

Evaluating Carbon Offsets from Forestry and Energy Projects

How Do They Compare?

Kenneth M. Chomitz

Under the Clean Development Mechanism, developing countries will be able to produce certified emissions reductions (CERs, sometimes called "offsets") through projects that reduce greenhouse gas emissions below business-as-usual levels. The challenges of setting up offset markets are considerable. Do forestry projects, as a class, have more difficulty than energy projects reducing greenhouse gas emissions in ways that are real, measurable, additional, and consistent with sustainable development?



Summary findings

Under the Kyoto Protocol, industrial countries accept caps on their emissions of greenhouse gases. They are permitted to acquire offsetting emissions reductions from developing countries — which do not have emissions limitations — to assist in complying with these caps. Because these emissions reductions are defined against a hypothetical baseline, practical issues arise in ensuring that the reductions are genuine. Forestry-related emissions reduction projects are often thought to present greater difficulties in measurement and implementation than energy-related emissions reduction projects.

Chomitz discusses how project characteristics affect the process for determining compliance with each of the criteria for qualifying. Those criteria are:

- *Additionality*. Would the emissions reductions not have taken place without the project?
- *Baseline and systems boundaries (leakage)*. What would business-as-usual emissions have been without the project? And in this comparison, how broad should spatial and temporal system boundaries be?
- *Measurement (or sequestration)*. How accurately can we measure actual with-project emissions levels?
- *Duration or permanence*. Will the project have an enduring mitigating effect?

- *Local impact*. Will the project benefit its neighbors?

For all the criteria except permanence, it is difficult to find generic distinctions between land use change and forestry and energy projects, since both categories comprise diverse project types. The important distinctions among projects have to do with such things as:

- The level and distribution of the project's direct financial benefits.
- How much the project is integrated with the larger system.
- The project components' internal homogeneity and geographic dispersion.
- The local replicability of project technologies.

Permanence is an issue specific to land use change and forestry projects. Chomitz describes various approaches to ensure permanence or adjust credits for duration: the ton-year approach (focusing on the benefits from deferring climatic damage, and rewarding longer deferral); the combination approach (bundling current land use change and forestry emissions reductions with future reductions in the buyer's allowed amount); a technology-acceleration approach; and an insurance approach.

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Contents

BACKGROUND AND MOTIVATION	1
ADDITIONALITY	2
CLASS I: DIRECT FINANCIAL BENEFITS, LOW BARRIERS TO ADOPTION.....	2
CLASS II: DIRECT FINANCIAL BENEFITS, HIGH BARRIERS TO ADOPTION	3
CLASS III: DIRECT FINANCIAL COSTS; EXTERNAL, POSSIBLY NONMONETARY BENEFITS	4
SUMMARY	4
BASELINE DETERMINATION AND SYSTEMS BOUNDARIES.....	4
CASE I: EFFECTIVELY ISOLATED SYSTEMS	4
CASE II: INTEGRATED SYSTEMS.....	5
<i>Forest protection projects</i>	5
<i>Grid-connected energy projects</i>	7
<i>Energy market considerations</i>	8
<i>Technical diffusion and negative leakage</i>	9
SUMMARY	9
MEASUREMENT	10
PERMANENCE	12
LIMITED TERM COMMITMENTS	12
MECHANISMS FOR ASSURING INDEFINITE SEQUESTRATION.....	14
<i>Discounting for risk</i>	14
<i>Bundling LUCF activities with subsequent emissions reduction activities</i>	15
<i>Tax LUCF CERs to fund emissions reduction technology research and development</i>	16
<i>Tradable development rights</i>	16
DOMESTIC IMPACTS	17
CONCLUSIONS	18
APPENDIX: A STYLIZED MODEL OF LEAKAGE	20
REFERENCES	22

Background and motivation

Under the Clean Development Mechanism, developing countries will be able to produce Certified Emissions Reductions (CERs) (sometimes called offsets) through projects that reduce greenhouse gas (GHG) emissions below 'business-as-usual' levels. The CERs can be used by developed countries to satisfy, in part, their obligations to keep their own GHG emissions below a specified cap. Similarly, economies in transition can produce emissions reductions units (ERU's) through joint implementation (JI) projects.

Because it is much cheaper, on the margin, for developing countries to abate GHG emissions, this arrangement theoretically facilitates cost-effective achievement of any target for GHG reduction. For instance, Ellerman *et al.* (1998) find that the global costs of achieving the Kyoto Protocol targets are \$120 billion if each nation must satisfy its commitments purely through domestic actions, but drop to \$54 billion if trading is permitted among Annex I countries and further to \$11 billion if CER transfers are permitted and efficiently supplied.

However, these gains are achieved only if the CERs are 'real and additional' – if they truly represent reductions from a business-as-usual baseline. Because that baseline can not be directly observed, some observers fear that emissions reductions will be exaggerated (Greenpeace 1998). Transfer of an 'exaggerated' CER to an Annex I country increases world GHG emissions above the Kyoto levels.

Some observers believe that CERs from land use change and forestry (LUCF) projects are less likely to be 'real and additional' than CERs based on energy projects, and claim that LUCF projects are less advantageous to host countries than energy projects (Greenpeace 1998, WWF n.d.). Largely for these reasons, the creditability of LUCF projects under the CDM remains under debate (Trexler and Associates 1998).

This paper argues that -- with one important exception -- LUCF and energy projects face parallel, comparable issues in measurement and in assuring social and environmental benefits. In general, it is not possible to assert that energy projects are superior as a class to LUCF projects on these grounds; rather, each subclass of projects has its own idiosyncratic features that determine the appropriate validation and certification approach.

The paper considers in turn each of the main criteria suggested for qualification of a project that produces CERs ('carbon projects', for convenience):

- *Additionality*: Would the emissions reductions not have taken place in the absence of the project?
- *Baseline and systems boundaries (leakage)*: What would have been the 'business-as-usual' emissions in the absence of the project? In comparing with-project and without-project emissions, how broadly should we draw the spatial and temporal boundaries of the system we are looking at?
- *Measurement*: How accurately can we measure the actual, with-project, levels of emissions?
- *Permanence*: Will the project have a long-lasting mitigating effect on atmospheric GHG concentration and on the economic and social consequences of global warming?
- *Local social and environmental impact*: Will the project benefit its neighbors?

The paper discusses how project characteristics affect the process for determining compliance with each criterion, and considers whether these characteristics are systematically different between energy and LUCF projects.

Additionality

CERs are quantified as the difference between emissions (or sequestration) with the project as compared to the hypothetical without-project level. Predicting the 'but-for' world is inherently difficult, and both buyers and sellers have an incentive to choose predictions of high baseline emissions (or low baseline sequestration). If this occurs systematically, the volume of CERs sold will overstate the actual emissions reductions, threatening the integrity of the system. Baseline methodologies must strive to be accurate on average without being too costly and difficult to implement.

Approaches to setting baselines will differ substantially among project types. Most carbon projects involve a discrete switch in technologies or choice of actions: coal boiler to gas boiler, forest protection vs. forest conversion. For these projects, it is often useful to distinguish two steps in determining the baseline:

1. determining additionality (is the new technology adopted? When?) Only if the project is shown to be additional is it necessary to proceed to the second step:
2. estimating baseline carbon emissions or storage (for the old technology, what's the rate of emissions?)

This section will concentrate on the first step; the following section will examine the reliability of methodologies for measuring carbon emissions or storage for a particular technology or situation.

There is some inherent tension between the requirement that carbon projects be additional and the requirement that they promote sustainable development – i.e., that they provide some benefit in addition to GHG abatement. The greater the noncarbon benefits, the more focused these benefits are on the project sponsor, and the easier the financing requirements, the greater the presumption that this project would be undertaken spontaneously, in the business-as-usual scenario.

