## CHAPTER 11

# FOREST CARBON SINKS: A TEMPORARY AND COSTLY ALTERNATIVE TO REDUCING EMISSIONS FOR CLIMATE CHANGE MITIGATION

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**Abstract.** The Kyoto Protocol (KP) requires signatories to reduce $CO_2$-equivalent emissions by an average of 5.2% from 1990 levels by the commitment period 2008-2012. This constitutes only a small proportion of global greenhouse gas emissions. Importantly, countries can attain a significant portion of their targets by sequestering carbon in terrestrial ecosystems in lieu of emission reductions. Since carbon sink activities lead to ephemeral carbon storage, forest management and other activities that enhance carbon sinks enable countries to buy time as they develop emission reduction technologies. Although many countries are interested in sink activities because of their presumed low cost, the analysis in this paper suggests otherwise. While potentially a significant proportion of required $CO_2$ emission reductions can be addressed using carbon sinks, it turns out that, once the opportunity cost of land and the ephemeral nature of sinks are taken into account, costs of carbon uptake could be substantial. Carbon uptake via forest activities varies substantially depending on location (tropical, Great Plains, etc.), activity (forest conservation, tree planting, management, etc.), and the assumptions and methods upon which the cost estimates are based. Once one eliminates forestry projects that should be pursued because of their biodiversity and other non-market benefits, or because of their commercial profitability, there remain few projects that can be justified purely on the grounds that they provide carbon uptake benefits.

## 1. INTRODUCTION

Global climate change constitutes a long-term threat to the earth's ecosystems and to the way people lead their lives. Some of the most serious threats include damages to agriculture, particularly subsistence farming in developing countries, and to coastal dwellers, who could lose their homes and livelihoods as a result of flooding caused by sea level rise. Climate change also poses a threat to forest ecosystems, resulting in changes to species composition and potentially threatening preservation of plants and biodiversity more generally. It will have impacts on sustainable forest management, creating challenges for foresters and decision makers.

*Kant and Berry (Eds.), Sustainability, Institutions, and Natural Resources: Institutions for Sustainable Forest Management, 233-255*

Most scientists are convinced that the discernible rise of 0.3 to 0.6 ºC in the earth's average surface temperature over the past century (Wallace et al., 2000) is related to the significant increases in carbon dioxide ($CO_2$) and other greenhouse gas (GHG) concentrations in the atmosphere. While the full extent of the potential damages from climate change remains unknown, scientists have argued that action should be taken to mitigate its potentially adverse consequences.

Does that mean that global society should immediately undertake activities to mitigate climate change? Economic principles dictate that mitigation activities should be implemented as long as the marginal benefits of so doing (i.e., the damages avoided by mitigation) exceed the marginal costs of actions to reduce atmospheric $CO_2$. However, while the (marginal) costs of mitigation measures tend to be unclear, estimation of the (marginal) benefits is even more problematic and controversial. Damages from climate change are expected in the more distant future and remain speculative, partly because they affect future generations and may be largely nonmarket in nature (e.g., affecting recreational activities, scenic amenities and biodiversity). Uncertainty about these damages (and thus the benefits of mitigation) exists in both the economic and scientific spheres.

Through the Kyoto Protocol (KP), the international community has prepared a policy response to global climate change as it relates to the emissions of GHGs. Although it is seriously flawed, the KP attempts to aid the international community in slowing or even preventing global anthropogenic emissions of greenhouse gases from rising in the future. For some countries, forest ecosystem sinks play an important role in KP compliance. Carbon uptake in forest ecosystems could be a potentially cheaper means of achieving compliance than decreasing $CO_2$ emissions (Obersteiner, Rametsteiner, & Nilsson, 2001; Sohngen & Alig, 2000). Our purpose in this chapter is to investigate in greater detail the potential role that forestry might play in helping countries achieve their KP targets. Our results indicate that, while forest carbon sinks can indeed reduce atmospheric $CO_2$, their role in enabling countries to meet their emission reduction targets is extremely limited, mainly because the creation of carbon sinks that are 'additional' is much more costly than initially recognized and, further, that such sinks are ephemeral.

Before examining carbon sinks as they relate to forestry activities in more detail, we begin by outlining the Kyoto Protocol in section 2, and in section 3, we explore how carbon sinks have been considered in lieu of $CO_2$ emission reductions. Potential carbon sinks allowed in forestry are discussed in section 4, while the question of discounting physical carbon and its impacts on estimates of the costs of carbon sequestration are the topic of section 5. This is followed, in section 6, by a more-detailed investigation into the costs of creating carbon credits in forest ecosystems through land use, land use change, and forestry (LULUCF) activities, and their limitations. In section 7, we discuss some additional difficulties related to the creation and trading of carbon offset credits. Policymakers have generally ignored landowners in their rush to create KP implementation plans, but owners may be reluctant to plant trees. This issue is discussed in section 8, because if landowners are not receptive to tree planting programs, their reticence will increase carbon uptake costs. The conclusions follow in section 9.

## 2. CLIMATE CHANGE AND THE KYOTO PROTOCOL

As a result of international concerns over anthropogenic emissions of GHGs, the Intergovernmental Panel on Climate Change (IPCC) was formed in 1988. The IPCC's first published report in 1990 led to the signing of the United Nations' Framework Convention on Climate Change (FCCC) in Rio de Janeiro in June 1992 by 174 countries. This agreement committed industrial countries to control greenhouse gas emissions to the 1990 level by year 2000, but subsequent Conference of the Parties (COP) meetings modified this target and further clarified how emissions were to be controlled.

In order to stabilize atmospheric concentrations of $CO_2$ and other GHGs, $CO_2$-equivalent emissions will need to be reduced by 50% or more from 1990 levels (Coward & Weaver, 2003).[2] Though falling far short of this target, industrial countries crafted the Kyoto Protocol at COP3 in December 1997, agreeing to reduce $CO_2$ emissions by an average of 5.2% from the 1990 level by 2008-2012. This implied a total reduction of 250 megatons (106 metric tons) of carbon[3], denoted Mt C, per year from 1990 levels. The KP will come into effect 90 days after it has been ratified by 55 states, as long as the industrialized countries that ratify account for 55% of the $CO_2$ emitted by industrialized countries in 1990. As of 26 November 2003, 120 countries had ratified, with ratifying industrial countries accounting for 44.2% of the 1990 emissions.[4] The United States, with 36.1% of industrial countries' emissions withdrew support for the KP during COP6 at The Hague in late 2000, citing high costs. Therefore, without the United States' participation, it is essential that Russia, accounting for 17.4% of 1990 industrial countries' $CO_2$ emissions, ratify the KP in order for the Protocol to come into effect.

