Title
Estimating Global Forestry GHG Mitigation Potential and Costs: A Dynamic Partial Equilibrium Approach

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Publication Date
2003-08-26

A Summary Note
Estimating Global Forestry GHG Mitigation Potential and Costs: A Dynamic Partial Equilibrium Approach

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Working Draft

26 August, 2003

1. Introduction

Forests play an important role in the global carbon cycle. It is estimated that there are 1,146 GtC stored within the 4.17 billion hectares of tropical, temperate and boreal forest areas, a third of which is stored in forest vegetation, and the rest in forest soils (IPCC, 2000). Another 634 Gt C is stored in tropical savannas and temperate grasslands. Tree growth in forests serves as an important means to capture and store carbon dioxide in vegetation, soils and forest products.

The IPCC Second Assessment Report (SAR) noted that the potential for carbon sequestration through forestry activities ranged from 55-76 Gt C (Brown et al., 1996). A more recent assessment of the technical potential of land use, land-use change and forestry (LULUCF) options for storing carbon suggests that the total potential may exceed 1 Gt C / year in 2010 (Watson *et al,* 2000). The achievable potential from LULUCF options, taking into consideration the many barriers to reaching the technical potential, is some unknown fraction of this estimate. The estimated LULUCF potential represents only about a sixth of the average annual carbon dioxide emissions from fossil fuel combustion and cement production estimated at 6.3 +- 0.6 Gt C /year between 1989 and 1998 (IPCC, 2001)[i].

The forestry mitigation potentials mentioned above vary across countries depending on their suitability of land for forestation and the implicit carbon sequestration potential, the levels of current and future greenhouse gas (GHG) emitting activities, potential for substitution in carbon-intensive services and products, potential for enhanced efficiency in utilizing forest biomass and other options for reducing deforestation.

Which forestry mitigation options contribute the most to carbon sequestration or emissions avoidance? How much carbon stock additional to a baseline or reference scenario might be created, and how much emissions reduction might be achieved through these mitigation activities under different carbon price scenarios? What are the cost per ton of carbon and total cost of these options? An earlier paper summarized the findings for several tropical countries (Sathaye et al., 2001). Using a common bottom-up model, COMAP (Sathaye, Makundi, and Andrasko, 1995), the authors of that study addressed the above questions for Brazil, China, India, Indonesia, Mexico, the Philippines and Tanzania.

In this paper, we extend the bottom-up COMAP model into a dynamic partial equilibrium model (GCOMAP) to address the same questions. We discuss the dynamic partial equilibrium concept as applied to forestation and forest protection (reducing deforestation) mitigation options in a global framework with about ten regions. The main purpose to pursue this extension of the model is to make the results readily usable by climate change modelers of the global economy. The proposed model will analyze and present carbon stock changes and price responses by major regions of the world.

A typical bottom-up approach includes a rich characterization of technologies that form the basis for climate change mitigation options. It includes information about their carbon performance and costs and benefits. However, the approach has certain drawbacks that were highlighted in a recent IPCC report, which our proposed dynamic partial equilibrium approach is able to address.

The IPCC Synthesis Report noted some key characteristics of bottom-up models (Watson et al., 2001), which include the use of low societal discount rates and lack of a representation of market dynamics. The models typically yield negative costs for the least expensive options. Negative costs raise questions about the lack of adoption of such mitigation options in the current market, or at a minimum in a future base case or reference scenario. Inclusion of negative costs poses a challenge to global economy models; since these normally assume perfect markets, where negative cost options do not exist. Another drawback of the bottom-up models is the absence of market dynamics. One consequence of this is that land and product demand and supply do not respond to carbon prices, and hence the mitigation potential estimated using a bottom-up model does not vary with changes in carbon prices. If the carbon price is high enough, then all of the estimated potential at costs below the carbon price is available and vice versa.

The dynamic partial equilibrium approach presented in this paper makes use of the same rich data set that characterizes the bottom-up COMAP model, but it includes explicit representation of land and product markets so that for a given carbon price a unique mitigation potential is estimated. Land change scenarios in COMAP are based on government plans or sustainable harvesting of land-based products. In the dynamic partial equilibrium approach, a carbon price scenario determines the amount of land brought under forests. Further, unlike in a typical bottom-up approach, discount rates are based on observed data on consumer and producer behavior. Another advantage of this approach is that it allows computation of changes in social welfare impacts of a mitigation scenario in comparison to a base case scenario. Table 1 shows the detailed differences between the two approaches.

