

Classification: Sustainability Science

Title: **Global Cost Estimates of Reducing Carbon Emissions through Avoided Deforestation**

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**Abstract**

Tropical deforestation is estimated to cause about one quarter of anthropogenic carbon emissions, and loss of biodiversity and other environmental services. United Nations Framework Convention for Climate Change talks are now considering mechanisms for avoiding deforestation (AD), but the economic potential of AD has yet to be addressed. We employ three economic models of global land-use and management to analyze the potential contribution of AD activities to reduced greenhouse gas emissions. AD activities are found to be a competitive, low-cost abatement option. A program providing a 10% reduction in deforestation in the period 2005 to 2030 could provide 0.3-0.6 Gt CO<sub>2</sub> yr<sup>-1</sup> in emission reductions, and would require US\$0.4-\$1.7 billion yr<sup>-1</sup> for 30 years. A 50% reduction in deforestation during the period 2005 to 2030 could provide 1.5-2.7 Gt CO<sub>2</sub> yr<sup>-1</sup> in emission reductions, and would require US\$17.2-\$28.0 billion yr<sup>-1</sup>. Finally, some caveats to the analysis that could increase costs of AD programs are described.

## Introduction

Tropical deforestation is considered the second largest source of greenhouse gas emissions (1) and is expected to remain a major emission source for the foreseeable future (2). Despite policy attention on reducing deforestation, around 13 million ha yr<sup>-1</sup> of forests continue to be lost (3). Deforestation could have the effect of cooling the atmosphere (4), but it also leads to reductions in biodiversity, disturbed water regulation, and the destruction of livelihoods for many of the world's poorest (5). Slowing down, or even reversing, deforestation is complicated by multiple causal factors, including conversion for agricultural uses, infrastructure extension, wood extraction (6-9), agricultural product prices (10), and a complex set of additional institutional and place-specific factors (11).

Avoided deforestation (AD) was included alongside afforestation as a potential mechanism to reduce net global carbon emissions in the Kyoto Protocol (KP), but until recently, climate-policy discussions have focused on afforestation and forest management. Discussions about new financial mechanisms that include AD provide optimism for more effective synergies between forest conservation and carbon policies (11-14). In 2005, Papua New Guinea and Costa Rica proposed to the UNFCCC that carbon credits be provided to protect existing native forests (15). The proposal triggered a flurry of discussion on the topic. Soares-Filho et al. (16), for example, suggest that protecting around 130 million hectares of land from deforestation in the Amazon could reduce global carbon emissions by 17 GtC over the next 50 years.

While the potential for AD activities to help mitigate climate change is widely acknowledged (16, 17), there is little information available on what the costs might be globally. This paper utilizes three different global forestry and land-use models to estimate carbon supply functions for emission reductions from AD activities. The use of global models is preferred in the case of climate mitigation with land use for two reasons. First, differences across regions in the carbon content of forests, opportunity costs of land, and the costs of access can have important implications for costs. Second, large-scale adjustments, which are likely with policies to reduce deforestation, will affect prices globally. These global changes need to be considered when estimating supply functions (marginal costs) for emission reductions. In addition to being global, the models in this paper are inter-temporal, taking into account changes that occur over time, such as incentives for deforestation (e.g., demand for agricultural land depending on changes in population, income, and technology). While agriculture is not explicitly modeled, our models do include different scenarios for agricultural land demand.

Comparing results from several models allows us to assess the sensitivity of results with respect to the use of different methods, datasets, assumptions about future markets, and other potentially important factors (carbon content of forests, interest rates, risk, etc.). While we do not develop confidence intervals, the results provide a set of estimates that can help policy makers understand the potential cost range of avoided deforestation.

