Chapter

5 Forest Carbon Sequestration*

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Key Messages for Policymakers

- An efficient forest carbon sequestration program could account for about a quarter of the desired global carbon dioxide (CO_2) mitigation over this century (with most of the remaining 75 percent from reducing carbon emissions from fossil fuels). An estimated 42 percent of this carbon storage could be achieved via reduced deforestation, 31 percent from forest management, and 27 percent from afforestation, with about 70 percent of overall carbon sequestration occurring in tropical regions.
- A serious deficiency in current sequestration programs is that each project is asked to prove additionality. However, it is not straightforward to identify which hectares are marginal and which would have stored carbon regardless. An administrative alternative is to establish a baseline level of carbon for forests in each country. Fees would then be charged for any reductions below the baseline and subsidies for carbon storage above the baseline. Setting the baseline equal to the existing level of carbon would lead to subsidies only for additional storage.
- Scaling-up small projects to promote forest carbon sequestration will be difficult given limited technical capacity and leakage. National programs are likely easier to administer.

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- National programs also allow national governments flexibility to address local institutions and property rights such as overlapping claims to timber, grazing, fuel wood, and nontimber forest products from the same forests.
- Measuring sequestered carbon can be problematic. Monitoring and enforcement is critical to maintain incentives for long-term storage. International agreements should encourage inexpensive monitoring technologies to keep these costs limited.
- The design of incentives is critical. For example, using forest coverage as a proxy for carbon storage provides no incentive to increase carbon per hectare. Similarly, lump sum payments for carbon give no incentive to protect established forests. Annual payments for the annual value of stored carbon encourage continued efforts to safeguard standing carbon.

Over a trillion tonnes of carbon dioxide (CO_2) are currently stored in biomass in the world's forests. Even without a carbon sequestration policy, forests appear to be sequestering an additional 4 billion tonnes of CO_2 per year. This net gain of 4 billion tonnes comes from a gross gain of 10 billion tonnes through forest planting and growth minus 6 billion tonnes of CO_2 lost from tropical deforestation each year. Some of this deforestation is harvesting for forest management, but a great deal of it is land conversion to agriculture. If one examines just the lost carbon from deforestation, forestry/land use causes 15 percent of man-made emissions. However, carbon cycle measurements confirm that forests are likely the sink for the 4 billion tonnes of "missing carbon." Whether forests can continue to be a sink depends upon the future effect of CO_2 fertilization and climate change on forest carbon stocks.

The key policy issue is not the baseline land-use emissions but rather what policy can do to increase carbon sequestration in forests. The Kyoto Protocol includes specific mechanisms to try to increase the stock of carbon in forests (Kyoto Protocol, Article 3.3). First, carbon storage can be increased by reducing deforestation. For example, the Forest Carbon Partnership Facility at the World Bank has developed a fund of about $400 million (World Bank, 2011) to reduce carbon emissions from deforestation. Second, carbon can be increased by planting trees in areas that are no longer forested (afforestation). Third, carbon storage can be enhanced by increasing forest intensity with plantations, fertilizer, or forest management.

How much additional carbon can be stored in forests depends on two things—what society is willing to spend to store more carbon and how quickly the carbon must be stored. The more rapidly carbon must be stored, the more expensive it is. A number of literature reviews have now shown that it may be possible to increase carbon in forests by about 4 billion tonnes CO_2

per year with a price per tonne of CO_2 of up to US$30 (in current dollars). This level of sequestration essentially doubles the net natural sequestration that is already occurring. Starting with an efficient price path for CO_2 from an integrated assessment model, an efficient universal program of forest carbon sequestration could account for 25 percent of all carbon mitigation (energy would be responsible for the bulk of the remaining mitigation). Many economic studies of carbon sequestration, however, have not addressed important administrative hurdles that a global program will have to face. Some of these, listed as follows, could be managed by carefully designing the sequestration program.

- "Leakage" can dramatically reduce the effectiveness of carbon sequestration if the program is not consistent across sites and is not universal.
- The process of storing carbon in forests is dynamic because it takes time for trees to grow and because the price of carbon changes over time. The sequestration instrument must be able to capture these dynamic properties.
- There are potential measurement and verification issues that need to be overcome to ensure that forests are being properly managed over time.
- Historically, carbon mitigation programs have tried not to pay for forest activities that might have been done anyway, and so they have been burdened by proving "additionality."

The following are also some problems that simply have not yet been addressed.

