The Costs and Benefits of Reducing Carbon Emissions from Deforestation and Forest Degradation in the Brazilian Amazon

Reducing Emissions from Deforestation & Forest Degradation

REDD

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The Woods Hole Research Center

For more information, please contact

Daniel Nepstad
Senior Scientist
The Woods Hole Research Center

149 Woods Hole Road
Falmouth, MA 02540
USA

508 540 9900, x131

dnepstad@whrc.org

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The Woods Hole Research Center

149 Woods Hole Road
Falmouth, MA 02540
USA

whrc.org

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Authors:

Daniel Nepstad (WHRC, IPAM), Britaldo Soares-Filho (Univ. Federal Minas Gerais),
Frank Merry (WHRC), Paulo Moutinho (IPAM, WHRC),
Hermann Oliveira Rodrigues (UFMG), Maria Bowman (WHRC)
Steve Schwartzman (ED), Oriana Almeida (Univ. Federal Para), Sergio Rivero (UFPa),

The Woods Hole Research Center

IPAM - Instituto de Pesquisa Ambiental da Amazônia

UFMG Universidade Federal de Minas Gerais

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Executive Summary:

- Tropical deforestation and forest degradation contributed 7 to 28% of world-wide, human-induced carbon emissions to the atmosphere in the 1990s (0.5 to 2.4 billion tons) climbing to more than 3.0 billion tons during years of severe drought and forest fire. An important new carbon credit regime is under negotiation within the UN Framework Convention on Climate Change (UNFCCC) for the post-2012 period that could compensate tropical countries for their nation-wide reduction in emissions from deforestation and forest degradation (REDD).

- Brazil is a prime candidate for a REDD program because of its ground-breaking successes in reducing and monitoring deforestation and forest degradation in the Amazon region, where most of its emissions occur (~70%). Brazil contains more carbon in tropical forest trees than any other country—47±9 billion tons in 3.3 million square kilometers of forest in the Amazon alone. But there is considerable debate and discussion over how REDD programs will work, and how much they will cost to the implementing nations.

- This report presents a conceptual framework for estimating the costs to tropical nations of implementing REDD programs and applies this framework to the Brazilian Amazon region. We estimate the opportunity costs of forest conservation and, separately, calculate the annual and 30-year costs of reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon to close to zero over a ten year period. We end with an initial assessment of the benefits of these reductions to Brazilian society and elements of the institutional arrangements that will be necessary to manage this new market.

- REDD programs will be complex and must be refined through dialogue, debate, and exchange of ideas and approaches among a diverse, international group of stakeholders. This report is designed to stimulate this dialogue and "demystify" key challenges of REDD by proposing a practical conceptual framework and an initial estimate of how much REDD would cost in the Brazilian Amazon.

The purpose of this report is to demystify the key challenges of REDD, and to stimulate dialogue and innovation toward solving these challenges.

Premises

- #1. The costs vs. the value of reduced emissions. Our goal is to estimate the cost of developing a REDD program in the Brazilian Amazon, not the value of such a program. The value of Amazon forest conservation far exceeds the costs of protecting it, although these values are difficult to monetize. The ultimate price of REDD carbon credits and, hence, the flow of money into REDD, will be determined by the size of the world carbon market which is, in turn, defined by the emissions reduction targets that developed countries commit to.
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- #2. National opportunity costs. The costs of REDD programs should be bounded by the nation-wide opportunity costs of forgone profits from forest-replacing agricultural and livestock production systems applied to forest lands and potentially forested lands less profits/savings associated with forest maintenance.

- #3. All forest lands. Opportunity costs should be estimated for all forest lands since parks, forest concessions, and forest law can be undone to permit forest-replacing agriculture. The portion of these opportunity costs that are recovered through carbon payments may vary by land category (e.g. protected areas vs. private forests).

- #4. Compensating forest stewards. Forest-based cultures, including indigenous groups, traditional societies, and some smallholder farmer communities, should be compensated for their historical and ongoing role—or potential role—as forest stewards.

- #5. Current government budget outlays continue. Payments to the government are for costs above and beyond current budget outlays for the management and protection of forests.

- #6. Carbon payments for governance. Within REDD, payments for the ecosystem services of carbon retention in forest biomass are applied to the entire REDD program, including payments to forest stewards and to government.

- #7. The deforestation scenario. We assume that the REDD program reduces deforestation in the Brazilian Amazon to approximately zero over a ten year period from a current baseline of 20,000 km^2 per year.

- #8. A century-long payment schedule. Brazil should receive REDD payments at a rate that is commensurate with the rate of reductions in emissions. At current rates, it would take more than a century to clear the forests of the Brazilian Amazon, hence payments should continue over this period.

Three Funds

- Our approach envisions three major components of a REDD program:
  (a) a Public Forest Stewardship Fund,
  (b) a Private Forest Stewardship Fund, and
  (c) a Government Fund.

In this report, we present one scenario of illustrative estimates of the costs of each fund. More detailed presentation of the methods can be found at http://whrc.org/Brazilcarbonsupplement/

Forest allocation

- In the scenario presented here, the eventual allocation of the 3.3 million km^2 of forest remaining in the region would be: 40% "Social" Reserves; 30% "Biological/Ecological" and "Production" Reserves; and 30% private land reserves.

Opportunity costs

- We estimate the opportunity costs (OCs) of complete forest conservation as an initial upper benchmark for assessing the cost of REDD. OCs are calculated using spatially-explicit models of potential rents from soy, cattle and timber production. For each forested parcel (4 km^2), rents for each competing land use (soy, cattle, timber) are summed for 30 years assuming a 5% discount rate and a pre-determined schedule of highway paving. Considering only the maximum opportunity cost of forgone profits from soy vs. cattle ranching, the OC of preserving the remaining forests of the Brazilian Amazon (3.3 million km^2 and 47 billion tons of carbon) is $5.5 per ton of carbon, and a total of $257 billion. This cost declines to $2.8 per ton of carbon and $123 billion overall if forest conversion to soy and cattle ranching is permitted on the 6% of remaining forested lands that have the highest opportunity costs (370,000 km^2 of forest containing 3 billion tons of carbon). One fourth of this high potential forest land would be cleared during the first ten years of the program. The subtraction of potential revenues from timber management reduces opportunity costs by only 4%.

Public Forest Stewards Costs

- Indigenous groups, rubber tappers, and other forest-based populations defend public forests—or could potentially become forest defenders—but have rarely received compensation to do so. They control 26% of the forests of the Brazilian Amazon, and we assume will eventually control 40% through the creation of new reserves. The Public Forest Stewardship Fund would compensate these populations with the goal of increasing the viability of forest-based livelihoods and strengthening their role as forest stewards. Payments would be tied to performance. To provide the annual equivalent of a 1/2 minimum salary ($1,200 per year) to all ca. 150,000 forest steward families living in "social" reserves (indigenous lands, extractive reserves, sustainable development reserves) would cost $180 million per year. Another $13 million would be needed to support these groups in perimeter patrol of their reserves. Annual compensation equivalent to one half of a minimum salary would enable an additional 50,000 smallholder families ($60 million per year) living in government agricultural settlements to restore forests on degraded land as they shift to high-carbon, stable production systems. Payments would decline over time as forest stewards shift to forest-based economies.

Private Forest Stewards Costs

- Private forest stewards in the Brazilian Amazon are private landholders with legal titles to their land. They are currently required to maintain 80% of their land in forest, but compliance is low and repeal of this law is frequently threatened. We assume that current legal[1] private landholders receive partial compensation (20%) of the opportunity costs of their private land forest reserves that are required for compliance with the law, and higher compensation (100%) of the opportunity costs of their private land forest reserves in excess of the legal requirement. If we also assume that half of the forests that are cleared each year in the Brazilian Amazon are privately, legally owned, annual compensation of private forest stewards would begin at $9 million, climbing to a maximum of $90 million after ten years. Thereafter, payments to private forest stewards would decline as the pool of legally owned, uncompensated private forest land diminishes. Those who acquire their private forests after a cut-off date do not qualify for the compensation of private forest opportunity costs, since these costs should be reflected in the land sale price.

Government Costs

- The governments of Brazil (federal and state) will incur added costs to achieve lasting reductions of carbon emissions. We estimate the annual added costs of monitoring, protecting, and managing existing public forests at $25 million, with an additional $8 million per year to establish new public forests. The development of a private forest monitoring and licensing system would cost $16 million per year to establish and implement. Additional services to forest steward families beyond current levels of support (an added $700 per family per year for improved education, health, justice, and technical assistance services) would cost an additional $140 million per year for 200,000 rural families. Total, additional, annual government fund outlays would be a maximum of $190 million per year.

A thirty-year cost and emissions trajectory

- Over the first 10 years of a Brazilian REDD program, annual costs to Brazil would climb from $72 million per year to $530 million per year as annual emissions fall from the 250 million ton carbon baseline to roughly zero. Ongoing costs after year 10 decline as public forest stewards shift to forest-based economies, the pool of uncompensated private forest declines, and government costs decline through greater efficiency and tax revenues. Over the 30-year period, carbon emissions would be approximately 6 billion tons below the historical baseline and 13 billion tons below projected emissions at a cost of $8 billion. Full payment of the opportunity costs of these reduced emissions would be approximately $18 billion. There is therefore a margin for adjusting the three cost categories upward. Carbon emission reductions would climb from ~25 million tons in year 1 to ~250 million tons in year 10 and beyond.

Additional benefits

- Substantial co-benefits of this program include: the doubling of income of 200,000 rural forest-based families, a reduction in fire-based costs to society (respiratory illness, deaths, agricultural and forestry damages) of $10 to $80 million per year, and protection of the rainfall system that may supply much of the Brazilian grain belt and hydro-electric energy production of the industrial southwest of the country. Substantial non-monetized benefits include biodiversity conservation, such as avoidance of the near-elimination of five ecoregions.