### **Marginal Cost Curves for Avoided Deforestation**

The three models utilized here are the Dynamic Integrated Model of Forestry and Alternative Land Use (DIMA) (18,19), the Generalized Comprehensive Mitigation Assessment Process Model (GCOMAP) (20,21), and the Global Timber Model (GTM) (22,23). A brief description of each model follows, but a more detailed discussion can be found in Appendices 1-3. DIMA assesses land use options in agriculture and forestry in 0.5 degree grid cells across the globe. The model predicts deforestation in forests where land values are greater in agriculture than in forestry and, vice versa, afforestation of agricultural and grazing lands where forestry values exceed agricultural ones. GCOMAP is a dynamic partial equilibrium model that analyzes afforestation in short and long-run species, and reductions in deforestation in 10 world regions. GTM is a dynamic optimization model that optimizes the land area, age class distribution, and management of forestlands in 250 timber types globally. Although the model also deals with afforestation and biofuels as mitigation options, this analysis focuses on results for AD.

To estimate the costs of reduced emissions from avoided deforestation, each model must generate a baseline projection of future deforestation. The baseline is assumed to occur when AD carbon prices are US\$0 t<sup>-1</sup> CO<sub>2</sub>. Each model's baseline embeds model-specific assumptions about future changes in economic conditions, *inter alia* population, technology, and trade. The economic assumptions for each model are described in detail in Appendices 1-3. In addition, carbon emissions from deforestation will depend on assumptions about the quantity of carbon in forest biomass (Table 1).

Different economic and biological assumptions cause the three models to present variable deforestation and carbon-emission projections (Table 2). Estimated deforestation fluctuates over time between 2005 and 2030, but the table presents only the average. GCOMAP estimates the largest area deforested by 2030. GTM projects a smaller area of land deforested, but a larger emission of carbon because that model assumes the largest aboveground storage of carbon per hectare. DIMA shows the lowest emission, due to both lower loss projections and lower carbon content assumptions in Latin America.

To determine the marginal costs of carbon storage resulting from AD, additional simulations are conducted with the three models assuming constant carbon prices ranging from US\$0 t<sup>-1</sup> CO<sub>2</sub> to US\$100 t<sup>-1</sup> CO<sub>2</sub>. Higher carbon prices will induce the models to allocate more land to forests, and consequently less deforestation will occur. Reductions in carbon emissions from AD are obtained by comparing baseline emissions with the emission path when AD is compensated. The models project results for a longer period, but we present results here only for 2005-30.

Marginal cost curves, with annual CO<sub>2</sub> emissions reduced on the X-axis and the carbon price on the Y-axis, are shown for each model for three years – 2010, 2020, and 2030 (Figures 1-3). Forest owners would maintain land with the lowest-valued alternative uses (lowest conservation opportunity costs) in forests at the lowest carbon prices, while progressively higher carbon prices are required for land with higher opportunity costs.

The results generally indicate that substantial emission reductions can be accomplished over the entire 25 year period examined. For US\$20 t<sup>-1</sup> CO<sub>2</sub>, the models project that the average global emission reduction from AD activities between 2005 and 2030 would be in the 1.6-4.3 Gt CO<sub>2</sub> yr<sup>-1</sup> range. For higher prices (US\$100 t<sup>-1</sup> CO<sub>2</sub>), the models project emission reductions of 3.1-4.7 Gt CO<sub>2</sub> yr<sup>-1</sup>. The time path of marginal costs suggests that the low cost emission reductions occur earlier on. At \$100 t<sup>-1</sup> CO<sub>2</sub>, the emission reduction averaged for all three models in 2010 is 4.0 Gt CO<sub>2</sub> yr<sup>-1</sup>, but this falls to 3.1 Gt CO<sub>2</sub> yr<sup>-1</sup> by 2030. Marginal costs tend to rise over time because the lowest-cost opportunities are adopted first and rates of deforestation decline, while later the opportunity costs of land rise due to rising productivity in agriculture.

The marginal cost curves differ across models for a number of reasons, including the input datasets (e.g., underlying estimates of the opportunity costs of land), modeling methodologies and assumptions, and ecological parameters (e.g., carbon per hectare). GTM has lower land opportunity costs and higher carbon densities per hectare than the other two models, and consequently model simulations using GTM generally result in the lowest marginal cost estimates (the largest emission reduction per US\$ spent – see Panel A, Figures 1-3). GCOMAP has the highest global estimates of marginal costs in 2010, but by 2020 and 2030, DIMA projects the highest global estimates of marginal costs. The marginal costs in DIMA become substantially more expensive over time.