Using this simple framework, let's consider three classes of carbon projects.

Class 1: Direct financial benefits, low barriers to adoption

It is most challenging to demonstrate additionality where:

- a) the sponsor is a large, commercial entity with good access to financing
- b) the new technology is well-understood
- c) investment in the new technology yields a direct monetary return to the sponsor

Many potential projects, both LUCF and energy, meet this description. Industrial timber and cellulose plantations, for instance, sequester carbon but also produce a stream of revenue or inputs for their owners. Cogeneration and methane recovery projects produce saleable or usable energy streams; improved boilers save fuel costs and reduce the cost of complying with air pollution regulations; installation of high-efficiency electric motors reduces expenditure on electricity; reductions of the clinker proportion in cement yields substantial energy savings.

The challenge is that these projects make money for their owners. Some of these projects might therefore be undertaken spontaneously, and won't be additional. For others, the financial returns will be too low or the risks too high to justify the investment. These latter projects are particularly attractive because the net cost of supplying emissions reductions may be quite low. That is, they may require only a small carbon-funded inducement to adopt the emissions-reducing technology.

There has been extensive debate on how to distinguish additional versus nonadditional projects, balancing error rates against the costs of making the determination (Chomitz 1998, Ellis and Bosi 1999). While benchmarking approaches have practical advantages, the concept of additionality is more directly captured by simulating the project sponsor's investment decision process, and

confirming that the sponsor would not undertake this project in the absence of CER prospects¹. (Chomitz 1998) For large commercial ventures, this decision process is likely to involve a formal financial analysis that compares the level and risk of returns to the project with the returns from other possible investments. Using this approach, we can establish that certain types of projects offer benefits that not large enough to induce investment without CER sales, and may therefore be considered additional. For instance, Sedjo (1999) evaluates the potential profitability of industrial timber plantations in remote regions of Patagonia. These require investments of \$1150 per hectare. But because tree growth is slow and markets are distant, the present value of returns, discounted at a modest 10%, is just \$581, over a 27 year period. This strongly suggests that even if wood price is underestimated, these plantations are unattractive investments and are unlikely to be established without the added inducement of CER sales.

Other projects – for instance, energy efficiency projects with very short payback periods, or cellulose plantations in agroclimatically suitable areas – may be attractive enough to be adopted spontaneously and will fail an additionality test. In between is a gray area where firms will have difficulty deciding on their course of action, because risk-adjusted returns from investment will be comparable to returns available elsewhere. As a result, CER certifiers will also have difficulty in establishing the additionality of these borderline commercial projects.

Class II: Direct financial benefits, high barriers to adoption

Now consider projects where:

- a) the sponsor or actor is a small business or household with limited access to financing
- b) information about the new technology is limited
- c) investment in the technology leads to a direct but uncertain monetary return

Again both energy and LUCF projects fall into this class. Examples include adoption of agroforestry systems by small landholders and adoption of high-efficiency light-bulbs by households. In both cases, average rates of return to investment can be reasonably high, and yet the technologies may not be adopted. Lack of information, lack of access to financing, and risk aversion may all be obstacles to adoption. On the other hand, these innovations are sometimes adopted spontaneously, so additionality tests are needed. As in Case I, additionality may be difficult to determine in some cases. For instance, Stockholm Environmental Institute (SEI 1998) performed a retrospective analysis of JI-sponsored boiler conversions in Estonia. The baseline assumption was heating plants would continue to use fuel oil despite potential savings from fuel-switching, due to informational and market barriers. The analysis found that the boilers realized considerable cost savings from switching to renewables, and that use of gas and renewables in Estonia grew rapidly outside the JI-sponsored projects. While the JI projects might have helped to diffuse knowledge and catalyze earlier adoption of the new technologies, it seems likely that these technologies would have been adopted fairly soon even in the absence of the projects, in part because of unexpected changes in relative fuel prices.

For this class of projects, because there are typically a large number of potential adopters, it may be possible to use *control group* methods to establish baselines and additionality. It may also be possible directly to model household decision making and use the model to establish baseline behavior. Both these approaches have been used in the US to establish baselines for computing energy savings under demand-side-management incentive programs. (Hagler Bailly 1998)

¹ A simulation model might well be more complicated than a simple rate-of-return test. It will involve parameters that are imperfectly observed, such as the project owner's cost of capital. In practice, then, determination of additionality using this approach requires both model validation and sensitivity tests against variation in key parameters.

Class III: Direct financial costs; external, possibly nonmonetary benefits

Some carbon projects impose ongoing costs on the project owner but provide benefits to others and therefore contribute to sustainable development. In the absence of institutions for beneficiaries to compensate project owners, these projects are unlikely to be undertaken spontaneously, and therefore are likely to be additional.

Some types of LUCF projects fall into this category. A prominent example is the maintenance of forest cover on land that is suitable for agriculture. It is now well-established that in the absence of effective regulation, landholders often find it more profitable to extract saleable timber from the forest and convert it to agriculture than to manage the primary forest for sustainable extraction. (Tomich et al. 1998; Kishor and Constantino 1993; Vosti, Witcover and Carpentier 1998; Arima and Uhl 1997) Thus maintenance of forest cover imposes real opportunity costs on the landholder, and is unlikely to occur spontaneously where markets for timber and agricultural goods are accessible. Therefore there is a strong presumption that forest conservation projects are additional when they occur in areas of demonstrable pressure for agricultural conversion. At the same time, maintenance of forest cover may provide benefits to the landholder's neighbors and compatriots such as regulation of water flow, maintenance of water quality, and conservation of biodiversity.

Similarly, projects that sponsor restoration of natural habitats using native species are likely to be additional. These projects can be expensive relative to the potential financial returns (if any) from extractive products, given the relatively slow growth of native species, and are therefore rarely undertaken spontaneously. However, such projects might produce valuable local benefits including biodiversity conservation (restoration of degraded habitats), and stream protection (restoration of riverine forests) (Hardner, Frumhoff and Goetze, forthcoming).

Projects of this category are also possible in the energy sector. Imagine, for instance, a project that switches vehicles or boilers from a high-carbon to a low-carbon fuel and reduces air pollution, but requires both a substantial initial investment and higher subsequent operating costs. Such a project may be presumed both additional and beneficial.

Summary

Ease of additionality determination depends on the project's returns and riskiness, and on the project owner's access to finance and information. These criteria cut across the energy vs. LUCF distinction. Projects that provide financial returns to their owners – including many plantation projects and many energy efficiency projects – offer potentially low costs of carbon emissions reductions, but require special attention to additionality determination. Projects that impose ongoing costs on their owners but benefit a larger community – including forest restoration, forest protection, and some fuel-switching projects – present a clearer *a priori* case for additionality.

Baseline determination and systems boundaries

The previous section distinguished between additionality determination – would the project really not take place in the absence of CER sales – and baseline determination – given that the project would not take place, what are the projected levels of GHG emissions or storage? It's useful to consider two cases for baseline determination. In the first case, it is reasonable to view the project in isolation from the broader economic system. In the second, the project is integrally linked with the larger system, so that baseline determination must consider the entire system.

Case I: Effectively isolated systems

Consider a project that sequesters carbon by restoring a degraded forest ecosystem, but neither produces saleable timber nor displaces agricultural production. Sequestration on this site therefore does not appreciably interact with the rest of the economic system, and can be considered in

isolation. The baseline question becomes: in the absence of active intervention to re-establish forest cover, what is the expected rate of natural biomass accumulation and carbon storage? It should be possible to establish the baseline by reference to contemporaneous or historical comparison plots. This requires identification of such plots and measurement of biomass over time (see the section on measurement, below). In some cases, the baseline may be straightforward to establish – it may be possible to show, for instance, that the initial, degraded vegetation never spontaneously recovers in certain agroclimatic circumstances. In other cases, we may observe natural regeneration in some locations but not others, due to both biophysical and anthropogenic factors. Here, we will need to explain how these conditioning factors would influence biomass in the project location.