Carbon credit insurance reserve

- Emissions reductions from deforestation or fossil fuels combustion made today may always be cancelled tomorrow, if a country or firm that has traded reductions later emits beyond its target. Any emissions trading regime needs mechanisms to insure against such failures. In the case of REDD, a carbon credit insurance reserve could be created, such that some of the reductions achieved and demonstrated would be held in reserve as carbon insurance in case of future increases in deforestation or fires.

1. Introduction

Tropical deforestation and forest degradation released 0.5 to 2.4 billion tons of carbon each year during the 1990s (Houghton 2005), and was therefore 0.8 to 2.8% of the annual worldwide human-induced emission of carbon to the atmosphere. During El Niño episodes, when severe drought affects large areas of tropical forests in the Amazon, SE Asia, and elsewhere, emissions can double through fires that burn forests and tropical peat soils (Page et al. 2002, Alencar et al. 2006). Tropical deforestation emissions may increase in the coming decade as rising worldwide demand for animal ration, meat, and biofuel places new pressures on potential agricultural lands in the tropics (Soares-Filho et al. 2006, Nepstad et al. 2006c, Nepstad et al. in press). We estimate that in a business-as-usual scenario, 55% of the forests of the Brazilian Amazon will be cleared, logged, or damaged by drought by the year 2030, releasing 20±5 billion tons of carbon to the atmosphere (Figure 1). These predictions do not include the effects of regional or global climate change.

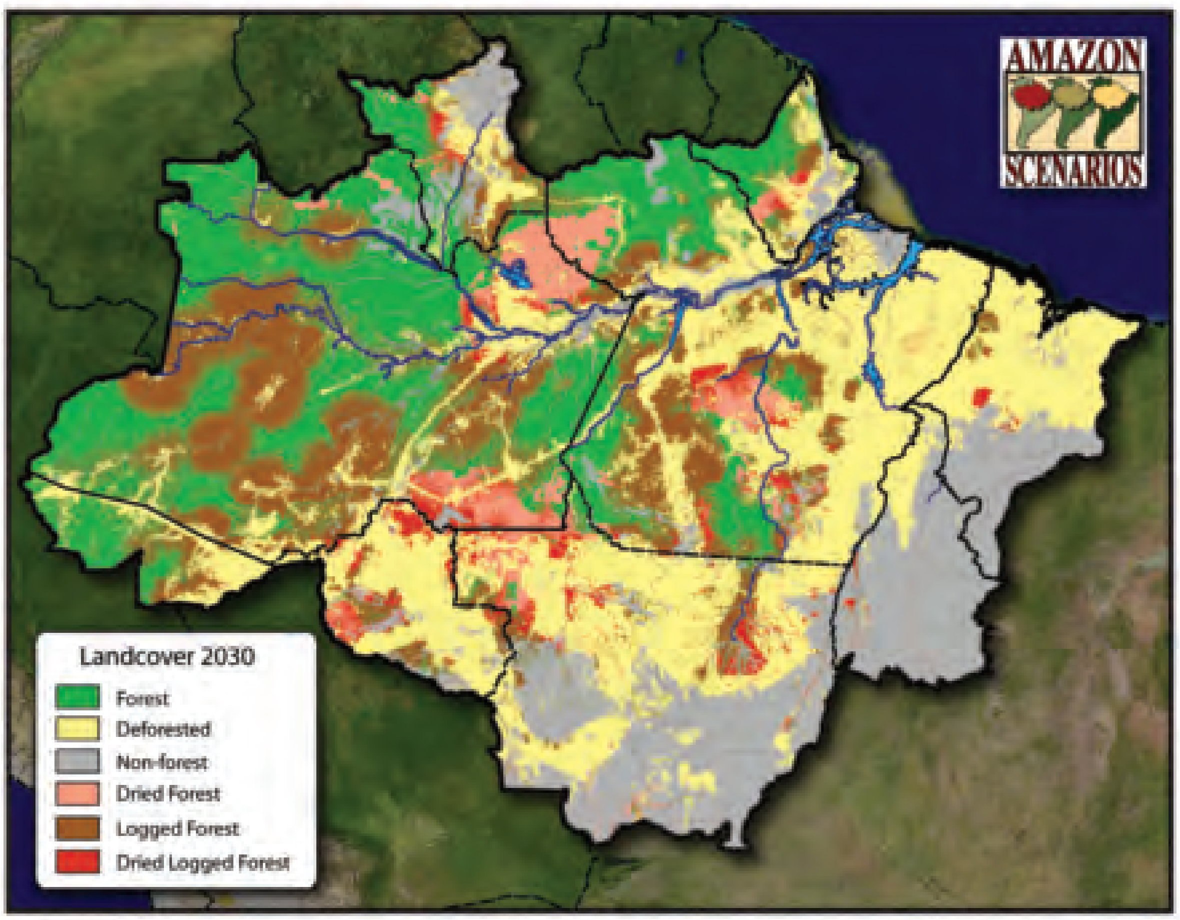

Figure 1. The Brazilian Amazon in 2030, showing drought-damaged, logged, and cleared forests. This map assumes that deforestation rates of 1997-2003 continue into the future, and that the climatic conditions of the last 10 years are repeated into the future. From Soares-Filho et al. 2006, Nepstad et al. 2004, 2007, Nepstad and Stickler in press, Merry et al. in review. (See Supplemental Online Material for description of methods at http://whrc.org/Brazilcarbonsupplement

Although greenhouse gas emissions from deforestation were excluded from the UN Framework Convention on Climate Change (UNFCCC) negotiations of the Kyoto Protocol (Fearnside 2001, Moutinho and Schwartzman 2005, Gullison et al. 2007, Schlamadinger et al. 2007a), such a system is part of the current negotiations focused on the post-Kyoto (post-2012) period (Schlamadinger et al. 2007a). A proposal to compensate tropical countries for nation-wide reductions in greenhouse gas emissions from deforestation and forest degradation (referred to here as "REDD"), first presented at the Milan Conference of the Parties in 2003 (Santilli et al. 2005). A similar proposal was advanced by Papua New Guinea, Costa Rica, and other tropical nations at the Montreal COP in 2005 (Silva-Chavez and Petsonk 2006, Schlamadinger et al. 2007b, Skutsch et al 2007, Sedjo and Sohngen 2007). Brazil endorsed a similar "tropical forest fund" at the Nairobi COP, but did not support a market mechanism for supplying this fund (Government of Brazil 2006, Griffiths 2007). SBSTA[2] negotiations on REDD will conclude with recommendations to COP 13 in Bali.

The Brazilian government's opposition to the carbon market-funded compensation of reductions in carbon emissions from deforestation is surprising since it is superbly positioned to benefit from a REDD program. Roughly two thirds of Brazil's annual carbon emissions come from deforestation, mostly in the Amazon (Moutinho and Schwartzman 2005), and Brazil has been a world leader in developing innovative and successful approaches to forest conservation, as described below.

One of the obstacles to the eventual approval of a REDD mechanism within the UNFCCC process is uncertainty about how REDD would work, how much it would cost, and how much carbon would potentially come into the carbon market at what price. In this report, we provide a conceptual framework for the development of a REDD program for the Brazilian Amazon, an initial estimate of the cost of implementing this program over a thirty year period, and the amount of carbon that could enter the carbon market. We complete the report with a preliminary assessment of the co-benefits of a Brazilian Amazon REDD program.

The purpose of this report is to help move discussions of REDD forward by providing a practical framework for assessing costs and volumes of carbon at stake. The actual costs of developing and implementing a REDD program in Brazil would depend upon several premises and refinements of cost analyses.

2. Can deforestation in the Brazilian Amazon be reduced to zero?

One of the biggest questions of the REDD dialogue is: can it be done? Brazil has provided several important examples that illustrate the feasibility of lowering deforestation. For example, from January 2004 through December 2006, 23 million hectares of public forest reserves in the Brazilian Amazon were created, including large forest reserves at the edge of the active agricultural frontier (Campos and Nepstad 2006, Nepstad et al. 2006a). Brazil's Mato Grosso state has a sophisticated system of private forest reserve monitoring (Fearnside 2003, Chomitz and Wertz-Kanounnikoff 2005, Lima et al. 2005) and one of the world's most advanced systems of rainforest monitoring (INPE 2007). An ambitious federal government program to reduce Amazon deforestation succeeded in cutting rates in half from 2004 to 2006, (aided by the plummeting prices of soy and beef). More recently, the "National Pact for Valuing the Amazon forest and Ending Deforestation"[3], with political support from the Federal Government, four Amazon state governors, the environmental NGO community, and segments of the private sector, has proposed a seven-year target to reduce deforestation to zero. Among the Pact's supporters is Blairo Maggi, Governor of the state of Mato Grosso State, which emits more greenhouse gases from deforestation than any other state during most years. The Brazilian Congress has also developed legislation proposals that would establish national deforestation emission reduction targets.

3. Premises

- #1. The costs vs. the value of reduced emissions. Our goal is to estimate the cost of developing a REDD program in the Brazilian Amazon, not the value of such a program. (The value of Amazon forest conservation far exceeds the costs of protecting it, although these values are difficult to monetize.) We assume that nations estimate the acceptable carbon price for their REDD programs in a way that is commensurate with the cost of achieving these reductions less the economic benefits that accrue to that nation through forest conservation. This report contributes to discussions on the amount of carbon that could come into the carbon market from tropical forests, and at what minimum price. The ultimate price of REDD carbon credits and, hence, the flow of money into REDD, will be determined by the size of the world carbon market which is, in turn, defined by the emissions reduction targets that developed countries commit to.

- #2. National opportunity costs. The maximum costs of REDD programs should be constrained by the nation-wide opportunity costs of forgoing forest clearing and thinning less profits from low-emissions forest-based economic activities. These costs include forgone profits from forest-replacing agricultural and livestock production systems applied to forest lands and potentially forested lands. These costs are offset by revenues from forest-based economic activities, such as timber production, and other local and national benefits that are often more difficult to monetize, such as reduced economic damages from fire. This report considers opportunity costs incurred over a 30-year time horizon.