As expected, the marginal costs of emission reductions will vary by region (24). The three models suggest unanimously that the lowest-cost region is Africa, followed by Central and South America and Southeast Asia. Over the period 2005-2030, the models project that Africa could provide 0.9-1.5 Gt CO<sub>2</sub> yr<sup>-1</sup> for \$20 t<sup>-1</sup> CO<sub>2</sub>, while Latin America could provide 0.8-1.7 Gt CO<sub>2</sub> yr<sup>-1</sup>, and Southeast Asia could provide 0.1-1.1 Gt CO<sub>2</sub> yr<sup>-1</sup>. At \$100 t<sup>-1</sup> CO<sub>2</sub>, the projections rise to 1.4-1.7 Gt CO<sub>2</sub> yr<sup>-1</sup> for Africa, 1.1-1.9 Gt CO<sub>2</sub> yr<sup>-1</sup> for Latin America, and 0.3-1.1 Gt CO<sub>2</sub> yr<sup>-1</sup> for Southeast Asia.

### **Costs to Reduce Deforestation by 10 and 50%.**

Current AD policy proposals focus on compensating reductions in deforestation vis-à-vis pre-defined national baselines. Countries would estimate their projected baseline deforestation rates for a given period (using methods not yet determined), and then agree to develop policies at the national level to reduce the rates of change. Presumably, with compensated reductions, they would then be paid *ex post* for the reductions they achieve. How much would it cost to achieve 10% and 50% reduction levels between 2005 and 2030? The three models can conveniently link deforestation rates to specific carbon and land rental payments (Table 3).

Our results indicate that a 10% reduction in deforestation rates over the time period would cost US\$2-5 t<sup>-1</sup> CO<sub>2</sub>, and a 50% reduction in deforestation rates would cost US\$10-21 t<sup>-1</sup> CO<sub>2</sub>. Payment levels in the 10-50% range could generate substantial financial flows to landowners who reduce deforestation. Given the carbon intensities described above, carbon prices of \$2 t<sup>-1</sup> CO<sub>2</sub> could translate into carbon rental values of \$20-\$35 ha<sup>-1</sup> yr<sup>-1</sup> for standing forests, while carbon prices of \$10 t<sup>-1</sup> CO<sub>2</sub> would trigger land rental values of \$85-\$252 ha<sup>-1</sup> yr<sup>-1</sup>. Agricultural rents at the margin of infrastructural

improvements (e.g., along new roads in newly accessed regions), where most deforestation occurs, are quite often lower than these estimates, suggesting that in many cases carbon payments could provide powerful economic incentives for reducing deforestation.

Present value techniques are used to calculate the total costs of reducing deforestation by 10% and 50%. The annual costs of reducing deforestation between 2005 and 2030 are first calculated by multiplying the annual reductions in emissions by the carbon price. The present value of this stream of costs is then calculated, followed by the annual equivalent amount. For internal consistency, individual modelers used their own interest rates to calculate these costs. In the three models, reducing deforestation by 10% globally between 2005 and 2030 could provide 0.3-0.6 Gt CO<sub>2</sub> yr<sup>-1</sup> in emission reductions globally, with annual equivalent costs of US\$0.4-\$1.7 billion yr<sup>-1</sup>. Correspondingly, halving global forest loss could reduce emissions by 1.5-2.7 Gt CO<sub>2</sub> yr<sup>-1</sup>, triggering annual equivalent costs of US\$17.2-\$28.0 billion yr<sup>-1</sup>.

Costs of these land-use actions compare favorably to other options for abating carbon emissions. A recent assessment, using three well-known energy models, suggested that meeting a 550 ppmv stabilization target would require society to reduce CO<sub>2</sub> emissions by approximately 3.5 Gt CO<sub>2</sub> yr<sup>-1</sup> between 2010 and 2030, and would cost \$9 t<sup>-1</sup> CO<sub>2</sub> (25). None of the models used in that study considered avoided deforestation, but our estimates indicate that \$9 t<sup>-1</sup> CO<sub>2</sub> could reduce deforestation by 10-50% over the next 30 years, and provide an emission reduction of 0.8-2.5 Gt CO<sub>2</sub> yr<sup>-1</sup>. AD could thus provide substantial additional emission reductions at costs levels consistent with the energy models, while providing numerous ecological and environmental benefits in addition to GHG mitigation.

