high cost, '+' indicates significant cost, '0' indicates little or no cost.

energy savings[9] (i.e., substituted fuel that need no longer be purchased) (Hall et al. 1991, Swisher 1995).

In addition, monitoring of all project types is a necessary expense to verify project success and carbon storage. Monitoring costs include the costs of conducting and updating site surveys, before and after soil testing, destructive tree measurements, and other procedures. These costs are roughly equivalent for the four types of plantations considered here.

Some costs, particularly maintenance and monitoring costs, may recur over the life of the project. To ensure that these costs are covered, and to provide an on-going incentive for participation in the project, recurring costs may be anticipated and provided for in the initial project funding.[10] In addition to direct costs of the project, externality costs (e.g., offsite damages from soil erosion) may be associated with some planting practices. These costs are most often associated with practices that are poorly performed, and may be minimized with appropriate monitoring and management activities.

The opportunity costs of not employing project resources in alternative uses (e.g., the value of land in agricultural use) require the definition of an alternative to the project (a reference case). This important category of costs will be discussed under project evaluation, after a discussion of benefits.

5. BENEFITS

The benefits from tree planting projects include those that may or may not be included in markets. Market benefits include the value of commodities produced by the tree plantation. For roundwood, bioenergy, and plantations for nonwood products, these can include harvested trees marketed for wood product resources (e.g., lumber, pulp and fuelwood), and nonwood extractions (e.g., latex for producing natural rubber). It is clearly possible for plantations to provide benefits that may be of value outside markets (e.g., stored carbon, reduced soil erosion, biologically diverse plant and animal communities). Some important benefits (e.g., socio-cultural, infrastructure, and political benefits) may not readily be quantified.

5.1. Quantifiable Economic Benefits

The value of marketed commodities may depend on the location of the market relative to the planted trees. Prices used to value timber commodities (stumpage prices) are often reported net of production costs, including transportation. It is possible for some services to influence the costs for marketed products produced away from the planted forest. For example, benefits attributable to reduced soil erosion may include larger fish stocks and decreased costs for fishing. In developing countries, the value of marketable commodities may be difficult to evaluate if markets do not exist or are far away from the planted trees.

Individuals may directly or indirectly benefit from planted environments (e.g., use values, and nonuse or existence values, respectively). Estimates of use values may be obtained by observing related market transactions. For example, observations of recreation site visits or property values are often used to estimate the value of recreation or aesthetic values.

Nonuse values can be divided into two categories, user's nonuse value and existence value (Freeman 1993). For remote locations, introducing planted trees can create or change amounts of environmental services (e.g., habitat for biologically diverse plant and animal communities) that individuals may value but not directly partake through use. A variety of hypothetical valuation methods (e.g., contingent valuation) have been developed to gain insight into nonuse values.

Whether goods and services provided by the plantations accrue to producers (as products or inputs) or consumers (as use or nonuse values) they can be further classified based on their degree of publicness. Rivalry and excludability are used to distinguish between public and private goods (Dixon and Sherman 1990). Public goods are nonrival and nonexcludable (e.g., aesthetic or scenic values).

5.2. Socio-Cultural, Infrastructure, and Political Benefits

Benefits may also include those which cannot readily be assigned a monetary value, either because data are not available or reliable enough, or because it is not clear how to quantify changes in their levels (e.g., limits to economic measurement, Dixon et al. 1994). Some nonquantifiable benefits can be crucial to long-term success of tree planting projects. The list of these benefits may be long, but many could be grouped into socio-cultural (including employment and equity), infrastructure (both human and capital), and political (both domestic and international) categories.

While some of these benefits may be evident to project implementors, they may not directly accrue to local land owners, individuals, and communities (Dixon and Sherman 1990). When benefits are not readily apparent, community members may not manage or protect the project for C storage benefits. Examples of this harm include deliberate fires, damage by animals, neglect of the plantation, and degradation of the plantation via open access use.

Socio-Cultural Benefits

For projects to succeed at the local level, benefits must accrue to individuals and local communities, in addition to entrepreneurs and the government.[11] Local benefits may be evident in a number of ways, such as off-season employment and the employment of community members in the collection or use of forest products and services. Depending on the type of tree planting project, these products may include fruit, medicines, fuelwood, grazing, fodder, and grasses. Some projects may influence intra-and intergenerational equity by changing the distribution of income or environmental benefits within and between generations.