- #3. All forest lands. Opportunity costs should be estimated for all forest lands and potentially-forested lands, not just those that are privately held. Parks and forest concessions can be undone to permit forest-replacing agriculture. Land laws can be modified to liberate landholders to clear their forests. Ongoing positive economic incentives are needed to keep forests standing.

- #4. Compensating forest stewards. Forest-based cultures, including indigenous groups, traditional societies, and some smallholder farmer communities, should be compensated for their historical and ongoing role—or potential role—as forest stewards (Nepstad et al. 2006b, Griffiths 2007). This compensation should be designed to foster the development of forest-based livelihoods, maximizing the social and environmental benefits of the REDD program. Similarly, REDD must provide positive economic incentives to agricultural and livestock producers who hold legal[1] titles to their land and demonstrate their commitment to sound forest stewardship and compliance with the law.

- #5. Current government budget outlays continue. Payments to the government are for costs above and beyond current budget outlays for the management and protection of forests. We assume that governments maintain current investments, thereby increasing the additionality of the REDD program. This premise carries the moral hazard of rewarding countries that have invested little in natural resource conservation in the past.

- #6. Carbon payments for governance. Within REDD, payment for the ecosystem service of carbon retention in forest biomass is applied to the entire REDD program, including payments to forest stewards and to the government. This expanded concept of payments for ecosystem services is necessary since REDD is a nation-wide program.

- #7. The deforestation scenario and forest allocation. We estimate that a well-designed REDD program could reduce deforestation in the Brazilian Amazon to approximately zero over a ten year period from a current baseline of 20,000 km^2 and approximately 250 millions tons of carbon emissions per year. The allocation of forest land at the end of the REDD program would be 40% social reserves, 40% biological and production forest reserves, and 30% private property, from the current distribution of 26%, 31%, and 20%, respectively. (The remaining forest land is undesignated.) The allocation of forested land defines the cost estimates, since costs vary among social forests (and their inhabitants), biological reserves, production reserves, and private forested lands. These premises will be the subject of considerable analysis and debate. We use a 20,000 km^2/year deforestation baseline since average deforestation from 1997 through 2006 was 19,200 km^2/year (INPE 2007) and deforestation is projected to increase in the future (Soares-Filho et al. 2006).

- #8. A century-long payment schedule. Brazil should receive REDD payments at a rate that is commensurate with the rate of reductions in emissions. At current rates (20,000 km^2/yr), it would take more than a century to clear the forests of the Brazilian Amazon (3.3 million km^2). This simple premise creates a long-term incentive for tropical countries to invest in maintenance of their forest carbon stock, and it reduces the risk that a large flow of REDD carbon credits would dilute the carbon market.

4. The conceptual framework of a Brazilian Amazon REDD program

Most efforts to quantify the costs of reducing greenhouse gas emissions from tropical deforestation and forest degradation have focused on estimating the opportunity costs associated with forgone profits from agriculture and livestock production that are incurred when restrictions to forest clearing are imposed. These analyses have employed equilibrium and partial equilibrium global economic models to estimate these opportunity costs and have had to make simplifying assumptions about potential rents from agriculture and livestock on tropical forest lands (Kremen et al. 2000, Sedjo et al. 2001, Sathaye et al. 2006, Obersteiner et al. 2006, Sohngen and Sedjo 2006, Kindermann et al. 2006). We are unaware of published analyses that estimate the opportunity costs of REDD programs from the ground up, beginning with the biophysical, climatic, and infrastructure constraints to agriculture and livestock expansion in tropical forest regions, and then refining these costs through analysis of a REDD program framework. In this report, we present results of a model of opportunity costs of forest maintenance estimated using spatially-explicit rent models for high-carbon (timber) and low-carbon (agriculture, ranching) uses of Brazilian Amazon forests. (Additional details on the methodology used to make these estimates can be found on-line at http://whrc.org/Brazilcarbonsupplement)

We estimate opportunity costs of forgone profits from non-forest land uses as an upper limit benchmark to the cost of REDD programs. The actual costs of REDD programs should be considerably lower than full compensation of these opportunity costs since Brazilian society has already taken steps to remove much of these forests from the agricultural/livestock land market through the creation of formal forest reserves. The cost of REDD should also be lower than full compensation of opportunity costs because of the benefits of forest protection that accrue to Brazilian society. For example, there is some evidence that the rainfall system of central and southwestern Brazil is partially dependent upon moisture coming from the Amazon region and that this moisture is, in turn, dependent upon Amazon forest evapotranspiration (Clement and Higuchi 2006). Hence, the rains that feed Brazil's grain belt and extensive hydroelectric reservoir network appear to depend, in part, upon Amazon forests.

The institutional steps to achieve lasting reductions in carbon emissions from tropical deforestation and forest degradation are also in need of a clarifying conceptual framework. REDD programs will depend upon effective governance of remote forest regions and an equitable, efficient system of channeling these incentives to the people who control tropical forests. We propose three general targets of REDD funding to help meet these goals. First, a "Public Forest Stewardship" fund would compensate those people who have defended forests against forest-replacing economic activities, or who could potentially defend forests. This funding targets forest-based indigenous groups, traditional rural populations (such as rubber tappers, Brazil-nut gatherers, and others), and some smallholder populations that are taking steps towards stable land-use systems that maintain or expand carbon stocks in forest vegetation.

A "Private Forest Stewardship Fund" would compensate those legal private landholders who retain forest on their properties. (This fund is complicated by the difficulty of defining land ownership in the Brazilian Amazon.) We propose a differential rate of compensation for forest conservation on private land, with lower compensation going to forest reserves that are legally required, and higher compensation going to reserves that are above and beyond this legal requirement.

A "Government Fund" would compensate government programs and expenditures that are necessary for REDD above and beyond current budget outlays. These expenditures include heightened monitoring and management of public forests, expansion of the protected area and indigenous land network of public forests, improved provision of services (education, health, technical assistance) to rural populations, and the expansion of existing systems for environmental licensing and monitoring of private land forests to the entire Brazilian Amazon region.

5. A spatial map of opportunity costs

The opportunity costs of maintaining the forests of the Brazilian Amazon (Figure 2) was mapped using spatially-explicit models of potential rents for soy, cattle, and timber production. These models were developed as part of the "Amazon Scenarios" program of the Woods Hole Research Center, the Universidade Federal de Minas Gerais, and the Instituto de Pesquisa Ambiental da Amazonia. The soy model integrates a biophysical yield model, a transportation model, and a production cost model in estimating the economic returns to soy production for the Brazilian Amazon (Vera Diaz et al. in press). Soy expansion is constrained by a soil and climate suitability map that is applied as a filter (http://whrc.org/Brazilcarbonsupplement). Soy rents are positive only in areas where suitability is high. The cattle ranching model integrates a herd development model, a production cost function (that includes land purchase, herd establishment, and periodic pasture reformation), and a transportation cost model (Merry et al. in preparation). The timber model integrates a transportation model, a harvesting and processing cost model, and simulates the expansion, contraction, initiation, and extinction of timber processing centers depending upon each center's neighborhood of timber stocks that could be profitably harvested (Merry et al. in review). (See online supplemental information for more details (http://whrc.org/Brazilcarbonsupplement)

These three rent-based models are integrated within the "SimAmazonia" modeling system (Soares-Filho et al. 2006). In this report, the net present value of each of the three competing land uses is estimated over a 30-year time period by summing rents into the future for each forested pixel of the Brazilian Amazon (Figure 3-5). Future rents are discounted at a 5% annual rate. All three models are highly sensitive to changes in transportation costs. We therefore developed a schedule of highway paving based upon an analysis of current policies and capital availability (Soares-Filho et al. 2006). Hence, the rent of each forested pixel changes differentially through time for each competing land use depending upon expansion of the paved highway network as prescribed.

We estimate the opportunity cost of maintaining forest for each 4-km^2 forest "pixel" as the maximum net present value of deforestation-dependent land use (the maximum, discounted, 30-year rent of soy vs. cattle ranching). We also estimate the "net" opportunity cost, in which the net present value of timber production is subtracted from that of soy or cattle, since timber maintains most of the carbon stock of forests. In this report, we "force" the timber industry into a sustainable mode by limiting annual harvest for each processing center to 1/30th of the total timber volume around each processing center that could be profitably harvested. (This assumes that each forested pixel can be harvested every thirty years because of tree growth.) This opportunity cost is divided by the carbon stock for each forested pixel using the forest carbon map developed by Saatchi et al. (2007, Figure 6), to estimate the payment per ton of carbon that would fully compensate the opportunity costs of forest maintenance (Figure 6, 8). The net opportunity cost is calculated by dividing the difference in net present value (soy or cattle minus timber) by the difference in carbon stock of agriculture/livestock vs. timber[4]."

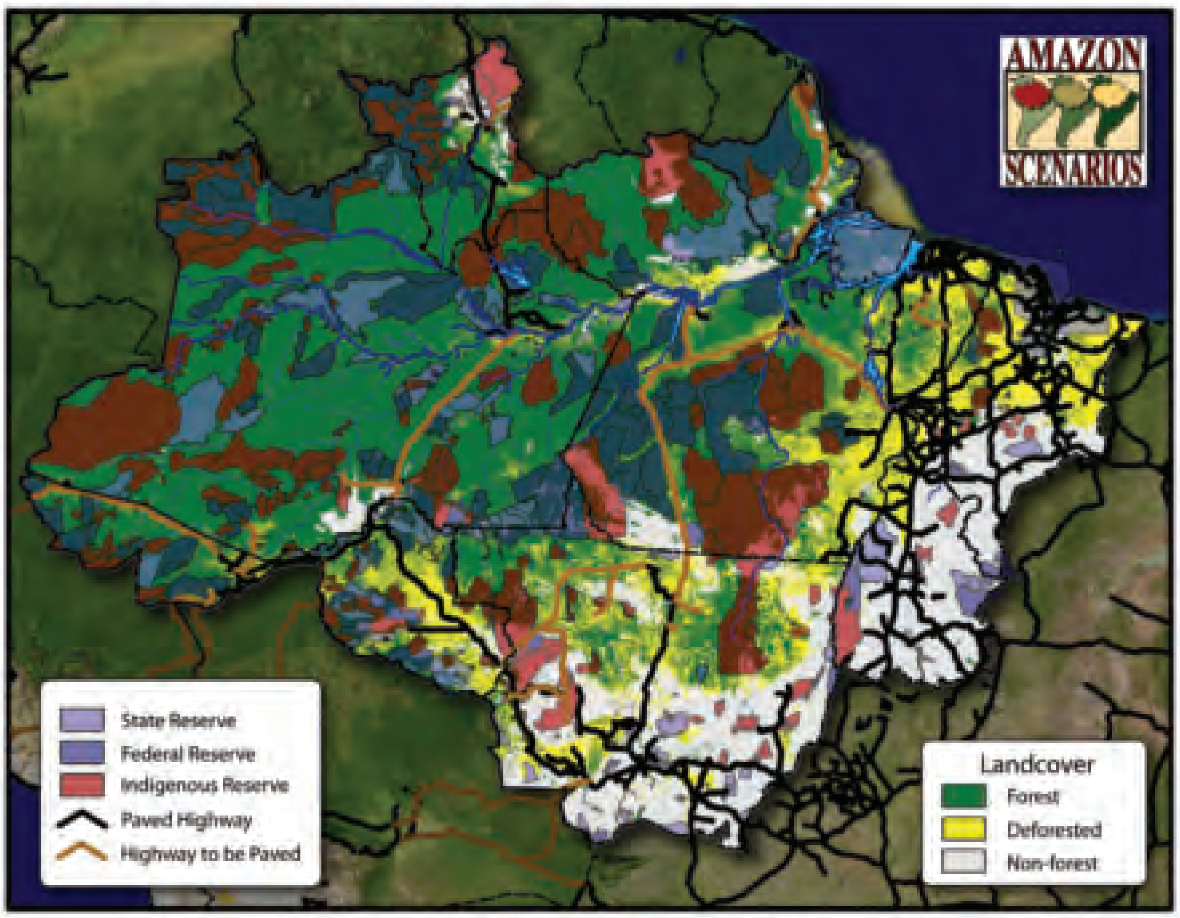

Figure 2. The forests in the Brazilian Amazon. This 5-million square kilometer region has 3.3 million square kilometers of forest, with roughly half (49%) in public forests, including indigenous reserves, biological reserves and parks, "sustainable use" (community development forests and production forests), and military reserves. Source: (http://whrc.org/Brazilcarbonsupplement)

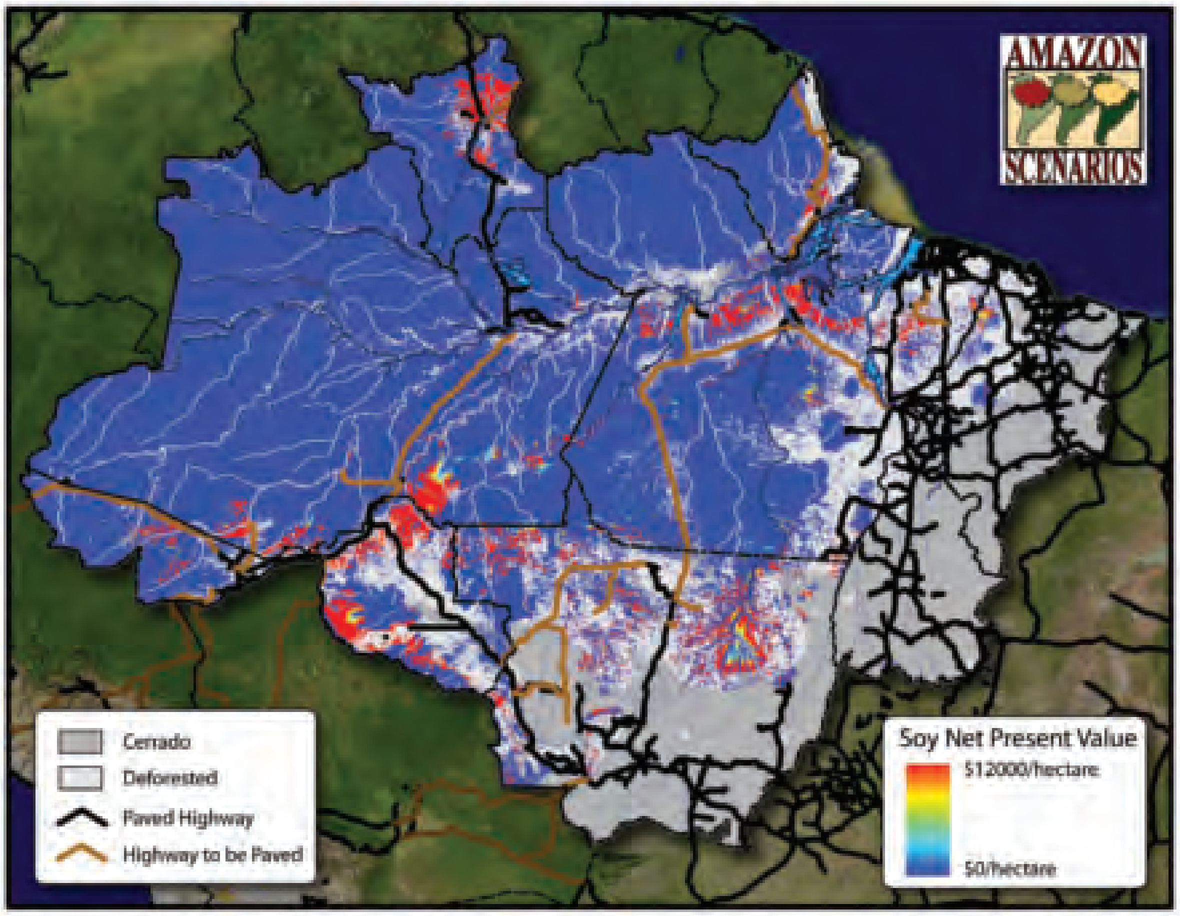

Figure 3. The potential net present value (2007 through 2037) of soy production on the forested lands of the Brazilian Amazon. (http://whrc.org/Brazilcarbonsupplement, Vera Diaz et al. 2007.)

The 3.3 million square kilometers of forests in the Brazilian Amazon contain 47±9 billion tons of forest carbon (excluding soil carbon) (Saatchi et al. 2007, Soares-Filho et al. 2006). The opportunity cost of protecting this forest all at once, in 2007 dollars, is $257 billion and $5.5 per ton of carbon. Only 6% of the forests of the region have opportunity costs of more than $10 per ton carbon, however. If these forests are removed from our estimate, the cost of fully compensating OCs declines to $123 billion and the per-ton cost to $2.8 (Tables 1, 2). Outside of protected areas, there are 24 billion tons of carbon in forests with opportunity costs of $137 billion ($6.05 per ton carbon). By excluding the high-rent forest parcels (representing 6% of total forest area outside of protected areas), it would be possible to fully compensate OCs of 22.2 billion tons of forest carbon for $56 billion ($2.75 per ton C) (Tables 1, 2).

These surprisingly low per ton values for carbon are attributable to the low profitability of cattle ranching in the Amazon (Figure 4). The animal grazing density of Amazon cattle pastures averages 0.8 animal units per hectare, and yields profits that are generally well below $50 per hectare per year (Arima et al. 2006, Margulis 2003, Mattos and Uhl 1994). The opportunity costs of forgone profits from soy production (Figure 3) represent the steep part of the carbon supply curve in the final 6% of the forest carbon stock (Figure 8). These OCs decline by 4% if profits from sustainable timber management (Figure 5), which can retain at least 85% of forest carbon stocks, are subtracted from the OC estimate (Table 1).

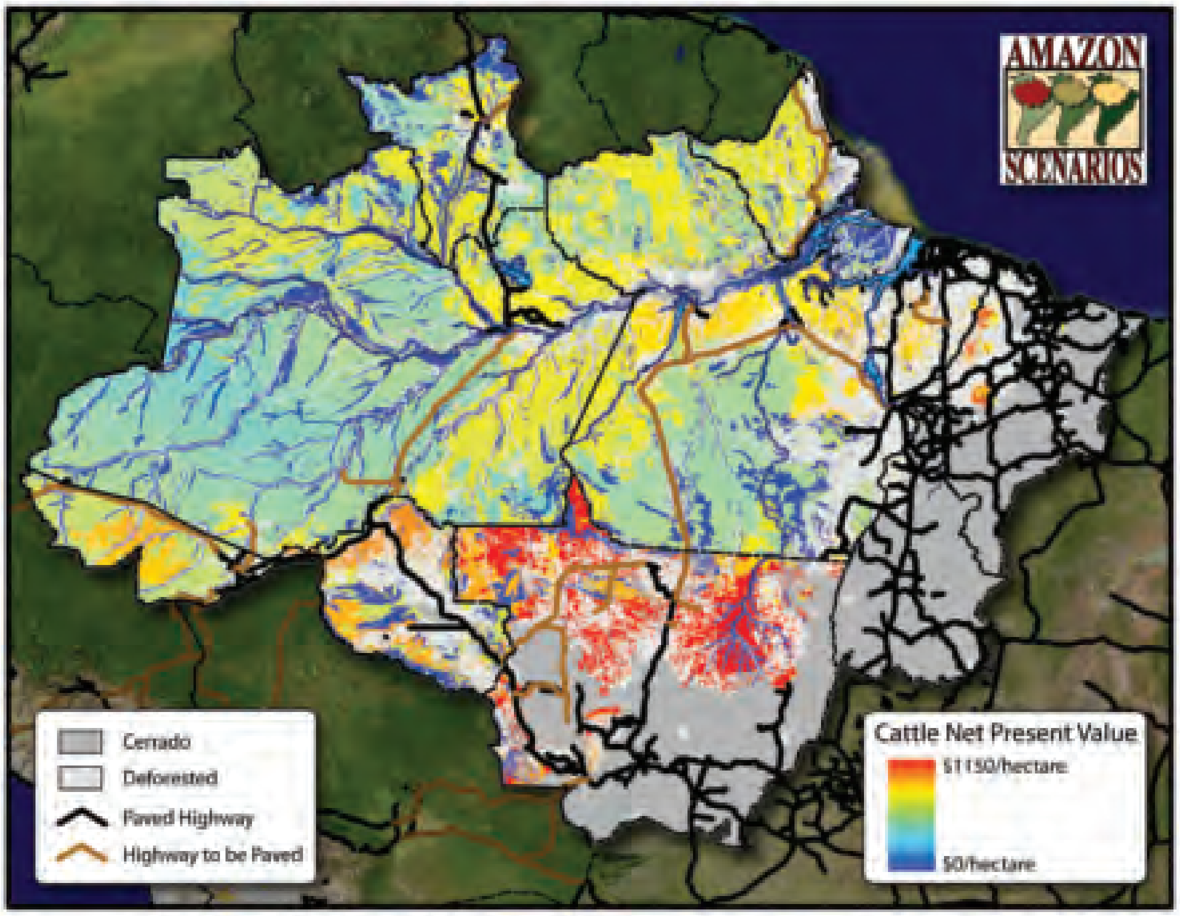

Figure 4. Potential net present value of cattle production (2007-2037) on the forested lands of the Brazilian Amazon. (http://whrc.org/Brazilcarbonsupplement).

Table 1. Opportunity Costs of forest maintenance outside of protected areas, inside of PAs, and for the entire Brazilian Amazon.	**With Timber Rents ($B)**	**Without Timber Rents ($B)**	**Percent Reduction**
Outside protected areas	137.5	143.4	4.1
Outside protected areas, <$10/ton	56.3	61.5	8.5
Inside protected areas	120.8	121.6	0.7
Inside protected areas <$10/ton	60.4	61.1	1.1
Total	247.3	257.1	3.8
Total <$10/ton	114.6	123.3	7.1

Table 2. Carbon stocks and opportunity cost per ton C outside of PAs, inside of PAs, and for the entire Brazilian Amazon.	**Carbon Stocks**	**$ per ton C**
Outside protected areas	23.8	6.03
Outside protected areas, <$10/ton	22.2	2.75
Inside protected areas	23.1	5.26
Inside protected areas <$10/ton	21.7	2.81
Total	47.1	5.65
Total <$10/ton	44.1	1.56

6. A deforestation reduction schedule and forest allocation

Our analysis is based upon a ten-year timetable for lowering deforestation to ~zero kilometers per year from an historical baseline of 20,000 km^2 per year (Fig. 8). We use a 20,000 km^2 per year rate as our baseline since deforestation for the last 10 years was 19,200 km^2 but reached an average of 24,000 km^2 per year during the 2002-2004 period (INPE 2007). Deforestation is projected to increase in the future under business-as-usual assumptions (Soares-Filho et al. 2006). Deforestation is assumed to be reduced by 2,000 km^2 per year until year ten, when deforestation is reduced to ~0 km^2 per year. The deforestation reduction schedule is presented for 30 years, which is the time period for which opportunity costs were estimated. In practice, compensation would continue into the future at a rate that is commensurate with ongoing emissions reductions. During the 30-year period, the deforested area would be reduced by 490,000 km^2 below the baseline and carbon emissions would be reduced by 6.3 billion tons. If the 90,000 km2 of deforestation that takes place during the first ten years of this period is on forested lands with high opportunity costs of forest maintenance, then the remaining area of potentially high-profit forest declines to 280,000 km^2.

Our calculations also depend upon the ultimate allocation of forest land. Roughly one third of Brazilian Amazon forests today are without formal designation (called "terra devoluta", Lentini et al. 2003). Thirty-one percent of forests are public forest reserves (26% of these being "social" reserves, including indigenous lands, extractive reserves, and sustainable development reserves). The remainder of the land is private. We assume that remaining forests of the Brazilian Amazon will be allocated as: 40% social forests (where the public forest stewardship fund applies), 30% biological and production forest, and 30% private land.

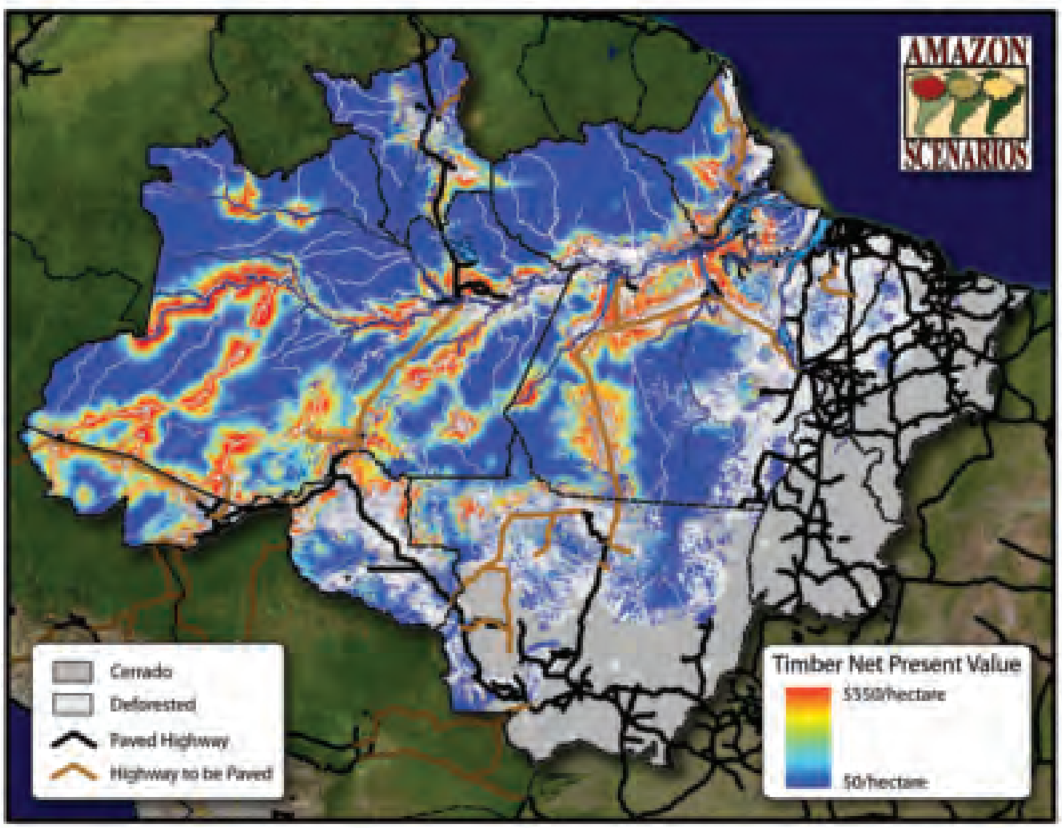

Figure 5. Potential net present value of sustainable timber production (2007-2037) for the forests of the Brazilian Amazon. Processing centers in this run of the timber rent model are restricted to annual harvests of 1/30th of the profitably harvestable timber stocks, thereby "forcing" the industry into sustainable, 30-year rotations. See http://.whrc.org/Brazilcarbonsupplement for model description.

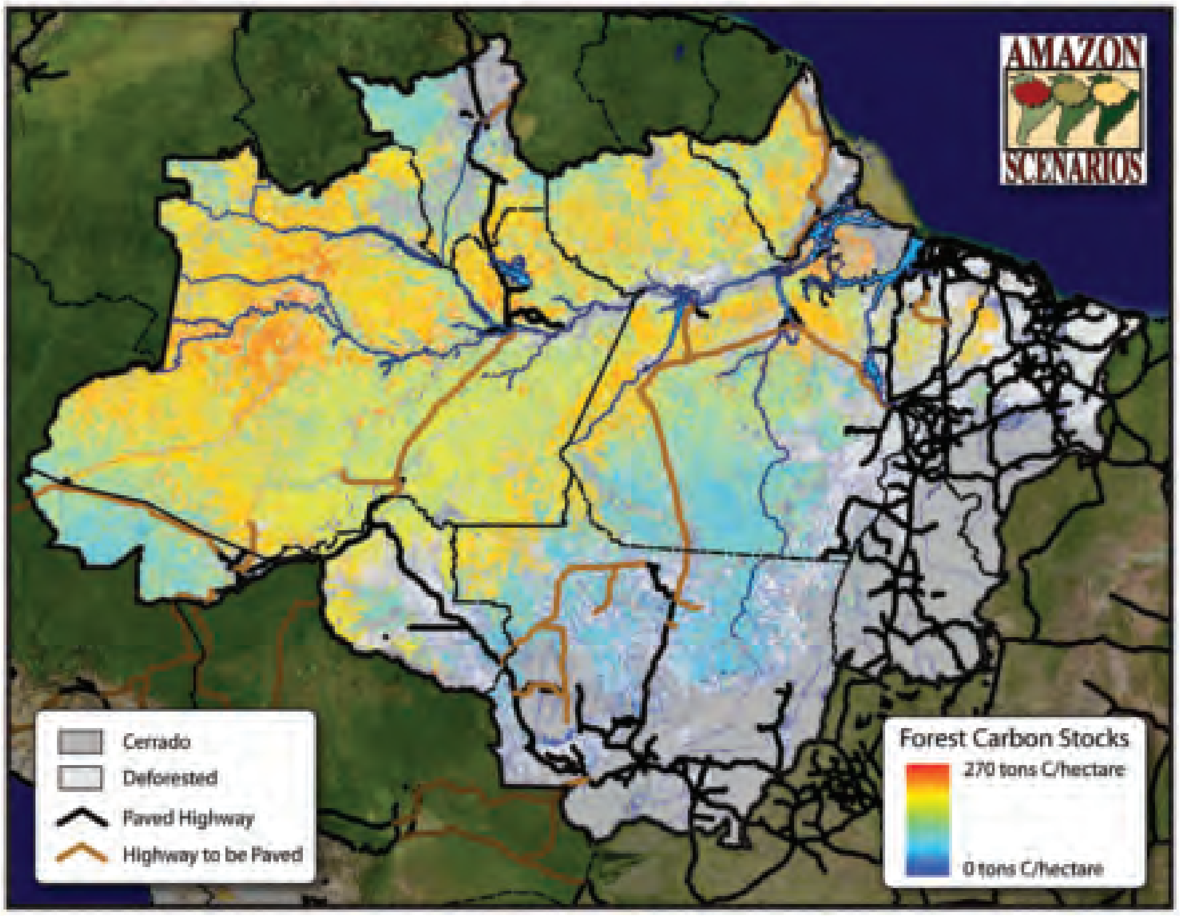

Figure 6. Forest carbon stocks of the Brazilian Amazon. Aboveground and roots. (Assumes that root biomass is 21% of live aboveground biomass and that dead biomass is 9% of live aboveground biomass.) Source: Saatchi et al. 2007.

7. The Public Forest Stewardship Fund

Indigenous communities inhibit deforestation at the same level as biological reserves and parks (Nepstad et al. 2006b), providing an important rationale for strengthening their role as stewards of these public forests. This rationale is further supported by the fact that 25% of current Brazilian Amazon forests are allocated to some form of "social forest" use (indigenous land, extractive reserve, sustainable development reserve), and these social reserves are much more common in active deforestation frontiers than are biological reserves and parks (Nepstad et al. 2006b). The "Aliança dos Povos da Floresta" (the Forest Peoples' Alliance) has defined several forms of compensation that it expects from a REDD program[5]. These forms of compensation include economic incentives for forest-based livelihoods, improved health, education, technical assistance services, and payments for patrolling reserve perimeters, and are described in greater detail in supplemental online information (http://whrc.org/Brazilcarbonsupplement).

We estimate the cost of providing incentives for forest-based livelihood on a per-family basis. We simplify this calculation by assuming that a payment of one-half of a minimum salary ($1,200 per year) would be sufficient to provide a strong incentive to stabilize agricultural systems (through a shift to swidden fallow that does not depend upon primary forest clearing) and to develop forest-based economies (e.g. McGrath et al. 2006). The exact form of compensating forest stewards will depend upon a deeper analysis, and may include price subsidies for non-timber forest products such as have already been established in Acre and Amazon states for native rubber. Direct payments to forest families also have a precedent in the Amazon through the Proambiente program and, more recently, through the Amazonas state "bolsa florestal" program. In the case of Proambiente, payments of $50 per month (half of our estimate) were sufficient to foster changes in farmer agricultural strategies. In Amazonas, payments are $25 per month. A payment of $1,200 per year for all 50,000 indigenous families, all 50,000 extractivist families, and for 50,000 forest-margin smallholder families would cost $180 million per year (Table 3). We assume that it would take ten years of linearly increasing payments to reach all families contemplated.

We estimate the cost of perimeter control based at $10 per square kilometer upon estimates from the Aliança dos Povos da Floresta at $10 per square kilometer. The 1.3 million square kilometers of social reserves would require $13 million per year to be monitored by their residents (Table 3).

An additional incentive is included for those smallholder families that are in public settlement projects that hold potential for forest restoration and a shift to stable agricultural systems. Sixty million dollars per year would be necessary to compensate 50,000 smallholder families (out of a total of 650,000 smallholder families across the Brazilian Amazon) (Table 3).

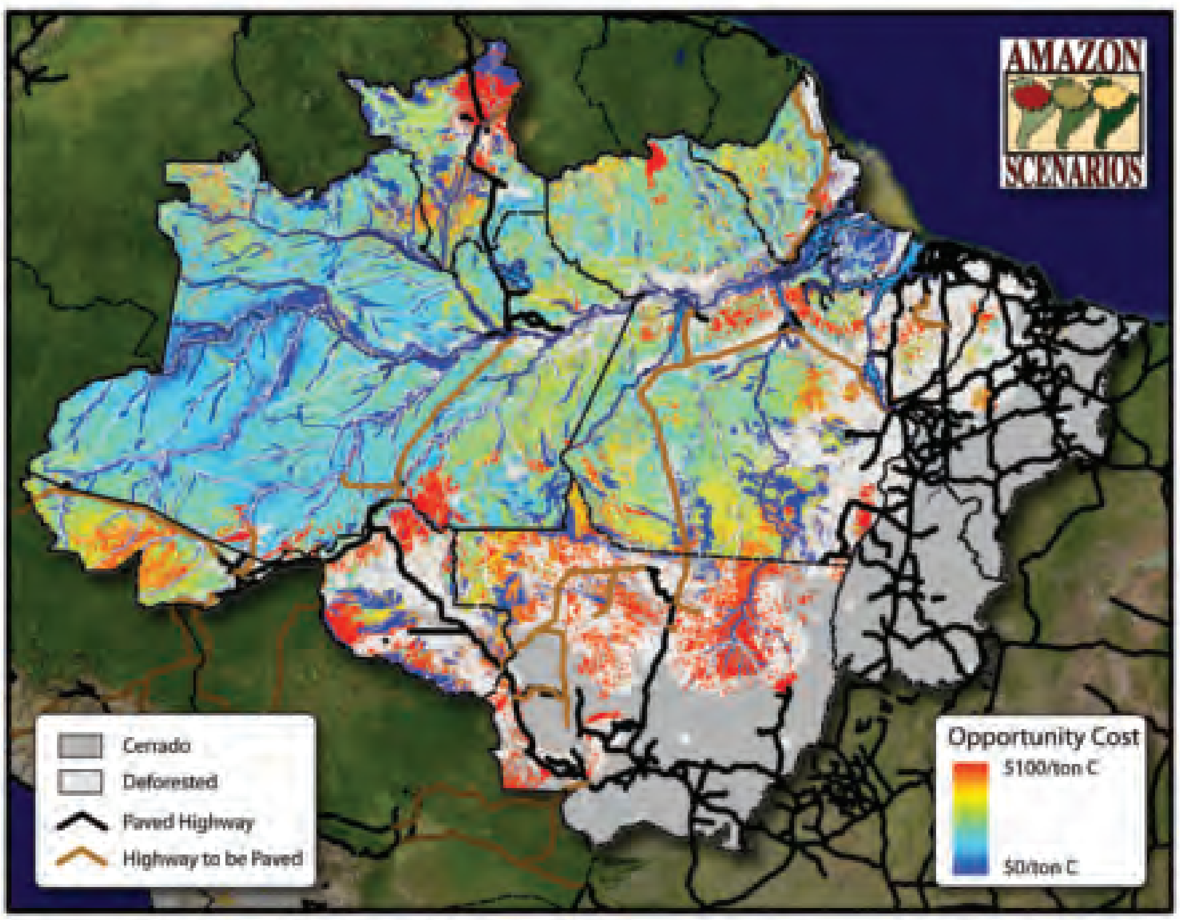

Figure 7. Net opportunity cost of forest protection in the Brazilian Amazon. Calculated as maximum net present value of soy or cattle production minus NPV of timber. The value was then divided by forest carbon stocks (Figure 6).

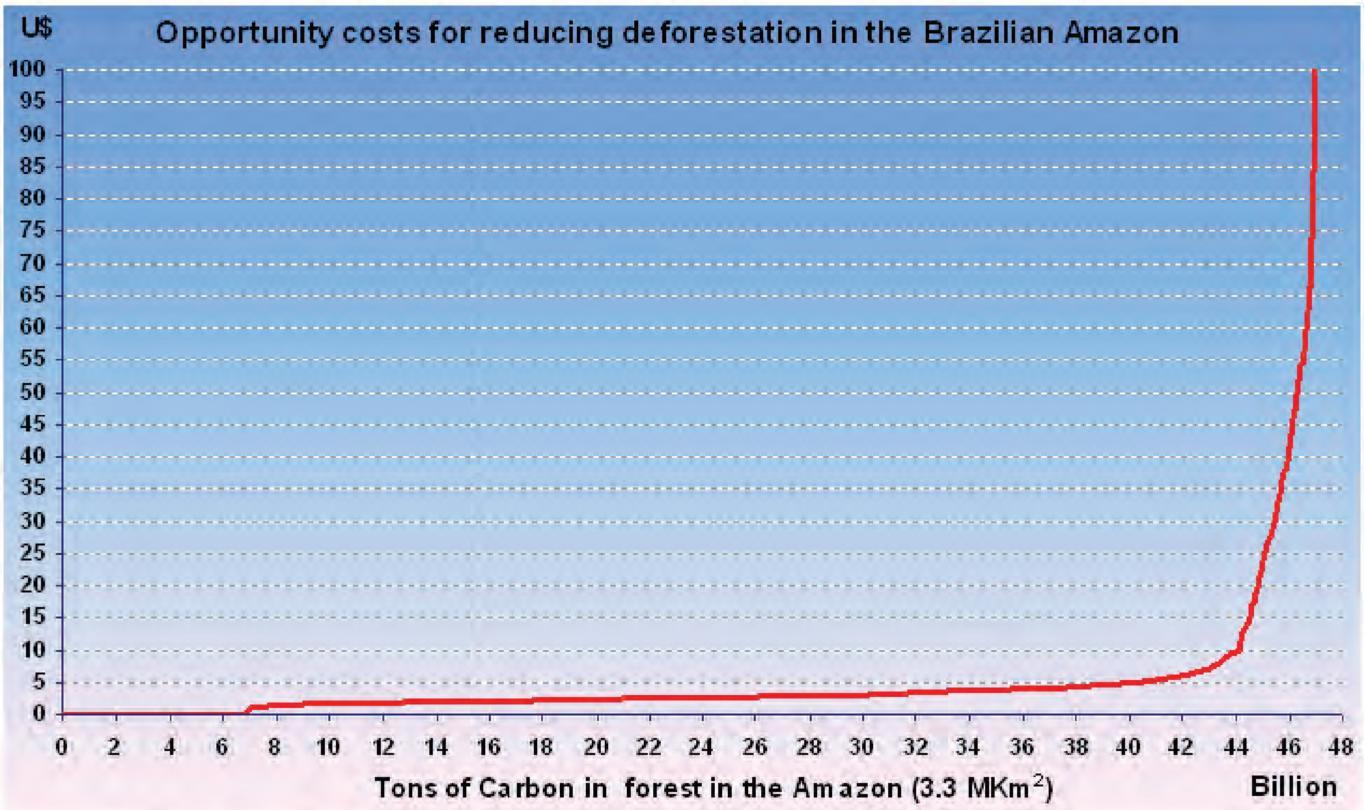

Figure 8. Marginal opportunity cost of reductions in carbon emissions for the Brazilian Amazon. This graph plots the opportunity cost per ton of carbon, as described in Figure 7, from the cheapest to the most expensive emissions reductions. Ninety percent of the opportunity costs are less than $5 and 94% are less than $10. The total opportunity cost to maintain the entire forest is $257 billion (if paid all at once in 2007 dollars) for 47 B tons of C; the cost of compensating 94% of the "cheapest" forests is $115 billion, with carbon stocks of 44 billion tons C.

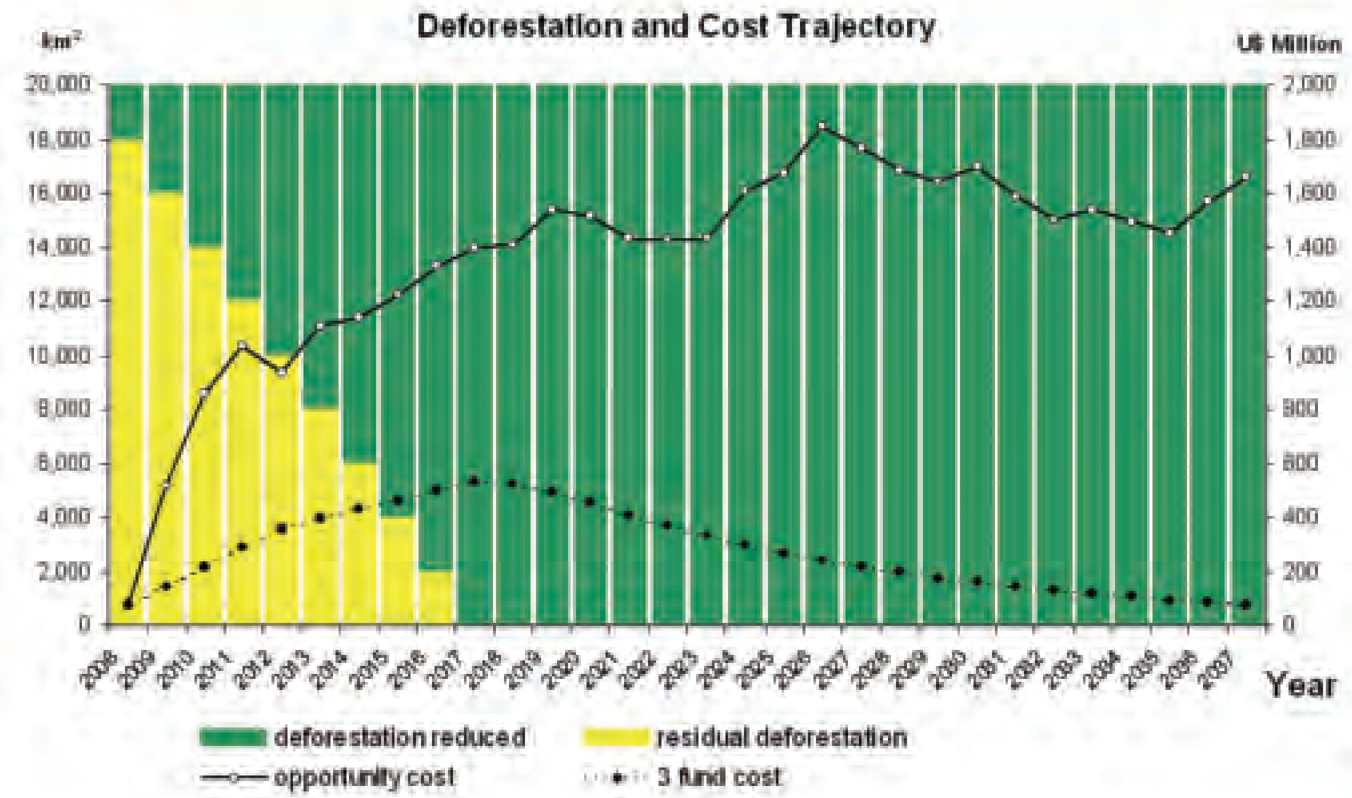

Figure 9. Trajectory of deforestation, reduced deforestation, the opportunity costs of this reduction, and an initial estimate of the cost of achieving the reduction (the sum of the Public Forest Stewardship, Private Forest Stewardship, and Government funds) in the Brazilian Amazon for a thirty-year period. The values of each fund are found in Figure 10.

Table 3. Summary of costs of Brazilian Amazon REDD program in Year 10	
Public Forest Stewardship Fund (Forest People)	
a. Forest steward compensation	
Annual payment per family	$1,200
100,000 indigenous and extractivist families	$120,000,000
50,000 qualifying forest margin smallholders	$60,000,000
b. Forest monitoring, protection, management	
Average annual cost per square kilometer	$10
1,000,000 km^2 indigenous reserves	$10,000,000
200,000 km^2 extractive reserves	$2,000,000
100,000 km^2 community reserves	$1,000,000
c. Forest settlement restoration	
Average annual cost per family	$1,200
50,000 smallholder families	$60,000,000
d. Total annual forest people payments	**$253,000,000**
Private Forest Stewardship Fund	
Opportunity costs compensation, extensive ranching	**$90,000,000**
The Government Fund	
a. Public forest protection, management, creation	
Monitoring: average annual cost per square kilometer	$20
Maintenance of current public forests	$24,800,000
Cost to create new protected area ($/$km^2$)	$50
Creation of new protected areas (10%/yr)	$7,800,000
b. Private forest registration, monitoring	
Env'l registration system establishment (10%/yr)	$10,000,000
Cost to register private lands ($/$km^2$)	$50
Property registration (10% per year, $200 per km^2)	$6,000,000
c. Services (health, education, justice, technical support)	
Annual payment per family	$700
Annual payments for forest peoples	$140,000,000
d. Total Government Fund	**$188,600,000**
Total cost of all funds in year 10	**$531,600,000**

8. The Private Forest Stewardship Fund

It is very difficult to quantify the area of Amazon forests that are legally owned or that could be legalized without rewarding flagrant fraud (Alston et al. 1999). Antiquated titling processes, competing land claims, and sophisticated illegal land grabbing operations make it virtually impossible to map legal land claims. For the purpose of this report, we assume that one half of the forests cleared each year are on private properties that are legally held or that will eventually be legalized. Those who purchase forest lands in the future do not qualify for compensation of their opportunity costs, since these costs should be reflected in the sale price of the land. (If we assume that Brazil will enter a regime of forcefully lowering deforestation rates, land prices should decline as the possibility of forest conversion to agriculture or livestock declines.) Landholders are legally required to maintain 80% of their property as private forest reserve. However, there are frequent attempts to turn back this legislation and compensation of these legally-mandated forest reserves is therefore appropriate. We estimate compensation of 20% of the opportunity costs of forest maintenance for these legally-mandated private forests. Compensation of opportunity costs should be higher for forests held in excess of this 80% requirement, but the number of properties with more than 80% forest cover is too small to affect these estimates. We estimate that compensation of private forest stewards increases linearly until year 5, when these payments would equal $90 million per year (Table 3).

9. The Government Fund

The cost of government monitoring and management of existing public forests is estimated at \$20 per km^2 and would cost an additional \$28 million per year to be accomplished successfully. We assume that protected area expansion would take place over 10 years to achieve the final land allocation of 40% in social reserves and 30% in biological and production reserves, adding 36,000 km^2 each year. If protected area creation costs an additional \$50 per km^2, this cost would be \$7.8 million per year. (The added burden on the government of an expanding protected network is counterbalanced by the growing capacity of public forest stewards to defend and manage these areas.) Development of state-run private land environmental licensing and monitoring systems, similar to Mato Grosso State's "Sistema de Licensiamento Ambiental de Propriedades Rurais" (Rural Property Environmental Licensing System) (Fearnside 2003, Lima et al. 2005, Chomitz and Werth-Kanounnikoff 2005), would cost \$10 million per year for ten years, with an additional \$50 per km^2 to bring new private properties into the system (\$6 million) (Table 3, http://whrc.org/Brazilcarbonsupplement).

The largest governmental cost would be enhancement of its services provided to forest stewards. Additional investments in and improvements to public health, education, and technical support programs are estimated at \$700 per family, for a total of \$140 million per year (Table 3, http://whrc.org/Brazilcarbonsupplement). These additional funds would be channeled through existing institutions, such as the "Sistema Única de Saúde", in the case of health for non-indigenous families.

10. The costs of REDD in the Brazilian Amazon over 30 years

We estimate the costs to Brazil of carrying out this REDD program over 30 years, which is the period for which opportunity costs were calculated (Figure 7, 8). We assume that the Public and Private Forest Stewardship Fund increases linearly over ten years to their maximum values presented in Table 3 (Figure 10). Government costs must build up more rapidly to provide necessary law enforcement early in the program. We assume that the Government Fund builds up linearly over a five-year period. First year combined expenditures of \$72 million climb to \$530 million in year 10 as deforestation declines from 20,000 km^2 to ~0 km^2 and emissions decline from ~250 million to ~0 tons of carbon per year. After the initial ten-year period, ongoing costs are incurred as Brazil continues to compensate remaining private land forest stewards, and for protecting/managing the 2.3 million km^2 public forest estate. These ongoing payments are theoretically justified as the continuing, partial compensation of opportunity costs that will end >100 years into the future. This long time horizon is necessary to fully compensate these opportunity costs because compensation is commensurate with emissions reductions, which are determined by the 20,000- km^2 per year baseline. This long payment schedule also provides an ongoing incentive to Brazil to continue its forest governance. We assume that the cost of achieving forest governance declines over time as institutional efficiency increases, and as the tax base of the government expands through a thriving timber industry.

Over the thirty-year period, \$8.2 billion are expended to reduce emissions of carbon by 6.3 billion tons. In other words, for a bit more than a dollar per ton of carbon, emissions of carbon to the atmosphere could be reduced by an amount equivalent to about seven months of worldwide emissions (which, in 2006, passed 10 billion tons per year, Canadell et al. 2007) while conserving the world's largest tropical rainforest. The full opportunity cost of avoiding the emission of 6 billion tons of carbon would be \$3 per ton, or \$18 billion, if we assume that the highest 6% of opportunity costs are not compensated (Table 2, Figure 8). Part of the difference between these two estimates of REDD costs (\$8 vs. \$18B) is diminished by the benefits to Brazilian society of a REDD program. In other words, there are substantial benefits to Brazilian society of protecting Amazon forests that should be counted against opportunity costs as the real cost of a REDD program is estimated.

11. Co-benefits of REDD

The proposed REDD program would have direct impacts on the livelihoods of 200,000 low-income rural families, including all of the indigenous and traditional families of the Brazilian Amazon. These families would more than double their incomes as they shift to forest-based economic activities. They would also receive $700 per family per year in added educational, health, and technical support services. The program would reduce the likelihood of deforestation-driven reductions in rainfall in the Brazilian grain belt (Clement and Higuchi 2007), and would also reduce the likelihood of drought-driven energy shortages, such as the one that crippled the Brazilian economy in 2003 when hydroelectric reservoirs dried up. By reducing the incidence of fire, the program would avoid $11 to 83 million dollars per year in fire-related costs associated with respiratory ailments and deaths, agricultural damages, and damages to timber if we assume that the incidence of fire in the region will decline together with the reductions in emissions (Mendonça et al. 2004 and http://whrc.org/Brazilcarbon supplement). The slowing of deforestation would also prevent the devastation of at least five ecoregions whose ranges would decrease by at least 85%. These ecoregions include the Maranhão babaçu forest, the Marañon dry forest, and the Tumbes/Piura dry forest (Soares-Filho et al. 2006).

12. How will it work?

Detailed analysis of the mechanics of a Brazilian REDD program is beyond the scope of this report. Instead, we propose a few key characteristics of the REDD program that would make it more likely to succeed.

- Carbon credit insurance reserve. Emissions reductions achieved today for deforestation or fossil fuel may always be cancelled tomorrow if a country or firm that has traded reductions later emits beyond its target. This problem is particularly important for REDD because of the risk of forest fire. Any emissions trading regime needs mechanisms to insure against such failures. In the case of REDD, a carbon credit insurance reserve could be created, such that some of the reductions achieved and demonstrated would be held in reserve as carbon insurance in case of future increases in deforestation or fires. Contractual liability rules should be established as part of the REDD negotiation to determine whether the seller, the buyers, or both are responsible for the insurance reserve. If Brazil were to assume responsibility for a very conservative ratio of insurance reserve to marketable reductions, of 1:1, this would in effect double the cost of implementing REDD. The greater the seller's willingness to provide such insurance, the more competitive its reductions would be in the market.

- Transparency and oversight. The Brazilian Amazon REDD program will depend upon major strides in improving the efficiency of government institutions. The success of the program will depend upon the design of efficient, transparent systems for managing REDD funds, for issuing and implementing deforestation permits during the first ten years of the program, for managing the timber sector, for developing programs that support a transition to forest-based economies among public forest stewards, and for determining the fair compensation cost to private forest stewards will be central to the success of the program.

- Monitoring and validation. Brazil has developed the world's most successful system of rainforest monitoring (INPE 2007). This system could become even better as it begins to incorporate recent innovations in the mapping of Amazon forest degradation (Asner et al. 2005, Oliveira et al. 2007) and cloud-free mapping of land cover and biomass using new radar sensors, such as ALOS/PALSAR (Kellndorfer et al. 2007, companion report). In the near term, Brazil's "PRODES" monitoring program could be supplemented with annual mapping of the entire Brazilian Amazon forest formation, with no interference from clouds and with biomass estimates for a large portion of cleared lands, for a price that is well below optical sensor methods.

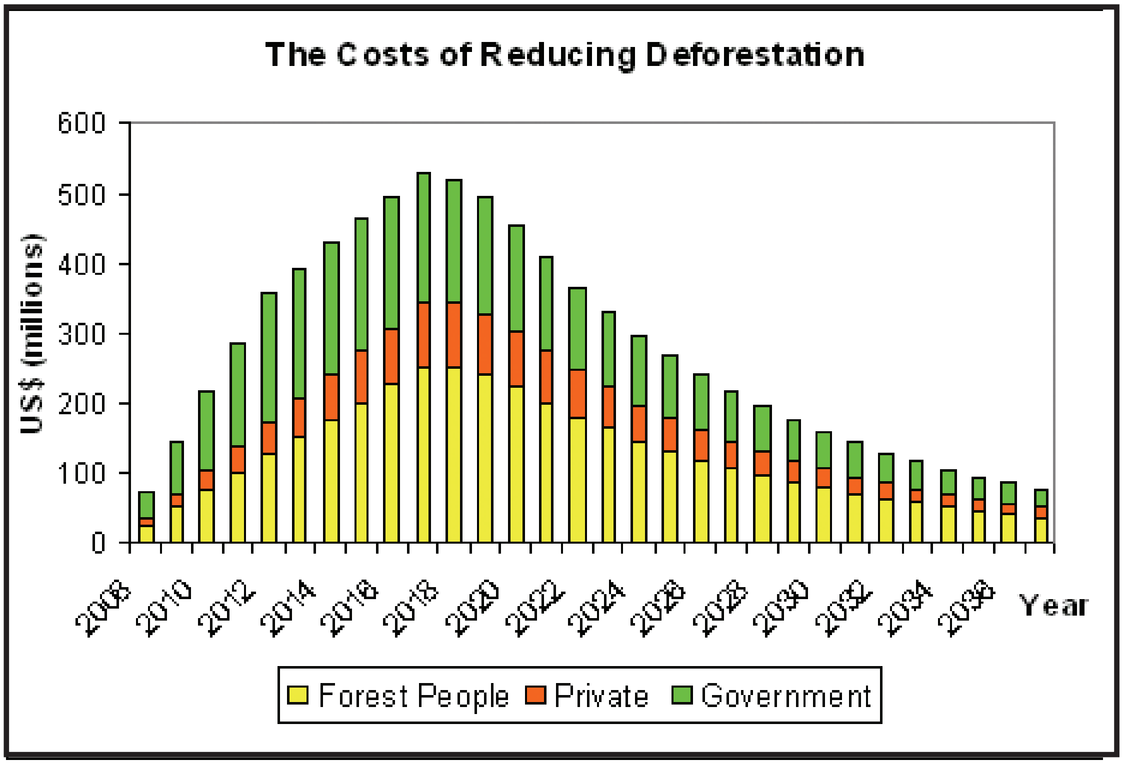

Figure 10. Example of the estimated costs of the Public Forest Stewardship Fund (Forest People), the Private Forest Stewardship Fund, and the Government Fund over a thirty-year period using the premises set forth in this report.

13. Conclusion

This analysis indicates that carbon emissions from the Brazilian Amazon might decrease by six billion tons over a thirty-year period through a fairly modest flow of funding into the region—about $8 billion. This estimate is lower than previous estimates of REDD (Sathaye et al. 2006, Obersteiner et al. 2006, Sohngen and Sedjo 2006, Stern 2006), largely because opportunity costs are not fully compensated, and spatially-explicit modeling of land use rents demonstrates that most carbon emissions carry very low opportunity costs. A REDD program that compensates at a level that is less than opportunity cost is justifiable given the very substantial benefits that this program would provide to Brazilian society. These include the doubling of income and improved health, education, and technical assistance services for 200,000 forest-dwelling families. The benefits also include a more secure rainfall system for central and southern Brazil, and the avoidance of $11 to 83 million per year in fire-related damages to the Amazon economy. The successful reduction of emissions to nearly zero over a decade is a daunting task, and will depend upon innovation and major strides in the development of efficient, transparent institutions.

Footnotes

[1] Landholders are "legal" if they have clear title to their property or have been issued legal declarations ("Termo de Ajuste de Conduto") through which they commit to take the necessary steps to legalize their properties.

[2] Subsidiary Body for Scientific and Technological Advice

[3] The Pact was launched on October 3rd 2007 within the National Congress (Committee of Environment and Sustainable Development). This launching session was attended by the Minister of Environment, Marina Silva, two state governors (Mato Grosso and Amapá), Secretaries of two others states (Amazonas and Acre) and the main environmental relevant congressmen. The Pact establishes an agreement among different sectors (State Amazon governors, Federal governor, representatives from the rural producers, from the agribusiness industries, socio-environmental organizations, social movements, indigenous and traditional population living in the forests) to acknowledge the value of the standing forest and eliminate the deforestation in Amazonia over the next seven years.
[4] We assume that logging decreases carbon stocks by 15% (Asner et al. 2005) while soy and pasture reduces stocks by 85% (Fearnside 1997). Carbon emission reduction is taken as the difference between these two for a given forest pixel that is not cleared.

[4] We assume that logging decreases carbon stocks by 15% (Asner et al. 2005) while soy and pasture reduces stocks by 85% (Fearnside 1997). Carbon emission reduction is taken as the difference between these two for a given forest pixel that is not cleared.

[5] This report is not an official representation of the expectation of the Aliaca dos Povos da Floresta, but is informed by discussions with its members.

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