Environmental externalities play a large role in the KP, necessitating government action to address the associated market failure. Three economic coordination methods that attend to this market failure are outlined by economists: i) Command and control (C&C), ii) common values and norms, and iii) market incentives. C&C consists mainly of standards (e.g., specifying fuel efficiency requirements of automobiles or the quality of insulation in new construction), bans and regulations (e.g., spelling out the amount of $CO_2$ a source may emit). Common values and norms constitute those elements of civil society that facilitate voluntary action, and are most often found in countries with a highly homogenous population (e.g., The Netherlands, Singapore). As to market incentives, it is well known that market instruments, such as carbon taxes or tradable emission permits (quotas), result in lower costs than C&C, because prices in the form of taxes or permits cause firms to seek the lowest cost means of reducing emissions (see Field & Olewiler, 2002). International trading of $CO_2$ emission and offset permits, and substitution of the most economical means of reducing emissions, would allow the most economic gain, while putting a value on the environmental externalities caused by $CO_2$ entering the atmosphere.

With this in mind, the KP outlines the following ways for a country to meet its commitments:

i. Countries can simply reduce their own emissions of GHGs to the target level, say R in Figure 11.1.

ii. Rather than reducing domestic CO2 emissions to R (Figure 11.1), a country can achieve R by sequestering an equivalent amount of carbon in domestic terrestrial ecosystems. These activities are discussed in more detail on the following pages.

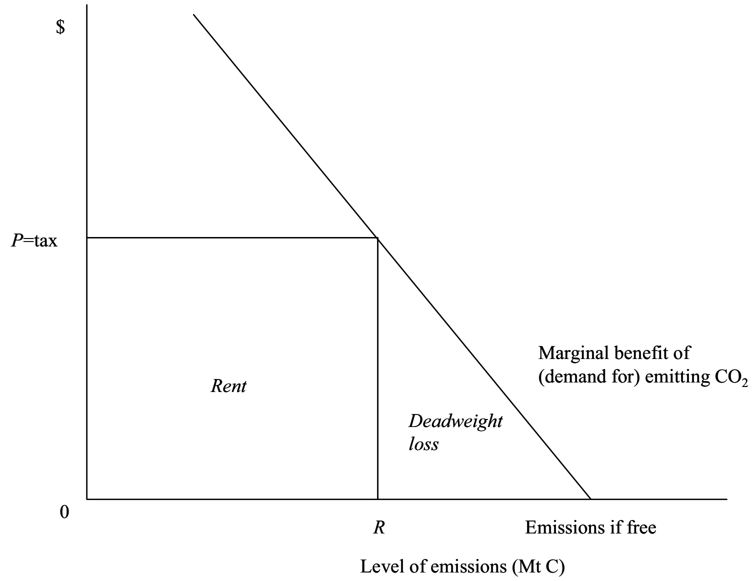

***Figure 11.1.*** *Controlling $CO_2$ Emissions using Economics Incentives*

iii. Joint implementation (JI) is encouraged under KP Article 6. JI allows an industrial (Annex B) country to participate in emissions-reduction or carbon sequestration activities in another Annex B country (essentially in Central and Eastern Europe), thereby earning "emission reduction units" (ERUs) that are credited toward the country's own commitment.

iv. Under the "clean development mechanism" (CDM) of KP Article 12, an Annex B country can earn "certified emission reductions" (CERs) by funding emissions-reduction or carbon sequestration projects in a non-Annex B (developing) country. However, only afforestation and reforestation activities can be used to generate carbon uptake CERs, and their use is limited (in each year of the commitment period) to 1% of the Annex B country's 1990 (base-year) emissions.

v. Finally, an Annex B country can simply purchase excess emission permits from another Annex B country (Article 17). Emission permits in excess of what a country needs to achieve its commitment are referred to as "assigned amount units" (AAUs) that can be purchased by other countries. These are particularly important to economies in transition that easily attain their KP targets because of economic contraction and the concomitant closure of inefficient power plants and manufacturing facilities, thereby creating "hot air" (AAUs) to be sold at whatever price is available.

While the availability of a variety of emissions-reduction and carbon sequestration options should reduce compliance costs relative to the situation where restrictions are placed only on emissions, the addition of these options in the KP complicated matters significantly. Compared to a more simplified scheme, monitoring and enforcement authorities will need more information, such as forecasts or projections of the potential supply of carbon offsets in future years, in order to set a quota on emissions. Transaction costs of operating the trading scheme will also increase significantly.

## 3. CARBON SINKS IN LIEU OF EMISSIONS REDUCTION

Negotiations since COP3 in Kyoto have focused primarily on the so-called flexibility mechanisms, most importantly Joint Implementation, the Clean Development Mechanism and International Emissions Trading. A number of parties argued that the role for terrestrial carbon sinks as replacements for emissions reductions was inadequate, so, at COP6$_{bis}$ at Bonn in July 2001, the European Union (EU) relented to a broader role for carbon sinks, mainly to appease Japan, Australia and Canada, and the United States in absentia. This permitted countries to substitute carbon uptake from LULUCF activities in lieu of greenhouse gas emissions. The IPCC (2000a) estimates that biological sink options have the potential to mitigate some 100,000 Mt C between now and 2050, amounting to 10% to 20% of fossil fuel emissions of $CO_2$ over the same period[5]. When using the Marrakech Accords (agreed to at COP7 at Marrakech, Morocco, October/November 2001) as the basis for calculating the carbon offset potential of biological sinks, it is clear that terrestrial sinks have become an important means by which some countries can achieve their KP targets (see Table 11.1). Nearly 200 Mt of carbon credits could potentially be achieved by LULUCF activities, amounting to 80% of the 250 Mt C annual reductions that would have been required of industrial countries in 1990 but will be much higher for 2008-20012.

Under the KP, permitted terrestrial sink activities include reductions in carbon release from net land-use change and forestry in Annex B countries that had net LULUCF emissions in 1990 (Article 3.7); net removals by sinks as a result of human-induced afforestation, reforestation and deforestation (Article 3.3);[6] and net removals through changes in agronomic practices (cropland and grazing land management and revegetation actions) and from enhanced forest management (Article 3.4). The problems with terrestrial sinks are fourfold: (i) their inclusion and use under the KP are examples of political maneuvering to avoid emissions reduction; (ii) they tend to be highly ephemeral and thus not equivalent to emissions reduction (see below); (iii) the 'value' of sinks to a country is tied to the land use existing in 1990 as the base year; and (iv) carbon flux is notoriously difficult to measure.

***Table 11.1.*** *Potential Role of Terrestrial Carbon Sinks in Meeting KP First Commitment Period Targets, Based on Marrakech Accords (Mt C per year)*

| *Item* | *Total Annex B* | *Central and Eastern Europe (in Annex B)* | *Rest of Annex B* |
|---|---|---|---|
| KP Article 3.3 (ARD) net increase in sinks | 12.28 | 0.00 | 12.28 |
| Maximum sinks due to forest management[a] | 97.87 | 38.59 | 59.28 |
| Increase in sinks due to agricultural activities | 33.56 | 3.61 | 29.95 |
| Maximum use of sinks under KP Article 12 (CDM) | 49.83 | 14.87 | 34.96 |
| **Total estimated potential of sinks to meet KP target** | **193.54** | **57.07** | **136.47** |

[a] At COP7, Russia increased its maximum sink level from 17.63 Mt C to 33.00 Mt C, thereby increasing the total here from 23.22 to 38.59. Not included is the annual 0.8 Mt C increase in permitted credits attributable to forest management as an offset against ARD debits during the commitment period, when comparing Bonn (COP6bis) with Marrakech (COP7).