These results imply that reducing emissions from avoided deforestation is a relatively low cost option, although those costs in absolute terms are not tiny. Reducing deforestation by roughly 10% over the next 25 years would cost \$1.2 billion yr<sup>-1</sup>. This estimate is lower than current global forestry investments of about US\$18 billion yr<sup>-1</sup> (26), but note that most current forestry investments are private, and they occur domestically in developed countries. Public funding of forestry through official development assistance (ODA) and official aid (OA) has averaged US\$564 million during 1996-2004 (27). Although they have not to date been widely used for forest and land use projects, carbon markets may provide additional opportunities for AD funding in the future. The market for Certified Emissions Reductions (CERs) currently trades US\$2.7 billion yr<sup>-1</sup> (28), but it continues to increase. Resources available for AD will grow if a climate policy framework for post-2012 is developed with explicit reference to AD activities (29).

### **Additional Factors Influencing Costs**

Examples of existing programs to protect forests in Costa Rica, Mexico, and India (11, 30) indicate that forest conservation is possible with well-designed tools and well-funded programs. Conversely, cases exist where few environmental services are paid for, and land users receive minimal payments with minimal incentive effects (31). Experiences with payments for environmental services are thus incipient. Some factors discussed in the above articles, but not counted in our estimates, could increase total costs.

First, setting up, implementing, and verifying projects to reduce deforestation could have additional costs beyond the carbon itself. For Clean Development Mechanism (CDM) type AD, afforestation, and other offsets projects, these “transactions” costs have been estimated to range from \$0.03 t<sup>-1</sup> CO<sub>2</sub> for large projects to \$4.05 t<sup>-1</sup> CO<sub>2</sub> for smaller ones, with a weighted average of \$0.26 t<sup>-1</sup> CO<sub>2</sub> for all projects (32). Even if AD programs shift from the project-based approach and instead focus on country-level “compensated reductions,” verification expenses could be higher yet because all tons of carbon in a country will have to be measured, not just the tons in areas where forest protection activities are undertaken.

Second, accounting for leakage could impose additional costs, given that current estimates of leakage in forestry projects range from 10% to over 90% (33, 34). Transactions costs and potential leakage may partly explain why the contribution from afforestation in the CDM has been minimal in the KP. The cap on Annex I use of credits from afforestation is 1% of 1990 emissions, but actual uptake of existing projects suggests that only around 1% of this 1% will be used for implementation during the first commitment period.

Third, the right type of incentive or policy to change land use will vary from country to country, and experimentation may take many failures before success is achieved. This may be particularly true in regions where there are no legal *a priori* owners of the land threatened by deforestation, and it is difficult to identify which actors are adequate targets for incentive payments (35). Experiences from micro-finance schemes and payments for environmental services from forests (36, 37) do provide useful frameworks for how to deliver, but the implementation challenges of this novel tool would probably not be small.

### **Conclusion**

Reducing emissions from deforestation, a major source of CO<sub>2</sub>, could potentially be a highly cost-effective option for climate policy. Using three global forestry and land use models, we calculate that emission reductions from AD activities could provide substantial quantities of carbon at prices suggested by energy models. For carbon prices of US\$100 t<sup>-1</sup> CO<sub>2</sub>, emission reductions of 3.1-4.7 Gt CO<sub>2</sub> yr<sup>-1</sup> could be obtained through AD activities during the period 2005-2030. A 10% reduction in deforestation could be accomplished for US\$0.4-US\$1.7 billion yr<sup>-1</sup>, providing emission reductions of 0.3-0.6 Gt CO<sub>2</sub> yr<sup>-1</sup> during 2005 to 2030 if efficiently implemented. A 50% reduction in deforestation could reduce emissions by 1.5-2.7 Gt CO<sub>2</sub> yr<sup>-1</sup> during 2005 to 2030, but it would cost substantially more, US\$17.2-\$28.0 billion yr<sup>-1</sup>. These estimates are based on economic models that do not consider transactions costs and other institutional barriers, which raise costs in practice. However, a 10% reduction in the rate of deforestation could be feasible within the context of financial flows available through the current CDM and ODA/OA assistance. Policy-makers need to develop clear incentives for countries to adopt baselines and national targets so that systems can be developed to credit reductions in deforestation, thus paving the way for funding AD activities.

## **Methods**

The three models used in this analysis have been developed separately by three different modeling groups. Appendices 1-3 provide further details on each of the models. Each model calculates a baseline quantity of carbon sequestered in forests over a varying time horizon, which depends on the specific model. This analysis presents results only through 2030. The baseline for each model embeds model-specific assumptions about the future evolution of agricultural land rents, demand for forestry products, technology change, and other economic drivers (see Appendices 1-3). As a consequence of these economic processes, the models will project deforestation into the future, and the resulting emissions of carbon into the atmosphere.

The models are then used to calculate the quantity of carbon in forests under alternative carbon price regimes. Carbon prices utilized in this analysis range from US\$0 t<sup>-1</sup> CO<sub>2</sub> to US\$100 t<sup>-1</sup> CO<sub>2</sub>. These prices are held constant across the entire time horizon for each model. Because carbon has value, less deforestation occurs in the models under the carbon price scenarios. Emission reductions are calculated as the difference between net annual emissions with a positive carbon price and net annual emissions in the baseline between 2005 and 2030. The marginal cost of emission reductions is the carbon price under the different scenarios. For Figures 1-3, the individual models are used to calculate the reduction in emissions from avoided deforestation at the specific time periods analyzed (2010, 2020, and 2030).

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### **Figure Headings**

Figure 1: Marginal costs in 2010 of emissions reductions with AD activities in three regions with predictions of the three models.

Figure 2: Marginal costs in 2020 of emissions reductions with AD activities in three regions with predictions of the three models.

Figure 3: Marginal costs in 2030 of emissions reductions with AD activities in three regions with predictions of the three models.

### **Table Headings**

Table 1: Average carbon per hectare and number of hectares for tropical forests in the three models used in this analysis.

Table 2: Average annual hectares deforested and carbon emitted as a result between 2005 and 2030.

Table 3: Carbon price in US\$ t<sup>-1</sup> CO<sub>2</sub> necessary to generate a 10% and 50% reduction in deforestation in 2030.

Figure 1: Marginal costs in 2010 of emissions reductions with AD activities in three regions with predictions of the three models.

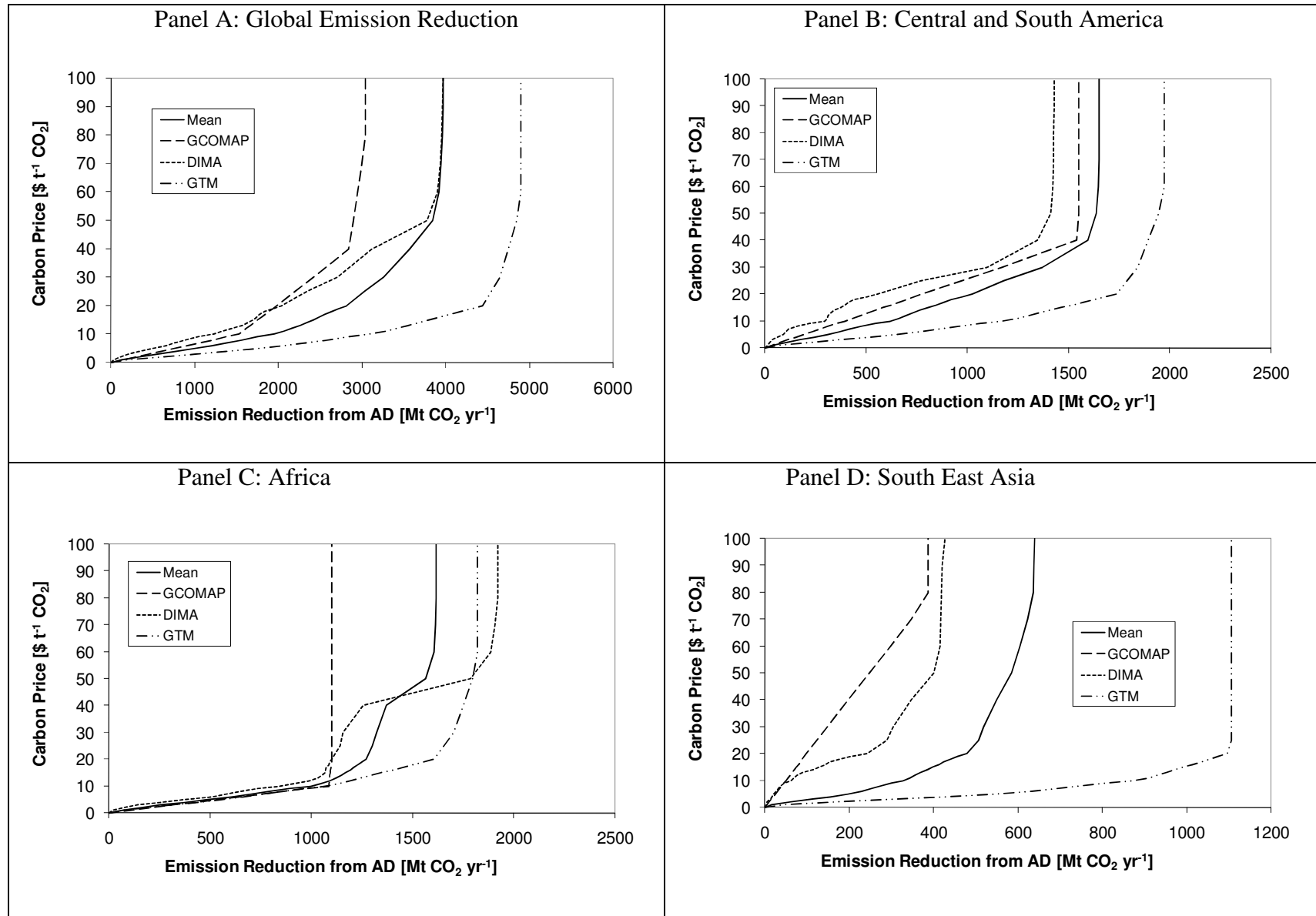


Figure 2: Marginal costs in 2020 of emissions reductions with AD activities in three regions with predictions of the three models.