Table 1: Generalized COMAP (GCOMAP) Features

Issue	COMAP	GCOMAP
Temporal	2000 — 2030 by year	2000 to 2100 by year
Land-use change scenarios	Country-specific --Based on government targets/plans, sustainable development criteria, or TFAP	Reference scenario — historical trends, modified government plans Mitigation scenario — Driven by elasticity of supply for land and future carbon prices
Timber and other product prices & quantities	Country-specific Static — Prices do not change with output Single timber and non-timber product; no market dynamics	Use supply and demand elasticities to estimate timber price and quantity changes Five timber and non-timber products Separates domestic and international markets
Discount Rates	Societal Country-specific 8-12%	Rate of return (ROR) remains unchanged between reference and mitigation scenarios. ROR derived from input cost, product prices and opportunity cost for deforestation.
Model mechanics	Country-specific Investment theory; mitigation scenario not driven by carbon prices Aggregation to Tropics outside the model Software: Excel	Country-specific Perfect foresight; based on investment theory Permits sensitivity analysis and analysis of alternative scenarios Software: Excel, Visual Basic
Macro-economic Implications	Usually not estimated.	Estimates changes in consumer and producer surpluses and hence social welfare changes

Table 2 shows the activities that are covered by GCOMAP, and the carbon pools that are included in the model. It also shows the regions included in the model.

Table 2: Mitigation options, geographic coverage, and carbon pools in GCOMAP

Mitigation Option	**Current Geographic Coverage**	**Carbon Pools**
Forestation – short rotation • without biofuels • with biofuels Forestation – long rotation • without biofuels • with biofuels	China India Rest of Asia Africa South America Central America USA/Canada EU (Incl. E Europe and Baltic States) Russia Oceania (Aus./NZ/Japan/PNG).	Above/below ground biomass Soils Litter Post-harvest waste Domestic timber products International timber products Fuelwood Mill-waste products Biofuels – used as a substitute for coal in power plants
Avoided deforestation (no biofuels)	Rest of Asia Africa South America Central America	

2. Approach

a. Forestation

Forestation options in GCOMAP include long- and short-rotation forestry, with and without biofuels. These options yield timber and non-timber forest products, part of which may be marketed. Some of the timber product and wood waste from processing of timber may be suitable for use as a fuel substitute.

Mitigation analysis requires the projection of land-use scenarios for a baseline, and for one or more mitigation cases. In parallel, it requires data on carbon sequestration or emission avoidance on a per hectare basis. Also required are data on costs and benefits, in order to estimate the net benefit per ha or per t C. In the absence of good estimates of the value of non-monetary costs and benefits, the net benefits per ha or per tC are computed from monetary costs and benefits. These estimates are then combined with a land use scenario in order to estimate cumulative or annual carbon and monetary costs and benefits over a future period. The land use scenarios are sensitive to future changes in carbon prices. In GCOMAP the land use pattern responds to future carbon prices and leads to faster conversion of land to forestry compared to a baseline. This faster conversion results in increased carbon sequestration over a given time period to the extent that land area is available for planting. Forestation options are evaluated in all regions in the model, and the rate of base case planting is held unchanged over time, i.e., equal amounts of land area is planted each decade in a region until the available land area is exhausted.

b. Avoided deforestation

Deforestation is defined as a long term or permanent removal of forest cover and conversion to a forested land use (Lund, 1999). The rate at which tropical forests are deforested is determined by the willingness of groups to pay for the goods and or services derived from deforestation (demand) and the costs or value of inputs needed to deforest (supply). The benefits include the value of wood products (including fuel wood and timber), agricultural land and pasture. The demand curve for deforestation is determined by vertically summing these benefits on each hectare of land to be deforested. In most parts of the world, the demand for agricultural land and wood products is fairly inelastic because the demanded goods and services are relative necessities in primary products based economy. The costs of deforestation include expenses concession fees, access costs e.g. road construction, logging and timber extraction costs, and land conversion expenses. In tropical developing countries, these costs are relatively low and elastic. The intersection of demand and supply for deforestation determines the quantity of forestland that is converted each year.