***Source:*** Authors' own calculations

The sequestration of carbon in terrestrial sinks will also in time encounter an equilibrium, beyond which point additional net sequestration will not be possible. Most likely, before reaching this point, the economics of continuing with sequestration as a substitute for emission reductions in other areas will no longer be feasible. Therefore, for long-term reductions in total net emissions, terrestrial carbon sinks will become less important and total emissions from fossil fuels will have to be addressed. At best, in the long-term, terrestrial carbon sinks are a stop-gap measure. The problem is that terrestrial sinks have become a distraction that prevents countries from making serious inroads with respect to emissions reductions, because it enables some countries to avoid implementing politically difficult actions.

## 4. CARBON SINKS IN FORESTRY

According to the Kyoto Protocol, while not initially included in the determination of baseline carbon emissions, afforestation, reforestation and deforestation (ARD) activities need to be considered in determining 2008-2012 emissions if forest carbon sink credits are to be claimed. Afforestation refers to human activities that encourage growing trees on land that has not been forested in the past 50 years, while reforestation refers to human activities that encourage growing trees on other land that was forested but had been converted to non-forest use prior to 1990 (IPCC 2000b). Afforestation and reforestation result in a credit, while deforestation (human-induced conversion of forestland to non-forest use) results in a debit. Since most countries have not embarked on large-scale afforestation and/or reforestation projects in the past decade, harvesting trees during the five-year commitment period (2008-2012) will likely result in a debit on the ARD account. Therefore, the Marrakech Accords permit countries, in the first commitment period only, to offset up to 9.0 Mt C each year for the five years of the commitment period through (verified) forest management activities that enhance carbon uptake, despite that fact that many of the activities can be business-as-usual (e.g., replanting, fire suppression). If there is no ARD debit, then a country cannot claim this credit, which amounts to the difference between mean annual increment (growth) and harvest on a (self-declared) managed forest. In Canada's case, the ARD debit for 2008-12 is estimated to be about 4 Mt C.

Some countries can also claim carbon credits from business-as-usual forest management that need not be offset against ARD debits. As a result of Marrakech, Canada can claim 12 Mt C per year, the Russian Federation 33 Mt C, Japan 13 Mt C, and other countries much lesser amounts – Germany 1.24 Mt C, Ukraine 1.11 Mt C, and remaining countries less than 1.0 Mt C. Japan expects to use forestry activities to meet a significant proportion of its KP obligation, while Canada can use forest management alone to achieve one-third of its emissions reduction target.[7]

In principle, a country should get credit only for sequestration above and beyond what occurs in the absence of C-uptake incentives, a condition known as 'additionality' (Chomitz, 2000). Thus, for example, if it can be demonstrated that a forest would be harvested and converted to another use in the absence of specific policy to prevent this from happening, the additionality condition is met. Carbon sequestered as a result of incremental forest management activities (e.g., juvenile spacing, commercial thinning, fire control, fertilization) would be eligible for carbon credits, but only if the activities would not otherwise have been undertaken (say, to provide higher returns or maintain market share). Similarly, afforestation projects are additional if they provide environmental benefits (e.g., regulation of water flow and quality, wildlife habitat) not captured by the landowner and would not be undertaken in the absence of economic incentives, such as subsidy payments or an ability to sell carbon credits (Chomitz, 2000).

The reason that the Kyoto negotiations have not addressed additionality explicitly is that this would disadvantage countries that have already undertaken forestry activities that generate carbon uptake benefits. For example, during the 1980s Canada invested heavily in the reforestation of not-sufficiently restocked forestland that had been harvested in previous decades but had failed to generate adequate cover on its own. The business-as-usual forest management provisions of Marrakech enabled Canada to salvage some credits for these investments, rather than penalize Canada relative to countries that had not attempted to implement sustainable forestry practices at such an early date, as would be the case under a strict additionality requirement.

## 5. DISCOUNTING PHYSICAL CARBON

Discounting implies that a unit of carbon emitted into (or removed from) the atmosphere at a future date is worth less than if that same unit were emitted (removed) today. By discounting carbon, you acknowledge that carbon sequestered in the present period has greater potential benefits than sequestration delayed until some future time. The idea of discounting physical carbon is anathema to many who would consider discounting only monetary values. However, the idea of weighting physical units accruing at different times is entrenched in the natural resource economics literature, going back to economists' definitions of conservation and depletion (van Kooten & Bulte, 2000, pp.245-47). Three approaches to discounting of carbon can be identified in the literature (Richards & Stokes, 2004; Watson, Zinyowera, Moss, & Dokken, 1996):

i. The 'flow summation method' sums carbon sequestered regardless of when capture occurs. Total (discounted or undiscounted) cost of the project is divided by the total sum of undiscounted carbon to provide a cost per ton estimate.

ii. Under the 'average storage method' the annualized present value of costs is divided by the mean annual carbon stored through the project.

iii. The 'levelization/discounting method' discounts both costs and physical carbon sequestered depending on when they occur, although costs and carbon can be discounted at different rates.

One cannot obtain a consistent estimate of the costs of carbon uptake, however, unless both project costs and physical carbon are discounted, even if different rates of discount are employed for costs and carbon. To illustrate why, consider the following example.

Suppose a tree-planting project results in the reduction of $CO_2$-equivalent emissions of 2 tC per year in perpetuity (e.g., biomass burning to produce energy previously produced using fossil fuels). In addition, the project has a permanent sink component that results in the storage of 5 tC per year for ten years, after which time the sink component of the project reaches an equilibrium. How much carbon is stored? If an annualized method (method 2) is employed, what is the annual amount of carbon that is sequestered? Is it 2 tC or 7 tC per year? Clearly, 7 tC are sequestered for the first ten years, but only 2 tC are sequestered annually after that time. Carbon sequestration, as stated on an annual basis, would either be that experienced in the first ten years (7 tC per year) or in the infinite number of years to follow (2 tC per year). Suppose the discounted project costs amount to $1,000,[8] or annualized costs of $40 if a 4% rate of discount is used. The costs of carbon uptake are then estimated to be $5.71 per tC if the higher amount of C sequestered is used, or \$20/tC if the lower amount is used. Most often the former figure is used to make the project appear more desirable.

Under the flow-summation method, the cost would essentially be zero because \$1,000 would need to be divided by the total amount of carbon absorbed, which equals infinity. To avoid an infinite sum of carbon uptake, an arbitrary planning horizon needs to be chosen. If the planning horizon is 30 years, 110 tC are sequestered and the average cost is calculated to be \$9.09 per tC; if a 40-year planning horizon is chosen, 130 tC are removed from the atmosphere and the cost is \$7.69/tC. Thus, cost estimates are sensitive to the length of the planning horizon, which is not usually made explicit in most studies (see section 6).