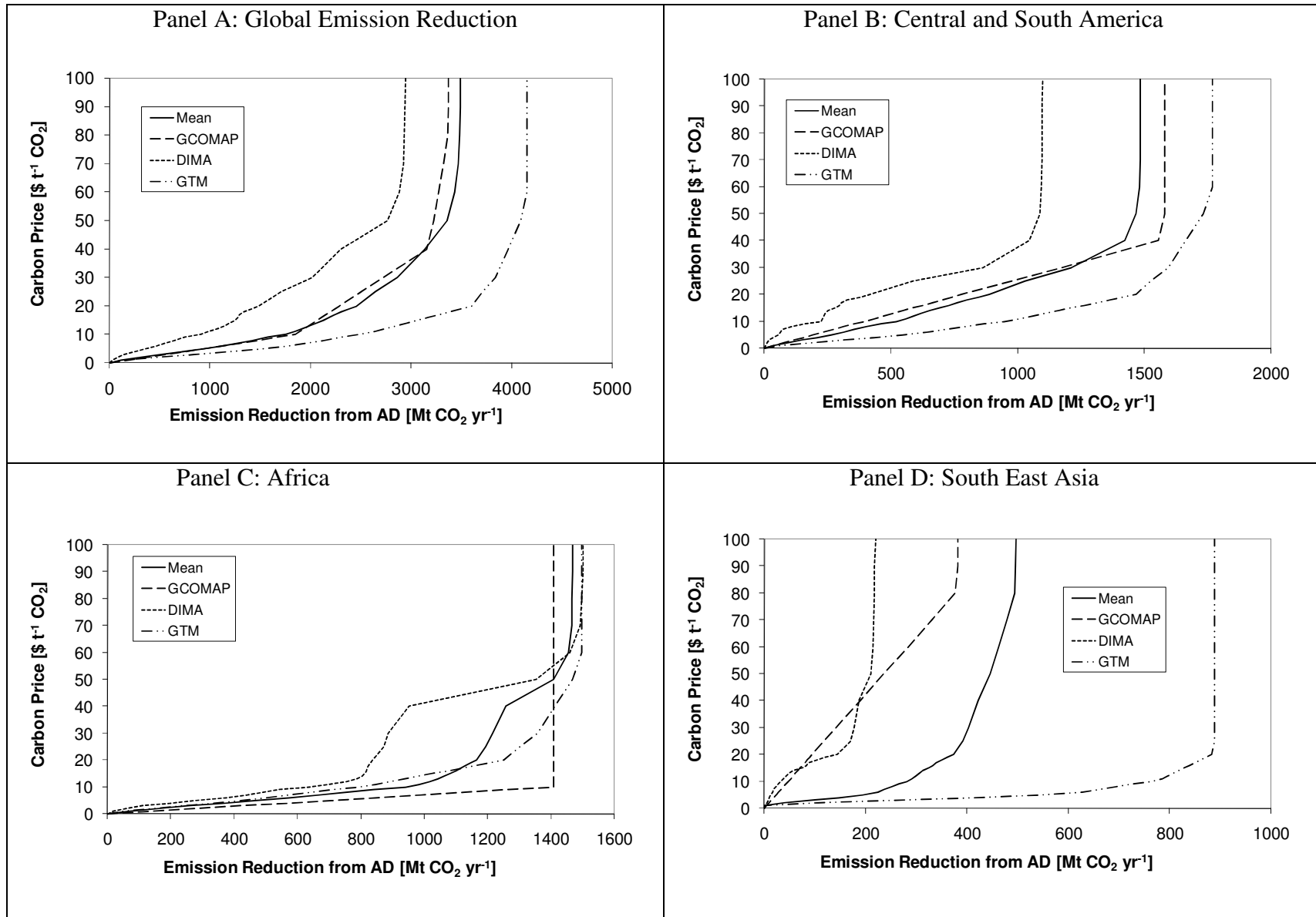


Figure 3: Marginal costs in 2030 of emissions reductions with AD activities in three regions with predictions of the three models.

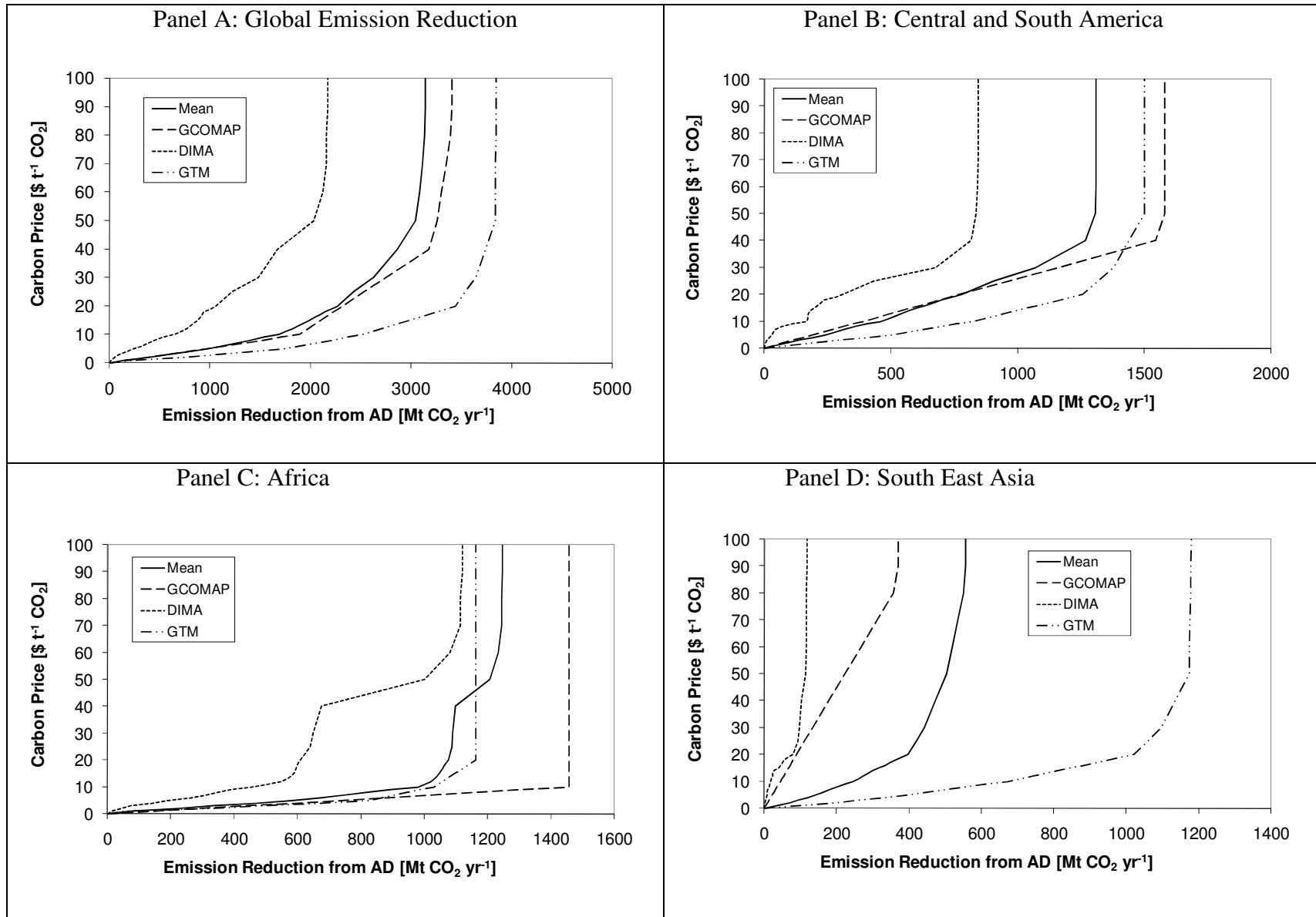


Table 1: Average carbon per hectare and number of hectares for tropical forests in the three models used in this analysis.

	Central & South America	Africa	Southeast Asia
	tC/ha (Million ha)		
GTM	106 (913)	100 (352)	132 (202)
DIMA	86.4 (842)	87.7 (684)	74.7 (181)
GCOMAP	97.2 (965)	54.6 (650)	48 (286)

Table 2: Average annual hectares deforested and carbon emitted as a result between 2005 and 2030.

	Central & South America	Africa	Southeast Asia	Global
	Million ha yr <sup>-1</sup> (Gt CO <sub>2</sub> yr <sup>-1</sup> )			
GTM	4.84 (1.86)	4.58 (1.72)	2.23 (1.07)	11.65 (4.69)
DIMA	3.62 (1.15)	4.98 (1.61)	1.14 (0.31)	10.60 (3.22)
GCOMAP	4.31 (1.57)	5.99 (1.37)	1.90 (0.38)	12.20 (3.31)

Table 3: Carbon price in US\$ t<sup>-1</sup> CO<sub>2</sub> necessary to generate a 10% and 50% reduction in deforestation in 2030.

	10% Reduction			50% Reduction		
	GCOMAP	DIMA	GTM	GCOMAP	DIMA	GTM
Central & South America	\$3.98	\$8.03	\$1.48	\$19.86	\$24.48	\$9.70
Africa	1.04	3.50	1.63	5.20	12.30	9.60
Southeast Asia	8.42	8.73	1.24	38.15	19.56	8.31
Globe	3.50	4.62	1.41	16.90	20.57	9.27