It is harder to imagine energy projects that are completely isolated from the energy market, because in principle almost any change in fuel demand will have market-wide repercussions (see discussion below). For simplicity, assume that these repercussions are small enough to be ignored. Consider, as an example, a project that uses renewable energy to replace diesel fuel in an off-grid rural electric power station. The baseline scenario will have to make assumptions about the future path of diesel capacity utilization in the without-project scenario. Actual (with-project) capacity utilization may or may not be a good guide to the hypothetical without-project capacity utilization, depending, for instance, on whether installation of the renewable power plant catalyzes the development of new rural industries, and on fluctuations in the price and availability of diesel fuel. The baseline scenario will also have to make assumptions about when the old diesel plant would have been retired, and what would have replaced it.

In both the energy and the LUCF examples, it is necessary to project future behavior of people and biological or mechanical systems. The use of past behavior (fuel consumption or natural regeneration rates) as a guide to the future may be reasonable in some circumstances, unreasonable in others. (SEI 1998). Dynamic baselines may be useful for both LUCF and energy projects to allow for unexpected changes in the prices of fuel or agricultural commodities. Because this case involves circumscribed project sites, it may be possible to identify control groups and use their emissions as a baseline.

Case II: Integrated systems

In general, most projects involving forest protection or on-grid power generation must be viewed as part of a larger system. To assess the impact of the project on emissions, it's necessary to consider the behavior of the overall system.

Forest protection projects

Preventing deforestation is a theoretically attractive route for GHG emissions reductions for several reasons. Tropical deforestation alone accounts for about 20% of total GHG emissions. The private opportunity costs of reducing deforestation may be low in areas being converted to pasture or subsistence crops. While the private benefits of deforestation are often low, they are usually positive – which means that the case for additionality is strong, as noted in the previous section. Finally, forest conservation can yield multiple environmental cobenefits.

However, some observers are concerned about the potential inaccuracy of baseline construction for forest protection projects. There are two concerns. First, *is it possible to predict without-project deforestation rates and patterns?* Clearly there are vast stretches of forest that are not at risk of deforestation; claims of CERs for 'protection' of these forests would frustrate the aims of the Kyoto Protocol. Second, in principle *protection of one plot of forest might merely result in the diversion of deforestation pressures to a neighboring plot – the 'leakage' problem.* How can we define the boundaries of the project system so as to ensure that leakage is accounted for?

Prediction

Deforestation is not a random phenomenon. On the contrary, research over the past decade has established that deforestation is motivated to a large extent by the profits from a combination of timber exploitation and agricultural conversion. Consequently, recent work on the economic geography of deforestation has shown that spatial patterns of deforestation are highly predictable as a function of road and market proximity, topography, and agroclimatic suitability (Chomitz and Gray 1996; Mamingi, Chomitz, Gray and Lambin 1996; Deininger and Minten 1996; Pfaff 1997; Nelson and Hellerstein 1997; Mertens and Lambin 1997). For instance, Chomitz and Gray (1996) show that in Belize, commercial agriculture locates in flat areas near roads, while subsistence-oriented agriculture favors areas with high soil fertility. They demonstrate a simple but theoretically well-grounded methodology for predicting areas at high risk of subsequent deforestation. Alves (1999) demonstrates that over the past 20 years, deforestation in Brazil has expanded incrementally outward from areas cleared as of 1978; these areas, in turn, closely follow the road network. (See also Liu *et al.* 1993 for a similar analysis of the Philippines.) Nepstad *et al.* (1998) provide a geographical model of fire susceptibility in the Amazon. Thus we have both theories and tools to identify forest areas that are high risk for deforestation and consequent carbon release.

Less progress has been made in predicting the *rate* at which these high-risk areas are deforested. This reflects the lack of places in the developing world for which reliable annual time-series data of deforestation exist. In the Brazilian Amazon, where annual data exist for the period 1988-1996, annual rates have been volatile but without obvious trend. Until more time-series data on deforestation are available, a conservative approach to baseline determination would be to identify areas with a very high likelihood of clearance over a 10 year period. This could be done by: a) using spatial models to map relative risk of deforestation; b) assuming that the highest-risk areas are deforested first, applying conservative deforestation rates (e.g. below the mean rate for the previous decade) to map the areas likely to be deforested in the coming decade.

Leakage

People clear or degrade forests in order to extract timber, or to use the land for agriculture. Protection of a forest plot potentially reduces the supply of crops and tree products, and of opportunities for formal or subsistence employment. Markets may react by encouraging extractive or agricultural conversion activities in a different, unprotected forest plot. To the extent that this happens, the apparent project-sponsored emissions reduction 'leaks' out of another forest area.

Under what circumstances would we expect leakage to be significant? Leakage might be very high where deforestation is undertaken by shifting cultivators of subsistence crops, with relatively fixed annual requirements for clearance and a wide geographic scope of activity. In this situation, simple protection of a forest plot – without interventions to address the cultivators' food needs – would probably not be an effective means of reducing carbon emissions.

This view of deforestation may however have limited applicability. Studies of deforestation increasingly show that it is geographically circumscribed and strongly linked to markets. As noted earlier, most deforestation occurs near roads and markets, and even subsistence production is somewhat sensitive to market access (Chomitz and Gray 1996). A village-level census of Indonesia showed that, in most forest areas, villages experiencing deforestation had high proportions of households engaged in the production of export-oriented tree crops. (Chomitz and Griffiths 1997). In many places, deforestation may be linked to large commercial operators rather than small subsistence farmers. For instance, INPE (1999) reports that 52% of deforestation in the Brazilian Amazon during 1997 occurred in individual clearings greater than 100 hectares. Because deforestation exhibits such strong market-linked patterns, spatial models of deforestation provide a useful platform for understanding leakage.

The venerable von Thünen model (von Thünen 1966; Angelsen 1995; Chomitz and Gray 1996;) provides such a platform. In this well-tested model, farmgate prices for agricultural commodities decline with increasing distance from the market. Hence the profitability of agricultural production or forest extraction declines with distance; the economic frontier of production is defined where profits decline to zero. Beyond this point there is no market-oriented deforestation. In this model, the degree of leakage will depend crucially on the price-elasticity of demand at the market. (See Appendix for an illustrative formal model.) If the market is a port, the product in question is an export commodity, and price is set by world markets, then there will be relatively little leakage. Protection of a forest area within the 'price-shed' of the port thus puts little upward pressure on the world price and therefore does not appreciably shift out the economic frontier – meaning that the rate of leakage is small². Leakage may be severe, on the other hand, if deforestation is motivated by a locally-consumed commodity whose demand is relatively inelastic – for instance, a staple food such as rice. In this case, protection of an area bids up the price at the marketplace, thereby extending the economic frontier. But this effect may be moderated by the tendency of higher prices to elicit more intensive production. Therefore leakage is expected to be less than 100%; part of the shortfall in production resulting from protection is met through intensification rather than extensification. Leakage will be especially low if the protected area is directly at the economic frontier, where output per hectare is the lowest.

There are two ways to deal with leakage. One is to expand the scope of the system so as to 'internalize' the leakage. For instance, the area for which carbon is measured could be drawn so as to include the regional cattle or food market. An attractive alternative is to design the project so as to be leakage-neutralizing (Brown *et al.* 1997). For instance, a forest protection project could be combined with a project that sponsors intensified cattle raising in existing pasture areas. If the intensification component supplies more beef and absorbs more labor than the protection component displaces, then, arguably, there is no leakage. The intensification component also serves directly to diminish pressures for deforestation. Note that the intensification component need not threaten the forest under protection, reducing the chance of unintended carbon release. For instance, intensification could be promoted through road system improvements in areas without forests that supply the same food markets.

In fact, as many authors have pointed out, leakage can be benign. That is, a project may catalyze additional GHG emissions reductions in other locations. For instance, establishment of a sustainable timber plantation will not only result in carbon sequestration, it will also tend to depress the world price of timber. This will reduce the incentive to exploit native forests for timber. (Sohngen, Mendelsohn and Sedjo 1998). As a result, the returns to 'liquidating' and converting native forests will decline, reducing carbon emissions from forest conversion³.

Grid-connected energy projects

Many carbon projects propose to reduce CO₂ emissions by sponsoring the construction of electric generation facilities powered by efficient gas combustion or by renewable energy (e.g., solar, hydroelectric, geothermal, or renewable biomass fuels). In some cases, the new climate-friendly plant is proposed as a substitute for a conventional (e.g. coal-fired) plant of identical capacity. In this case the systems boundary is clear and there is no leakage (except for the market effects describing in the following subsection).

² Leakage may be generated if protection depresses the wages of labor, thereby shifting the frontier outwards. The effect on wages depends on the mobility of labor.

³ However, establishment of carbon plantations will tend to 'crowd out' commercial plantations – another category of leakage.

Often, however, the proposed carbon project adds to the grid a new power plant whose capacity does not correspond to that of any planned conventional plants. Now the project's impacts on GHG emissions can only be assessed by considering the emissions of the entire grid. Addition of the new plant affects grid-wide performance in two ways. First, presence of the new plant will affect investment decisions in other plants. Installation of large, 'lumpy' plants may be deferred for some time. (Swaminathan and Fankhauser, nd.). The result might be either positive or negative leakage depending on the characteristics of the deferred plant – whether, for instance, it is a coal plant or a hydro plant. Second, connection of the new, project-supported plant will change patterns of plant dispatching (assignment of loads among plants) (EIA n.d.). Electric grids are managed to minimize generation cost, using low-cost sources first and operating high-cost (typically carbon-intensive) plants only during periods of peak demand or when hydropower reservoirs are low. The effect on GHG emissions of a new wind turbine, for instance, depends on daily and annual utilization patterns of both the new plant and existing plants. Depending on how much electricity is demanded, when peak demands occur, when the wind blows, and when the reservoirs are dry, the wind turbine might substitute for electricity from high or low emissions plants.

A rigorous estimate of emissions reductions from a grid-based energy project therefore requires: 1) simulation of system-wide plant capacity expansion; 2) simulation of capacity utilization and load dispatching under a probability-weighted range of weather scenarios. Simulation models are available for this purpose; often they are part of the tool-kit of a national planning authority. Simulation studies may indicate when simpler models yield adequate predictions.

Energy market considerations

Almost all energy-related carbon projects decrease the demand for fossil fuels. The combined effect of these actions will be to reduce the price of fossil fuels, particularly coal and oil. As a result, fossil fuel consumers who are not constrained by the Kyoto Protocol – that is, consumers in CDM or non-signatory countries that are not participating in a CDM project – will increase their consumption of fossil fuels and emissions of CO₂. This market-based leakage has rarely been discussed in the context of energy-related carbon projects (but see Michaelowa 1997 and Martin 1998). However, it is perfectly analogous to the market-based leakage of carbon that results from intervention in wood plantations.

The extent of market-based leakage depends on the supply for and demand of fuel. Suppose that we write the applicable (national or possibly global) supply curve for coal as:

$$P = s_0 + s_1 Q$$

$$s_1 > 0$$

Suppose that a particular facility has inelastic demand for coal:

$$Q = \delta_0$$

and that the overall demand curve can be written as:

$$Q = (d_0 + \delta_0) + d_1 P$$

$$d_1 < 0$$

Now suppose that a carbon project switches the facility out of coal into solar power. The project therefore claims a reduction in carbon emissions of about δ_0 tons (assuming for simplicity of exposition one ton of carbon emissions per ton of coal combusted).

However, the actual decline in marketwide coal consumption is:

$$\delta_0 / [1 - d_1 s_1]$$

This means that a proportion $-d_1s_1/[1-d_1s_1]$ of the claimed emissions reduction has 'leaked' back into the atmosphere through market effects⁴. Note that this proportion is independent of the scale δ_0 of the reduction. It doesn't matter if the project is very small relative to the market; according to this logic, the scale of the leakage is proportional to the scale of the project.

For leakage to be significant, however, demand has to be relatively elastic and supply has to be relatively inelastic. Intuitively, the project-led reduction in demand has to have a large price impact (inelastic supply), which in turn has to induce a big 'snap-back' effect among nonparticipating energy consumers (elastic demand). Note that

$$d_1s_1 = \varepsilon_D / \varepsilon_S$$

where $d_1s_1 = \varepsilon_D$ and ε_S are the price-elasticities of demand and supply. These magnitudes will differ from place to place, and over time. The overall price elasticity of demand for energy in Asia has been estimated (Pesaran and Smith, 1995) at -0.37 , but the price elasticity for a particular fuel such as coal will be higher. A review of sector-specific fossil fuel price elasticity estimates in India, Korea, and Thailand, Asia reported highly elastic demand in the basic metals industry (-1.65 to -3.07) and varying elasticities in chemicals (-0.38 to -1.81). (Ishiguro and Akiyama, 1995). Supply elasticities are more elusive. A recent econometric study of the US coal market (Mellish, n.d.) estimated $1/\varepsilon_S = .117$. A study of the Australian market found a less elastic response, with $\varepsilon_S = 1.9$. (IEA 1995). World supply will be more elastic than supply within any one country. These scattered estimates do not support a definitive calculation of leakage, but do suggest that leakage could be nonnegligible in some circumstances and underline the need for more attention to this issue.

If the project replaces gas-fired power plants with renewable energy, however, leakage could be negative. That is, system-wide carbon savings could exceed those calculated at the project location. This could happen if the price of natural gas is depressed, inducing substitution away from more carbon-intensive fuels.

Technical diffusion and negative leakage

Some emissions-reducing technologies are privately profitable, but are poorly understood and therefore not adopted. Carbon projects can reduce emissions by overcoming these information barriers. Such projects could catalyze adoption of the new technologies outside the formal boundaries of the project, as information diffuses and perceived risk and uncertainty declines. This too would result in negative leakage. These indirect impacts could be quite large.

Information-diffusion impacts are likely to be larger where the technology is small scale and readily replicable. These characteristics cut across the energy vs. LUCF distinction. Demonstration of easily replicated technologies for households, farms or small enterprises – agroforestry techniques, pasture intensification technologies, household energy efficiency options – reduces uncertainty among potential adopters, triggering diffusion of the innovation⁵.

Summary

Most carbon projects – both energy and LUCF – have indirect effects on the economic and physical systems in which they are embedded. By changing market prices and diffusing information, these

⁴ This is an overstatement. Some of the increase in coal consumption results from switches away from oil or gas. Reduced emissions from these fuels compensates for some of the leakage. As long as these fuels are more carbon-intensive than coal, the net effect is positive leakage.

⁵ See Current, Lutz, and Scherr (1998) regarding demonstration effects in agroforestry.

projects can have far-reaching, even global impacts on GHG emissions and sequestration. As a result, the total net emissions reduction due to the project can be greater or less than that measured at the project site.

Baseline emissions scenarios therefore have to describe the behavior of the entire system. In some cases we have relatively sophisticated tools for modeling systems behavior. It is possible that experience with these models will show that simple rules of thumb are sufficient to estimate baseline emissions in many circumstances.

Forest protection projects have both disadvantages and advantages in baseline construction relative to energy and other types of projects. The principal disadvantage is that it is hard to predict year-to-year deforestation rates. However, methodologies are available to predict the total area subject to deforestation (and therefore the total release of CO₂) over the medium to long run. By coupling forest protection projects with agricultural intensification projects, leakage can be neutralized or even reversed.