Cost estimates that take into account all carbon sequestered plus the timing of uptake can only be achieved under the third method. Suppose physical carbon is discounted at a lower rate (say, 2%) than that used to discount costs. Then, over an infinite time horizon, the total discounted carbon saved via our hypothetical project amounts to 147.81 tC and the correct estimate of costs is \$6.77 per tC. Reliance on annualized values is misleading in this case because costs and carbon are discounted at different rates. If carbon is annualized using a 2% rate, costs amount to \$13.53 per tC (=\$40 ÷ 2.96 tC). If the same discount rate of 4% is employed for costs and carbon, the \$10.62/tC cost is the same regardless of whether costs and carbon are annualized.

As Richards (1997) demonstrates, the rate at which physical carbon should be discounted depends on what one assumes about the rate at which the damages caused by $CO_2$ emissions increase over time. If the damage function is linear so that marginal damages are constant – damages per unit of emissions remain the same as the concentration of atmospheric $CO_2$ increases – then the present value of reductions in the stock of atmospheric $CO_2$ declines at the social rate of discount. Hence, it is appropriate to discount future carbon uptake at the social rate of discount. "The more rapidly marginal damages increase, the less future carbon emissions reductions should be discounted" (p.291). Thus, use of a zero discount rate for physical carbon is tantamount to assuming that, as the concentration of atmospheric $CO_2$ increases, the damage per unit of $CO_2$ emissions increases at the same rate as the social rate of discount – an exponential damage function with damages growing at the same rate as the social rate of discount. A zero discount rate on physical carbon implies that there is no difference between removing a unit of carbon from the atmosphere today, tomorrow or at some future time; logically, then, it does not matter if the carbon is ever removed from the atmosphere. The point is that use of any rate of discount depends on what one assumes about the marginal damages from further $CO_2$ emissions or carbon removals.

The effect of discounting physical carbon is to increase the costs of creating carbon offset credits because discounting effectively results in 'less carbon' attributable to a project. Discounting financial outlays, on the other hand, reduces the cost of creating carbon offsets. However, since most outlays occur early on in the life of a forest project, costs of creating carbon offsets are not as sensitive to the discount rate used for costs as to the discount rate used for carbon.

***Table 11.2.*** *Carbon Content of Biomass, Various Tropic Forests and Regions*

| *Region* | *Wet Tropical Forest* | *Dry Tropical Forest* |
|---|---|---|
| Africa | 187 t C ha$^{-1}$ | 63 t C ha$^{-1}$ |
| Asia | 160 t C ha$^{-1}$ | 27 t C ha$^{-1}$ |
| Latin America | 155 t C ha$^{-1}$ | 27 t C ha$^{-1}$ |

***Source:*** Papadopol (2000)

***Table 11.3.*** *Depletion of Soil Carbon following Tropical Forest Conversion to Agriculture*

| *Soil Carbon in Forest* | *New Land Use* | *Loss of Soil Carbon with New Land Use* |
|---|---|---|
| *Semi-arid region* | | |
| 15-25 t C ha$^{-1}$ | Shifting cultivation (arable agriculture) | 30-50% loss within 6 years |
| *Sub-humid region* | | |
| 40-65 t C ha$^{-1}$ | Continuous cropping | 19-33% loss in 5-10 years |
| *Humid region* | | |
| 60-165 t C ha$^{-1}$ | Shifting cultivation | 40% loss within 5 years |
| | Pasture | 60-140% of initial soil carbon |

***Source:*** adapted from Paustian et al.(1997)

***Table 11.4***. *Total Carbon in Tropical Ecosystems by Sink, Percent*

| *Land Use* | *Tree* | *Under story* | *Litter* | *Root* | *Soil* |
|---|---|---|---|---|---|
| **Original Forest** | **72** | **1** | **1** | **6** | **21** |
| Managed & logged over-forest | 72 | 2 | 1 | 4 | 21 |
| Slash & burn croplands | 3 | 7 | 16 | 3 | 71 |
| Bush fallow | 11 | 9 | 4 | 9 | 67 |
| Tree fallow | 42 | 1 | 2 | 10 | 44 |
| Secondary forest | 57 | 1 | 2 | 8 | 32 |
| Pasture | <1 | 9 | 2 | 7 | 82 |
| Agroforestry & tree plantations | 49 | 6 | 2 | 7 | 36 |

[a] Average of Brazil, Indonesia and Peru

***Source:*** Woomer et al. (1999)

## 6. FORESTRY ACTIVITIES AND CARBON OFFSET CREDITS

In recent decades probably all of the net carbon releases from forests have come from tropical deforestation (since temperate and boreal forests are in approximate C balance[9]), thereby contributing to the build-up of atmospheric $CO_2$. Houghton

(1993) estimates that tropical deforestation was the cause of 22-26% of all GHG emissions in the 1980s. This is roughly consistent with findings of Brown et al. (1993), who report that total annual anthropogenic emissions are nearly 6.0 gigatons ($10^9$ metric tons, Gt) of carbon, with tropical deforestation contributing from 1.2 to 2.2 Gt per year. Tropical forests generally contain anywhere from 100 to 300 $m^3$ of timber per ha in the bole, although much of it may not be commercially useful. This implies that they store from 20-60 tons of carbon per ha in wood biomass, although this ignores other biomass and soil organic carbon (SOC).

An indication of total carbon stored in biomass for various tropical forest types and regions is provided in Table 11.2. The carbon sink function of soils in tropical regions is even more variable across tropical ecosystems (Table 11.3). This makes it difficult to make broad statements about carbon loss resulting from tropical deforestation. Certainly, there is a loss in carbon stored in biomass (which varies from 27 to 187 tC $ha^{-1}$), but there may not be a significant loss in soil organic carbon. While conversion of forests to arable agriculture will lead to a loss of 20-50% of SOC within 10 years, conversion to pasture may in fact increase soil carbon, at least in the humid tropics (see Table 11.3). In some (likely rare) cases, the gain in SOC could entirely offset the loss of carbon stored in biomass when forestland is converted to pasture. The conversion of forestland to agriculture tends to lead to less carbon storage, and a greater proportion of the ecosystem's carbon is found in soils as opposed to biomass (Table 11.4). To address this market failure (release of carbon through deforestation), policies need to focus on protection of tropical forests (see van Kooten, Sedjo, & Bulte, 1999).

Reforestation of deforested areas needs to take into account the carbon debit from harvesting trees, but it also needs to take into account carbon stored in wood product sinks (and exported carbon) and additional carbon sequestered as a result of forest management activities (e.g., juvenile spacing, commercial thinning and fire control). Even when all of the carbon fluxes are appropriately taken into account (and product sinks are not yet permitted under the KP), it is unlikely that 'additional' forest management will be a cost-effective and competitive means for sequestering carbon (Caspersen et al., 2000). However, as noted above, many countries can claim carbon offset credits for forest management activities that are not additional. Global data on the potential for carbon uptake via forest management are provided in Table 11.5.