Infrastructure Benefits

The availability and training of planners, entrepreneurs, managers, and skilled labour may be enhanced by the tree planting project, and physical assets may accompany its implementation. For some projects (including many that are funded by international lending agencies), improvement of human and technical capital, within the area of the project and nationwide, is a prerequisite for obtaining the long-term commitment needed for the projects to succeed.

Political Benefits

The public's perception that environmental issues, such as C storage or rehabilitation of degraded lands, are being addressed by tree planting projects is important both in domestic and international political decision making (e.g., devoting publicly-owned lands to planted forests). Vested commercial and institutional interests may have agendas inconsistent with long-term carbon storage, and thus must be considered when trying to ensure success of a project.

The existing institutional structure relevant to the proposed project (e.g., the level at which forest resource management decisions are made) should be consistent with the assumptions used to evaluate the planting project. In particular, the economic conditions under which planted forest commons (e.g., social forestry) succeed or fail may be important (Wade 1988).

6. PROJECT EVALUATION

This section presumes that an economic decision-maker (e.g., land owner, policy analyst, policy maker) must determine whether a specific tract of land should be devoted to a tree planting project that may result in C storage. Tree planting projects are frequently among a set of several alternatives for emissions reduction or land use. Because resources such as project funds or land may be scarce, not all projects may be pursued. As a result, the decision-maker must select among projects, including tree planting projects, based on their costs, benefits, and carbon effects.

For simplicity, we consider that the decision to plant trees will be made after considering the present value of net quantifiable benefits (Dixon et al. 1994), carbon storage, and unquantified benefits; other decision rules (cf. 'safety first' rules for subsistence agricultural production, or safe minimum habitat standards for species survival) may be relevant for evaluating specific tree planting projects. The decision-maker's concerns are very likely to include considerations (i.e., constraints) other than available land and funds. Such considerations may include desired levels of socio-cultural, infrastructure, or political benefits (see above) and carbon storage goals that must be met by specified dates within the planning horizon.

By pursuing the tree planting project, the decision-maker accomplishes carbon storage of *C*. Economic aspects of the project include quantifiable benefits and costs, for which the present net value may be written *PVNB*,[12] and unquantified benefits *B*. Carbon storage and unquantified benefits may be considered matrices of outcomes accrued over the planning horizon for the project, that is $C\ [C_0\ C_1 \ldots C_t \ldots C_T]$ and $B\ [B_0\ B_1 \ldots B_t \ldots B_T]$. Whether the decision-maker should pursue the project crucially depends on the alternative(s)[13] to the project and the evaluation criterion.

The decision-maker's alternative to the project (the reference case) accomplishes carbon storage of $C^0\ [C_0^0\ C_1^0 \ldots C_t^0 \ldots C_T^0]$, net economic benefits of $PVNB^0$ and unquantified benefits of $B^0\ [B_0 B_1^0 \ldots B_t^0 \ldots B_T^0]$. Possible reference cases include the most likely projection of land uses without the project (cf. 'business as usual' or *status quo* alternatives). For planted trees intended to replace natural stands, the reference case may be the standing forest. For planted trees intended to afforest agricultural lands, the reference case may be agricultural land use. As will be seen, the attributes of the reference case are as important to the decision-maker's decision as the attributes of the tree planting project. A correct decision cannot be made without some knowledge of both alternatives.

The decision-maker selects an alternative according to a criterion ('welfare') that incorporates the present value of net benefits, the carbon storage, and the unquantified benefits, $W=W(PVNB,\ C,\ B)$. For simplicity, consider the linear and separable function $W=w_1 PVNB + w_2 C + w_3 B$, where the weights w_1, w_2, and w_3 describe the relative importance of economic benefits and costs, carbon, and unquantified benefits in the decision-maker's decision.[14] Alternatives that provide acceptable levels of carbon storage and unquantified benefits (described by the matrices *C* and *B*, respectively) can be compared by the decision-maker using the criterion *W*.

Pursuing the tree planting project necessarily means that the decision-maker does not pursue its alternative. This fact defines the opportunity cost to the decision-maker of whichever alternative is selected. For example, if the project is pursued, W is obtained and W^0 is not obtained. The decision-maker's net welfare from pursuing the project is W minus W^0, and it is in this context that W^0 (welfare forgone) may be considered the opportunity cost of pursuing the tree planting project. The decision-maker's opportunity cost is comprised of welfare values of *(i)* economic net benefits (e.g., returns to land, labour, or materials in alternative uses), *(ii)* carbon (e.g., carbon sequestered in crop ecosystems), and *(iii)* unquantified benefits.[15] In developing countries, the value of forgone subsistence agricultural uses displaced by the project may be difficult to quantify; when this is the case, minimum subsistence production may be included in the constraints, B.

For example, the welfare derived from the reference case is $w_1PVNB^0 + w_2C^0 + w_3B^0$. If the decision-maker chooses the tree planting project, then the welfare change is $W = W - W^0$. It is convenient to represent the welfare change as the sum of its components, for example, $W = w_1PVNB + w_2C + w_3B$. The change in the carbon stock, $C = C - C^0$, must (by assumption) be compared to any obligated emissions reductions targets.

The decision-maker's choice to pursue the tree planting project includes determining the net economic gain from pursuing the project; if w_1PVNB exceeds zero, then the project contributes a net economic gain. In some circumstances (e.g., when carbon storage and unquantified benefits are roughly the same with and without the project), no further analysis may be needed. However, if w_1PVNB fails to exceed zero, then the project cannot be justified on economic grounds. If the decision-maker chooses to pursue the project under these circumstances an outside observer must conclude that the net welfare contributions from carbon storage and unquantified benefits, $w_2C + w_3B$, outweigh the economic costs of pursuing the project.[16]

Conversely, if added funds are required to induce the decision-maker to pursue the project, then the minimum amount required indicates a price for an outside transaction (e.g., a carbon offset trade) under the joint implementation provisions of the Framework Convention on Climate Change.[17] A potential buyer's maximum price for such an offset might be determined by the minimum marginal cost of emission reductions, applicable carbon tax or emissions charge rates, and the market price of other available carbon offsets.

When comparing a tree planting project to a reference case, the difference in carbon stock with and without the project is of crucial importance. As discussed earlier, $C = C - C^0$, which is comprised of changes in stock components. Omitting stock components (e.g., substituted fuel) in an analysis is equivalent to the assumption that $C_f = C_f - C_f^0 = 0$. Whether such assumptions are valid clearly depends on both the planting project and the reference case; however, the rationale and validity for omissions such as these should be discussed in all studies.

6.1. Monitoring

Once a project has been implemented it is essential to have an ongoing program of monitoring in place (and adequately funded). This is necessary to ensure the viability of the project for optimal long-term C storage. Thus the project management requires adequate data and feedbacks (both economic and non-economic) so that an adaptive management strategy (e.g., Walters 1986) can be used. This strategy should direct the project along the

C storage pathway (the main objective) while ensuring that the benefits are adequate to the investors and the local communities.

7. SUMMARY AND CONCLUSIONS

Economic evaluations of tree planting for C storage must consider the social and institutional settings of the land owners. Settings and institutions will vary by country, particularly between developed and developing countries and among boreal, temperate, and tropical forest regions. In general however, the methodology presented is applicable to tree planting throughout the world.

Major tree planting project categories include restoration plantations, roundwood plantations, bioenergy plantations, and plantations for nonwood products; combinations of these categories are common. Plantations include contiguous areas of planted trees greater than one hectare. Total carbon stock comprises carbon in vegetation, decomposing matter, soil, product, and fuel substituted. Carbon stored in each of these components is dynamic, and may change over time.

Economic costs of tree planting projects may include: The prices of all direct and indirect inputs (e.g., land, labour, management, materials) employed in the tree planting project; External costs of practices (if any) associated with tree planting. Benefits may include the values of goods and services attributable to tree planting (may or may not be exchanged in markets). Other unquantified benefits may include socio-cultural benefits, infrastructure benefits, and political-institutional benefits.

The carbon storage, benefits, and costs associated with an alternative to the project (a reference case) must be identified before the tree planting project may be evaluated. Carbon storage may be defined as the net change in total carbon storage between that stored in the project and in the reference case. A net carbon storage statistic exists for each time period in the planning horizon for the tree planting project.

If a summary statistic is needed, mean carbon storage may be defined as the cumulative total carbon storage over the planning horizon, divided by the length of the planning horizon. The assumptions implicit in this definition must be carefully considered when the planning horizon is of infinite length. Employing a summary statistic such as mean carbon storage masks some of the dynamics of the carbon storage process.

If an economic summary statistic is needed, the present value of net benefits may be obtained by discounting quantifiable benefits and costs. A present value calculation necessarily omits unquantified aspects (e.g., equity). Employing a summary statistic such as present net benefit masks some of the distribution of benefits and costs within and between periods in the planning horizon.

Economic evaluation of tree planting projects must consider *(i)* the perspective of the analysis (e.g., individual, community, societal) *(ii)* methods to account for nonmarket and unquantified benefits and costs *(iii)* the implications of risk, uncertainty, and project reversibility. Projects may require monitoring to inform adaptive management decisions when new information develops about project viability, economic or unquantified considerations, and changes in carbon stocks.

NOTES

[1]See, for example, Climate Talks Enter Harder Phase of Cutting Back Emissions', *New York Times* 11 April 1995.

[2]The Framework Convention is among several Conventions (cf. the Biodiversity Convention) signed by numerous United Nations member countries during the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janiero. See Report of the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change on the Work of the Second Part of Its Fifth Session, Held At New York from 30 April to 9 May 1992', United Nations Document A/AC.237/18 (Part II). New York.

[3]Some industrialized countries are obligated by the Framework Convention limit net emissions to 1990 levels as early as the year 2000.

[4]Agroforestry in this context is the cultivation of trees on the same land with agricultural crops and/or livestock. Note that several types of projects commonly described as agroforestry, such as small tree plantings (at least 1 ha) intended for nonwood products, and plantings of multiple tree species, are still within the scope of our definition of plantations.

[5]Evidence includes the fact that U.S. primary wood-using mills make use of 94 percent of all bark and wood residue at the millsite: 40 percent is used for fuel, 38 percent for wood chips and pulp, and 16 percent for such miscellaneous products as cooperage, bark mulch, and soil amendments (Powell et al. 1993).

[6]Depending on the goals of the study, carbon stored in products, C_p, may be subdivided into that stored in short-term, mid-term, and long-term product classes.

[7]Soil carbon does not reach equilibrium in rotations usually used for these types of plantations. Using MCS for a single rotation as a proxy for a perpetual series of rotations may therefore underestimate accumulated soil carbon.

[8]A similar method may also be employed to analyse the carbon stored in standing biomass for projects involving the protection of natural forests (Swisher 1995).

[9]The consumption of nonbiomass fuel in the reference case (see below) must clearly be known in order to calculate this savings.

[10]The reason for emphasizing this endowment approach is to ensure not only that all relevant costs are included, but to capture the assumption that local market and non-market benefits are retained as necessary incentives to keep the project operating over multiple rotation periods (Swisher 1991). Alternatively, these cash flow considerations might be incorporated into the project evaluation as constraints that revenues exceed costs for relevant periods.

[11]See, for example, Dixon and Sherman (1990 pp. 194-195) and Footnote 10.

[12]When the distribution of benefits and costs within and between generations is important and may be influenced by the project, then it may be desirable to avoid summarizing benefit and cost streams in a single *PVNB* index.

[13]The problem as presented is a choice between two mutually exclusive alternatives. The logic is readily applicable to choice scenarios with more than two alternatives and to continuous decisions (e.g., choosing the amount of land to allocate to the project and other uses).

[14]This might arise when allocating H hectares between the project and the alternative (reference) use. Allocating h hectares to the project and H-h hectares to its alternative based

on *PVNB* subject to minimum total acceptable levels of C_{min} (carbon) and B_{min} (unquantified benefits) gives rise to the Lagrangian $PVNB(h)+PVNB^0(H-h)+M_1[C(h) + C^0(H-h) - C_{min}] + M_2[B(h) + B^0(H-h) - B_{min}]$, for which M_1 and M_2 are multipliers. This is of the form $W=w_1PVNB + w_2C + w_3B$ when economic values are the units used to measure welfare. In the present value calculation, the weights w_1 could be interpreted to indicate rates of time preference for benefits, i.e., w_1 $[1\ (1+r)^{-1}\ (1+r)^{-2} \ldots (1+r)^{-t} \ldots (1+r)^{-T}]$ where r is the rate of time preference.

[15]When welfare is only measured in economic terms, then the planner's opportunity cost will only consist of economic benefits forgone by pursuing the project (e.g. the value of land in its next best use).

[16]Alternatively, *PVNB* may be taken as a lower bound on the planner's willingness to exchange economic benefits for carbon and noneconomic benefits (e.g. Dixon et al. 1994 pp. 52-53, Krutilla and Fisher 1985 pp. 84-150).

[17]See Footnote 2.

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