Measurement

Emissions reductions are the difference between baseline levels and actual levels. To quantify emissions reductions, we need cheap, accurate means of quantifying actual emissions levels.

For project work, measurement generally relies on appropriately calibrated proxies: fuel consumption (for energy projects) and change in the stock of biomass (for LUCF projects). The cost of measuring and calibrating these proxies depends on the heterogeneity and geographical dispersion of the systems being measured.

CO₂ emissions for combustion sources can be estimated at negligible cost given information about fuel consumption and fuel composition. Fuel consumption is routinely tracked, and can be converted to CO₂ emissions using fuel-specific values⁶ of emissions/ton together with an assumption of a 99% combustion rate (EIA, n.d.). The accuracy of the estimate depends on the accuracy of the emissions/ton parameter, which will vary with changes in fuel composition; coal, for instance is heterogeneous in this parameter. Emissions of other greenhouse gases are much more sensitive to the particular type of combustion technology and pollution control equipment, and therefore require technology-specific parameters, possibly prone to uncertainty. Emissions of CO₂ can also be monitored directly using continuous emissions monitors (CEMs). These cost \$150,000 (Chin 1998), with an operating cost of about \$100,000/year per monitor⁷.

Monitoring and measurement costs increase for projects that involve a large number or geographic dispersion of actions or objects. In the energy sector, examples include fuel-switching projects for transport fleets, and energy efficiency projects aimed at households, commercial buildings, and small businesses. For these projects, it may be necessary to track energy consumption at thousands or possibly hundreds of thousands of geographically dispersed facilities. As the number of units gets larger and emissions/unit decreases, this leads to a statistical sampling scheme.

Statistical sampling is also the basis for monitoring the biomass in forests, plantations, and soils. Sampling techniques are well-developed, drawing on decades of experience in conducting forest inventories (MacDicken 1998; Vine Sathaye and Makundi 1999). Forest areas are stratified according to vegetation type. Sample plots are chosen in each strata, and several measurements are taken on trees in the sample plots. Calibration equations relate these measurements to total tree biomass. Carbon/biomass parameters are developed and applied to convert biomass measurements to stored

⁶ In fact, the EIA multiplies two fuel specific parameters: (thermal content/ton)*(emissions/thermal content)

⁷ Data from EPRI, http://www.epri.com/corporate/products_services/collaborative_mem/pf99/trgt083.html

carbon. Independent measurements must be taken of other carbon pools, such as soil carbon and leaf litter.

The total cost of sample-based measurement depends on the unit cost per sample and the number of samples. The accuracy depends, to a first approximation, on the number of samples and on the homogeneity *but not the size* of the universe being sampled. This principle is familiar from the world of opinion sampling, where about the same sample size is required to assess opinions in a state or in an entire nation. Consequently there will be large economies of scale in measuring carbon stocks in forest projects.

To illustrate the relation between cost and project scale, consider the analysis presented by Powell (1999), based on data for the carbon project at the Noel Kempff Mercado Climate Action Plan. The analysis computes the cost of measuring the carbon in a heterogeneous 634,000 hectare forest area, containing 118 million tons of carbon, at different levels of accuracy and statistical significance. The unit cost per sample plot ranges from \$230 to \$281. The number of samples, and thus the cost, increases approximately with the inverse square of the confidence interval. Estimation of the mean to within $\pm 10\%$, with 95% confidence, would require 81 sample plots and cost \$19,000 (not including setup costs). A confidence interval of $\pm 5\%$ would require 452 sample plots at a cost of \$108,000, or less than \$0.001/ton. Another halving of the confidence interval would boost costs to half a penny per ton.

Costs/ton of quantifying emissions *reductions* (rather than stock) could be higher, depending on how the baseline is defined and what the baseline deforestation rate is. Suppose that the spatial prediction models mentioned earlier are used to identify areas that will be deforested over the next 20 years, and that these areas comprise 10% of the total area and biomass. One quantification approach would be to estimate the carbon contained in the baseline deforestation region. At the end of the project, if remote sensing shows that there has been no disturbance of the area, then this estimate is taken as the amount of emissions reductions. If the survey costs are approximately the same, then measurement/ton of emission reductions is now ten times greater than before, but still only \$0.01/ton.

To take a much less favorable scenario, suppose that baseline emissions are stipulated as 10 million tons, actual emissions are estimated as:

$$(\text{initial carbon stock} - \text{end of project carbon stock})$$

and emissions reductions are calculated as:

$$10 \text{ million} - (\text{initial carbon stock} - \text{end of project carbon stock})$$

Suppose now that independent samples are carried out to estimate initial and final carbon stocks. Because actual emissions are estimated as the difference between two independent estimates, the variance of the difference is the sum of the variance of the two stock estimates. To keep the confidence interval of the difference small relative to the expected emissions reduction of 10 million, it is now necessary to use a much smaller confidence interval, say 1%. This boosts the costs of each survey to an unrealistic \$2 million⁸ – unrealistically high because there would be economies of scale in sampling and other measurement technologies would likely be brought to bear. Even so, the cost per ton of emission reduction is only about \$0.40.

In summary, projects that involve large point sources of combustion will tend to have low per-ton emissions measurement costs. The cost per ton of measuring carbon stored in biomass will be approximately inversely proportional to the size of the carbon sink, making measurement inexpensive in large projects but expensive in very small, heterogeneous ones. The latter would

⁸ Own calculations based on data supplied by Mark Powell.

require some kind of stipulated carbon storage parameters in order to be viable. However, rapidly evolving technologies for aerial and satellite surveys could result in order-of-magnitude decreases in survey costs.

Permanence⁹

A peculiar feature of most LUCF projects is the possible reversibility of carbon sequestration¹⁰. That is, the carbon embodied in a plantation or protected forest is always at risk of accidental or deliberate release. (However, Fisher *et al.* 1994 report that introduction of deep-rooted grasses to Colombian savannas results in 7.8 tons/hectare/year of soil carbon sequestration, most of which is well below the plough layer and therefore arguably resistant to subsequent oxidation.) In contrast, a properly-accounted-for reduction in current fossil-fuel consumption will result in a centuries-long reduction in atmospheric CO₂ levels. Is there any value, then, to emissions reductions from LUCF projects? If so, how does the value of a ton of LUCF reductions compare to a ton produced by an energy project?

There are two approaches to assigning value to LUCF-based reductions. The first is to assess the environmental and economic benefits of commitments to limited-term sequestration agreements—for instance, projects that guarantee to keep a plantation or threatened forest standing for 30 years. These benefits are then compared to the benefits of permanent emissions reductions projects in order to derive a conversion or discount factor for limited-term reductions. The second approach is to devise mechanisms that provide reasonable assurance of indefinite sequestration.

Limited term commitments

Limited term commitments to carbon sequestration offer practical and political advantages. First, it may be possible to arrange for formal insurance of 5 to 30 year commitments. Second, some host countries may not want to provide perpetual guarantees of unchanged land use, seeing this as an unacceptable constraint on sovereignty. They may also be reluctant to forfeit the option values associated with the possible future emergence of high value land uses. Perhaps for these reasons, existing LUCF projects often specify limited-term commitments.

Limited-term commitments help to mitigate climate change and its impacts in several ways. First, postponing emissions will postpone some radiative forcing. Radiative forcing has a cumulative effect on the climate. As a result, a temporary sequestration project shifts downward the future time path of temperature increases (or other climatic effects). In other words, thanks to such a project, temperature is a bit lower at every date in the future than it would have been. Damage levels at each point in time will be a little lower. If society has a positive discount rate, postponement of damages represents an economic benefit.