Evidence from Canada, for example, indicates that reforestation does not pay even when carbon uptake benefits are taken into account (when financial returns to silvicultural investments include a payment for carbon uptake), mainly because northern forests tend to be marginal (van Kooten, Thompson, & Vertinsky, 1993).[10] The reason is that such forests tend to regenerate naturally, and returns to artificial regeneration accrue in the distant future. Only if short-rotation, hybrid poplar plantations replace logged or otherwise denuded forests might forest management be a competitive alternative to other methods of removing $CO_2$ from the atmosphere. Hybrid poplar plantations may also be the only cost-effective, competitive alternative when marginal agricultural land is afforested (van Kooten, Kremar-

Nozic, Stennes, & van Gorkom, 1999; van Kooten, Stennes, Kremar-Nozic, & van Gorkom, 2000).

***Table 11.5.*** *Global Estimates of the Costs and Potential Carbon that can be Removed from the Atmosphere and Stored by Enhanced Forest Management from 1995 to 2050*

| *Region* | *Practice* | *Carbon Removed & Stored (Gt)* | *Estimated Costs ($US ×109)* |
|---|---|---|---|
| Boreal | Forestation[a] | 2.4 | 17 |
| Temperate | Forestation[a] | 11.8 | 60 |
| | Agroforestry | 0.7 | 3 |
| Tropical | Forestation[a] | 16.4 | 97 |
| | Agroforestry | 6.3 | 27 |
| | Regeneration[b] | 11.5 – 28.7 | 44 - 99 |
| | Slowing-deforestation[b] | 10.8 – 20.8 | |
| **TOTAL** | | **60 – 87** | |

[a] Refers primarily to reforestation, but this term is avoided for political reasons.

[b] Includes an additional 25% of above-ground C to account for C in roots, litter, and soil (range based on uncertainty in estimates of biomass density)

***Source:*** Adapted from Watson, Zinyowera, Moss, & Dokken (1996, pp.785, 791)

Surprisingly, despite the size of their forests and large areas of marginal agricultural land, there remains only limited room for forest sector policies to sequester carbon in the major wood producing countries (Canada, Finland, Sweden, Russia). We illustrate this using The Economic, Carbon And Biodiversity (TECAB) model for northeastern British Columbia (Krcmar, Stennes, van Kooten, & Vertinsky, 2001; Krcmar & van Kooten, 2003). The model consists of tree-growth, agricultural activities and land-allocation components, and is used to examine the costs of carbon uptake in the grain belt-boreal forest transition zone. Estimates for the study region, extended to other regions, provide a good indication of the costs of an afforestation-reforestation strategy for carbon uptake for Canada as a whole, and perhaps for other boreal regions as well. The study region consists of 1.2 million ha, of which nearly 10.5% constitute marginal agricultural land, with the remainder boreal forest. The boreal forest is composed of spruce, pine and aspen. For environmental reasons and to comply with BC's Forest Practices Code, the area planted to hybrid poplar in the model is limited only to logged stands of aspen and marginal agricultural land. Other harvested stands are replanted to native species or left to regenerate on their own, depending on what is economically optimal. Carbon fluxes associated with forest management, wood product sinks and so on are all taken into account. An infinite time horizon is employed, land conversion is not instantaneous (as assumed in some models), carbon fluxes associated with many forest management activities (but not control of fire, pests and disease) are included, and account is taken of what happens to the wood after harvest, including decay.

Results indicate that upwards of 1.5 million tons of discounted carbon (discounted at 4%) can be sequestered in the region at a cost of about \$100 per tC (\$27 per t $CO_2$) or less. This amounts to an average of about 1.3 t $ha^{-1}$, or about 52 kg $ha^{-1}$ $yr^{-1}$ over and above normal carbon uptake. If this result is applied to all of Canada's productive boreal forestland and surrounding marginal farmland, then Canada could potentially sequester 10-15 Mt C annually via this option in perpetuity. The total C sequestered in this manner would be about 20% of Canada's annual KP-targeted reduction of 65.5 Mt C per year. If prices for carbon offsets (or carbon subsidies) are higher, more carbon credits will be created, but marginal costs of creating additional carbon offsets rise rapidly.[11] This rapid increase in costs is partly due to the slow rates of growth in boreal ecosystems – boreal forests are globally marginal at best and silvicultural investments simply do not pay for the most part, even when carbon uptake is included as a benefit of forest management. Afforestation with rapid growing species of hybrid poplar provides some low-cost carbon, but thereafter marginal costs also rise rapidly (van Kooten 2000, also see below).

Globally, carbon sequestration in forest ecosystem sinks is expected to play a significant role in achieving KP targets, as indicated in Table 11.1, but at what cost? Manley, van Kooten, and Smolak (2004) address this issue by employing 694 estimates from 49 studies for a meta-regression analysis of the average and marginal costs of creating carbon offsets using forestry. Estimates of the uptake costs are derived from three meta-regression analysis models: (i) a linear regression model where reported costs per tC are regressed on a variety of explanatory variables; (ii) a model where costs are converted to a per ha basis and then regressed on the explanatory variables using a quadratic functional form; and (iii) a model where per ha uptake costs are regressed on the explanatory variables using a cubic functional form. Using the estimated regression models, average costs of carbon sequestration for various uptake scenarios and regions can be calculated. These are provided in Table 11.6.

Baseline estimates of the average costs of sequestering carbon (of creating carbon offset credits) through forest conservation in the tropics are US\$11-\$40 per tC. Sequestering carbon in terrestrial forest ecosystems is (generally) somewhat lower in the Great Plains than elsewhere, including the tropics. Surprisingly, costs are higher in the Corn Belt than in the tropics or Great Plains. Compared to simple conservation of existing forests, tree planting increases costs by nearly double, and agroforestry activities increase costs even more while forest management is the least costly option. Needless to say, if the opportunity cost of land is appropriately taken into account, costs are 3.5 times higher than the baseline where such costs are assumed negligible or ignored.

When post-harvest storage of carbon in wood products, or substitution of biomass for fossil fuels in energy production, are taken into account, costs are at their lowest – from US\$3.57/tC for a project that includes product sink carbon (Table 11.6) to US\$31.18/tC for a project that takes into account fuel substitution in other regions. Accounting for carbon entering the soil also lowers costs. The reason is that the inclusion of soil and wood-product carbon sinks, or fossil fuel substitution, results in more carbon being counted for the same costs.

***Table 11.6.*** *Projected Average Costs from Three Models of Creating Carbon Offsets through Forestry Activities, 2002 ($US per tC)*

| *Scenario* | *Model* | | |
|---|---|---|---|
| | *Linear* | *Quadratic* | *Cubic* |
| Baseline (Tropics/Conservation) | 11.06 | 30.22 | 40.44 |
| Tropics | | | |
| Planting | 17.98 | 55.79 | 77.46 |
| Agroforestry | 25.39 | 63.81 | 87.79 |
| Forest Management | 10.57 | 25.38 | 33.33 |
| Soil Sink | 8.02 | 14.64 | 16.29 |
| Fuel Substitution | 5.51 | 18.96 | 24.45 |
| Product Sink | 3.57 | 10.92 | 13.35 |
| Opportunity Cost of Land | 40.42 | 109.81 | 140.58 |
| Great Plains | | | |
| Conservation | 13.91 | 23.99 | 30.91 |
| Planting | 22.61 | 44.29 | 59.20 |
| Agroforestry | 31.93 | 50.66 | 67.09 |
| Forest Management | 13.30 | 20.15 | 25.47 |
| Soil Sink | 10.09 | 11.62 | 12.45 |
| Fuel Substitution | 6.94 | 15.05 | 18.68 |
| Product Sink | 4.49 | 8.67 | 10.20 |
| Opportunity Cost of Land | 50.83 | 87.18 | 107.44 |
| Corn Belt | | | |
| Conservation | 17.37 | 33.92 | 43.30 |
| Planting | 28.24 | 62.63 | 82.93 |
| Agroforestry | 39.88 | 71.64 | 93.99 |
| Forest Management | 16.61 | 28.50 | 35.68 |
| Soil Sink | 12.60 | 16.43 | 17.44 |
| Fuel Substitution | 8.66 | 21.29 | 26.17 |
| Product Sink | 5.61 | 12.26 | 14.29 |
| Opportunity Cost of Land | 63.50 | 123.27 | 150.51 |
| Other Regions | | | |
| Conservation | 18.41 | 39.92 | 51.58 |
| Planting | 29.94 | 73.70 | 98.79 |
| Agroforestry | 42.28 | 84.30 | 111.96 |
| Forest Management | 17.61 | 33.53 | 42.50 |
| Soil Sink | 13.36 | 19.34 | 20.77 |
| Fuel Substitution | 9.18 | 25.05 | 31.18 |
| Product Sink | 5.95 | 14.42 | 17.03 |
| Opportunity Cost of Land | 67.31 | 145.07 | 179.29 |

***Source:*** Manley et al. (2004)

However, some of the activities (wood product sinks) are not currently admitted under KP accounting rules, are difficult to measure and monitor (soil carbon), or are not easily implemented (biomass burning).

Finally, while the average costs reported in Table 11.6 are useful to decision makers, they are not truly indicative of the potential costs of creating carbon offsets because they are average estimates only. As already noted, they ignore transaction costs but they also fail to recognize that costs rise as additional carbon is sequestered in terrestrial ecosystems. This is true not only as tree planting activities gobble up agricultural land of increasing productivity and value, but also as an attempt is made to create more carbon offset credits on the same site. Manley et al. (2004) report that, for almost all regions, marginal costs are relatively flat, but rise very steeply once the lower cost opportunities are exhausted. For example, in the Great Plains region, they rise slowly from nearly US$2/tC to US$10/tC by 6-7 tC per ha, but then increase very quickly thereafter.

## 7. TRADING TERRESTRIAL CARBON CREDITS

Some trading of carbon credits has now been initiated through trading networks such as the Chicago Climate Exchange (CCX) and the UK market for carbon emissions allowances (CO2e.com), but they involve only large industrial emitters (LIEs) in a limited geographic area. While others, such as the Winnipeg Commodity Exchange, have proposed the establishment of carbon trading, continuing uncertainty about whether the KP will indeed be ratified hampers efforts to stabilize these markets. Trading so far has been focused on industrial emissions and has not included agricultural or forestry offsets, although the potential for trading offsets exists with the CCX and the Winnipeg Commodity Exchange. However, before a market-based approach to carbon sinks can be applied in practice, certain market conditions will need to be met. For example, carbon offsets need to be certified, a method for seamless trading between $CO_2$ emissions and carbon offsets needs to be found, and an overseeing body with well-defined rules and regulations has to be established (Sandor & Skees, 1999).

Carbon rights were first created in legislation in New South Wales, Australia, but they are rudimentary at best, as indicated by a judgment by Australian solicitors McKean & Park on the potential for carbon offset trading. They indicated that trading in carbon credits is unlikely to occur before 2005 because it would take that long to establish the required rules.[12] In order to buy and sell carbon offset credits, it is necessary to have legislation that delineates the rights of landowners, owners of trees and owners of carbon, because what any one of these parties does affects the amount of carbon that is sequestered and stored. Without clear legislation, buyers of carbon offsets are not assured that they will get proper credit – their claims to have met their emission reduction targets with carbon credits is open to dispute.

Landowners need clear guidelines as to how their activities would qualify for carbon offsets and how credits are to be certified so that they have a well-defined ‘commodity’ to sell in the carbon market. In the case of afforestation of private land as a carbon sink, even if all conditions for trade are present, there remain concerns about the extent of landowners' willingness to plant trees for carbon uptake on large tracts of (marginal) agricultural land. Tree-planting subsidies, for example, may be inadequate because of uncertainty about future farm payments and subsidies, implications for trade, or transactions costs associated with the creation of carbon sinks on agricultural land (van Kooten, Shaikh, & Suchánek, 2002).

The other problem of mixed $CO_2$ emissions-carbon offset trading concerns the factor for converting temporary into permanent removal of $CO_2$ from the atmosphere. Compared to not emitting $CO_2$ from a fossil fuel source, terrestrial sequestration of carbon is unlikely to be permanent, particularly for carbon stored in fast-growing tree plantations on agricultural land. Yet, temporary removal of carbon is important because it (i) postpones climate change, (ii) allows time for technological progress and learning, (iii) may be a lower cost option than simply reducing $CO_2$ emissions, and (iv) some temporary sequestration may become permanent (Marland, Fruit, & Sedjo, 2001, p.262).

The ephemeral nature of terrestrial carbon uptake can be addressed in a variety of different ways. First, instead of full credits, partial credits for stored carbon can be provided according to the perceived risk that carbon will be released from the sink at some future date. The buyer or the seller may be required to take out an insurance policy, where the insurer will substitute credits from another carbon sink at the time of default. Alternatively, the buyer or seller can provide some assurance that the temporary activity will be followed by one that results in a permanent emissions reduction. For example, arrangements can be put in place prior to the exchange that, upon default or after some period of time, the carbon offsets are replaced by purchased emission reduction permits. Again, insurance contracts can be used. Insurance can also be used if there is a chance that the carbon contained in a sink is released prematurely, but it is also possible to discount the number of credits provided by the risk of loss (so that a provider may need to convert more land into forest, say, than needed to sequester the agreed upon amount of carbon). However, the risk that default will occur remains. This is especially true in the case of the KP as there is currently no requirement that countries that count terrestrial carbon uptake credits during the commitment period 2008-12 are penalized for their release after 2012.

Another method that has been proposed is to employ a conversion factor that translates years of temporary carbon storage into a permanent equivalent that can be specified. The IPCC (2000a) uses the notion of ton-years to make the conversion from temporary to permanent storage.

Suppose that one-ton of carbon-equivalent GHG emissions are to be compensated for by a ton of permanent carbon uptake. If the conversion rate between ton-years of (temporary) carbon sequestration and permanent tons of carbon emissions reductions is $k$, a LULUCF project that yields one ton of carbon uptake in the current year generates only $1/k$ tons of emission reduction – to cover the one-ton reduction in emissions requires $k$ tons of carbon to be sequestered for one year. The conversion rate ranges from 40 to 150 ton-years of temporary storage to cover one permanent ton, with median estimates around 50:1. The choice of conversion rate really amounts to a choice of a rate for discounting physical carbon. For example, if

1 tC is stored in a forest sink in perpetuity and physical carbon is discounted at 2%, then the discounted amount of this perpetual storage equals 50 ton-years. With a 2.5% discount rate on physical carbon, the exchange rate between $CO_2$ emissions and carbon offsets is 40 ton-years, while it is 100 ton-years if the discount rate is 1%. Thus, the idea of ton-years is directly linked to the rate used to discount physical carbon.

As Marland et al. (2001) note, the ton-year accounting system is flawed: ton-year credits (convertible to permanent tons) can be accumulated while trees grow, for example, with an additional credit earned if the biomass is subsequently burned in place of an energy-equivalent amount of fossil fuel (p.266). To avoid such double counting and the need to establish a conversion factor, the authors propose a rental system for sequestered carbon. A one-ton emission offset credit is earned when the sequestered carbon is rented from a landowner, but, upon release, a debit occurs. "Credit is leased for a finite term, during which someone else accepts responsibility for emissions, and at the end of that term the renter will incur a debit unless the carbon remains sequestered and the lease is renewed" (p.265, emphasis in original). In addition to avoiding the potential for double counting, the landowner (or host country) would not be responsible for the liability after the (short-term) lease expires. Further, rather than the authority establishing a conversion factor, the market for emission permits and carbon credits can be relied upon to determine the exchange rate between permanent and temporary removals of $CO_2$ from the atmosphere.

The carbon sink potential in CDM reforestation and afforestation projects exceeds that within industrial countries, making impermanence of terrestrial sinks a more pressing issue for the CDM. The issue of the impermanence of carbon sinks in CDM projects was considered by COP8 in New Delhi in October 2002. Workshops early in 2003 discussed (1) insurance coverage against the destruction or degradation of forest sinks (referred to as iCERs), and (2) the creation of 'temporary' CERs (certified emission reductions) and RMUs (removal units), denoted rCER or tRMU, whereby the certified units would expire at the end of the commitment period or after a different specified period of time. When expired, these credits would have to be covered by substitute credits at that time or reissued credits if the original project were continued. Negotiations regarding definitions and modalities continued at COP9 in Italy, December 2003, but no final resolution has yet been announced. The reason is that countries with large sink potential generally oppose solutions, such as the idea of ton-years and rental rates, that reduce the value of carbon offsets relative to emissions reduction, thereby requiring such countries to make greater efforts to reduce $CO_2$ emissions.

This method for dealing with the question of permanence does not resolve the issue of higher (transaction) costs related to contracting. It is our view that the least cost option would be to tax emissions when they occur, whether these are emissions from LULUCF activities or fossil fuel burning, and to provide a subsidy of the same amount as the tax when carbon is sequestered through some LULUCF activity. The tax revenue should be more than adequate to cover the needed subsidies.

## 8. ARE LANDOWNERS WILLING TO CREATE CARBON SINKS?

A land-rich country such as Canada expects to rely on afforestation of agricultural land to meet a significant component of its KP commitment. As indicated in previous sections, there is a limit to the amount of carbon offset credits that can be claimed from forest management activities on existing forestlands. Thus, the focus will shift to afforestation of agricultural land, where the role of private landowners is more important as most forestland in Canada is publicly owned. Griss (2002) estimates that roughly 1.1-1.4 million ha of agricultural land in Canada could plausibly be converted to tree plantations for carbon uptake purposes, while the Sinks Table of Canada's National Climate Change Process suggested that 843,000 ha of agricultural land could be afforested. The problem of tree planting is not related to biophysical possibilities, however, but to the willingness of landowners to create carbon credits.

It is imperative to identify methods by which landowners are willing to create carbon credits and their capacity to create and market carbon offsets. Landowner preferences for different carbon sequestration methods are likely influenced by the available information and methods, institutional support and structure, and relative risk and uncertainty with regards to maintaining a profitable enterprise and remaining eligible for government programs.

Of course, farmers are generally interested in receiving carbon credits – that is, subsidies – for activities that result in soil conservation, such as a change in agronomic practices from conventional to conservation tillage or a reduction in the proportion of tillage summer fallow, both of which increase SOC by retaining organic matter. In addition, agricultural landowners may be willing to change land use by afforestation of previously cultivated land. If sinks are to be used as a flexible mechanism for meeting $CO_2$ emissions goals, it is important to understand landowners' incentives, motivations and preferences, as well as the transaction costs of implementing tree-planting programs. These issues have been studied using a survey of landowners in western Canada conducted in 2000 (Shaikh, Suchánek, Sun, & van Kooten, 2003; Suchánek, 2001; van Kooten, Shaikh, & Suchánek, 2002).

When asked about tree planning, landowners in west Canada generally express a preference for shelterbelts rather than large-scale afforestation (Suchánek, 2001). The survey also shed light on landowners' willingness to engage in carbon offset trading (see Table 7). Respondents stated that they preferred contracts with governments and large industrial emitters to change land use (or take on certain activities) over the sale of carbon credits per se (Suchánek, 2001). Contracts with government and LIEs shift responsibility for the carbon offsets away from the landowner to the government or LIE. Specifically, the landowner as agent does not have an incentive to produce carbon offsets beyond switching land use (and might even cut trees for firewood), thereby adding to transaction costs as the principal needs to monitor the contract (see van Kooten et al., 2002). Interestingly, survey respondents indicated that they preferred contracts with government and LIEs, and carbon trading, to contracts with environmental NGOs (Table 11.7). Perhaps this is because environmental NGOs are perceived to be more likely to enforce contracts and penalize agents for acting with guile than will government or LIEs.

It is also worth noting that van Kooten et al. (2002) found that past land use may affect the willingness of landowners to plant trees on a large scale. In particular, in regions that had previously been treed and where landowners or their forbears had incurred substantial sacrifice to carve out farms, there is a reluctance and even refusal to take part in tree planting programs.[13]

***Table 11.7.*** *Western Canadian farmers' ranking of means for establishing carbon sinks*

| *Governance structure* | *Normalized Rank* |
|---|---|
| Tree-planting contracts with government/state agency | 1.00 |
| Tree-planting contracts with private firms (large $CO_2$ emitters) | 0.87 |
| Sell carbon credits in markets established to allow trade | 0.71 |
| Tree-planting contracts with ENGOs | 0.44 |

***Source:*** van Kooten et al. (2002)

Finally, on a positive note, landowners who did indicate a willingness to participate in tree planting programs (and 25.3% would not consider planting trees under any circumstances) were willing to accept a payment below the opportunity cost of the next best alternative land use. Using survey data, willingness to accept compensation for block tree planting was estimated to be between $14.32 and $22.27 per hectare, while the opportunity costs of land were calculated to be $17.00/ha for pasture land, $19.12/ha for land in hay and $29.08/ha for land in grain production (Shaikh et al. 2003). It is likely that forested land provides benefits to some landowners that are not captured in the market. These include benefits from greater scenic diversity, increased wildlife habitat, water conservation and soil conservation.