In GCOMAP avoided deforestation option is evaluated only in Africa, Rest of Asia, South America, and Central America. The reference case deforestation rate is based on historical changes in deforestation rates, and the area deforested each decade changes from 2000 to 2100.

3. Data

Data on land use change, carbon pools, forestation and deforestation activity, and costs and benefits of planting and avoiding deforestation were gathered for each region. The afforestation and reforestation costs/benefits data as well as carbon sequestration data for the tropical countries are drawn from the COMAP model and then applied to representative tropical regions. Those for the industrialized countries were gathered from data sources unique to each region.

Data on land use change, and forestation and deforestation activity were gathered largely from the FAO 2003 statistics. The regionalization was based on FAO data on forestry lands, biomass volume, plantation and deforestation rates, industrial roundwood production, which was combined with yield and cost data from the individual countries listed above. The yield data were adjusted to ensure that all biomes are appropriately covered. The cost data were adjusted using labor cost (wage) ratios, and domestic prices of timber and non-timber products were adjusted using purchasing power parity indices across countries. The regionalization provides coverage of all tropical countries in Asia, Africa and Latin America, and China. Similar analysis was conducted for the industrialized regions, North America (USA/Canada), the EU countries, Russia, and Oceania. These were supplemented with additional country-specific data for the USA. The data compiled for each region are shown in the attached tables in Appendix B.

4. Results

We analyzed six mitigation or policy scenarios using the GCOMAP model, and compared land use change and carbon sequestration between these six scenarios and a common reference scenario. For each scenario, we estimated the increase in land use and carbon stock over time for ten global regions for the short and long-term forestation options. We also estimated the decrease in deforested area for the avoided deforestation option for four tropical regions (Africa, Asia, Central and South America) when compared to a base case or reference scenario.

The results are shown in four panels for each scenario. The first panel shows the amount of land either sequestered under short and long rotation options, and the amount lost due to deforestation. Since the first panel shows data for the reference scenario, which does not change across scenarios, the figure is identical in each set of figures. By 2100, short and long rotation planting amounts to 209 and 274 Mha. respectively, and deforestation leads to a loss of 900 Mha of forest area, which results in a net loss of 417 Mha of forested land. The deforestation rate is assumed to change over time in response to projected demographic and economic structural changes. It drops in Asia and Americas from now to 2050 by which time deforestation declines almost to zero. In Africa deforestation continues to rise until 2030, before beginning a decline to 2100. The second panel shows forest area change and C-potential under the mitigation scenario. The third panel shows the difference between the sets of lines for the same options in the two panels. The difference indicates the amount of forest land gained between the mitigation and reference scenarios each decade.

Table 3 shows the same results across scenarios for 2050 and 2100. The land area and carbon gained are consistent with the trends in carbon prices. Scenarios 1 and 3 have the lowest amount of land area and carbon gained by 2050, which is consistent with the lowest prices ($35 and $33) by 2050 across the six cases. Generally, the higher the carbon price by 2100 the higher the carbon gained by that date, except in scenario 5, where the very high up front carbon price leads to much higher land gain by 2050, tree planting on which leads to a delayed higher gain of carbon stock by 2100. All of the land conversion for forestation occurs during the first two decades in Scenario 5, with the carbon stock growth occurring over the entire 100-year period for long-rotation species in some of the temperate and boreal regions. The carbon price reaches $807 by 2100 in Scenario 2, which leads to continued high rates of planting throughout the 100 year period, and consequently results in the largest carbon gain of 98.4 Gt C by 2100.

While not shown in the attached table and figures, the regional distribution of carbon gains varies across scenarios. The total amount of land area available for planting is limited in two regions, India and China, and due to the high planting rates in the base case, the land cap is reached in each country by 2050 or before. The mitigation scenario accelerates the date by which the cap is reached depending on the magnitude, and rate of increase, of the carbon price. A similar cap is reached for long rotation planting in Russia in the base case by 2100. Elsewhere land availability is not a constraint to planting.

Deforestation is an issue in Africa, South and Central America and Rest of Asia. Since the revenue derived per ha from deforestation is low in Africa, a $100 per t C price (Scenario 5) is sufficient to halt deforestation in that region while significantly reducing it in other regions. In the highest carbon price scenario (Scenario 2) deforestation is halted by 2040 in Africa, 2060 in Central America, 2070 in Central America and by 2080 in Rest of Asia; the revenue and derived from deforestation being higher in countries with later dates for halting deforestation.