Second, there is a physical advantage to postponing CO₂ emissions. The marginal impact of CO₂ on radiative forcing declines as CO₂ concentration in the atmosphere increases. (Albritton *et al.* 1994.) Thus by postponing the release of some CO₂ until a time when concentrations will have increased, we have softened its impact.

Third, postponing emissions may buy time for technological progress in abatement. If sequestration is cheap, and if the marginal cost of abating industrial emissions is declining or growing more slowly than the discount rate, temporary sequestration may be a good bargain.

⁹ This section draws and expands Chomitz (1998b).

¹⁰ The issue might conceivably apply also to underground sequestration of CO₂ from industrial emissions.

Finally, and perhaps most important, some temporary sequestration may turn out to be permanent. Over the next 30 years, much forest in developing countries may be converted to low-value agricultural land, which is subsequently abandoned as higher wages and intensified agricultural technologies discourage subsistence farming and extensive pasture at the agricultural frontier. This pattern of agricultural expansion and contraction has been historically observed in the US and Western Europe (Walker 1993) and more recently in Malaysia (Vincent and Ali, 1997). Therefore, some limited-term sequestration commitments may result in permanent forest protection. At the end of the commitment period a combination of reduced pressure for agricultural conversion and increased local demand for environmental amenities may result in indefinite protection of forests that would otherwise have been destroyed for ephemeral economic gains. This yields permanent carbon emissions reductions if natural regrowth on abandoned agricultural lands does not attain the same biomass densities as the original forest. In tropical areas, incomplete biomass recovery may result from land degradation due to compaction, fire, erosion, or local climate change induced by deforestation (Cochrane *et al.* 1999).

These considerations have prompted suggestions of 'ton-year' crediting schemes. Projects would receive fractional credits for each year that a ton of carbon is kept out of the atmosphere. This is attractive from the viewpoint of the world community because the project owner bears all the risk of nonperformance. It is attractive to project hosts who wish to preserve future land use options, even if they are unlikely to exercise them. Clearly the equivalence factor (ton-years/'perpetual' ton) affects project viability and environmental impacts. There is however no unique way to determine the conversion rate between ton-years and perpetual tons. Rather, a number of scientifically justifiable approaches can be suggested and the choice among them is a policy decision.

A very similar problem arises in deriving equivalency measures for different greenhouse gases. These differ both in their impact per kilogram and in the length of time that they stay resident in the atmosphere. For instance, the instantaneous radiative forcing (in watts/cubic meter/kg of gas) of HCFC-225a is nearly a thousand times greater than that of CO₂, but the former's atmospheric lifetime is only about 2.5 years. (Albritton *et al.* 1994). How then can we assess the relative cost-effectiveness of abating the emissions of these gases?

The Kyoto Protocol requires the use of global warming potentials (GWP) to compute the carbon dioxide equivalences of the other five recognized greenhouse gases (article 5, paragraph 3). The GWP is a simple-to-compute proxy for climate impact (Lashof and Ahuja 1990). The absolute global warming potential for a particular gas is given by (Albritton *et al.* 1994):

$$AGWP(T) = \int_0^T \alpha x(t) dt$$

where α is a gas-specific value representing the radiative forcing effect of a unit of the gas and $x(t)$ is the gas-specific proportion remaining at time t of a unit pulse of the gas at time 0; α may be a function of t and of x , but for simplicity is treated as a constant here. The global warming potential therefore represents the cumulative forcing effect up to an arbitrarily-chosen time point T . The (relative) GWP is the ratio of a gas's absolute GWP to that of CO₂, the numeraire gas. An addendum to the Kyoto Protocol¹¹ specifies the use of a 100 year time horizon for these calculations.

¹¹ Decision 2/CP.3, para 3.

This approach can be applied directly to a project that delays deforestation-related emissions by one year. The result is an equivalence factor of about .0075 ton-years/'perpetual' ton¹². (This does not, however, allow for any possibility that the emissions reduction might persist after one year.) A factor of this magnitude would be too low to motivate most LUCF projects; it might suffice to deter conversion of high-density primary forest to low-value pasture.

The GWP approach has the advantages of simplicity and precedent. However, the application of this approach to calculating greenhouse gas equivalencies has been widely criticized (Eckaus 1992, Schmalensee 1993; Kandlikar 1996). First, the global warming potential does not adequately capture the complexities or dimensions of climatic impacts. Second, the 100 year horizon is an arbitrary choice. Third, and relatedly, the use of a zero discount rate is also arbitrary and difficult to defend. Thus, rather than looking at a measure of the climatic impact at an arbitrary point in time (the GWP's single horizon), we should compute the project's impact on mitigating damages from climate change.

In the special case of a linear damage function, and projects which postpone deforestation processes for a fixed period, the gains from the limited-term project are those associated with discounting the damages over the duration of the project period. On this approach, postponing deforestation by 20 years is worth one third as much as preventing it forever at a 2% discount rate, and 86% as much at a 10% discount rate. In fact, this approach gives a simple rule for computing the value of a 'ton-year' of sequestration services: one ton-year = r perpetual tons, where r is the discount rate. The choice of an appropriate social long-term discount rate has been much debated. A recent workshop devoted to this topic achieved a consensus in favor of using a positive discount rate for assessing climate policies over multigeneration time-spans (Portney and Weyant 1999).

Mechanisms for assuring indefinite sequestration

Host countries may favor projects that promise indefinite sequestration, where this promotes national goals such as watershed protection and restoration of national parks. Here the challenge is to devise mechanisms to assure the world community that emissions reductions associated with these projects are long-lived. Three such mechanisms are suggested here.

Discounting for risk

An obvious approach is to partially credit emissions reductions according to the likelihood that they will endure for a specified period such as 100 years. For instance, relatively high credits would be given to sequestration on lands unambiguously protected by national law, with well-functioning and securely-funded monitoring and enforcement agencies¹³. Lower crediting levels would apply to plantations. In this way the overall portfolio of LUCF-based CERs would be mutually insured. This generalizes the self-insurance scheme that Costa Rica has applied to its offering of forest-backed emissions reductions under the Protected Areas Project. In its first year of operation, it will only offer for sale half emissions reductions it plans to produce. The rest serve as an insurance buffer (Chomitz *et al.* 1999). The quantity of tons held in reserve varies from plot to plot based on the risk of nonperformance or loss.

¹² To derive the equivalence factor, consider that the GWP of a unit pulse of CO₂ in year zero is $g_0 = \int \alpha x(t)$, where the integral is taken from $t=0$ to 100. The GWP of a unit pulse of CO₂ emitted in year 1 is $g_1 = \int \alpha x(t)$ where now the integral is taken from $t=0$ to 99. A project that postpones CO₂ release by one year therefore yields a reduction, relative to the perpetual project, of $1-g_1/g_0$. Tipper and de Jong (1998) and Moura Costa (1999) derive a different, higher figure by calculating $\int \alpha x(t) = \text{approx } 60$ and concluding that 60 ton-years = one 'perpetual' ton (my terminology).

¹³ The Brazilian state of Paraná uses such a rating system in determining the size of fiscal incentives paid to municipios (counties) for protected areas. (Loureiro 1998).

In this approach, the risks of collective under or over performance would be borne by the world community. (Because of the long-term nature of the concerns, it is probably not feasible to find commercial insurance for these risks). It would probably be necessary for a centrally-designated task force to determine appropriate rules for assigning risk discounts. These rules could be revised over time, based on project experience.

Setting the partial crediting factor is analogous to setting baselines. If set too high – above the real but unknown value – these factors will overestimate the quantity of CER's produced, resulting in more GHG emissions than anticipated. If set too low, the world will enjoy an emissions reduction dividend on approved projects – but valid projects may be discouraged, raising the overall cost of meeting emissions reductions goals.

Bundling LUCF activities with subsequent emissions reduction activities

An alternative is to bundle a temporary carbon-sequestration project with a commitment to undertake a follow-on action that ensures the permanence of the carbon gain. Assume, for instance, that the Protocol results in a market for carbon allowances based on countries' "assigned amounts". Then the buyer of CERs from a 5-year sequestration project might commit to retire an equivalent tonnage of allowances at the end of the 5 year term. Then, even in the worst-case scenario – release of all the sequestered carbon – the time path of net emissions reductions would be the same as that associated with a current energy-related emissions abatement project or the current retirement of an allowance. In the more likely scenario of some continued sequestration after the project ends, the climatic impact of the "bundle" would be more favorable. A variant would allow the buyer to renew the sequestration project for another fixed term, deferring the commitment.

The bundling approach addresses the concerns of those who fear that LUCF projects are merely palliative and do not help to reduce the long-term emissions growth trend. An alternative view emphasizes the value of buying time to pursue low-cost abatement opportunities as capital stocks turn over. It is prohibitively expensive to scrap current capital equipment such as generators, cars, and buildings, even if the equipment is energy-inefficient and carbon-intensive. However, as that equipment is retired, there will be inexpensive opportunities to replace it with efficient, low-carbon-emissions technology. In addition, exogenous technological progress may result in cheaper renewable technologies over time. The combination approach gives both time and motive for buyers to undertake a long-term technology development program that will yield enduring emissions reductions, while also yielding immediate reductions in net carbon emissions.

A bundling deal makes sense for a buyer if the price of an allowance or 'permanent' CER is expected to go down, or to increase more slowly than discount rate, between commitment periods¹⁴. This might happen in the near term, for instance, if the early supply of CDM projects is limited, as hosts and project developers struggle to master an unfamiliar market with initially high transactions costs. Over the long run, simulations of optimal timing of emissions reductions suggest that carbon prices should rise at 3.5% annually over 2010-2040 (Nordhaus and Boyer 1999), less than the discount rate of private market participants.

"Bundling" current sequestration with future reductions in assigned amounts therefore allows more cost-efficient timing of emissions reductions. Achieving this result, however, probably requires that emissions caps for future periods be negotiated concurrently with the right to bundle or borrow against future allowances¹⁵. If borrowing were allowed before future allowances were determined,

¹⁴ See Schennach, n.d. for a discussion of the intertemporal dynamics of emissions allowance pricing when allowances can be banked, including the conditions under which prices can rise more slowly than the discount rate.

¹⁵ I am grateful to Dan Lashof for this point.

negotiators would strive to increase the allowances to cover existing levels of borrowing. On the other hand, the ability to use sequestration to borrow against future allowances might allow negotiators to agree on more rapid rates of emissions reductions than might otherwise be possible.

The relative price of a sequestered ton would depend on the expected rate at which CER prices rise between commitment periods. Suppose, for instance, that the current price of a CER is p_0 , the discount rate is r , the expected price five years from now is $p_5 < p_0(1+r)^5$. Then a buyer will be willing to pay

$$p_0 - p_5(1+r)^{-5}$$

for a five year sequestration commitment. (The price will be greater if partial credit is granted for the possibility that sequestration will continue past the sequestration contract period.) For illustration, if the discount rate is 10% and CER prices are expected to rise at 5%, then a five-year sequestration guarantee would be worth about 22% of a "permanent" CER.

Tax LUCF CERs to fund emissions reduction technology research and development

An alternative would be to have the buyer of an LUCF-based CER contribute to a fund that finances research and development in carbon-saving technologies. The size of the contribution (which would act like a tax) would be inversely related to duration of the sequestration commitment. The fund could be used to invest in a venture capital fund to develop renewable energy technologies. The host country might be assigned a proportionate share of the royalties from any discoveries. The fund might also be used to provide prizes for the inventors of emissions-reducing technologies that are difficult to patent (following the example of the famous 'longitude prize' for the first reliable naval chronometer). If these funds served to advance the time at which renewable technologies are adopted, worldwide, by even a few years, the emissions savings would be quite large and might compensate for premature release of sequestration-based CERs.

Tradable development rights

An alternative to the project-based approach is to adopt a sectoral or regional baseline on forest emissions. Emerging tradable development rights (TDR) mechanisms in Brazil (Chomitz 1999), though not motivated by GHG considerations, provide a template for establishing a defensible baseline, minimizing leakage, and assuring permanence.

A carbon-inspired TDR scheme might start with legislation mandating protection of areas of unique biodiversity (e.g. areas known to harbor endemic species) or hydrological interest (e.g. riverine forests). It would then issue rights for forest conversion of $x\%$ of the remaining area. Rights would be differentiated by biome or ecosystem. Ideally the rights should be auctioned; as a practical matter, most environmental permits are 'grandfathered'. In this case, they could be awarded to landholders who had preserved at least $(1-x)\%$ natural forest cover on their property. Landholders would be required by law to hold TDRs corresponding to all land not under natural vegetation.

The overall conversion allowance x would be chosen so that $(1-x)$ is a large enough proportion to maintain viability of key ecosystem populations, and that x is small enough so that there is demand for the rights. A market for TDRs (tradable within designated ecosystems) would tend to minimize the opportunity cost of conserving the domestically desired $(1-x)\%$ conservation allotment for each ecosystem. TDRs would be purchased by landholders with agroclimatically attractive land, convenient to market. Those with low value land would find it more attractive to sell their development rights and leave the land under forest. (See Chomitz 1999 for a simulation of how this might work.)

With this mechanism in place, TDRs could be purchased and retired in order to increase carbon sequestration, just as some environmentally-motivated individuals buy and retire SO₂ allowances in order to boost air quality. Retirement of a TDR would ensure that an additional hectare of land will

remain perpetually under forest. Conservative estimates of the marginal carbon density of forested land could be used to translate a hectare of forest protection into tons of CERs.

Clearly such a system requires sophisticated institutions for administration. If it could be implemented, it would offer a number of advantages. It conserves carbon at low opportunity cost in foregone agricultural production; the losses in agricultural production may well be less than the gains in local cobenefits of forest conservation. It avoids the potential moral hazard problem of inducing countries to relax their conservation efforts so as to be able to claim CERs for creating protected areas; here, CERs are claimed only for conservation efforts beyond a reasonable expectation of what is required for domestic interests. By encompassing a large geographic area, leakage is internalized to a large degree. By devoting CER revenues to agricultural intensification in existing cultivated lands, the project can alleviate poverty and further counteract leakage. Finally, by embedding enforcement in a broader legal structure for land use regulation, the system creates a reasonable expectation of permanence of sequestration.

Is such a system feasible to set up? There are some interesting recent precedents in Brazil (though they are motivated by conservation and have no connection with carbon). The point of departure is current policy debate in Brazil to allow 'relocation' or trade in landholders' legal forest reserve (*reserva legal*). This is a long-standing requirement that property owners maintain 20% of each property under native vegetation (50% to 80% in the Amazon). A recent trend towards increased enforcement of the rule has prompted recognition that a property-wise requirement is, in theory, an economically and environmentally inefficient way to satisfy an areal requirement for protection. Consequently, landowners and public officials have been exploring options that allow landowners to satisfy their forest reserve requirements off-site, on areas of greater ecological significance but lower opportunity cost. Provisional regulations for 'relocation' or trade in legal reserve rights are under debate at the national level and have been implemented in the states of Minas Gerais and Paraná (Bernardes 1999).

Paraná – a largely deforested state – has implemented a system which requires each landholder to file a plan for achieving compliance with the 20% requirement¹⁶. Compliance can be achieved either through regeneration of native vegetation or by maintenance of legal reserve on another property. 'Trading' of legal reserve is allowed only within river basins in order to ensure full representation of the state's biodiversity.

The Brazilian examples suggest that a TDR scheme may be both acceptable and feasible. Analogous mechanisms may be devised for areas with weaker institutional structure. For instance, Tipper (1998) proposes a sectoral baseline for the combined Oaxaca-Chiapas region of Mexico, against which carbon emissions savings can be reckoned.