## 9. CONCLUSIONS

While terrestrial carbon sinks do have potential to sequester carbon from the atmosphere, they are not the ‘silver policy bullet’ that many people are expecting, and they are more likely to be a distraction from the real goal of reducing fossil fuel $CO_2$ emissions. Because of their temporary nature, transaction costs to maintain the sinks are ignored. The use of sinks as a replacement for reducing $CO_2$ emissions during the earlier KP commitment periods may make it more difficult to reduce emissions in the future, when sinks are nearing their economic maximum level, because of the lack of investment in technology. The uncertainties with respect to carbon trading, additionality and leakage of projects, and the actual costs of sequestration are also of concern.

Although carbon sinks have some value, especially in the short term as countries seek to implement appropriate emission reduction policies, our view is that their value is highly overrated. It is true that carbon uptake considerations are likely an important impetus for sustainable forest management, but, if sustainable forest management has merit (which we believe it does), its value cannot be justified on the basis of the carbon sink function of forest ecosystems. Likewise, soil conservation (reduced tillage) and tree planting on agricultural lands cannot be justified solely on the basis of their carbon uptake benefits. If the argument to pursue conservation (reduced/zero) tillage and afforestation cannot be justified on the basis of their on- and off-farm (and nonmarket) benefits, it is highly unlikely (with some exceptions) that the addition of carbon offset benefits will prove a good enough reason to pursue them in any event.

## ABBREVIATIONS

**AAUs** – Assigned amount units – emission permits in excess of what a country needs to achieve KP commitment. Can be purchased by other countries.

**ARD** – Afforestation, reforestation, and deforestation

**CDM** – Clean Development Mechanism, where an Annex B country earns “certified emission reductions” by funding emission reduction or carbon sequestration projects in non-Annex B (developing) countries

**CER** – Certified emission reductions

**iCER** – CERs for which insurance coverage shall be maintained for a specified period

**rCER** – Removal CER, which is related to a tRMU

**COP** – Conference of Parties, followed by a number to indicate which meeting is referenced (e.g. COP6)

**COP6$_{bis}$** – The continuance of COP6 in Bonn in Spring 2001 after the breakdown of COP6 in The Hague the previous Fall (“bis” meaning “Part II”).

**ERU** – Emission reduction unit – earned as credit for a country that participates in JI activities in another country

**EU** – European Union

**FCCC** – The United Nation’s Framework Convention on Climate Change, signed in Rio de Janeiro in 1992

**GHG** – Greenhouse gas

**IPCC** – Intergovernmental Panel on Climate Change

**JI** – Joint Implementation, where an Annex B country participates in emissions reduction or carbon sequestration in another Annex B country

**KP** – Kyoto Protocol

**LIE** – Large industrial emitter of greenhouse gases

**LULUCF** – Land use, land use change and forestry

**NGO** – Non-governmental organization

**RMU** – Removal unit for carbon sinks

**tRMU** – Temporary RMU

**TECAB** – The Economic, Carbon and Biodiversity forest management model of the Forest Economics and Policy Analysis (FEPA) Research Unit at UBC

**SOC** – Soil organic carbon

## OTHER DEFINITIONS

**Annex I** – Countries listed in Annex I of the United Nations' Framework Convention on Climate Change of 1992: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and the United States. These agreed to limit GHG emissions to the 1990 level by 2000.

**Annex B** – Countries listed in Annex B of the Kyoto Protocol of December 1997 include those of Annex I minus Belarus and Turkey. These countries agreed to achieve self-imposed limits on GHG emissions by 2008-12 relative to 1990.

**Carbon offsets** – Carbon credits created via an approved terrestrial sink activity, and referred to as RMUs.

**Commitment period** – The KP commits countries to attain self-declared emission control targets by 2008-12. This period is referred to as the first commitment period in anticipation of successful future negotiations to limit $CO_2$ emissions even further by targeted dates.

**Economic efficiency** – Maximizing aggregate economic benefits which consist of consumer plus producer surpluses

## NOTES

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[2] In this chapter we consider only $CO_2$, because $CO_2$ is the most important anthropogenic greenhouse gas from the perspective of climate change. This is reported throughout the chapter in units of carbon (C), where $1\ tC = 3.67\ t\ CO_2$.

[3] The word "ton" is used to refer to "metric ton", as opposed to imperial ton.

[4] From the following website (accessed 18 February 2004): http://unfccc.int/resource/kpthermo.html

[5] This is an overly optimistic estimate of the role that carbon sinks might play because it ignores the ephemeral nature of sinks and continued deforestation in tropical regions. In fact, as of 1990, land use change in the tropics (mostly deforestation) represented C emissions ranging from 20 to 37% of global emissions from fossil fuel burning (Brown et al., 1993).

[6] Not included is the COP6$_{bis}$ (COP7) provision that a country can offset in any year of the commitment period an accounting deficit under Article 3.3, say from clear cutting, with a net increase in sinks due to forest management under Article 3.4 to a maximum of 8.2 (9.0 at COP7) Mt C. This is discussed in the next section.

[7] Excluding the ARD debit, since its emissions (along with those of most other countries) have risen dramatically since 1990, Canada needs to reduce emissions in 2008-2012 by 65.5 Mt C, with forest management to account for 18.3% of the targeted amount. Additional credits will be claimed for afforestation programs (see van Kooten, 2003).

[8] All monetary values are in Canadian dollars, unless otherwise indicated.

[9] Scientists are unable to identify all of the components of the annual $CO_2$ flux – a carbon sink appears to be 'missing'. Some analysts believe that this missing carbon sink can be explained by the expanding biomass in boreal forests, which is mainly due to the aging of these forests.

[10] $CO_2$ emission reductions are expected to trade for $55-$110 per tC ($15-$30 per t $CO_2$) in international markets (van Kooten 2003). Carbon offset credits will sell for about one-tenth of that amount because of their ephemeral nature. The research reported here finds that, even for carbon offset prices as high as $110/tC, investments in reforestation do not pay.

[11] Recall from the previous endnote that carbon offset credits, being ephemeral, are likely to trade for no more than a few dollars per tC, and not near the $100/tC reported in the study using TECAB.

[12] Their ruling could be found on April 30, 2003, but not as of February 20, 2004, at the website: http://www.mckeanpark.com.au/html/enviroprop/epcarbtrd/epcarbnav.htm#carboncredit. It might have been removed for political reasons, but that is pure speculation.

[13] Forestland continues to be cleared for agriculture. For the 2-year period 1995-1997, for example, 0.7% of Alberta's forestland (some 200,000 ha) was converted to agriculture (Alberta Environmental Protection 1998).

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