- Most analyses assume that forest carbon sequestration projects can be easily and quickly scaled-up from a few limited experiments to a globally comprehensive program with modest institutional costs.
- Forest ownership is often complex, especially in tropical countries. Many owners often have legitimate overlying claims on different forest amenities on the same piece of land.
- There are equity issues concerning who will be compensated by any carbon sequestration scheme.

We start this chapter by reviewing the potential of carbon sequestration in forests. The evidence suggests that forest sequestration is potentially an important source of mitigation. We then shift our focus to the administrative hurdles that must still be overcome to take advantage of carbon sequestration in forests.

Finally, we discuss the measurement and monitoring problems and the feasibility of scaling-up forest carbon sequestration globally in light of these complexities.

The Potential of Carbon Sequestration

Although some visionaries call for forests to be planted in deserts and other hostile locations, only a fraction of land is hospitable to forests. Growing forests in places without adequate soil and water would be prohibitively costly.

On lands that can support forests naturally, carbon sequestration can be achieved via three basic forestry activities—afforestation, forest management, and avoided deforestation. Afforestation involves converting former agricultural and abandoned crop lands back into forests. In areas where forests are most productive (i.e., moist tropical regions), they can sequester up to 11 tonnes of CO_2 per hectare per year in above-ground biomass and additional carbon below ground. Up to 2 billion hectares of forests have previously been deforested and converted to agriculture worldwide. All of this land could potentially be converted back to forests. Of course, this would leave us with little agricultural land. There is consequently a trade-off between forestland and agricultural land. The more land that is converted back to forestland, the higher the opportunity cost will be (from lost farmland). And carbon saved from afforestation takes a long time to be stored as it takes decades for trees to grow large enough to store substantial amounts of carbon.

Reducing emissions from deforestation is more promising. According to the Food and Agricultural Organization (FAO), an additional 6 million hectares of deforestation occurs each year globally, with most of the gross changes occurring in the tropics. Mature tropical forests contain a large stock of carbon per hectare (300 to 400 tonnes CO_2 per hectare). In the case of many tropical countries, a great deal of this stock is burned to prepare land for pasture or farming and therefore leads to a vast amount of immediate carbon emissions.

It is also possible to increase carbon in forests by changing forest management. According to the FAO, over 1 billion hectares of forests globally are currently production forests, but only 70 to 100 million hectares of forest are fast-growing plantations. Converting more forestland to plantations could quickly increase carbon sequestration. Additional potential management actions include postponing timber harvests, tree planting rather than natural regeneration, thinning to increase forest growth, fighting forest fires and other disturbances, and fertilizing.

If forest owners were paid US$30 per tonne of CO_2 permanently stored, they would be willing to sequester about 4 billion tonnes of additional CO_2

in forests each year. In an efficient program, approximately 42 percent of this carbon storage could be achieved via reduced deforestation, 31 percent via forest management, and 27 percent via afforestation. Afforestation accounts for relatively little of the additional carbon storage because it takes a long time for young forests to actually accumulate carbon and because the opportunity cost of forestland is high. In an efficient program, about 70 percent of carbon sequestration should occur in tropical regions (developing economies). Globally, 20 countries contain over 80 percent of the world's forest carbon. This group includes the five largest carbon-storing countries (Brazil, Canada, the Democratic Republic of Congo, Russia, and the United States) as well as Indonesia, Malaysia, and other countries in South America and Africa that are responsible for most of the global deforestation.

If forest owners were paid significantly more than US$30 per tonne of CO_2, they would be willing to store even more carbon. It is also true that forests could store more carbon if given more time. With more time, programs such as afforestation become increasingly effective. By 2100, for example, approximately 367 billion tonnes of CO_2 could be stored in forests cumulatively with a final price of US$50 per tonne CO_2, providing about 25 percent of the cumulative abatement over this period. With a price of US$110 per tonne CO_2, over 1.4 trillion tonnes could be stored by 2100 (Sathaye and others, 2006).

Institutional Hurdles

Scaling-Up

There are a host of small programs and case studies that have tried to reduce deforestation and increase afforestation in order to capture carbon in forests. Can these small projects easily be scaled-up to a global program in a decade? Past experience suggests that it is often very difficult to scale-up small experiments to even a national level, much less a global level. The experts and volunteer (nongovernmental) organizations that support all of these small-scale efforts are not sufficient to manage a global program. The program would have to expand to between 1,000 and 10,000 times its current size. The existing capacity could not manage such a vast increase. Many more people would have to be trained in forestry. It would take time and resources to increase the scale of current efforts.

Of course, scaling-up may be easier in some countries or regions than others. For example, the U.S. Conservation Reserve Program (CRP), which sets aside farmland in the United States for environmental protection, scaled up from 0 to over 12 million hectares in 5 years (U.S. Department of Agriculture, Farm Services Agency). The current administrative cost of the CRP is about $7 per hectare of land enrolled. This includes costs of administering the contracts and verifying that the practices are still in place in the 10–15 years of the contract length.

Although the CRP shows that it is possible in some circumstances to scale-up environmental protection programs relatively quickly, there were many complaints early on that the program did not pay full attention to environmental (primarily conservation) benefits. Many lands enrolled in the initial stages were low-value croplands in regions far from human population where the environmental benefits were less valuable. In addition, this program was conducted in the United States where land ownership is usually fairly easy to prove. An enlarged global forestry carbon program would require substantial attention be paid to the benefits of the program, and it would probably require clear titles to be obtained in regions where ownership may be disputed. These factors could make the program difficult to implement in many regions.

Dynamics

There are two reasons that a carbon sequestration program should be dynamic. First, the marginal benefit of carbon storage (social cost of carbon [SCC]) is the damage avoided by permanently sequestering a tonne of carbon. This marginal value increases over time as greenhouse gas concentrations rise. Consequently, the marginal cost of carbon sequestration programs should also rise over time as the marginal benefit rises. This makes the carbon sequestration program inherently dynamic, with more carbon being stored over time. Second, trees grow according to a sigmoid growth function (growth increases with age up to a maximum and then it decreases with age). Trees do not grow at a constant rate. Afforestation and forest management programs generate different amounts of carbon storage over time.

One way that carbon sequestration programs can be accurately tied to what each forest can provide is to rely on rental payments for annual carbon storage (rather than one-time payments for permanent storage; see, for example, Marland, Fruit, and Sedjo, 2001; and Sedjo and Marland, 2003). Using annual payments also provides a continued incentive for the forest owner to protect the forest. This is lost once an up-front lump-sum payment is made. Rental payments should equal the SCC (the present value of the stream of marginal damage caused by a tonne of carbon) times the interest rate. For example, with a real interest rate of 4 percent, the rental payment for an SCC of US$30 per tonne of CO_2 is equal to US$1.20 per tonne per year ($30 times 0.04).

Measurement

Measurements of forestlands and timber volumes have been under development for decades. For example, the U.S. Forest Service samples sites across the 700 million acres of U.S. forest every 5 years (although the exact sampling regimen varies by state). These ground measurements are then supplemented with aerial and remote sensing information. The FAO estimates global forest areas by country. Unfortunately, the quality of the data varies greatly across countries, so there is considerable uncertainty around their estimates. The total amount of land in forests is somewhat uncertain because there is a complicated edge between forested savannah and fully grown forests. However, the biggest uncertainty concerns the stocking per hectare of forests (the amount of carbon per hectare). This can vary by land productivity, by species, and by land management. For example, the annual sequestration rate for a typical New England forest is 0.5 tonnes per hectare per year, a southern pine plantation is 1 tonne, and a moist tropical forest could be as high as 11 tonnes.

It is somewhat easier to verify whether an acre of intact forest has been clear-cut. Satellite pictures over time can reveal dramatic changes in land cover such as a clear-cut. However, what is more difficult to verify is the biomass per hectare of forested land. The actual biomass is important because selective harvesting can reduce biomass without causing visible clear-cuts. Further, intensive forest management can increase biomass, but again, this is not visible to a satellite. Verification of the biomass per hectare in forests may require ground-truthing, which is very expensive. Current estimates of the monitoring costs of the U.S. system are $72 million per year, or $0.24 per hectare. The annual change in carbon in above-ground stocks is about 635 million tonnes of CO_2 per year, so the cost of measuring a change in carbon in forests in the United States is about $0.11 per tonne CO_2. This is relatively high compared to the annual value of a tonne of carbon storage, which is less than $1.20 per tonne.

The cost of monitoring is even higher with small isolated projects. Specific projects for smaller areas of 1,000 to 600,000 hectares could cost US$1 to US$2 per tonne CO_2 (see Antinori and Sathaye, 2007; and Antle and others, 2003). Measuring and monitoring regimens could be done every 5 years to keep these costs down. Measuring just above-ground carbon (usually about three-fourths of the total carbon) could also keep costs down. Some new promising technologies, such as Light Detection and Ranging (LIDAR), that rely on low-level aerial photography can estimate wood volumes much more cheaply than ground-truthing. However, the carbon content depends upon weight, not volume, and hence some activities in addition to LIDAR are required.

Additionality

The total cost of the carbon sequestration program depends not only on the price of carbon (rental rate per year), but also upon what carbon must be purchased. The simplest program to administer is to pay every forest owner the rental rate on every tonne of carbon stored. For example, if the rental rate is US$0.60 per tonne per year and there are 1 trillion tonnes of carbon stored in forests, that would involve a payment of US$60 billion per year every year. However, many architects of carbon policy wish to pay just for the additional carbon stored (not the baseline that would have been stored anyway). If a program stored 4 billion additional tonnes, that would require an annual payment of just US$0.024 billion. Only the additional tonnes would be paid for. Of course, this raises the intriguing question of what tonne is additional versus baseline. In practice, this is very difficult to determine, and past case study projects have been handicapped by proving additionality. It is very difficult for a project to prove what would have happened anyway and what will now happen with a carbon sequestration program. Would there, in fact, be a change in behavior because of the program or is there an incentive for every forest owner to simply claim it? It is very hard to identify the actions that are on the margin.

Other ways to avoid this problem with additionality involve switching the property rights. The rental methods described above assume that landowners or land managers have the right to sell carbon credits onto markets. The current policy discussion embraces this property right. However, society could instead decide to treat forests as a potential emission source and tax carbon emissions. A carbon tax at the time of timber harvest combined with a subsidy for annual growth would have the same overall economic costs as the carbon rental scheme described above, but it would not require society to determine additionality with each carbon project. A carbon tax and subsidy scheme would change the distribution of carbon payments, but it would not require spending resources to prove additionality. Of course, taxing forest owners for releases of carbon from their forests suddenly makes forests a liability. If not carefully handled, this could create perverse incentives for reducing forests even further prior to program implementation.

Leakage

Economic analyses of land use suggest a carbon storage program must be universal to be effective. Of particular concern is the global trade-off between forestland and farmland. If some lands are in the carbon storage program and some are not, the scarcity that the program lands create for farmland encourages non-program lands to convert forests to farming. This phenomenon is called leakage. It can dramatically reduce the effectiveness of the carbon storage program. For example, a reduction of timber harvests in one region may simply result in an increase in the market price and increased harvests elsewhere, either within the country but also perhaps beyond its boundaries. Also, suppose one set of countries joins the program and sets aside an additional 50 million hectares of land for carbon storage by converting farmland to forestland. This would dramatically increase the scarcity of farmland and create a huge incentive for the countries not in the program to convert their forestland to farmland. Depending on how substitutable the land might be, the nonparticipating countries could actually convert 50 million hectares of forestland to farmland in response to the incentives created by the program, making the carbon storage program completely ineffectual. Although this is a worst case scenario, the problem of leakage is not trivial.

One solution to leakage is a universal program. If all land everywhere faces the same incentive to store carbon, there would be no leakage. The carbon storage program does not technically have to be identical in every country. Some countries might use regulations or taxes, whereas other countries might be inclined to use subsidies and tax breaks. However, all of the programs must use the same effective marginal incentive to store carbon; otherwise, the leakage problem will reduce the effectiveness of the global effort. Of course, what is important is that most of the potential forestlands in the world face the same incentive. Therefore, what is really important is to have agreement across the countries with most of the world's forest. If the agreement could cover the 20 countries with the most forest in the world, about 80 percent of forests would be covered.

Some researchers have proposed discount factors to correct for potential leakage. Discount factors work by requiring suppliers of carbon credits to provide additional carbon for each credit claimed. For instance, if the discount factor is 2, a country would have to provide 2 units of carbon credits for each 1 unit that receives a payment. Discount factors penalize countries that engage in carbon sequestration by giving them rights to only a certain percentage of the carbon they could store, thus reducing the value of their carbon stock. Discounting for leakage raises costs arbitrarily, gives incentives for countries to remain out of the program, and creates other inefficiencies. When designing a carbon system, it is preferable to include elements that provide incentives for new countries to enter into the system and not for them to stay out of the system.

Permanence

The question of permanence arises because forests store carbon only temporarily, while the tonnes of carbon released into the atmosphere by energy processes are "permanently" added to the atmosphere. Forests planted expressly for carbon sequestration, for instance, will sequester and hold carbon only so long as they remain standing. There is some probability that forests will be affected by fires, pests, windstorms, human-directed harvesting, or any number of other natural or human factors. As a result of the "impermanence" of forests, many researchers have suggested discounting carbon credits, similar to what is proposed with leakage. A number of prominent voluntary carbon standards have now taken this approach (e.g., the Verified Carbon Standard).

As in the case of leakage, when ad hoc discounts are used, inefficiencies are created. The inefficiency is particularly problematic with permanence, however, because rental contracts, as we have discussed, provide a clear alternative. Rental contracts pay for temporary carbon storage. If forests are not permanently maintained, then rental payments would stop. As long as the buyer is liable for ensuring that the carbon credits are offset somehow, the buyer can go onto the market and buy new credits or rent new forests.

Forest Ownership

Another complexity that must be overcome to create a global program involves overlapping forest ownership. In many forests in the developed world, forests are owned privately by an individual or firm. Most carbon storage programs imagine that they must deal with only a single owner. However, even in developed economies, a great deal of forest is owned by the government or held in some type of common ownership. Here there may be many interest groups that cherish very different aspects of the same forest. A program that encourages more carbon in the forest would enhance some of those services but threaten others. For example, people who would enjoy old growth should welcome storage programs that lengthen tree rotations. However, water flows from such forests would likely be reduced as older forests tend to evaporate more water. People who like species that depend on younger forests would also be negatively affected by the carbon storage program. The carbon storage program may not be universally accepted as an improvement in forest management by these diverse interests.

In many developing economies, the issue of forest ownership is even more complex. Overlapping interests are typical in many tropical forests. The government or timber concessions may have the right to harvest the timber. But local inhabitants may have the right to harvest the wildlife, collect nontimber forest products or firewood, or graze their animals. What incentives will be given to each group to store more carbon? What if the forest is owned by a village or large family? How will the carbon program interact with the village? It is far more difficult to make transactions with villages or large families than a single forest owner. Current economic analyses have not grasped the cost of this problem at all. In principle, one would need to encourage each party to cooperate with a separate payment.

Equity

There are also important equity issues associated with forest ownership. Some of the poorest people in the world are rural inhabitants of forestlands in tropical countries. Some of the richest people in the world own forest concessions. Global forest programs may pay developing economies to store carbon on forestland, but who actually receives these payments? Do local inhabitants of these forests get any of the compensation? Is the compensation limited to timber concessions? There are important equity issues facing carbon storage programs that have not been resolved. Some of these issues may well raise the cost of the program. They will certainly raise the administrative cost. They may even dramatically affect the social desirability of the programs.

Implications of Measurement and Monitoring Limitations

The measurement and monitoring issues discussed above suggest that a project approach to collecting forest carbon has very serious limitations, particularly in the form of leakage. It may be that only broad national approaches are truly viable. Under a nationalized approached, payments would only be made for total forest carbon at the national level. Internal leakage would be offset, and payments would be made for net changes over time. International leakage would become the responsibility of the country, and the country would need to offset these if it were to receive credits. Internal issues would need to be addressed by the national authority, but failure to do so would mitigate any carbon payments. In addition, this approach would have the advantage of not requiring payment for all forest carbon, but only for positive increments over an agreed base. Broad negotiations (such as those undertaken for Indonesia) that envisage direct payments in return for broad corrective forestry practices and performance might negate the need for precise estimates of forest carbon.

Policy Conclusions

In this chapter, we have explained how carbon storage in forests has enormous potential but also that any meaningful system would be difficult to implement. Forest carbon storage could be responsible for one-quarter of all mitigation and hence cannot be ignored.

There are several important administrative and institutional hurdles that must be overcome for forest carbon storage to be effective. However, many of these hurdles have known solutions. For example, leakage and additionality are serious drawbacks to current forest projects. Universal programs can solve both problems. However, universal subsidies would involve a large income transfer to forest owners. Universal liability would involve a large income transfer away from forest owners. Some combination of liability and subsidies could provide a balanced budget approach that avoids large income transfers and provides the right incentives on the margin. Carbon sequestration and forestry are both dynamic phenomena. The carbon sequestration program must therefore be nimble with respect to time to capture these dynamics accurately. Many policy planners wish to pay only for extra carbon stored. Finally, measurement and verification are important limitations. The program must encourage least-cost measurement technology (such as LIDAR) or the administrative costs could skyrocket.

But even with these administrative innovations, there are two more issues that have yet to be addressed. The carbon storage program must be able to deal with common-property forests (forests that are owned by many). The carbon storage program must also come to terms with equity issues related to local forest inhabitants. One approach may be to nationalize the approach to internalize the leakage problem and place the ownership and equity problems with the national government, which will now have a financial incentive to address these. If carbon storage programs can overcome these administrative hurdles, there is every reason to believe forestry can live up to its mitigation potential. If the programs fail to address these issues, forestry will likely prove to be an ineffective source of carbon mitigation.

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Verified Carbon Standard, www.v-c-s.org.

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