Domestic impacts

Carbon projects are required to contribute to sustainable development, hoped to stimulate technology transfer, and feared to endanger the environment. Again each project must be evaluated on its specific merits

Sustainable development. Most carbon projects provide an environmental cobenefits. For instance, most energy-efficiency and fuel-switching projects reduce emissions of particulates and other harmful air pollutants. Most forest conservation and regeneration projects will provide biodiversity, hydrological, and recreational benefits.

Employment and distributional impacts will be more varied. Some fuel-switching and energy-efficiency projects will involve switches to more capital-intensive technologies, with a consequent

¹⁶ SISLEG - Sistema De Manutenção, Recuperação E Proteção Da Reserva Florestal Legal E Áreas De Preservação Permanente, created by decree 387/99.

loss of employment. Savings may accrue to the owners of large companies or to the consumers of their products. On the other hand, sustainable biomass projects may provide employment to low-wage workers. Agroforestry and agricultural intensification projects may benefit the rural poor, both landless workers and smallholders.

Technology transfer Energy-related carbon projects are sometimes thought to be more favorable for technology transfer than forest carbon projects. The magnitude and benefits of technology transfer, however, will depend on the nature of the technology. Small-scale, locally replicable technology may diffuse faster, and with greater impact on employment and poverty alleviation, than large-scale sophisticated technologies. Diffusion and learning effects, for instance, have been observed for small-scale boiler technology (SEI 1998) and for renewable energy technologies. Similarly, many kinds of agroforestry technologies lend themselves to local adoption, replication, and diffusion and may be particularly important for combating poverty among the rural poor.

Environmental impacts. Both energy and LUCF projects can cause environmental damage. Hydropower dams, for instance, can directly or indirectly destroy natural habitats and threaten fresh-water biodiversity. Forestry projects involving plantations of exotic monocultures such as eucalyptus raise a number of potential concerns. Depending on the species used, these may deplete groundwater and affect soil fertility. Some observers also fear that there could be perverse incentives to deforest standing forests in order to gain CERs from reforestation.

These risks are shared, of course, by projects that are not motivated by the CDM. The standard response is to institute a system of environmental assessment that screens out undesirable projects and assures that others are implemented in an environmentally friendly way. (Brown 1998) Some of these screens can be quite simple. For instance, a prospective plantation project (whether or not motivated by the CDM) might be required to show evidence that the proposed site had already been degraded by, say, 1995. Worldwide archives of remote-sensing imagery are available for this purpose.

Conclusions

Would-be suppliers of CERs face a variety of challenges in demonstrating that their projects produce real, additional, measurable, permanent emissions reductions in a socially and environmentally responsible fashion. Each project type will present a different pattern of advantages and disadvantages in terms of demonstrating consistency with these criteria. For all the criteria except permanence, it is difficult to find generic distinctions between LUCF and energy projects, since each of these two categories comprises a great variety of project types. Instead, the important distinctions have to do with such things as:

- The level and distribution of direct financial benefits that result from the project
- The degree to which the project is integrated with a broader physical and economic system
- The internal homogeneity and geographic dispersion of the project components
- The local replicability of project technologies

These dimensions cut across the energy vs. LUCF distinction.

The challenges of setting up offset markets are considerable. There are however some existing, large scale programs that may provide useful lessons. Most importantly, demand-side management incentive systems in US utilities reward utilities for saving energy (and as a byproduct, reducing GHG emissions) against a hypothetical baseline (Chomitz 1998, Hagler Bailly 1998). A typical incentive payment is roughly equivalent to \$20/ton of carbon¹⁷. These programs have received rate-payer

¹⁷ Eto et al (1995) report mean shareholder incentives, weighted by program size, of 4 cents/kWh in a sample of 40 large commercial DSM programs; we apply a rough estimate of an emissions rate of 200 tons C/gWh.

funding of over \$16 billion. An econometric study by Parfomak and Lave (1996) suggests that the utilities' estimates of energy savings are accurate on average (see Chomitz 1998 for a further discussion). Another relevant program is the US Conservation Reserve Program, which pays about \$1.6 billion/year in incentives for farmers to replace marginal cropland with trees and other protective vegetative cover; in 1997, about 33 million acres were enrolled, including 2.35 million under tree cover. (USDA, n.d.) Analysis of farmer responsiveness to these incentives may provide useful insights into baseline-setting and permanence in sequestration projects. (See e.g. Parks and Schorr 1995).

Permanence is an issue specific to LUCF projects. Several potential approaches are available. The ton-year approach focuses on the benefits from deferring climatic damage, and rewards longer deferral. The combination approach assures permanence by bundling current LUCF CERs with future reductions in the buyer's allowed amount. A technology-acceleration approach taxes LUCF CERs to fund accelerated research and development of emissions abatement technology. An insurance approach adjusts LUCF CERs for the risk of premature release, spreads the risk across a world portfolio of projects, and supports institutions that minimize the risk.

Appendix: A stylized model of leakage

This highly stylized model of leakage is intended to illustrate how the spatial structure of markets, together with supply and demand responses, determine the degree of carbon leakage in a project that protects forests or retires croplands. For policy analysis, it would be possible to apply a fully articulated empirical model of spatial supply and demand, such as that of Chomitz, Griffiths, and Puri (1999).

Imagine a rectangular island bisected by a road of length L along which the population lives. The population demands an agricultural good which can be produced at zero cost anywhere on the island. There is a fixed cost α per ton-kilometer of transporting the good to the road, but transport costs along the road are zero. The good sells at a price of P along the road. Both farmgate price p and productivity per hectare q decline with distance x from the road:

Market price of agricultural commodity: P

Distance from road: x

Farmgate price: $p(x) = P - \alpha x$ [$\alpha > 0$]

Farm productivity: $q(x) = \beta p(x)$ [$\beta > 0$]

Demand for the agricultural good Q^D is a function of price:

Market demand: $Q^D = \gamma \delta P^2$ [$\gamma, \delta > 0$]

Cultivation extends from the road to a frontier at distance x^* where the farmgate price is 0:

Limit of cultivation: $x^* = P/\alpha$

Supply is the total production within the limit of cultivation on both sides of the road:

$$Q^S = 2L \int_0^{x^*} q(x) dx = L\beta P^2 / \alpha$$

Equating demand and supply yields:

$$x^* = \frac{1}{\alpha} \sqrt{\gamma / (\delta + \beta L / \alpha)}$$

Everything within distance x^* of the road is converted to agriculture; beyond the frontier, carbon is stored undisturbed in forest cover.

Now suppose that a carbon project proposes to reforest the eastern half of the agricultural land. Retiring this land from agriculture will drive up the price of the agricultural good, leading to the expansion of the frontier in the western half of the island and consequently to carbon leakage. The new frontier in the western part of the island will be

$$x^{**} = \frac{1}{\alpha} \sqrt{\gamma / (\delta + \beta L / 2\alpha)}$$

Note however that the total area under cultivation has decreased: withdrawing some land from cultivation did not result in hectare-for-hectare leakage. In the western half of the island, the new frontier is not twice as distant from the road as the old one, but rather has increased by a ratio:

$$x^{**}/x^* = \sqrt{\frac{\delta + \beta L/\alpha}{\delta + \beta L/2\alpha}}$$

(Of course, the effect on carbon leakage depends on the carbon densities of the newly deforested land and the newly reforested land.) In the extreme case that demand is fixed and completely insensitive to price ($\delta=0$) then the new frontier has moved out by a factor of $\sqrt{2}$, because the reduction in supply is partly compensated by increasing intensiveness of cultivation. The more elastic is demand, the lower the areal extent of leakage; in the limit, when P is fixed, there is no leakage at all.

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6/9