5. **Summary**

This paper describes a dynamic partial equilibrium model (GCOMAP) that is based on bottom-up data for the tropics from the COMAP model, region-specific data from several sources for the temperate countries, and FAO data on regional forestation and deforestation rates. The model estimates the additional land area that will be forested, and/or the additional deforestation that will be avoided, due to a response to future carbon prices, and tracks the changes in carbon stocks in vegetation, soils and products over time. By 2100, for six carbon price scenarios, the model estimates a global gain in carbon stock between 48.8 and 98.4 Gt C. The time profile of carbon gain follows the carbon price trajectory; higher prices earlier lead to more carbon gain sooner, and vice versa. Avoided deforestation accounts for carbon gain between 40% and 65% by 2100, with the percentage generally increasing from Scenario 1which has low initial price to Scenarios 5 and 6 with higher initial prices.

Table 3: Land area and carbon gained across scenarios

Scenario*	Carbon Price ($/ t C)		Land Area Gained** (Mha)		Carbon Gained** (Mt C)	
	2050	2100	2050	2100	2050	2100
1. $5 + 5% / year	35	404	150	530	13,460(42)	73,362(41)
2 $10 + 5% / year	70	807	250	740	21,900(41)	98,400(41)
3 $10 + 3% / year	33	143	160	440	14,000(54)	48,800(54)
4 $20 + 3% / year	65	286	290	670	25,800(57)	79,500(52)
5 $100 + 0% / year	100	100	480	740	52,600(55)	85,320(61)
6 $75 + 5% / year; (2050 cap)	528	528	420	630	41,000(73)	68,200(65)

(..) The numbers in parenthesis are % of the C-sequestered from deforestation avoidance.

* All carbon prices are zero until 2009, and begin with the stated value in 2010.

** Gained amount refers to the difference between mitigation scenarios and the base or reference case scenario by 2050 and 2100

Appendix A:

Baseline Deforestation rates:

In general, we assume that deforestation will decline as the economies move towards manufacturing and service economies, as more people become less dependent on primary resources. In the past 2 decades the three regions showed a decline in the annual rate of deforestation, though the decline shown for South America may have began a reversal based on evidence in the last few years from Brazil. Africa's rate of deforestation is still rising in step with the continued dependence on agriculture and primary resources, a situation which we are projecting to peak by 2020 as the economies pick up though with a lag compared to the other regions. Here are the region specific assumptions on annual deforestation rates and their projected trends.

Central America

Initial rate of reforestation was that which existed in 2000, (-1.19%) and assumed a similar rate of change as that between 1980-2000 (0.011%/year) up to 2050 and dropped the rate by half for the balance of the period in order to retain some minimum conversion of forests for habitats, communication, infrastructure etc.

Africa:

The deforestation rate increases at the 1990-2000 pace and peaks in 2020, then it begins a decline at a rate half that of the incline, and slows down further by 2060 an leaves the region with a decadal deforestation rate of 2.5% by the end of the century.

Rest of Asia:

We assume the same rate of decline in Deforestation as between 1980 to 2000 which was almost stable, declining by .05% over the decade. This rate is assumed to hold up to 2010 and then decline much faster up to 2030 as the economies in the region become more industrial after which it continues to decline in a much slower rate of 0.08% per decade.

South America:

The deforestation rate declined by 0.026% per year between 1990-2000 and this rate is assumed to slow down by half up to 2010 and slows down further to 25% up to 2030 and continues to decline by 0.001% per year resulting into a 0.13% deforestation rate by the end of the decade, which still leads to a loss of about 750,000 hectares in 2100.

Region	1990 –00 rate %/yr	2000	2020	2040	2050	2100
Africa	+0.026	0.80	1.29	0.78	0.65	0.26
Central America	-0.011	1.19	0.97	0.75	0.65	0.37
Rest of Asia	-0.005	1.03	0.82	0.60	0.52	0.12
South America	-0.03	0.40	0.26	0.21	0.20	0.13

The deforestation rate gives the percent decline in the forest area per year

(-) rate is an annual decline in the deforestation rate

Appendix B: Key Variable Input Data: