EXTENDED ANALYSIS

FOREST CARBON INDEX

The geography of forests in climate solutions

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Forest Carbon Index

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Visit www.forestcarbonindex.org to download the *Summary for Policymakers* and use the interactive maps.

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EXECUTIVE SUMMARY

The Forest Carbon Index uses the best available data to to analyze the potential of every piece of land on earth to combat climate change by storing carbon in forests, whether existing or newly planted. It illuminates the likely geography of forest carbon asset supplies to determine which areas have the potential to generate forest carbon credits. The index also estimates forest carbon market conditions—including prices, quantities, and revenues, both locally and nationally—by considering opportunity costs, carbon mitigation potentials, investment risks, and government readiness.

The geography of potential supply indicates that many low-cost opportunities for forest carbon exist across the tropics. Countries in the Congo Basin, Amazon–Andes, and Southeast Asian Islands have the least-cost forest carbon opportunities. The way in which policy is designed and rules are set will drastically influence the geography of supply. Brazil, Mexico, Peru, and Bolivia have the most immediate potential for forest carbon generation due to low costs, large supplies, good governance, market functionality, and readiness conditions.

The number of credits each country can supply to global carbon markets may depend more on their historical deforestation rates than on the availability of low-cost forest stocks. Countries like Brazil and Indonesia, with the highest historical deforestation rates, will be able to supply the largest quantities to the market, whereas countries like Peru, with low historical deforestation but large quantities of low-cost stocks, will not have high supply potential. In fact, Brazil and Indonesia will likely become the largest suppliers of credits in the world.

As the market develops and countries improve their governance and market readiness, countries like Malaysia, Mexico, and Nigeria will hold great potential to become big players in the forest carbon market. Moreover, if countries are permitted to supply forest carbon despite low historical deforestation rates, countries like Colombia, Democratic Republic of Congo, Gabon, Guyana, Republic of Congo, and Central African Republic may also become some of the biggest players in the forest carbon market as their readiness improves and their governance conditions stabilize.

The Forest Carbon Index demonstrates that tropical forests could be a huge part of the immediate climate change solution. Forest conservation and regrowth will mitigate almost 1 gigaton of carbon dioxide equivalent ($GtCO_2$-eq) of greenhouse gas emissions each year from 2013 to 2020. Avoiding deforestation, in particular, will be a cheap way to mitigate climate change at a large scale and has the potential to create a forest carbon market worth approximately $18 billion per year from 2013 to 2020.

Such a robust forest carbon market will provide numerous co-benefits beyond climate change mitigation. If the rules of the market are appropriately designed, forest carbon markets could help protect tropical biodiversity and alleviate poverty in many rural communities in the tropics. These co-benefits, alongside the improved governance conditions that will be required for market participation, will also improve national security both within these tropical forested countries as well as the developed nations that are financing these efforts.

Policymakers will also need to carefully consider a broad set of safeguards to ensure that the forest carbon market successfully achieves its intended goals. For example, the rules that describe how countries get compensated for forest carbon will ultimately determine the geography and quantity of supply. If countries are only compensated for reducing their historical deforestation rates, many countries that currently have low deforestation will face increased pressure to clear their forests, a problem known as international leakage. The result will only be a change in the location of deforestation, rather than a global reduction in deforestation.

Policymakers will also need to create safeguards to protect food production, and in some cases it will be appropriate to dedicate funds toward comprehensive land-use planning. To ensure that the increasing demand for food is met, forest carbon markets should be designed to avoid shifting significant areas of agriculturally productive land into forests.

The broad range of country circumstances indicates the need for multiple financing mechanisms. These include a market-based program to pay for performance through carbon credits and a government-to-government fund that will drive governance reforms in countries that are not yet ready to participate in markets. Alternate funds may also be necessary to promote global forest monitoring systems and to enhance food production in vulnerable regions.

Upcoming forest carbon policies that provide innovative new financial incentives hold the potential to conserve tropical forests unlike any effort in history. These policies will be able to unleash private-sector financing and ensure that forested countries are compensated for managing one of the most important global resources: standing forests.

CHAPTER 1. INTRODUCTION

This chapter provides the backdrop to how the recent confluence of science, policy, and economics has come to shape a need for the Forest Carbon Index (FCI).

The Scientific Basis

Human activities have caused the destruction of vast areas of forests across the globe for decades. This forest loss not only results in the disappearance of habitat for many species, but also contributes greatly to climate change, which threatens the livelihoods of millions of people worldwide.

Despite the millions of dollars spent over the years on forest conservation, deforestation continues at an alarming rate. Each year, about 50,000 square miles of forests are cleared, an area roughly the size of New York State.[1] Most of this deforestation occurs in the tropics, typically to clear land for cattle ranching and agricultural expansion.[2]

Trees naturally store carbon in their wood, roots, and leaves, and increase the amount of carbon that is stored in soils. This natural carbon stock is collectively referred to as *forest carbon*. When forests are cut or cleared by using slash-and-burn techniques, the forest carbon is emitted into the atmosphere and contributes to climate change. These emissions will continue for several years after forest are cut as the forest litter decays and the soil is tilled, releasing even more of the naturally stored carbon.

Rapid deforestation in the tropics is therefore a huge contributor of greenhouse gas emissions. Studies show that between 12 and 25 percent of annual greenhouse gas emissions come from tropical deforestation.[3] This amounts to a greater release of greenhouse gases than that produced by the entire global transportation sector. In other words, tropical deforestation results in more emissions than all the cars, trains, planes, and boats in the world combined. [4]

Three approaches have emerged for to tackling emissions from deforestation: (1) avoiding deforestation, (2) growing new forests, and (3) managing existing forests to increase carbon stocks. Avoiding deforestation and forest degradation stops emissions before they happen and maintains the carbon stocks at their existing levels. Growing forests through afforestation (growing new forest) and reforestation (regrowing a cleared forest) helps to recapture carbon dioxide and store it in forests. This occurs because, as new trees grow, their respiration sequesters carbon from the atmosphere and converts it to biomass. Forests can also be managed to increase carbon stocks. For example, many existing timber plantations are cut on relatively short rotations to maximize profits. Simply by extending these rotations, trees will sequester more carbon. Policymakers are now exploring a combination of all three approaches to tackle global deforestation.

Emerging Forest Carbon Policy

The current negotiations under the UN Framework Convention on Climate Change will determine the future of international climate change policy. Meanwhile, domestic policies are emerging in a broad range of countries that will create a complex interplay between international and domestic climate law.

The first international climate treaty, known as the Kyoto Protocol,[5] is set to expire at the end of 2012. Representatives from almost every country in the world are now meeting regularly to craft a post-Kyoto international climate treaty. The topic of forest carbon has become increasingly central to these international negotiations.[6]

Existing international climate change policy addresses deforestation in a limited fashion. The Kyoto Protocol recognizes activities that create new forests, like afforestation and reforestation (A/R), under a program known as the Clean Development Mechanism (CDM). The CDM allows developing countries to sell emissions reduction credits to industrialized countries as offsets, which help industrialized countries meet their emissions reduction targets more cheaply.

The Kyoto Protocol does not, however, contain any provision for avoiding deforestation outright. U.N. negotiations now focus enormous attention on how to reasonably incorporate a policy that promotes reducing emissions from deforestation and degradation, or REDD. The goal is to include REDD and A/R as well as sustainable forest management in the next commitment period of the Kyoto Protocol, which begins in 2012.

A new forest carbon policy has not yet been defined in detail, but the framework will be complex. The policy will contain new financial incentives for these forest activities but will also require fundamental reform in forest governance. And unlike the Kyoto Protocol, a new forest carbon policy will attempt to engage the participation of virtually every country in the world. Each country will have unique demands, thus increasing the complexity of the ultimate framework.

The complexity of forest carbon policy may ultimately be an important strength, however. A global policy will be the first opportunity in human history to comprehensively manage the world's forests under a guiding framework that makes all participating countries accountable. Indeed, it will also be the first opportunity to engage many developing countries, where most deforestation occurs, in climate change mitigation.

Under the Kyoto Protocol, only industrialized countries are obligated to set emissions reduction targets,[7] and yet developing countries are now experiencing rapid growth in their greenhouse gas emissions. Indeed, developing countries are expected to account for almost all of the projected 45 percent increase in global greenhouse gas emissions by 2030.[8] Indonesia, for example, is now the third-largest emitter of greenhouse gases in the world, below China and the United States,[9] and the vast majority of Indonesia's greenhouse gas emissions are due to deforestation.[10] If Indonesia receives financial incentives to preserve standing forests under a new forest carbon policy, it quickly could become a major player in climate change mitigation efforts.

Forest carbon concerns are also making their way into the domestic policies of various countries. The United States and Brazil have made especially advanced strides toward establishing effective forest carbon policies.

The U.S. House of Representatives passed, in June 2009, the American Clean Energy and Security Act of 2009 (H.R. 2454), which heavily emphasizes emissions reductions from international forest carbon. This bill would demand as little as 720MtCO_2-eq and as much as 2.22GtCO_2-eq from international forest carbon. The forest carbon provisions in the Senate bill may be similar to those of the House bill, although they could be weakened as much as the more conservative bill proposed in the Senate in 2008 (S 2191).

The European Union has a more general goal, not yet articulated in any specific legislation, to reduce tropical deforestation by 50 percent by 2020 and halt all forest cover loss by 2030.[11] Japan and Australia will also likely establish national policies that create a demand for forest carbon.

Some developing countries are also developing their own national forest carbon policies in anticipation of future forest carbon markets. The most notable case is Brazil, which launched the Amazon Fund in 2008 (with coordination and funding from the Norwegian government). The Amazon Fund sets the ambitious target of halting all deforestation in Brazil by 2020, providing there is sufficient funding from developed countries. At least 25 other developing countries have indicated interest in participating in forest carbon markets by applying for World Bank funds to build capacity for market participation.[12]

Economics of Forest Carbon Markets

The rapid movement in climate change policy to favor forest carbon is largely due to the fact that deforestation is a large source of emissions that can be abated at a relatively low cost. Compared to many other forms of emissions abatement, forest carbon activities that include both REDD and A/R can be inexpensive once forest governance is well established. For this reason, current U.S. climate legislation uses forest carbon offsets to control costs. Forest carbon credits will likely serve a similar role in other countries. Developed countries that use forest carbon offsets will be able to control some of the costs of climate regulation, easing the burden on domestic industries and providing them time to adapt to new climate regulations.

In order to meet the coming demand for forest carbon credits, it is critical to understand which countries hold the best opportunities for investing in forest carbon, and at what cost. A number of early studies estimated the potential supply and costs of forest carbon by using a broad range of methodologies.

Many provide simple global or country-level estimates of supplies while attempting to capture expected policy conditions.[13] These studies have been important in testing the general effects of various policy assumptions, especially regarding the selection of baselines.[14] They typically focus on REDD, but in some cases also consider A/R.[15]

Several studies have analyzed the costs of carbon sequestration and the costs of avoiding deforestation at the local, grid level and helped to propel the spatial modeling work and more advanced economic modeling of land-use costs.[16]

The cost estimates vary across this broad range of methodological approaches. Among the most important factors that affect estimates are (1) the baseline deforestation rates, (2) the expected market price of carbon credits, and (3) the amount of reduced deforestation per year. While cost estimates have a wide range, from \$1 to over \$100/tCO_2-eq, most studies estimate costs below \$10/tCO_2-eq.[17, 18] A broad review of the economic literature estimates that carbon prices of \$10 to \$30/tCO_2 could generate 1 to 4 GtCO_2 in carbon credits from avoided deforestation.[19] This amount could potentially be doubled with additional forest regrowth and management.

Contributions of the Forest Carbon Index

The FCI combines the best available data and methodological approaches to achieve two specific objectives:

- Illuminate geography of potential forest carbon, and
- Estimate forest carbon costs, quantities, and revenues

The FCI is a powerful tool for policymakers and market players because it achieves these objectives by employing the most relevant sets of conditions. These include:

- **Forest activities:** Incorporates both REDD and A/R
- **Policy relevance:** Models the most likely policy and market conditions
- **Scale:** Provides insight at the global, national, and local levels for all countries with forest carbon potential
- **Risk factors:** Explicitly accounts for risk factors such as country governance, ease of doing business, and readiness
- **Geography:** Uses a hybrid of stock and flow approach to predict the geography of supply

These factors are all combined to create a single index that provides a relative ranking comparing countries and specific locations for their relative capacity to supply forest carbon credits. The results are presented in maps to illustrate the potential geography of forest carbon and in tables to show the estimated costs, quantities, and revenues from forest carbon.

CHAPTER 2. GEOGRAPHY OF FOREST CARBON

The geography of forest carbon is illustrated at two spatial scales: the country scale and the local scale. The global FCI model therefore shows how each country and each grid cell (location) compares in its relative ability to generate forest carbon credits.

The country scale will be useful for investors to get a "big picture" for their investment strategy. Should they start looking into potential project sites in South Africa or Botswana? Argentina or Chile? The country scale is also important for policymakers to see which countries will be the big winners in an eventual forest carbon market. This may result in two outcomes. First, there could be greater involvement in forest carbon markets by countries that previously did not recognize an opportunity to attract investment. Second, there could be less involvement by countries that thought they would be big players, but realize that they might be outcompeted by many other countries. The second result will likely be tempered by providing results at the local scale so that almost all countries will see specific areas within their borders where forest carbon will be possible.

Local-level results will show the governments of each country exactly where they have good investment opportunities for forest carbon. Even countries that may not be major players may still have a few locations where they will be able to provide forest carbon credits at a competitive price. The local scale will also be useful for investors to see particular locations where there are good opportunities for forest carbon investment if they want the geography to be more specific than the country scale will allow.

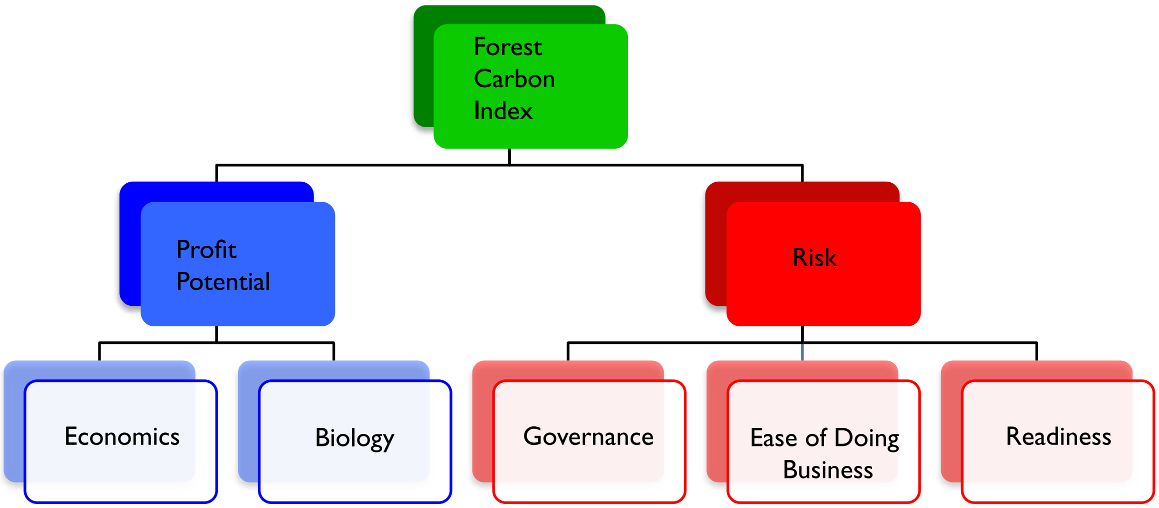
We model separately two major forest-related climate change mitigation activities: REDD and A/R. Since the biology and economy underlying the generation of REDD and A/R are fundamentally different, it is necessary to use different approaches for modeling each activity. We do assume, however, that as long as forest carbon credits are fungible across REDD and A/R, the carbon markets will not care which source generates the credits. This assumption allows us to combine REDD and A/R into a total forest carbon supply.

Forest Carbon Index Framework

The FCI makes it possible to compare the ability of individual countries, or even specific locations within countries, to produce forest carbon credits. The ability of any given place to produce forest carbon is based on a multitude of factors that range from economics and biology to investment risks and market readiness. The FCI captures each of these factors in one composite score that reflects the full set of conditions that influences forest carbon generation (Figure 1).

FCI scores are set to a scale from 0 to 100, with 100 as the best score in the world. These scores are unitless and therefore provide only a descriptive comparison across locations.

Figure 1. FCI Framework



Within the FCI, the two most important factors are profit potential and risk. Profit potential describes the ability of any location to generate abundant, low-cost forest carbon credits based strictly on the economic and biological conditions of that location. The risk factor captures a set of real-world conditions that can create market barriers, make business operation difficult, and discourage investment. The risk factor can therefore be thought of as adjusting the profit potential to reflect real-world market conditions. Profit potential and risk are combined to create the FCI by using the following model:

$$\text{FCI} = \text{Profit Potential} \times \text{Risk Factor}$$

These two metrics that comprise the FCI are also aggregate measures. Profit potential combines a set of economic and biological information about a location to estimate the profit margin per credit and the quantity of credits for a given location. The profit potential metric is calculated locally for every square kilometer of the terrestrial globe and is also aggregated to the country level. It is calculated by using the following model:

$$\text{Profit Potential} = \text{Profit Margin} \times \text{Quantity of Credits}$$

The risk factor combines governance, ease of doing business, and readiness to capture a broad range of different potential market barriers. Risk is only calculated at the country level due to data constraints. And unlike any other piece of the FCI, the three risk metrics are not evenly weighted. *Governance* and *Ease of Doing Business* are given twice the weight of *Readiness*, due to data quality constraints of *Readiness*. *Risk* is calculated by using the following model:

$$\text{Risk} = (\text{Governance} \times 0.4) + (\text{Ease of Doing Business} \times 0.4) + (\text{Readiness} \times 0.2)$$

The FCI also attempts to capture realistic policy and market conditions. Since forest carbon policy is still being developed at the national and international levels, we estimate FCI scores and producer surplus values by using several likely policy scenarios and constraints.

Policy Scenarios

We created three policy scenarios for the FCI that capture two different policy-relevant time periods and two carbon-crediting systems. The three policy scenarios are shown in Table 1 and described in detail below.

Table 1. Policy Scenarios

	Scenario Name	Time Period	Crediting
1	Reference	2013–2020 (Near-term Compliance)	Ex-post
2	Ex-ante	2013–2020 (Near-term Compliance)	Ex-ante
3	Long-term Compliance	2013–2030 (Long-term Compliance)	Ex-post

The time period under the *Reference and Ex-ante* scenarios represents a policy *commitment period*, a period of time within international climate change policy during which countries set emissions reduction targets and try to meet their targets. The current commitment period for the Kyoto Protocol will end in 2012 and the next one will begin in 2013 and end in 2020. This 8-year period will likely be the first commitment period during which all forest carbon activities are governed by international climate policy and are explicitly included in national targets. We refer to this as the *Near-Term Compliance* period. We also create a *Long-Term Compliance* period spanning from 2013 to 2030 to estimate the forest carbon markets further into the future.

The two crediting systems we include are *ex-post* and *ex-ante* accounting. These describe two ways in which forest carbon suppliers can be paid for their assets. The two credit accounting approaches drastically change the outcome for A/R activities and their relative cost-effectiveness compared to REDD. In *ex-post* crediting, credits are only counted once they are generated in order to reduce the opportunities for fraud, which may be large when monitoring and enforcement is poor. Since trees are often slow-growing, revenue trickles in only as fast as the tree can sequester carbon. In the eight years of the N*ear-Term Compliance* period, an A/R project would therefore not be able to generate many credits.

In contrast, an *ex-ante* system of crediting allows suppliers to sell the full quantity of expected future credits from the start of a project. In other words, suppliers can sell, from the outset of a project, the total expected future carbon sequestered. This allows a large quantity of credits to be sold right away, allowing A/R to be cost-competitive with REDD. *Ex-post* accounting drastically reduces the potential carbon content from A/R that could be used for the sale of forest carbon credits than if we used *ex-ante* accounting.

We chose the *Reference Scenario* as the scenario that captures the most relevant policy conditions. The *Reference Scenario* models the first commitment period of the post-Kyoto carbon markets, from 2013 to 2020. The *Reference Scenario* also uses ex post crediting for forest carbon (see Box 1). We chose ex post crediting as the default policy condition because it is the crediting system used by the Voluntary Carbon Standard, which is the main standard used within the voluntary markets.

The second scenario we model is the *Ex-Ante Scenario*, which is identical to our reference scenario except that we use ex ante crediting for A/R. This second scenario is meant to show how drastically the selection of the accounting system will affect the forest carbon markets.

The third scenario we model is a *Long-term Compliance Scenario*, which models the same conditions as the reference scenario out to 2030. This scenario is meant to be slightly more forward looking than the *Reference Scenario.*

The majority of this report focuses on the results from the *Reference Scenario,* but selected results from each scenario are presented throughout the report.

Policy Constraints

Across each of the policy scenarios, we imposed several policy constraints that capture policy and market conditions that will constrain the quantity or price of forest carbon supplies. The four primary ones that we use are:

1. Price constraints,
2. Non-permanence risk buffer, and
3. Additionality threshold.
4. Quantity limits

Price Constraints

Forest carbon credits will ultimately have to compete with credits generated from all other sectors of climate mitigation in the carbon markets. If offsets generated through energy efficiency projects or methane recapture projects are cheaper than forest carbon offsets, these competing offsets will be preferred in the market. The purpose of the price constraint is to reflect that buyers of forests carbon credits realistically have an entire credit market to choose from under a cap-and-trade system. These buyers will always have the option to purchase the most affordable offsets on the international carbon markets, and if forest carbon credits are too expensive, buyers will have the option of purchasing non-forest credits. The effect of the price constraint is that only the affordable forest carbon credits are counted in the model as a part of the global supply, and the excessively expensive credits are excluded.

In order to set the price constraints, we use reasonable estimates of the price of carbon credits on the international carbon markets in the years 2020 and 2030 based on the most trusted price estimates available.[20]

The summary formulation of the price constraints is presented in Table 2.

Table 2.Price Caps for Each Scenario

Scenario	Price Estimate Year	Price Constraint
Reference	2020	\$20/tCO2-eq
Ex-ante	2020	\$20/tCO2-eq
Long-term Compliance	2030	\$40/tCO2-eq

For the *Reference* and *Ex-Ante Scenarios*, we exclude all locations where it would cost more than \$20/tCO_2-eq to produce forest carbon, and for the *Long-term Compliance Scenario,* we exclude all locations where it would cost more than \$40/tCO_2-eq.[21]

Non-Permanence Risk Buffer

Trees are not permanent because they can die as a result of many causes, both natural and human-induced. The risk of mortality introduces the possibility that a conserved forest set could be harvested or burned down as soon as credits are sold.

The current approach being used to address this problem within existing voluntary forest carbon markets is to set aside a quantity of credits into a buffer pool that serves as a reserve of forest carbon credits. To model this approach in the FCI, we subtract a fixed percentage of credits from the potential number of credits produced on each hectare. The methodology in the FCI is taken specifically from the Voluntary Carbon Standard, one of the major forest carbon certifiers within the voluntary carbon markets.

The Voluntary Carbon Standard sets aside different percentages of credits from projects based on their risk ratings: high-risk projects have a higher percentage of credits set aside than low-risk ones. We select a high-risk buffer value due to the uncertainty around permanence in our analysis, and doing so results in a more conservative estimate in the quantities produced. A project with a high risk rating under the Voluntary Carbon Standard is initially 30 percent. This percentage decreases over time, and credits can be regained as projects prove to be less risky. We therefore select the fraction of credits that correspond with the length of each policy scenario.

The Voluntary Carbon Standard only allows for credits to be regained in five-year increments; 15 percent of the remaining buffer can be regained after each five-year period. Adjusting their values for our commitment periods and rounding to the nearest percentage provides the following buffers:

1. 2013–2020: 22 percent
2. 2013–2030: 17 percent

As an approximation to this methodology, we use simplified non-permanence risk buffer values for each commitment period due to the uncertainty inherent in these estimations as well as for simpler presentation (shown in Table 3).

Table 3. Non-Permanence Risk Buffer for Each Scenario

Scenario	Length of Period	Non-permanence Risk Buffer
Reference	8 years	20%
Ex-ante	8 years	20%
Long-term Compliance	18 years	15%

The most important effect of this buffer is that it reduces the total number of credits that can be produced from any given location and thus globally. Indeed, the buffer also means that 20 percent fewer credits will be available globally in 2020.

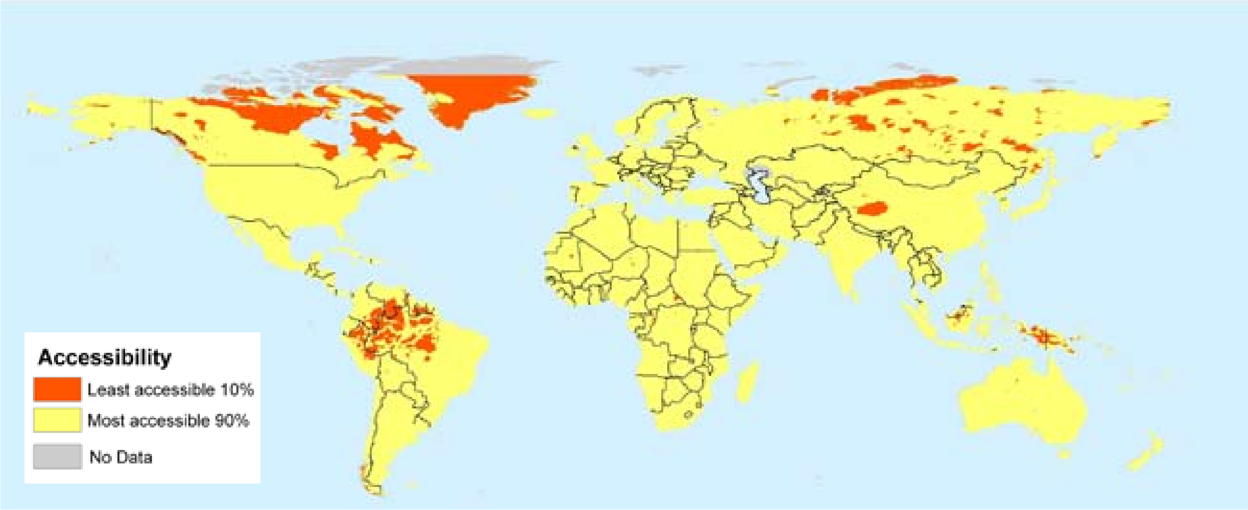
Additionality Threshold

The final policy constraint in the FCI is an additionality threshold, which serves to exclude forests that are isolated from human encroachment. This policy constraint is currently used in voluntary markets to prevent REDD projects from selling credits by protecting forests that were never in danger of being cut. The credits from such isolated forests would be considered non-additional because the revenue spent on these credits would not help to reduce deforestation.

We assume that the least accessible forests in the world would not be able to easily establish additionality and will therefore not be eligible locations to produce REDD credits. We therefore exclude all forests that fall within the 10 percent least-accessible areas of the world on the basis that they are nonadditional for REDD. The regions in orange in Figure 2 are the 10 percent least-accessible areas and are excluded from the FCI.

Accessibility is measured using a model that measures the amount of human effort required to access an area of forest.[22] Effort is estimated with a combination of variables, including distance to transportation infrastructure, topography, eco-region type (vegetation density), and population density.

Figure 2. Accessibility to Human Encroachment



The 10 percent least-accessible areas (shown in orange) span 44 countries across the globe. Most of the areas excluded were already in regions outside the geographic scope of A/R and REDD, such as the tundra and Arctic areas of northern Canada, northern Russia, and Greenland, as well as parts of Tibet. Of the areas excluded, however, 38 percent were forested, and therefore potentially usable for REDD. This excluded area amounts to only 0.11 percent of the total forest area of the world and so does not drastically reduce the total forest area available for REDD. The largest forested area excluded is in Canada's northern boreal forest—approximately 4 million km^2. Just over 1 million km^2 of forested area was excluded from the Brazilian Amazon. At least some forested areas were also excluded from virtually every country containing significant forested area.

These estimates of accessibility are only a snapshot in time, and do not reflect the construction of new transportation infrastructure that could make many areas more accessible.

Quantity Limits

Developed country governments are likely to cap demand for forest carbon by imposing quantitative limits on forest carbon tons that qualify under various national, regional, and global climate policy frameworks. The purpose of this constraint is to calculate the expected global demand for forest carbon credits based on the most likely current policy proposals. The global demand will set cap on the quantity of credits purchased on the market and therefore limit the total number of credits included in the model. All credits generated above the quantity cap for each scenario are excluded.

The U.S. Congress is in the midst of crafting a climate bill that will set a limit to the U.S. demand for forest carbon. The House and Senate legislative proposals would limit U.S. demand for tropical forest carbon to between 1-1.5 $GtCO_2$-eq a year. In contrast, the allocation for forest carbon for the next phase of the EU Emission Trading System is not yet established, and will likely change to accommodate the outcome of the UN negotiations. The same will likely also be true for other major compliance markets in Japan and Australia.

As a rough upper-end approximation, the FCI limits the global demand for forest carbon to twice the maximum U.S. demand, or 3$GtCO_2$-eq per year. However, since the FCI projects that the quantity supplied never exceeds this cap, this policy constraint has no effect on the results of the index.

Profit Potential

Profit potential is one of two fundamental pillars of the FCI. Profit potential captures the economic and biological capacity of a location to hold abundant and cost-effective forest carbon credits. It represents the net profit (in dollars) that could be obtained by selling all the potential forest carbon credits from a given location.

Profit potential is calculated at both the country and local levels. Country-level profit potential (which can also be thought of as the national-level producer surplus of forest carbon supplies within each country) compares countries based on both the quantity and price of forest carbon generated.[23] Profit potentials at the national levels should not be confused with expected profits. They are calculated by using forest carbon stocks, or the total quantity of credits that is available below the price constraint. Expected profits, in contrast, are calculated limited only to the quantity of credits that countries will be able to sell that effectively reduce their deforestation rates to zero. Expected profits are the actual projected country-level profits.

At the local level, we provide profit potential results for every square kilometer of the terrestrial global that has the biological potential to grow forests. Since there is great within-country variation in the potential carbon contents and costs of land, local-level profit potentials help highlight the best specific places within a country for forest carbon.

In order to calculate profit potentials at the country and local levels, we created forest carbon supply curves for each country. Supply curves show, for each country, how much forest carbon is available and at what costs.

We next show how the supply curves were created, first by describing the geographic scope of A/R and REDD, and then by describing the two core component variables that dictate forest carbon supplies, carbon content of forests and the opportunity costs of land.

We then construct our forest carbon quantity and cost models by combining carbon contents and opportunity costs with the policy constraints discussed previously.

From our forest carbon quantity and cost models, we can calculate local profit potentials and generate country-level supply curves to calculate country-level profit potentials.

Geographic Scope of A/R and REDD

Forests cover approximately 37 percent of the earth's surface and even more used to be forested before humans cleared the land. Much of the land that is not forested today therefore has the potential to grow new forests for A/R. The FCI captures the capacity of both REDD and A/R activities to serve as cost-effective climate change mitigation activities. To separate potential locations for A/R versus REDD across the globe, we categorized every terrestrial grid cell as either a location for REDD or A/R, or as having no forest carbon.

In order to categorize each grid cell at the local level, we used a global land-cover map that classifies over 20 land types.[24] Each grid cell was classified as either nonforested lands suitable for A/R (including crop lands, shrub lands, savannah, and grasslands) or forested land for REDD. A/R therefore only occurs on grid cells with no existing forests.

Including savannahs and grasslands as areas potentially available to A/R poses a significant problem, because these ecotypes have their own biodiversity value. Savannahs and grasslands host many species that do not exist in forests and would be lost if these ecotypes were converted to forest. In addition, the soils of these ecotypes may not be optimally suited for A/R, and in many cases already contain high below-ground carbon stocks.[25] These potential restrictions are not accurately reflected in our model. Nevertheless, there does not yet appear to be any biodiversity safeguards in the prominent existing policy proposals, so while this is problematic, we still opted to model the likely policy outcome that would allow all non-forest ecotypes to be available for A/R.

Grid cells that were not suitable for forest carbon, such as urban areas and deserts, were excluded from the analysis altogether.

The geographic scope of A/R and REDD can be seen in Figure 3.

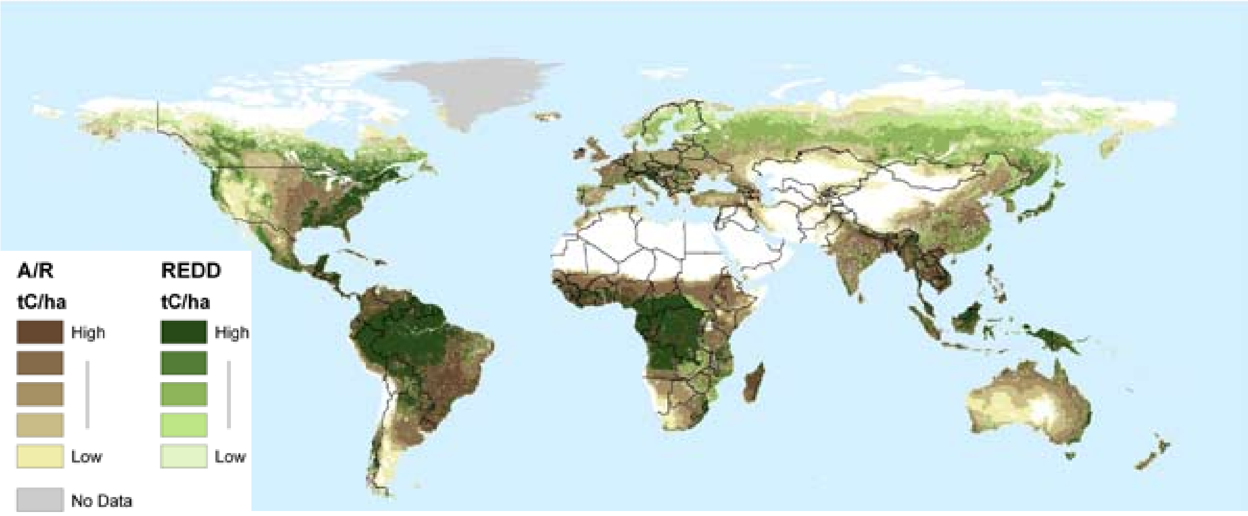
Carbon Content of A/R and REDD

The carbon content of land refers to the amount of carbon that is stored, or could potentially be stored, on that land. Carbon content forms the basis for measuring the quantity of carbon credits that can be generated on any given piece of land. Before any policy constraints are applied to find the potential quantity of A/R and REDD produced on each grid cell, we first calculate the potential carbon contents for REDD and A/R based strictly on biological factors.

The potential A/R carbon content on each grid cell is based on a forest growth model that estimates the potential above-ground net carbon accumulation for each grid cell designated as A/R land based on site-specific net primary productivity. [26]

The REDD carbon content of each grid cell is based on the existing carbon content in the forests (in tons of carbon per grid) rather than the potential growth in forests. This existing forest carbon content model[27] estimates local-level forest carbon stocks by combining a local-level net primary productivity model[28] with country-level biomass estimates from the UN Food and Agriculture Organization.[29] The model also tries to account for degradation by using local-level human influence data as a proxy for degradation; the more human influence[30] an area of forest has, the more degraded it is assumed to be. Figure 3 shows the geographic scope and potential carbon contents of A/R and REDD.

Figure 3. Above-Ground Carbon Content without Policy Constraints[31]



These models generate a potential geographic scope of A/R that is overly generous, but they are meant to show all locations where growing forests is biologically possible. In fact, this model finds that 85 percent of the terrestrial surface could theoretically be used for growing forests, despite the fact that on much of the land it would not be cost effective to do so give the local conditions. A total of 37 percent of the terrestrial surface area could be used for REDD, and 49 percent for A/R. This estimate for A/R is also overly generous, because much of the land that is designated as potential forest land may actually not be as productive in terms of growth than the forest growth model assumes. The total potential forest carbon stock is 4,403 Gt CO_2-eq. The total biological potential for A/R is a carbon stock of 3,641 $GtCO_2$-eq, which is an absolute maximum biological potential.The existing carbon stock in forests is 763 GtCO2-eq.This value compares with other estimates in the literature, which range from about 400 to 1,100 $GtCO_2$-eq. [32]

The tropics contain the highest above-ground carbon content at any given location. Focusing just on the locations with the top 1 percent of carbon content quantities (see Figure 4), the richest carbon content locations are in southern and central Brazil, western Venezuela/northern Colombia, and the Republic of Congo, as well as a spattering of locations across the Congo Basin and Southeast Asia.

While we use the best available global estimates of potential forest carbon supplies from A/R and REDD that are spatially explicit, these results should be interpreted with some caution. The potential quantities of forest carbon generated from A/R projects will depend greatly on the tree species used, the forest management practices, and the highly localized soil and climatic conditions. For example, the forest growth model we use assumes natural forest growth rates, but A/R projects often use intensively managed fast-growing species that may grow much more quickly. This model also assumes forests can grow in many areas where the soil and precipitation may not be conducive to growing trees, and in habitats like grasslands and savannahs where afforestation might not make sense. As a result, there are cases for which these data could either underestimate or overestimate the actual potential carbon content, and for each location there will always be a range of possible values that are not captured here.

Figure 4. Top 1 Percent of Above-Ground Carbon Content Without Policy Constraints

The carbon content of existing forests will also depend on forest degradation, which is not well captured here. Remote sensing techniques for measuring degradation directly are a major area of research today,[33] but as yet no global datasets provide such information.

Forest Carbon Quantity Models

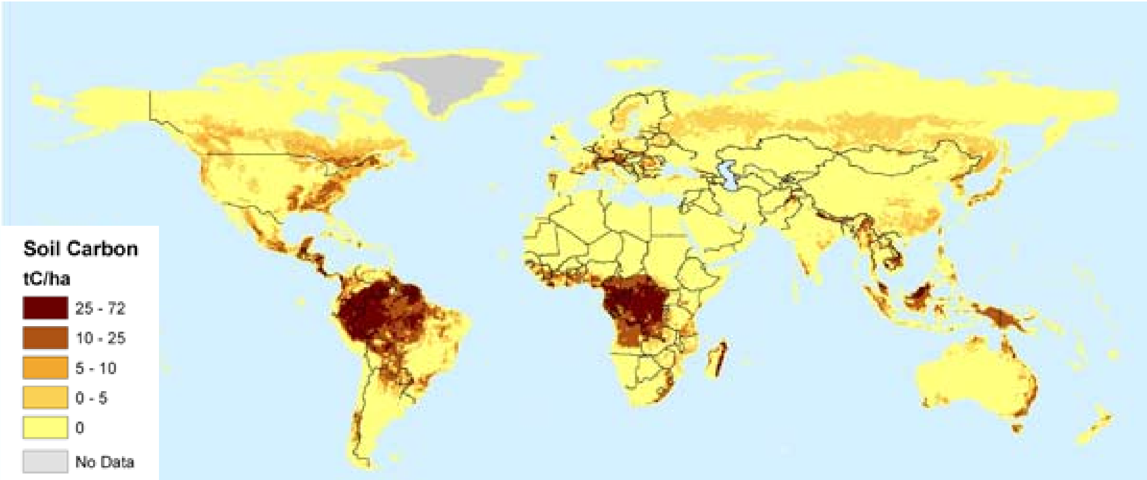
Above-ground carbon content values show the maximum biological potential of forest carbon in any given area, but they do not show the actual quantity of forest carbon credits that could be sold. The quantity of credits depends on policy, which can drastically affect supply. Illuminating the geography of policy-constrained forest carbon credits across the globe identifies the highest-yield locations for investing in forest carbon.

The models used to derive the quantities of REDD and A/R are different due to the fundamental difference in protecting trees versus growing new trees.

Box 1. Soil Carbon

The FCI does not account for soil carbon, and yet the quantity of carbon in the soil can vary significantly across different ecoregions. Soil carbon content can be especially high in the tropics. It tends to be less in cooler areas, and arid regions of the world generally have the lowest soil carbon content (see Figure 5).

Figure 5. Soil Carbon Stocks[34]



Until soil carbon accounting improves, carbon markets will continue to be reluctant to allow the sale of soil carbon credits. Governments are likely to agree on methodologies for measuring soil carbon in the near future, but no systematic effort to measure soil carbon globally yet exists.Because of this lack of global data, and the uncertainty in how or whether soil carbon will appear in the near-term compliance markets, soil carbon was left out of the FCI entirely.

A/R Quantity Model with Policy Constraints

The quantities of A/R credits that can be generated from a given area of land depend on a number of biological and policy variables. In addition to the geographic scope and potential carbon contents of A/R, the quantity of credits also depends on the crediting system (ex post versus ex ante) and the quantity of credits taken out for the non-permanence risk buffer. The quantity of A/R credits generated in any given grid cell under the Reference Scenario is determined by using the following model:

$$\text{A/R Quantity} \Rightarrow \left(\frac{\text{tCO}_2\text{eq.}}{\text{cell}}\right) = \left(\frac{\text{tC}_{\text{Year8}}}{\text{ha}}\right)\left(3.66\,\frac{\text{CO}_2\text{eq.}}{\text{C}}\right)(0.8)\left(\frac{\text{ha}}{\text{cell}}\right)$$

This model contains four terms: the first term is the potential carbon content (in tons of carbon per hectare) that would accumulate over eight years (2013–2020) through A/R; the second term is a conversion factor converting C to CO_2-eq; the third term (0.8) is a non-permanence risk buffer, and the fourth term puts the value in terms of quantity of CO_2-eq per grid cell.

The third term, the non-permanence risk buffer, is the main policy constraint adjusting A/R quantities. In the case of the reference scenario, the non-permanence risk buffer allows 80 percent of A/R credits to be available for sale after eight years.

The model output provides the number of credits that can be sold on each grid cell (in tons of CO_2-eq).

REDD Quantity Model with Policy Constraints

The quantity of REDD credits that can be generated in a given area also depends on biological and policy conditions, as in the case with A/R. The main difference, however, is that the crediting system plays no role in determining the quantity of credits generated. Since all of the carbon is already in the trees from the outset of a REDD project, the quantity of credits available does not change over time. The quantity of REDD credits can therefore be derived from the following model:

$$\text{REDD Quantity} \Rightarrow \left(\frac{\text{tCO}_2\text{eq.}}{\text{cell}}\right) = \left(\frac{\text{tC}}{\text{ha}}\right)\left(3.66\,\frac{\text{CO}_2\text{eq.}}{\text{C}}\right)(0.8)\left(\frac{\text{ha}}{\text{cell}}\right)$$

Like the A/R model, the REDD quantity model contains four terms: the first term is the existing carbon content (in tons of carbon per hectare); the second is a conversion factor converting C to CO_2-eq; the third (0.8) is the non-permanence risk buffer; and the fourth puts the value in terms of quantity of CO_2-eq per grid cell. The REDD quantity model output also provides the number of REDD credits that can be sold on a given grid cell.

Forest Carbon Cost Models

Deriving the cost of generating forest carbon credits allows us to identify the least-cost locations for investing in forest carbon. The cost of forest carbon at any given location depends not only on the quantities of credits that can be sold from a given location, but also on the cost of land, known as the *opportunity cost*. By combining the opportunity costs with the forest carbon quantities, we construct the cost models for A/R and REDD.

Opportunity Costs of Land

The opportunity cost of land plays a critical role in determining the cost of generating forest carbon credits. Because forests require a significant amount of land area, that land must be either purchased or rented to ensure the land can be used exclusively to grow and protect a forest. The opportunity cost represents the value of that land by estimating how much revenue the next highest-valued use could generate. For example, forested land is often slashed and burned to grow crops or raise livestock. The opportunity cost in any given year is therefore the amount of revenue that agriculture could generate on that land.

Opportunity costs of land are, by far, the largest cost associated with A/R or REDD, and we assume that all the foregone revenue into the future from agriculture and timber represent the total value of the land or the cost of purchasing the land. For both A/R and REDD, we use a generalized model that calculates the present value of foregone rents over the next 100 years. We modeled the opportunity costs of A/R and REDD land differently, since the alternative land uses on each can be different, and therefore generate different rents.

We assume that the opportunity costs of A/R are the present value of foregone rents from only agriculture over the next 100 years:[35]

$$\text{Opportunity Costs}_{\text{A/R}} \Rightarrow \frac{\$}{ha} = \sum_{t=1}^{100} \frac{\$A/ha}{(1+r)^t}$$

Where *$A/ha* is the annual agricultural rents per hectare, *t* is the number of years (100), and *r* is the discount rate in terms of the time preference for a landowner in valuing his or her land over the 100 years. The discount rate *r* can be one of three values, depending on the location of the grid cell. In Organisation for Economic Co-Operation and Development (OECD) countries, the discount rate is 5 percent; in least-developed countries (LDCs), the discount rate is 20 percent; and in all other countries, the discount rate is 15 percent.[36]

In contrast, we calculate the opportunity cost of REDD by choosing the highest value of one of two possible land-use scenarios: (1) forests are converted straight to agriculture (e.g., through slash-and-burn), and so all annual rents are exclusively from agriculture in all years, or (2) forests are first harvested for timber in year 1, and in all subsequent years the land is used for agriculture.

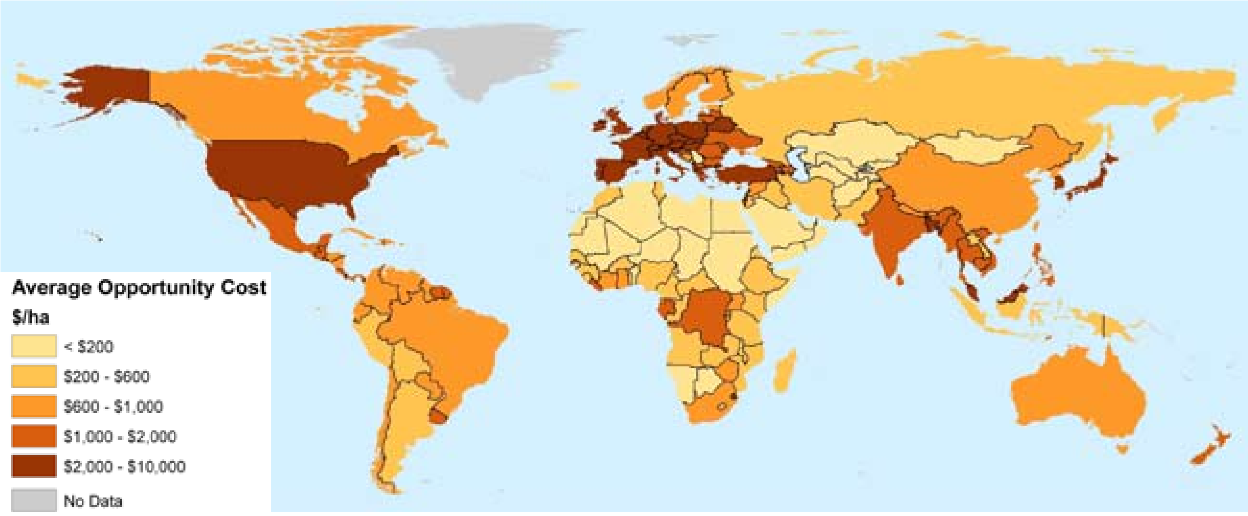
$$\text{Opportunity Costs}_{\text{REDD}} \Rightarrow \frac{\$}{ha} = Max\left\{\sum_{t=1}^{100} \frac{\$A/ha}{(1+r)^t}, \$T + \sum_{t=1}^{99} \frac{\$A/ha}{(1+r)^t}\right\}$$

Where *$T* is timber rents in year 1.[37]

The determination of which of the two land-use scenarios provides the highest returns to landowners will depend on the relative value of timber versus agriculture in any given location. Higher potential agriculture revenue relative to timber would lead to scenario 1, whereas higher timber revenue relative to agriculture would lead to scenario 2.[38]

At the country level, there is wide variation in the average opportunity cost of land. Country-level comparisons of opportunity costs illustrate a trend that should be self-evident: wealthier countries have higher opportunity costs of lands than poorer countries. Figure 6 shows the average opportunity costs of land by country.

Figure 6. Average Opportunity Cost of Land by Country



As expected, the opportunity costs are highest in the developed countries, and generally lowest in the least-developed countries. For example, the average opportunity cost of land on the entire African continent is only $382/ha, whereas in Europe it is $2,413/ha.

Notable variations in opportunity costs also exist among tropical forest countries. For example, Brazil and the Democratic Republic of Congo have relatively higher opportunity costs due to high timber rents, whereas in most other Central African countries they are very low. The significantly higher opportunity costs of land in the Democratic Republic of Congo are especially striking due to an artifact of overestimated timber rents in the country. Despite this flaw in the data, we did not opt to alter original datasets that went into the FCI.

Figure 7 shows within-country variations in opportunity costs of land.

In China, for example, the opportunity costs of land are lowest in the western part of the country, whereas along the coast the costs of land are much higher. In Brazil, the northeastern sertão or backcountry has the lowest opportunity costs. In the United States, the mountain west has the lowest opportunity costs, in contrast to more agriculturally fertile or highly populated regions of the country. Within many countries with large areas of tropical forests, potential timber revenue drives up the opportunity cost of land, such as central Amazonia in Brazil.

The local- and country-level opportunity cost maps begin to suggest where some of the cheapest locations for forest carbon may occur. Specifically, low-cost areas with forests or potential forested areas, such as Bolivia, Peru, Congo, Cameroon, Angola, and the Central African Republic, may be especially affordable locations to invest in forest carbon.

Box 2. Transaction Costs

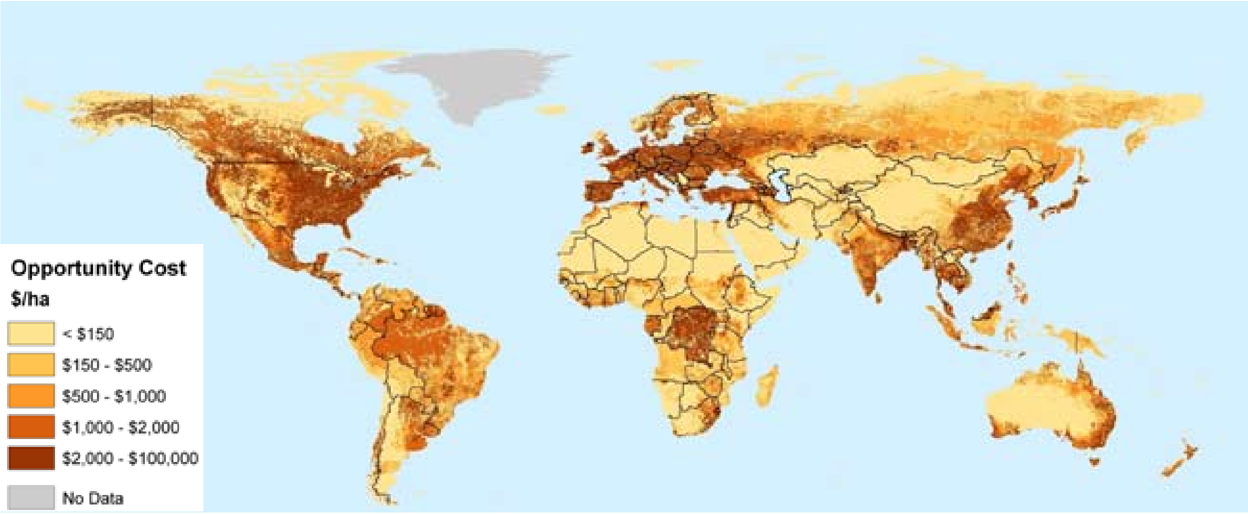
Transaction costs are left out of the cost models, and yet they can play a significant role in determining the cost of generating forest carbon. Transaction costs come in two general forms: project-level transaction costs and country or regional administrative costs.

Project-level transaction costs are the costs associated with growing and protecting a forest, including the cost of human labor and machinery used to grow trees. Empirical analysis has shown that project-level transaction costs for forest carbon projects are quite small when compared to opportunity costs and also small when compared to the transaction costs of other nonforest mitigation projects.[39] In fact, transaction costs make up on average 13 percent of project costs, although the range spans from 8 to 19 percent.[40] Since project-level transaction costs are dependent on the unique business model of project managers, we excluded them with the understanding that costs would be slightly underestimated overall.

Administrative transaction costs are included in the FCI but are not monetized in the cost models. These include everything from licensing costs to the costs of government programs to enforce land laws. Administrative transaction costs are captured in the FCI by the risk factor, which serves as a proxy for all administrative transaction costs.

The cost of measuring forest carbon and its change over time is a transaction cost that can occur at the project or country level. At present, measures come from a mix of on-the-ground and satellite and aircraft-based remote sensing. These costs are variously borne by national governments, space agencies, and the private sector. They can range from several cents to over $20 per square kilometer, depending on the accuracy required. [41] As these technologies improve, these costs will decrease.

Figure 7. Opportunity Cost of Land by Location



A/R Costs with Reference Policy Assumptions

Determining the geography of A/R costs will highlight where the best investments for A/R may exist. A/R costs are determined by the quantity of credits that is available in a given area and, depending on the crediting system, on the amount of time that trees have been growing. The costs also depend on the opportunity cost of land.

In simple terms, the costs of A/R are the opportunity costs of land (in dollars per hectare) divided by the quantity of forest carbon assets that can be generated from that land (in tons of CO_2-eqper hectare) plus several policy constraints. This yields the cost of an individual credit in dollars per ton of CO_2-eq.

The formal A/R cost model is as follows:

$$\text{AR Cost} \Rightarrow \left(\frac{\$}{tCO_2\text{eq.}}\right)_{A/R,2020} = \left[\frac{\sum_{t=1}^{100}\frac{\$A/ha}{(1+r)^t}}{(tC_{Year8}/\text{ha})*(3.66)*(0.8)}\right](1.12)^8 \leq \$20/_{tCO_2\text{eq.}}$$

The numerator, $\sum^{100}\frac{\$A/ha}{(1+r)^t}$ represents the opportunity cost of land in terms of the net present value of agricultural rents per hectare over 100 years, and the denominator is the potential carbon content of A/R forests after eight years discounted for non-permanence risk. This is a slight variation of the A/R carbon content quantity model in that it keeps the units in terms of tons of carbon per hectare rather than tons of carbon per grid.

The final multiplier term is included to reflect time preferences. We assume that there is an up-front cost (numerator/denominator described above), but no money can be made through the sale of A/R credits until the end of the compliance period, or after eight years in 2020 in the case of the reference scenario. Therefore, this term reflects the adjusted sale price the seller will require, having to wait eight years to make a sale. The adjustment uses a 12 percent discount rate for sellers of A/R credits, which we assume to be constant globally.

The geographic distribution of A/R with costs below \$20 is largely in the tropics and especially on the margins of currently forested areas, but sporadic overall (Figure 8).

The opportunities for A/R below \$20/CO_2-eq exist in almost 90 countries, but the majority are in tropical forested countries with cheap land and high levels of deforestation. Almost 900,000 km^2 is available at less than \$20 per ton under our reference policy assumptions across the globe. Twenty-five percent of that area is in the Amazon–Andes region, and another 25 percent is in the southeast Asian islands. The Congo Basin is a similar low-cost region, holding 17 percent of the global area that could be used for cost-effective A/R.

The Amazon-Andes is the region with the most cost-effective tons of A/R, with the capacity to generate 36 percent of the total potential quantity of credits. Brazil alone holds about 12 percent of the global area and 17 percent of the total potential quantity that could be cost-effective for A/R (below \$20/tCO_2-eq). Brazil could generate these credits at an average cost of \$8/tCO_2-eq. Colombia and Bolivia could also be major suppliers of cost-effective A/R credits, potentially supplying 18 and 11 million tCO_2-eq, respectively. Venezuela and Peru could both also supply well over a million tons CO_2-eq.for less than \$20/tCO_2-eq.

Figure 8. A/R Costs

(Reference Scenario: 2013–2020)

The Congo Basin could also generate a large fraction (over 21 percent) of credits. The Democratic Republic of Congo is by far the largest potential supplier of credits within the Congo Basin, and could produce about 24million tCO_2-eqat an average of \$5/tCO_2-eq. The Republic of Congo may also be a major supplier of A/R credits, with the potential for almost 5 million tCO_2-eq. Cameroon, Gabon, and the Central African Republic also have sizeable potential supplies of A/R credits—each country could supply over a million tons of CO_2-eq.

REDD Costs with Reference Policy Assumptions

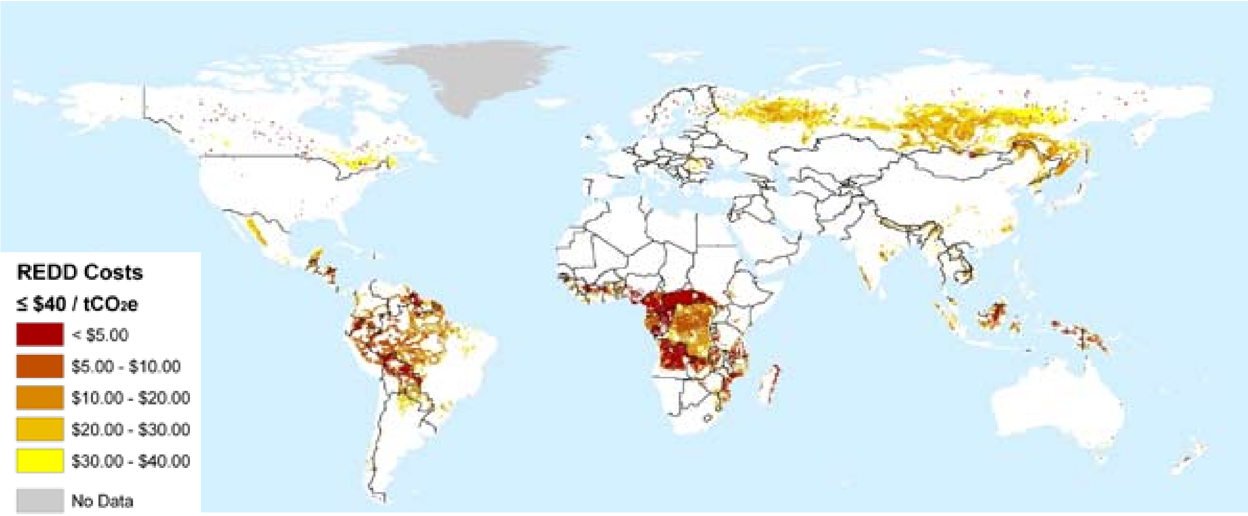
Determining the geography of REDD costs will identify which forests will cost the least amount of money to protect. The formal REDD cost model under the reference scenario uses the opportunity cost of protecting forests, the quantities of REDD produced in an area, and also applies all aforementioned policy constraints. The REDD cost model is as follows:

$$\text{REDD Cost} \Rightarrow \left(\frac{\$}{\text{tCO}_2\text{eq.}}\right)_{\text{REDD,2020}} = \left[\frac{Max\left\{\sum_{t=1}^{100}\frac{\$A/ha}{(1+r)^t}, \$T + \sum_{t=1}^{99}\frac{\$A/ha}{(1+r)^t}\right\}}{(\text{t C/ha}) * (3.66) * (0.8)}\right](1.12)^8$$

$$\leq {}^{\$20}/_{\text{tCO}_2\text{eq.}}$$

The numerator, $Max\left\{\sum_{t=1}^{100}\frac{\$A/ha}{(1+r)^t}, \$T+\sum_{t=1}^{99}\frac{\$A/ha}{(1+r)^t}\right\}$, is the opportunity cost of land used for REDD based on the net present value of agriculture and timber rents over 100 years. The denominator is the carbon content of existing forests per hectare on a given grid cell discounted for non-permanence risk. As in the A/R cost model, the final multiplier term $(1.12)^8$ is a discount rate that adjusts the costs to reflect the time preference of the project developer. Under the reference scenario, REDD emerges as producing far more credits than A/R for less than \$20/tCO_2-eq (Figure 9).

Figure 9. REDD Costs



(Reference Scenario: 2013–2020)

Like the geography of A/R, most cost-effective REDD credits emerge from the tropics, especially the Amazon–Andes region in South America, the Congo Basin in Central Africa, and the Southeast Asian islands, with some other patches in West Africa and across Russia and Canada. On average, the cost of REDD stocks is \$9.35/tCO_2-eq, but many regions of the world hold forests that could be conserved even more cheaply.

The Congo Basin holds 24 percent of the global cost-effective REDD area and 41 percent of the cost-effective quantity due to the high carbon content of land in the Congo Basin. The average cost of REDD stocks in the Congo Basin is relatively cheap, only \$8.41/tCO_2-eq. The Democratic Republic of Congo alone contains 25 percent of the world's cost-effective quantity, or 65 GtCO_2-eq of forest carbon stocks. The Republic of Congo and the Central African Republic could both be major suppliers of cost-effective REDD credits; both hold over 10 GtCO_2-eq., or about 5 percent of the world's supply of REDD stocks.

The Amazon–Andes region contains 26 percent of the global cost-effective REDD area and 30 percent of the cost-effective quantity. The average cost of REDD stocks in the Amazon-Andes is

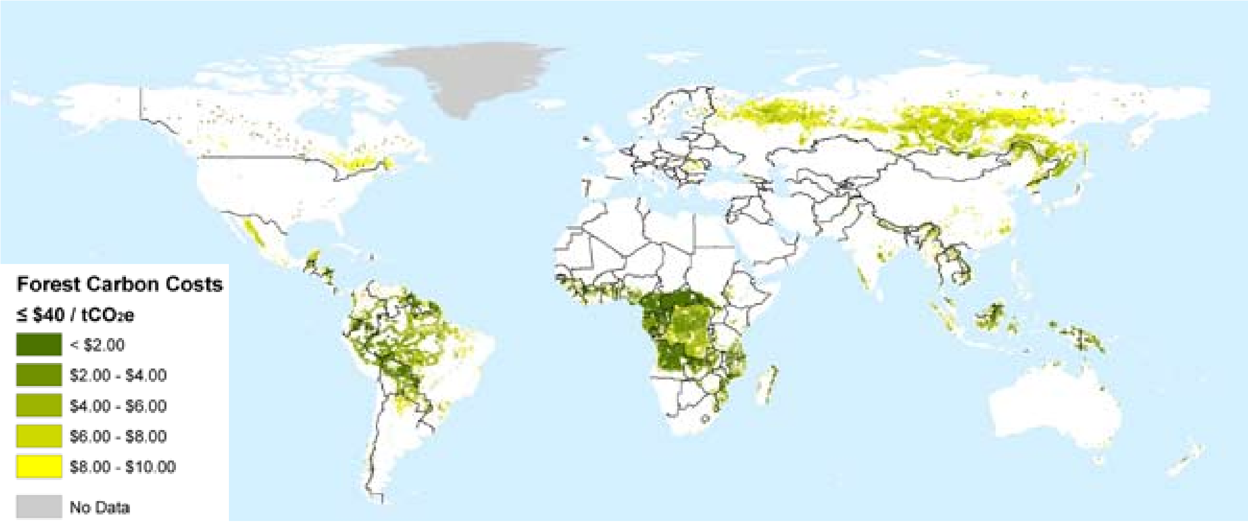
$8.41/tCO_2$-eq, slightly above the global average. Nevertheless, the quantities available are quite large and typically well below the expected $20/tCO_2$-eq expected carbon price in 2020. Brazil alone contains 17 percent of the global cost-effective quantity, or 46 $GtCO_2$-eq. Peru and Bolivia also hold large quantities of cost-effective tons, with each country holding almost 4 percent of the global stocks of REDD below $20/tCO_2$-eq.

Total Forest Carbon Costs

The geography of cost-effective forest carbon spans the tropics, but it covers some temperate and boreal forests as well. The total cost of conserving all stocks below the $20 market price would be a staggering $2.3 trillion over 8 years, or an average of $293 billion per year. The average cost of forest carbon stocks below the $20 market price would be $9/tCO_2$-eq.

The geography of cost-effective forest carbon spans the tropics, but it covers some temperate and boreal forests as well (Figure 10). The total cost of conserving all stocks below the $20 market price would be a staggering $2.3 trillion over 8 years, or an average of $293 billion per year. The average cost of forest carbon stocks below the $20 market price would be $9/tCO_2$-eq.

Figure 10. Forest Carbon Costs

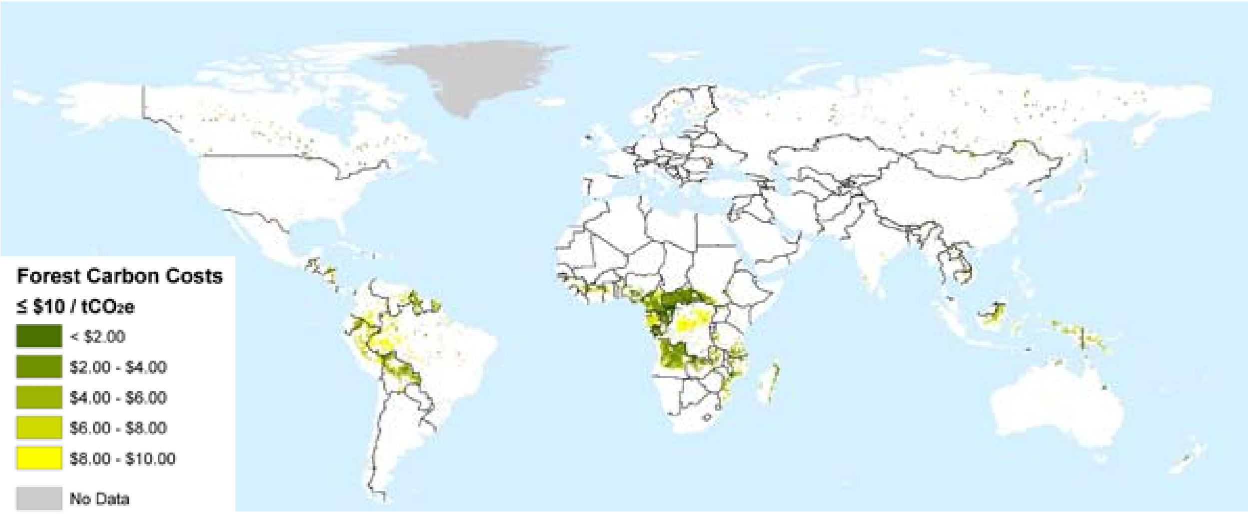


(Reference Scenario: 2013–2020)

The total potential forest carbon stock under the reference scenario is about 264$GtCO_2$-eq. Of these stocks, less than 1 percent is A/R by 2020 due to ex-post accounting, although over 7 percent of the area will be A/R. The vast majority of stocks and area will be REDD, which is shown by the extent of geographic overlap between the REDD map and the total forest carbon map. Since most potential stocks come from REDD, the Democratic Republic of Congo and Brazil emerge as the top two countries with the most overall potential forest carbon stocks, with the Democratic Republic of Congo holding 25 percent (at an average of \$12/tCO_2-eq) and Brazil holding about 17 percent (at an average of \$12/tCO_2-eq) of the cost-effective stocks. Of the top ten countries with the largest potential stocks, seven have forest carbon stocks at an average cost below \$10: Angola (\$5.25), Central African Republic (\$2.82), Republic of Congo (\$2.11), Bolivia (\$7.01), Peru (\$7.81), Gabon (\$8.39), and Cameroon (\$5.26).

While using the projected \$20 price as a benchmark for looking at potential supplies reflects a likely cutoff point in the market, focusing on the cheapest places illuminates where the best low-cost investments are. Importantly, large quantities of forest carbon credits will be available at less than \$10 per ton, well below the projected \$20 price of carbon in 2020 (Figure 11).

Figure 11. Best Places for Low-Cost Investments



(Reference Scenario with \$10 Price Cap, 2013–2020)

Capping the price at \$10/tCO_2-eq reaveals that the best places for low-cost investments in forest carbon are the Congo Basin, the Amazon–Andes, Borneo–New Guinea, the Guyana Shield, and Mesoamerica. The total quantity of forest carbon stocks that could be available for under \$10/tCO_2-eq is almost 157GtCO_2-eq covering over 7 million km^2—an area over three times the size of the Democratic Republic of Congo. The Congo Basin emerges as having the majority of low-cost forest carbon, namely in the Republic of Congo, Central African Republic, Cameroon, Angola, Gabon, and the Democratic Republic of Congo. If not for governance and readiness issues, these locations would be the lowest hanging fruit, where forest carbon sellers would likely go to produce forest carbon credits in the early stages of the market.

The two other policy scenarios show the very different geographies of forest carbon costs across the globe. If we allow for ex ante crediting of A/R credits under the ex ante scenario, the picture for forest carbon supplies changes dramatically (Figure 12).

A/R becomes available for under \$20/tCO_2-eq in virtually all areas where forests can be suitably grown, and even in some areas where forests would likely have a difficult time growing (like the margins of the Sahara desert and in parts of the Gibson desert in Australia). A/R is also available at low costs (less than $7/t CO_2-eq) in virtually all of sub-Saharan Africa and much of Australia and South America.

Under the long-term compliance scenario, forest carbon stocks in A/R are able to accumulate out to 2030, and more credits also become available from both REDD and A/R because the expected market price in 2030 is $40/t$CO_2$-eq. The resulting geography is a slight expansion beyond the reference scenario (Figure 13).

Figure 12. Forest Carbon Costs (Ex Ante Scenario: 2013–2020)

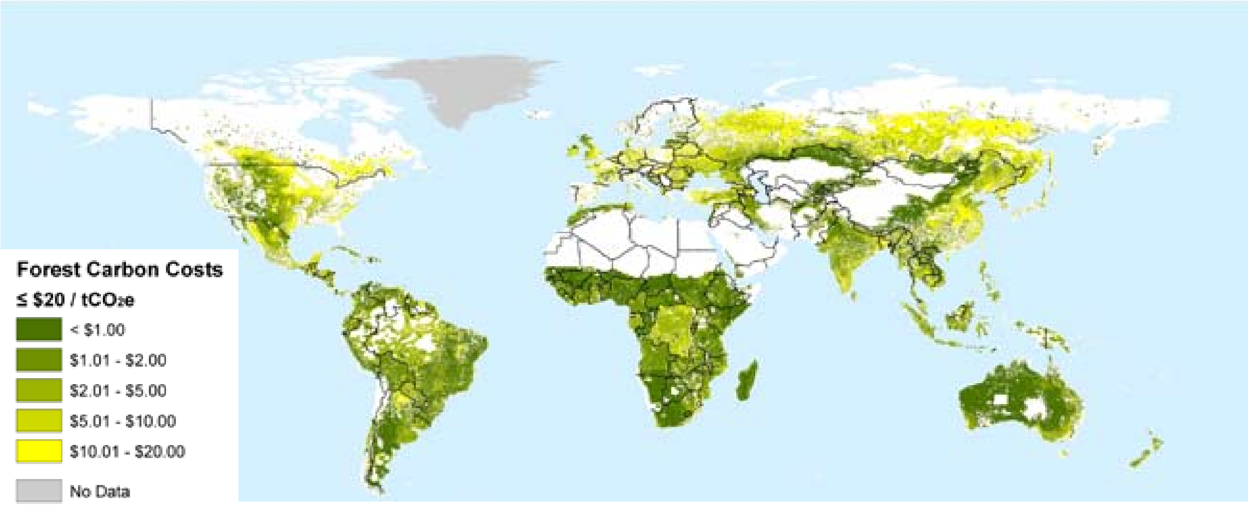
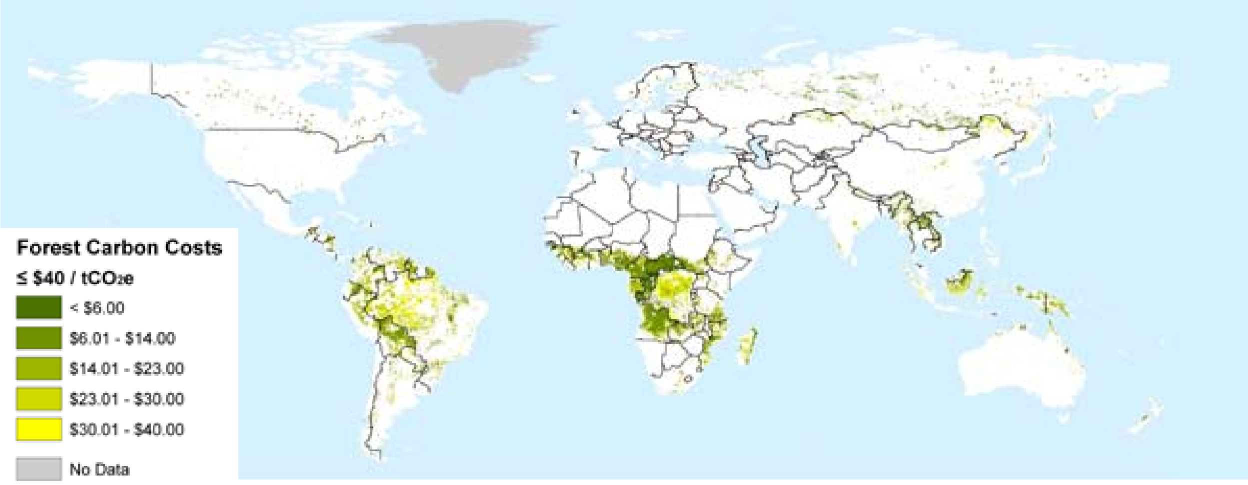


Figure 13. Forest Carbon Costs (Long-term Compliance Scenario: 2013–2030)



More parts of Central Africa, West Africa, and southeast Africa become available for forest carbon production. In addition, some additional areas of the Amazon–Andes region and Indonesia are able to produce forest carbon. But by and large, the geography of forest carbon costs looks very much like the reference scenario.

Forest Carbon Profit Potential Model

Forest carbon profit potential demonstrates the best places to invest in forest carbon on the basis of economic and biological conditions. The geography of profit potential therefore shows where the best investment locations are before risk factors are taken into consideration.

We illustrate the geography of profit potentials at the country and local levels by combining the cost and quantity models with the market price for carbon credits by using the following model:

$$\text{Profit Potential } \Rightarrow \$ = (\text{Price} - \text{Cost}) \times \text{Quantity}$$

Under the reference scenario assumption of a \$20 price for carbon credits, the profit margin on each grid cell is therefore \$20 – cost, and the profit potential is as follows:

$$\text{Profit Potential}_{\text{Reference}} \Rightarrow \$ = \left({}^{\$20}\!/_{\text{tCO}_2\text{eq.}} - {}^{\$}\!/_{\text{tCO}_2\text{eq.}} \right) \times \text{tCO}_2\text{eq.}$$

At the country level, we sum up all local-level profit potentials of forest carbon to illustrate the relative comparison across countries in their potentials for low-cost, high-quantity forest carbon. These profit potentials do not reflect the actual profits countries will receive, but instead reflect the total potential based on stocks.[42]

The Democratic Republic of Congo ranks as the country with the most profit potential in their forest carbon stocks (Table 4). The forest carbon stocks in this nation hold a profit potential as high as 25 percent of the global profit potential from 2013 to 2020. Brazil, ranked second, contains potential forest carbon stocks with 17 percent of the global profit potential.

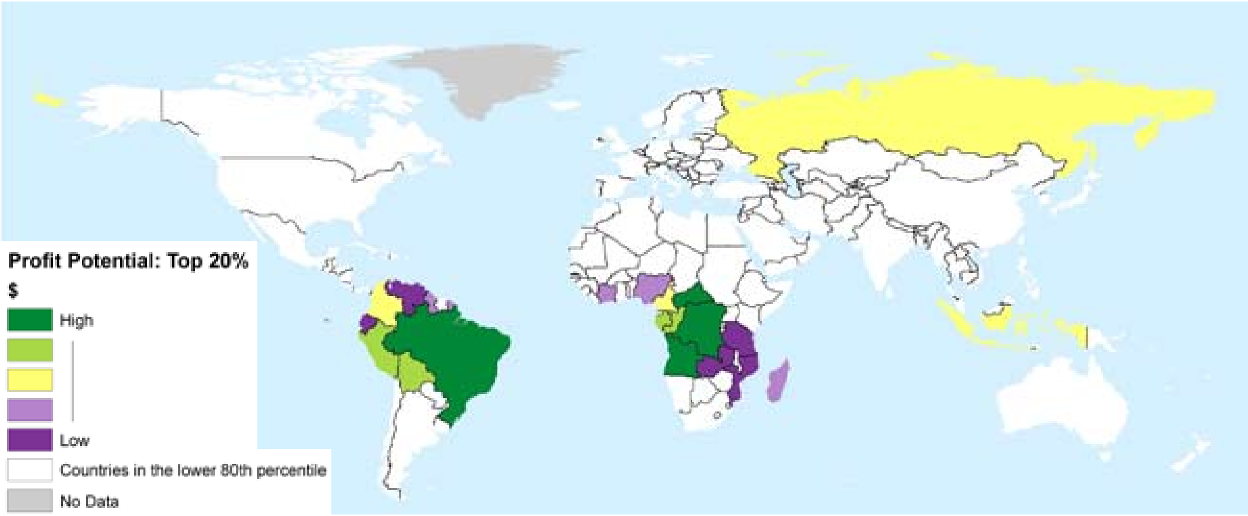
Even some relatively small countries hold large profit potentials from forest carbon. In Africa, both the Central African Republic and Angola's potential forest carbon stocks are each over 5 percent of global profit potential. In Latin America, Bolivia and Peru's forest carbon stocks each hold almost 4 percent of the global profit potential.

Geographically, the countries in the Congo Basin hold the greatest profit potential, followed by the Amazon–Andes countries, then the Southeast Asian islands (see Figure 14). Russia stands out as doing reasonably well due to its large carbon stocks over a huge area, but it turns out to be a poor place to invest since its deforestation rates are quite low and its costs are quite high.

Table 4. Profit Potential by Country

Country Rank	County	Percent of Global Profit Potential
1	Democratic Republic of Congo	24.7%
2	Brazil	17.4%
3	Angola	5.3%
4	Central African Republic	5.3%
5	Republic of Congo	4.8%
6	Bolivia	3.9%
7	Peru	3.9%
8	Gabon	3.6%
9	Russia	2.6%
10	Cameroon	2.6%

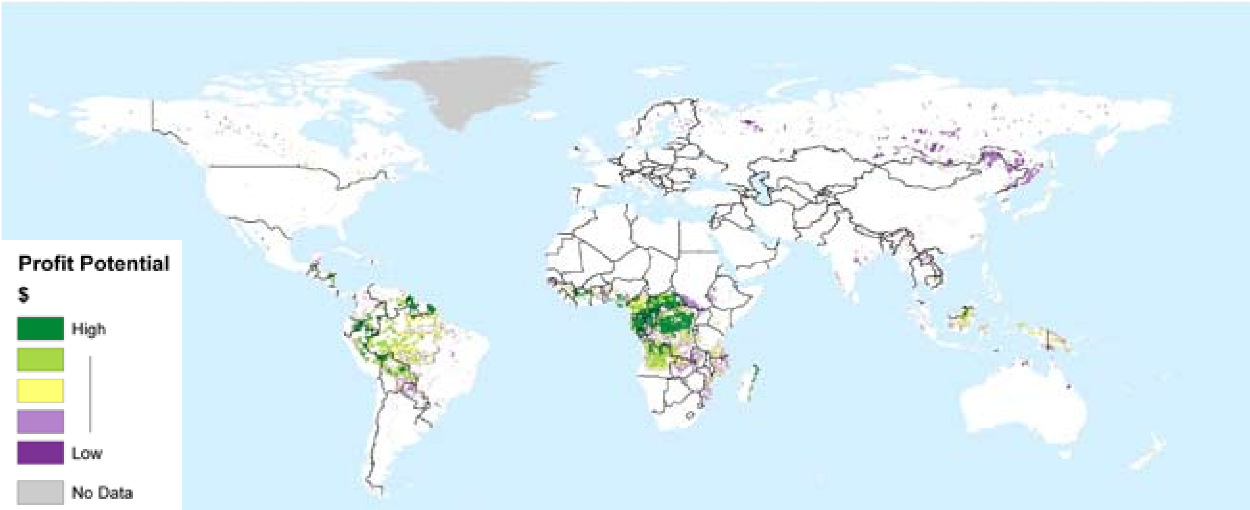
Figure 14. Country-Level Profit Potential, Top Quintile



(Reference Scenario: 2013–2020)

The profit potentials at the local level depict the very best locations for investing in forest carbon within any given country. A global view of all locations that could produce cost-effective credits (below \$20/tCO_2-eq) shows that most regions in the tropics have the highest profit potentials, whereas temperate and boreal regions tend to have low profit potentials (Figure 15).

Figure 15. Local-Level Profit Potential



(Reference Scenario: 2013–2020)

The Congo Basin stands out as an even more promising location based on profit potentials, as do some locations in Peru, Ecuador, Colombia, Guyana, French Guiana, and Borneo.

By focusing on just the top 15 percent of locations for forest carbon profit potential, the areas that stand out as the best economic investments are the northern Democratic Republic of Congo, southern Central African Republic, Republic of Congo, and Gabon (Figure 16). High-profit-potential grid cells also exist in Malaysian Borneo, the Amazon—Andes, the Guyana Shield, eastern Madagascar, and northern Côte d'Ivoire.

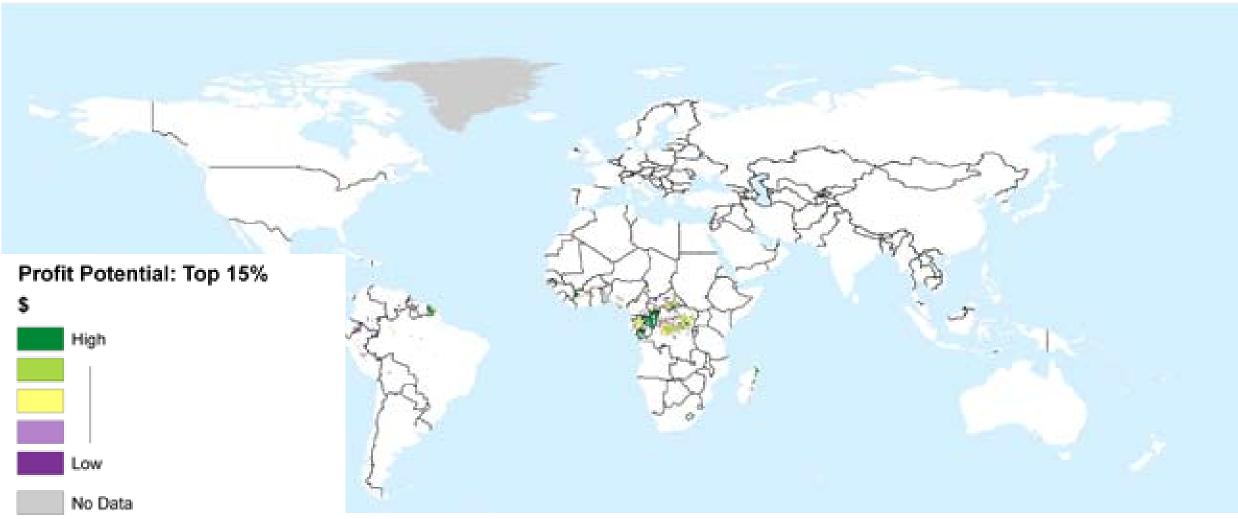
While Russia has opportunities to supply forest carbon credits, these grid cells hold the lowest profit potential due to relatively high costs and low quantities, and therefore do not fall within the top 15 percent of locations to invest.

Risk Factors

Inherent in any real-world market is a set of market barriers that influence the efficacy of that market. These real-world conditions related to investment risks will have tangible impacts on forest carbon supplies. Profit potentials illustrate the baseline economic and biological conditions that dictate forest carbon supplies. The risk factor serves to adjust the profit potential numbers to more accurately reflect real world-costs and investment decisions. This risk-adjusted profit potential is the essence of the FCI.

The risks and market barriers in the forest carbon market span political, social, and technical issues. The risk factor used in the FCI is composed of three separate metrics: governance, ease of

Figure 16. Top 15 Percent of Profit-Potential Locations



(Reference Scenario)

doing business, and readiness. Government stability and the government's ability and willingness to create and enforce laws related to land rights and forests will influence the extent to which forest conservation projects are sufficiently protected by the government. Conversely, intrusive governments that create burdensome application procedures for starting a business and obtaining permits will slow the ability of a forest carbon project to establish itself. Finally, the extent to which there is an institutional capacity within a country to access forest carbon markets and the technical capacity to monitor forests with remote-sensing systems will also affect the degree to which investors feel comfortable investing in a location. When these capacities are weak, the ability to operate a forest carbon project may be compromised, or investors may be dissuaded from investing in a project in a specific location; either result could greatly impact supply.

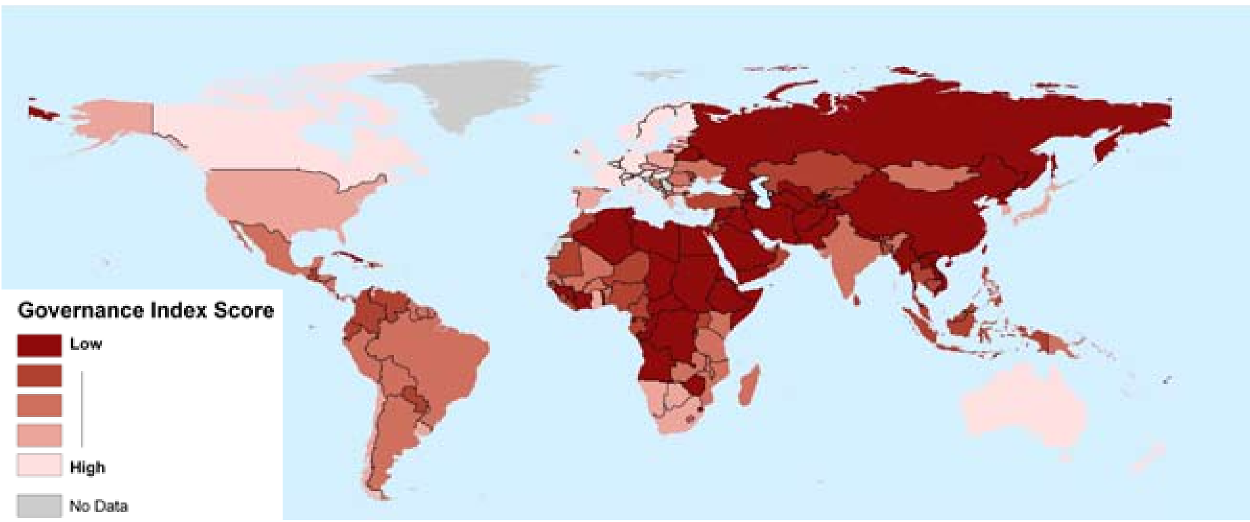
The three metrics of risk are each set to a scale of 0 to 1, where 1 is the best-performing country in the world. These metrics are then combined into a single *Risk Factor* for each country, using a weighted average of the three scores. Each of the three metrics of the risk factor is described in detail below.

Governance

Countries that have good governance will have a higher potential for forest carbon assets because they will be more attractive for investment. Several organizations have quantified governance conditions. For the FCI, we selected the World Bank Governance Index, which was created by the bank and is currently used by the investment community.[43] It provides country-level scores on a set of issues.

Authors of the World Bank Governance Index define governance as "the traditions and institutions by which authority in a country is exercised. This includes the process by which governments are selected, monitored and replaced; the capacity of the government to effectively formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions among them."[44] The Governance Index includes six dimensions of governance: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. In the context of forest carbon, good governance is important because it indicates that there is the rule of law, control of corruption, political stability, and other factors necessary to decrease investment risks. The relative governance scores are mapped in Figure 17.

Figure 17. World Bank Governance Index



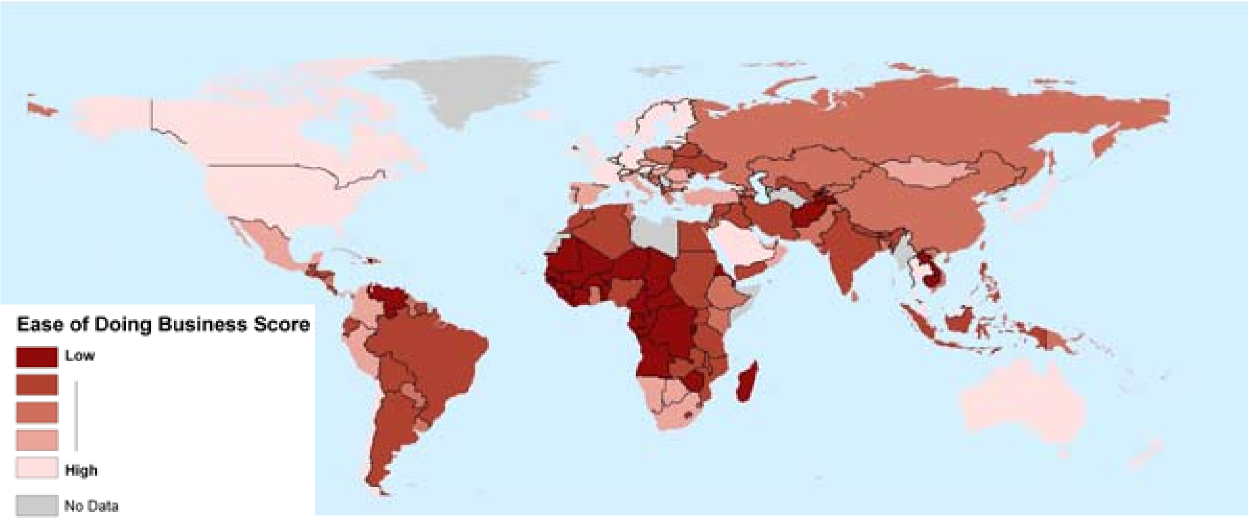
Ease of Doing Business

The Ease of Doing Business Index, also created by the World Bank, combines a set of quantitative indicators on business regulations and protection of property rights.[45] They measure regulations affecting 10 stages of a business's life: starting a business, dealing with licenses, employing workers, registering property, getting credit, protecting investors, paying taxes, trading across borders, enforcing contracts, and closing a business. The data are current as of June 1, 2007. The relative ease of doing business scores are mapped in Figure 18.

Readiness Index

Organizations that have been working in forest carbon and investing in forest carbon assets and capacity building do not yet have systematic criteria for readiness. Although various organizations are involved in assessing and/or enhancing readiness—like the World Bank Forest Carbon Partnership Facility's Readiness fund and Woods Hole Research Center's current endeavor to survey readiness activities in order to inform other countries' readiness activities—no global assessment of readiness currently exists. Case studies on readiness for select countries and subnational bodies exist, but they are often based on in-depth knowledge of on-the-ground capacity, employ a lot of qualitative analysis, and are not practical for use in scaling up to a global level.

Figure 18. World Bank Ease of Doing Business Index



For the FCI, we had to determine how to assess readiness by using information that would be available for countries worldwide. With this in mind, the readiness index comprises two elements: remote-sensing capacity and environmental market experience.

We gave each country a score from each element from 0 to 1, and then took the unweighted average of the two scores to create each country's readiness score. The methodology for each element is described below.

Remote-Sensing Capacity

Remote sensing is an important part of a forest monitoring program. Not only does it allow local and national stakeholders to assess changes in forest cover, it also allows for third-party verification of changes in forest cover. Remote-sensing capacity is one of the most often-cited indicators of readiness.

The remote-sensing capacity metric describes the willingness of countries to provide or participate in efforts to measure their forest carbon. Many countries own and operate their own satellites for this purpose. Others have access to remote-sensing data through collaboration with owner/operator countries. In many cases, countries are members of an international consortium for remote sensing. Membership in such organizations requires no exchange of funds or sharing of technology, but it does signal interest and willingness to participate in conferences and other meetings on use of remote sensing of natural resources. In the past, some countries have argued that remote sensing of their territory violates national sovereignty. Such a concern could impede the monitoring and assessment of forest carbon assets. Membership in organizations for remote sensing may demonstrate willingness for some transparency, although it is not a requirement for participation.

The readiness indicator has three parts. One part represents whether a country owns and operates a space remote-sensing system able to observe terrestrial land use, including forests. A second represents whether a country collaborates in such a space remote-sensing system by co-owning or co-operating the system, or having contributed an instrument, part of the satellite or other system component, or launch of the satellite. A third is whether a country is a member of the Group on Earth Observation (GEO), a voluntary consortium of governments and international organizations. As of July 2008, GEO's members include 74 governments and the European Commission.[46] (See Appendix 9 for data sources.)

There are, however, several limits to this indicator. Satellite remote-sensing systems differ widely in their observing capability and may not be optimized to monitor forests. Many countries host data-receiving stations (to which data from the satellite are sent) and not all host countries may be represented here. And there is at least one example, SERVIR, of a regional consortium of countries organized to use observations from other countries' satellites. Based in Panama, SERVIR provides Earth observation data to Panama, Costa Rica, Guatemala, El Salvador, Belize, Honduras, and Nicaragua.

Environmental Market Experience

Experience with environmental markets indicates a country's openness to market-based incentives for ecosystem services. If all other factors were equal, a country with greater experience with environmental markets would be of greater interest to investors.

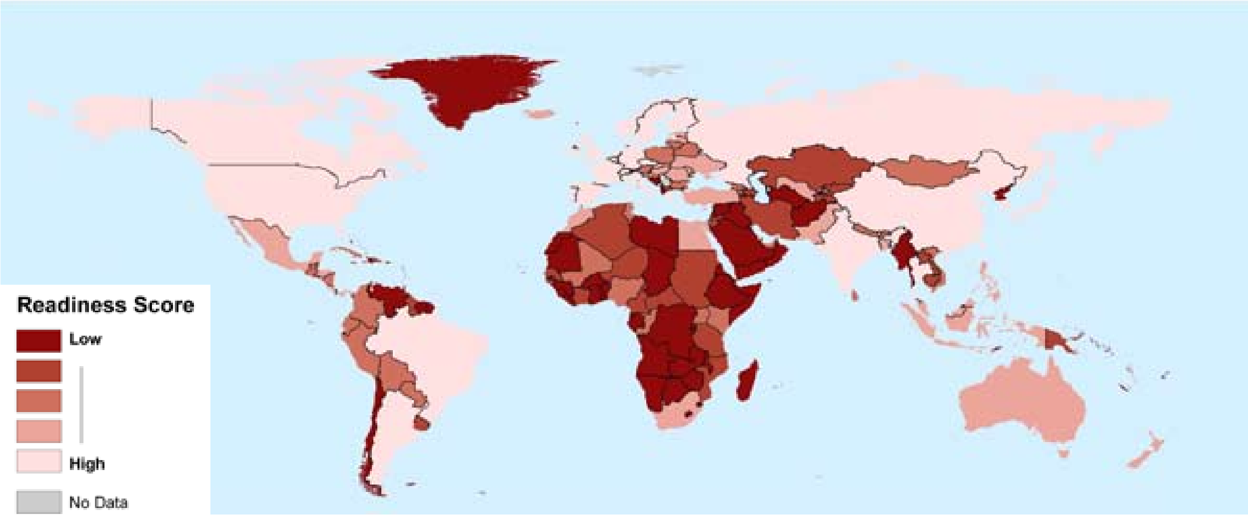
Ideally, we would have information on countries that have originated credits from CDM projects, have credits for the voluntary carbon market, and have participated in true market-based payment for ecosystem services (PES) programs. However, we only have information on CDM projects. Data on the voluntary market is not available on a country scale. The existing inventories of PES programs are either not global, sector specific, or are too broadly defined. Ecosystem Marketplace, CIFOR, and Climate Focus and Point Carbon are currently working on inventories of forest carbon projects, but none are complete global inventories yet.

The environmental market experience indicator scores each country based on the number of CDM projects either completed or in the project pipeline. If a country has no projects in the pipeline or completed, then it receives a score of zero. With one to five projects, a country receives a score of 1, and with more than five projects, a score of 2. The rationale behind this scoring system is that countries that have proven that they understand the CDM process and can consistently deliver certified emissions reductions should be scored higher.

Combined Readiness

The remote sensing capacity and environmental market experience indicators were both normalized on a scale from 0 to 1, with 1 as the highest score in the category. The two indicators were weighted equally and combined by taking the average of the two scores. The combined readiness index is shown in Figure 19.

Figure 19. Readiness Index



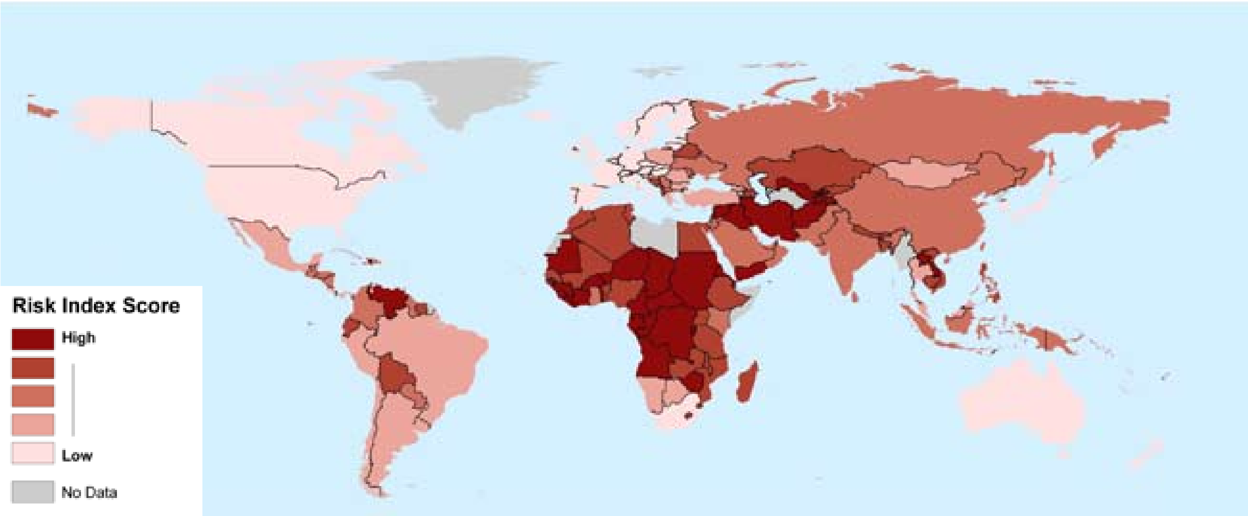
In line with their poor scores on the ease of doing business and governance indices, Central African countries are among the least ready in the world, with the exception of the Republic of Congo, which has a moderate level of readiness (scoring 0.42). In contrast, Brazil's readiness is among the highest in the world (scoring 1.0). The Andean countries and Guyana do moderately well with readiness (scoring between 0.40 and 0.50), and Indonesia has a medium-high level of readiness (scoring 0.67).

Country Risk

Combining investment risk and readiness for each country, we can score and rank each country on all risks associated with participating in forest carbon markets. These aggregate risk scores make up the risk factor, the second major pillar of the FCI, which is used to adjust the profit potentials. Countries are scored on a scale from 0 to 1 for risk, with the lowest-risk countries having the highest scores (closest to 1).[47]

The geography of risk indicates that wealthier countries—such as the United States, Canada, Australia, Japan, and Western Europe—tend to be lower risk, whereas the least-developed countries have the highest risk (Figure 20).

Figure 20. FCI Composite Risk Index



Notably, the Democratic Republic of Congo ranks as the highest-risk country, and other countries in central Africa with high profit potentials for forest carbon, like Angola, Central African Republic, and Congo, also rank among the worst in the world with very high risk. Countries such as Thailand, Malaysia, Mexico, Belize, Costa Rica, and Brazil all have relatively lower risk and have good opportunities for forest carbon based on profit potentials.

Forest Carbon Index Scores

FCI scores combine the profit potential with the risk factor to show the best places to invest in forest carbon based on economics and investment risk. The FCI serves as a useful metric to make relative comparisons across the entire geography of potential forest carbon locations, either countries or specific regions within a country. As such, we calculate FCI scores at both the country level and local level.

The basic formula for calculating FCI scores multiplies profit potential by risk and normalizes the scores from 0 to 100 to create an index in which 100 is the highest scoring country or location. The general model is as follows:

$$\text{FCI} = \text{Profit Potential} \times \text{Risk Factor}$$

where

$$\text{Profit Potential} = \text{Profit Margin} \times \text{Quantity of Credits}$$

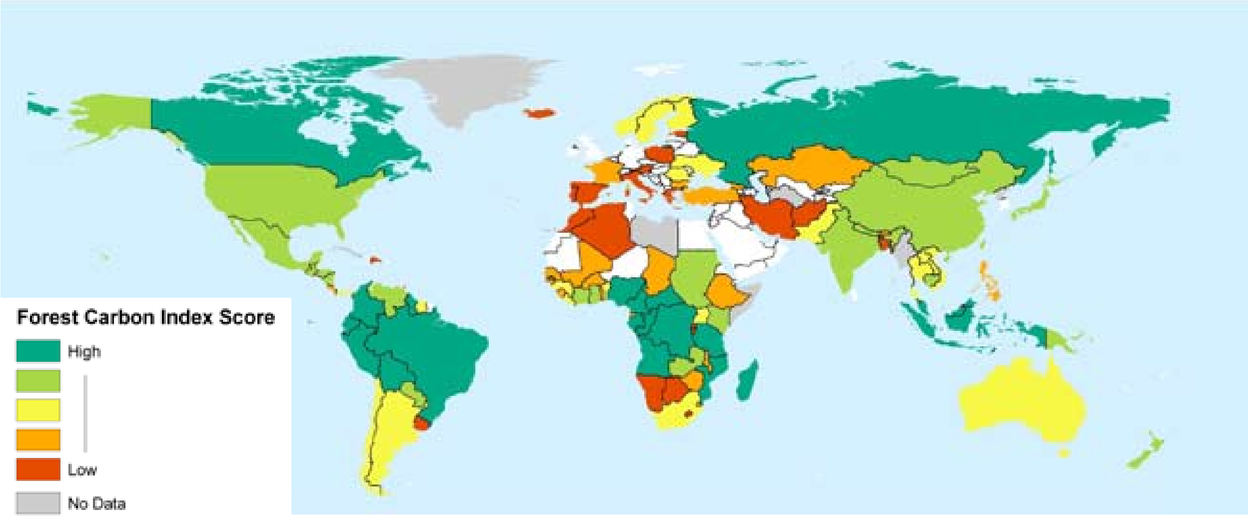
$$\text{Risk Factor} = (\text{Governance} \times 0.4) + (\text{Ease of Doing Business} \times 0.4) + (\text{Readiness} \times 0.2)$$

Actual scores were set to a natural log scale, because on a standard scale Brazil scores much higher than all other countries due to its extremely high producer surplus and low risk. The result is a more even distribution of scores, which facilitates comparison across countries of all types.

To calculate FCI scores at the country level, we add all local-level profit potential values within a country to find a country-level profit potential and multiply that value by the country-level risk.

The geography of FCI scores at the national level shows that tropical countries generally do the best; however, countries such as Canada and the United States do well due to low risk ratings (Figure 21).[48]

Figure 21. Country-Level FCI Index Scores



Of the top 20 scoring countries, 18 are developing countries in the tropics (Table 5).

Table 5. FCI Top 20 Scoring Countries

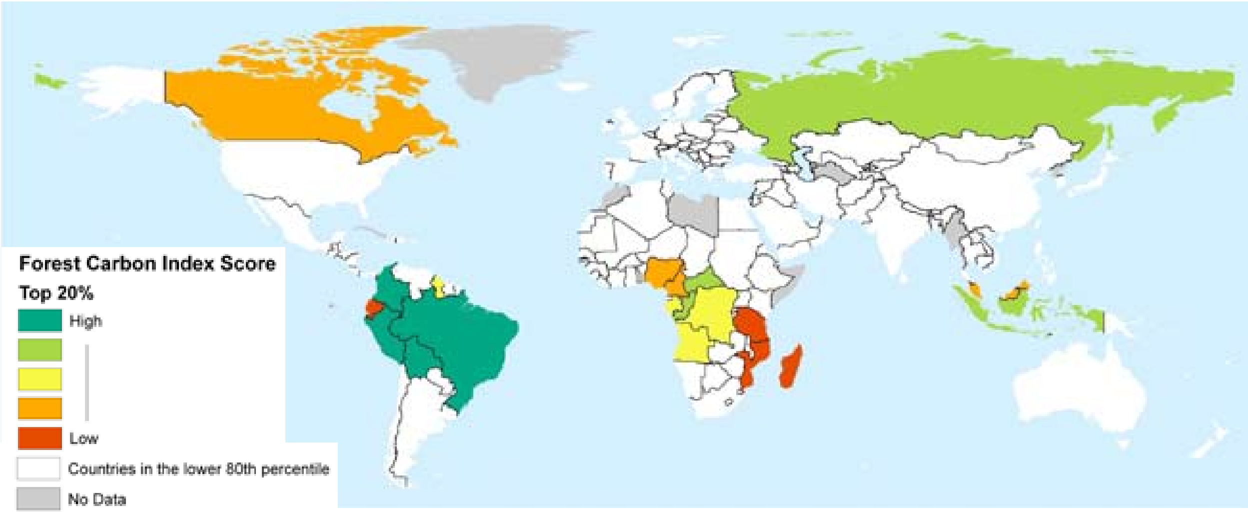
FCI Rank	Country	FCI Score
1	Brazil	100
2	Russia	96
3	Peru	95
4	Bolivia	93
5	Colombia	93
6	Indonesia	92
7	Republic of Congo	92
8	Canada	91
9	Democratic Republic of Congo	91
10	Central African Republic	91
11	Gabon	91
12	Guyana	91
13	Malaysia	90
14	Angola	90
15	Nigeria	90
16	Cameroon	90
17	Mexico	89
18	Madagascar	88
19	Tanzania	88
20	Ecuador	88

Brazil emerges as the top country (scoring 100) in the world due to a combination of very high profit potential and low risk. Peru (scoring 95) and Bolivia (scoring 93) also emerge as top countries for the same reasons, but with much lower profit potential scores compared to Brazil.

Russia, ranking as the second-best country in the world for forest carbon, scores a 94 in the FCI. Even though the investment risk is relatively high and the local profit potentials not very high, the sheer number of places where forest carbon can occur make Russia one of the top producers of forest carbon. Since it has very low deforestation, however, Russia may not be able to sell many of its potential credits into the forest carbon markets. Moreover, Russia may not qualify to sell forest carbon credits into the international carbon markets because it is not a developing country. This important detail will not be known until the rules are defined within the United Nations Framework Convention on Climate Change negotiations.

The Congo Basin countries rank within the top 20 percent of countries, but they are hit hard by having high risk (Figure 22). The Democratic Republic of Congo, for example, ranked at the top of the list of countries based on producer surplus, but its low risk score knocks down its place in FCI rankings to ninth in the world. The high-risk countries in the Congo Basin will therefore need to spend proportionally more resources on improving governance issues to ensure that investments in forest carbon are secure and can be adequately monitored.

Figure 22. Top 20 Percent Best Countries among Country-Level FCI Scores

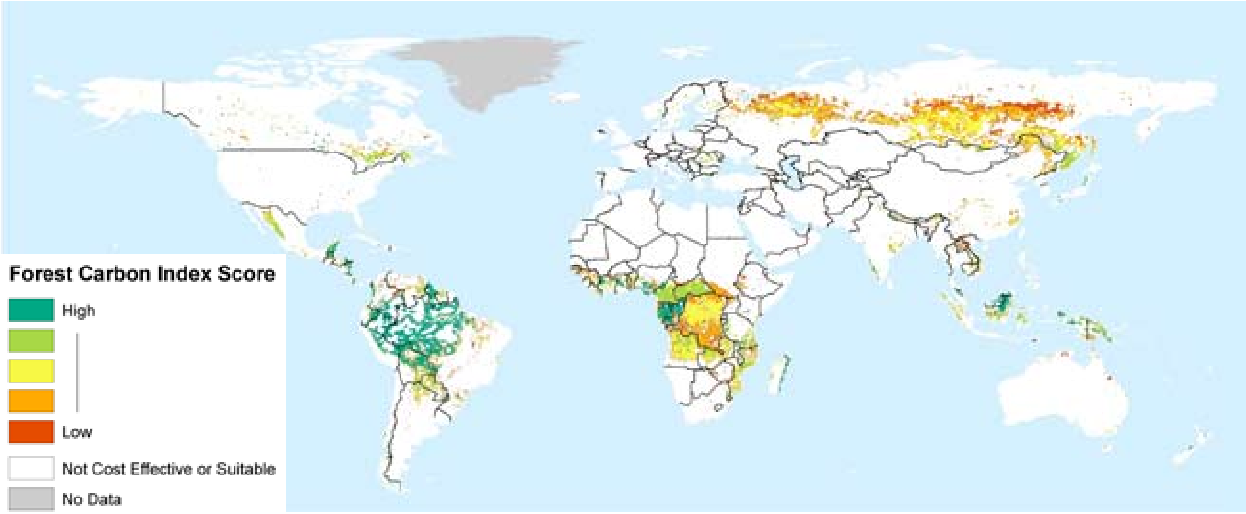


Indonesia also ranks quite high among countries to invest in forest carbon. Although it does not score at the top of any single indicator within the FCI, it scores consistently well on both producer surplus and risk to be among the best places when all factors are taken together.

Local-level FCI scores show the best places within countries to invest in forest carbon, accounting for country-level risk factors. Therefore, we calculate FCI scores at the local level by multiplying local-level profit potential values by country-level risk scores.

At the local level, the Amazon–Andes region emerges as the best place to invest in forest carbon (Figure 23). All of the cost-effective locations for producing forest carbon in Russia are, in fact, poor locations for investing in forest carbon, and the same is essentially true for the Democratic Republic of Congo. These countries receive high national scores because they are so large they can generate large country-level producer surpluses. But local-level results illuminate that neither country has good locations for forest carbon investments.

Figure 23. Local-Level FCI Scores



In contrast, some small countries show up as good investment locations, despite receiving somewhat lower country-level scores. Gabon, Guyana, Ecuador, Malaysia, Guatemala, Ghana, Côte d'Ivoire, and Nicaragua are all relatively small countries with locations that would be good investments.

Virtually all of the top 5 percent of locations for investing in forest carbon lie in the Amazon–Andes, although the Guyana Shield, western Madagascar, and Malaysian Borneo and the Mesoamerican corridor also make it into the top 5 percent of investment areas (Figure 24).

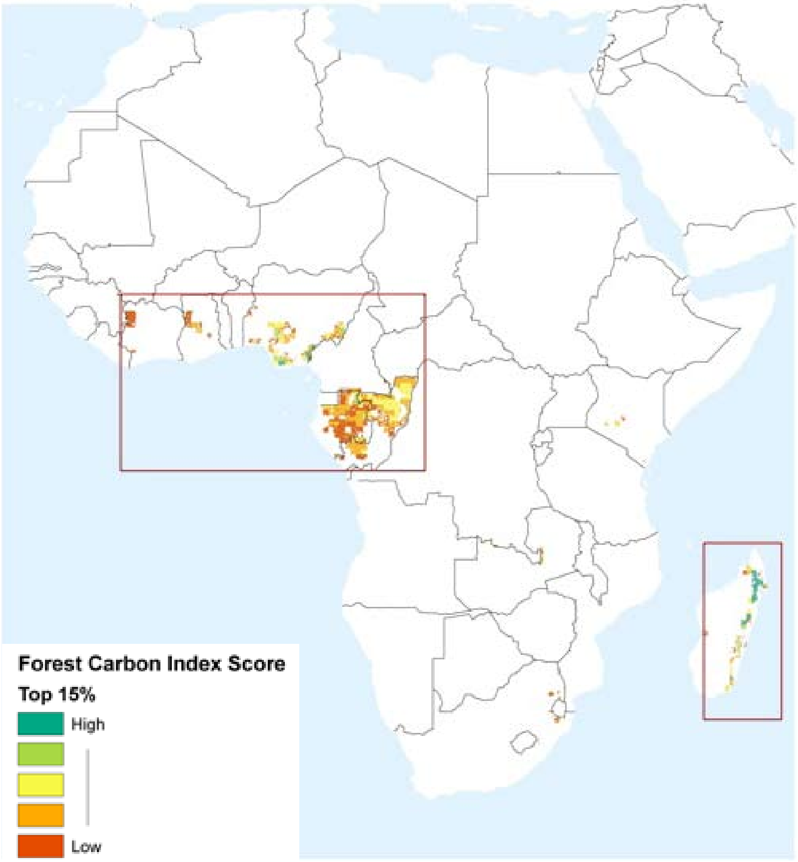
Figure 24. Global Best Places for Early Investments at Local Level (Top 5 Percent FCI Scores)

CHAPTER 3. PRICES, QUANTITIES, AND REVENUES

While forest carbon stocks are effective at showing the geography of forest carbon, they are not suitable for projecting actual market prices, quantities of forest carbon supplies, and expected revenues. These values are dependent on specific country-level quantity restrictions that measure forest carbon *flows* rather than *stocks.*

The quantity of forest carbon that reduces deforestation to zero is the flow of forest carbon that would be allocated to a country as the maximum available quantity to sell in the carbon market (Figure 26).

Figure 25. Best Places in Africa for Early Investments at Local Level (Top 15 Percent FCI Scores)

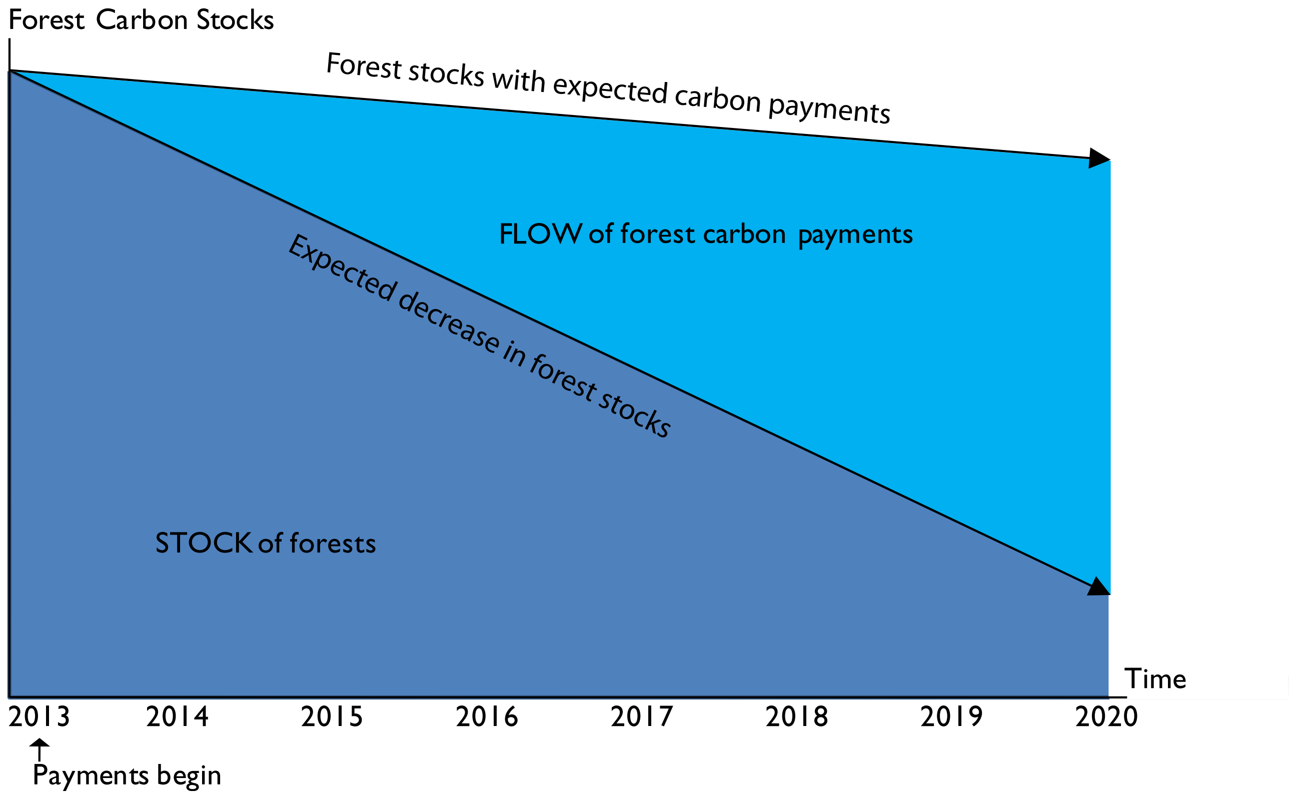


The idea is that every country with historical deforestation also has expected future deforestation—in other words, an expected decrease in forest stocks. International policy will allow developing countries with expected future deforestation rates to be paid up to an amount that brings deforestation rates to zero, or to the point at which stocks remain constant. This amount of payment is strictly for additional tons of forest carbon, since payments for the entire stock of carbon would result in large payments for forests that would have never been cut over a given time period. Thus, any given flow of forest carbon payments should reduce the expected decline in stocks by a certain quantity (as shown by the two arrows in Figure 26).

Limiting forest carbon payments to only flows results in a drastic decline in potentially available quantities available for sale in any given country. Moreover, any country without deforestation will not be eligible for generating forest carbon.

Ideally, we would want flow information at the local level to determine the specific places that will likely be deforested. There is not yet any global local dataset of this kind available; instead there are only local-level stocks and national-level flows. From this, we can project forest carbon flow quantities by using a hybrid of stocks and flows.

Figure 26. Forest Carbon Stocks versus Flows



To calculate country-level flow baseline quantities, we use country-level deforestation rates that describe the average area of forest cover lost each year from 2000 to 2005.[49] To find baseline emissions from country-level forest area loss, we first project which grid cells are the most likely to be deforested. We do this by ranking forested grid cells by their opportunity costs, with the assumption that the cost-effective forested locations with the highest opportunity costs would be the most likely to be cut since they would generate the most revenue in an alternate use. We select the number of grid cells with the highest opportunity costs that equal the area of projected annual deforestation on the basis of historical deforestation rates. This selection of high-opportunity-cost REDD grid cells provides the baseline flow numbers.

The baseline data on country-level deforestation estimate the global annual emissions from deforestation to be about 2.7 $GtCO_2$eq. but should be taken with some caution. These Food and Agriculture Organization (FAO) measures, which are based on self-reported inventories by countries, are widely recognized to be limited due to differences among countries in their technical capacity for measurement. The FAO is implementing new measures by incorporating remote sensing, beginning with its 2010 Forest Resource Assessment. We therefore opted to use these data because they are global and will be updated and improved in the future.

Given that the REDD grid cells most likely to be deforested are also among the most costly locations for REDD, A/R activities could be more cost competitive within a country. A/R grid cells can therefore be substituted for REDD grid cells if they are able to generate higher profit potentials than REDD. This competition between REDD and A/R results in each country having a mix of somewhat costly REDD and cheaper A/R tons that they will sell into the forest carbon markets.

Finally, the predicted quantities of REDD and A/R are discounted by being multiplied by the risk factor. This makes it so that even countries with high rates of deforestation and high economic and biological potential to generate forest carbon still would not be able to necessarily slow deforestation to zero if they have high country-level risk.

REDD Market Projections

Although it is difficult to predict future market conditions with certainty, the stock data in the FCI, combined with country flows, can provide predictions that capture likely market conditions.

Over the first compliance period (from 2013 to 2020), 7.3 $GtCO_2$-eq will be supplied to the markets at an average of about 0.9 $GtCO_2$ each year. The average cost of REDD credits from all suppliers will be \$13.43/tCO_2-eq in 2020, with REDD activities covering 910,000 km^2 worldwide.

Brazil stands out above and beyond all other countries as the major supplier of REDD credits (Table 6).

Table 6. REDD Quantity and Cost Projections

Country Rank	Country	Quantity (GtCO2-eq)	Percent of Quantity	Average Cost ($/tCO2-eq)
1	Brazil	3.53	48.2%	$15.74
2	Indonesia	0.86	11.8%	$12.53
3	Malaysia	0.33	4.4%	$17.28
4	Mexico	0.29	4.0%	$17.94
5	Nigeria	0.25	3.4%	$6.85
6	Bolivia	0.17	2.3%	$14.98
7	Tanzania	0.15	2.0%	$13.84
8	Ecuador	0.13	1.8%	$12.17
9	Zambia	0.12	1.6%	$15.11
10	Argentina	0.11	1.5%	$16.81

Brazil is poised to supply 48 percent of the supply of REDD credits during the first commitment period, generating about 3.5 $GtCO_2$-eq. On average, Brazil would therefore provide about 0.4 $GtCO_2$-eq of REDD each year during that period, although in reality the quantity may vary drastically from year to year. The average cost of credits generated from Brazil is almost $\$16/tCO_2$-eq. Brazil's dominance as a major supplier is the result of a relatively high deforestation rate over a massive area of forest, resulting in a very large net loss in total forest area.

Indonesia also generates a relatively large fraction of credits due to a high deforestation rate over a relatively large area of land. Indonesia is set to provide almost 0.9 $GtCO_2$-eq over the first commitment period at an average cost of $\$12.53/tCO_2$-eq. This represents almost 12 percent of all REDD credits produced during this period. If Indonesia is able to quickly improve its risk (specifically its governance and ease of doing business scores), it could generate significantly more carbon credits.

A/R Market Projections

Even though there are some very low-cost opportunities for A/R across the globe, the low potential quantities of A/R over the first commitment period drastically restrict the expected quantities to be available in the markets.

By 2020, we expect only 3.4 $MtCO_2$-eq to be produced at an average cost of about $\$6/tCO_2$-eq. A/R activities will cover about 28,000 km^2 in 42 countries.

Brazil and Indonesia will both be major suppliers of A/R credits. Brazil is likely to be the dominant supplier of credits, and could sell 0.99 $MtCO_2$-eq of A/R by 2020 (Table 7). This amounts to 29.4 percent of the global quantity of A/R generated.

Table 7. A/R Quantity and Cost Projections

Country Rank	Country	Quantity (MtCO2-eq)	Percent of Quantity	Average Cost ($/tCO2-eq)
1	Brazil	0.99	29.4%	$0.49
2	Indonesia	0.55	16.5%	$0.11
3	Paraguay	0.34	10.1%	$0.84
4	Argentina	0.33	10.0%	$1.73
5	Papua New Guinea	0.17	5.1%	$0.02
6	Peru	0.11	3.2%	$0.02
7	Malaysia	0.10	3.1%	$0.12
8	Colombia	0.09	2.6%	$0.45
9	Uganda	0.08	2.5%	$3.29
10	Mexico	0.08	2.4%	$3.61

Indonesia is expected to provide 0.55 $MtCO_2$-eq from 2013 to 2020, representing 16.5 percent of the A/R global supply.

Unlike the concentrated generation of REDD in a few large tropical countries, A/R production is more evenly spread across countries covering both temperate and tropical areas. For example, Argentina is expected to provide 10 percent of the total quantity of A/R credits during the first commitment period.

The costs of A/R predicted here are generally quite low, typically as a result of very low opportunity costs of land. These values are probably artificially low since they do not capture transaction costs, and these would likely be most impacted by a fixed transaction cost to grow new forests. The result is that somewhat less A/R may be available than this model suggests, and at a higher average cost.

Forest Carbon Market Projections

Since the vast majority of forest carbon credits will come from REDD in the first commitment period, the global and national price and quantity projections for all forest carbon are almost identical to those of REDD.

From 2013 to 2020, 7.3 $GtCO_2$-eq of forest carbon will be available or 0.91 $GtCO_2$-eq each year; the average cost will be \$13/tCO_2-eq by 2020. This would protect about 973,000km^2 of forests over 8 years, an area almost the size of Bolivia.

Almost all of the forest carbon will come from developing countries, with the largest portion coming from Brazil (Table 8).[50]

Table 8. Forest Carbon Quantity and Cost Projections

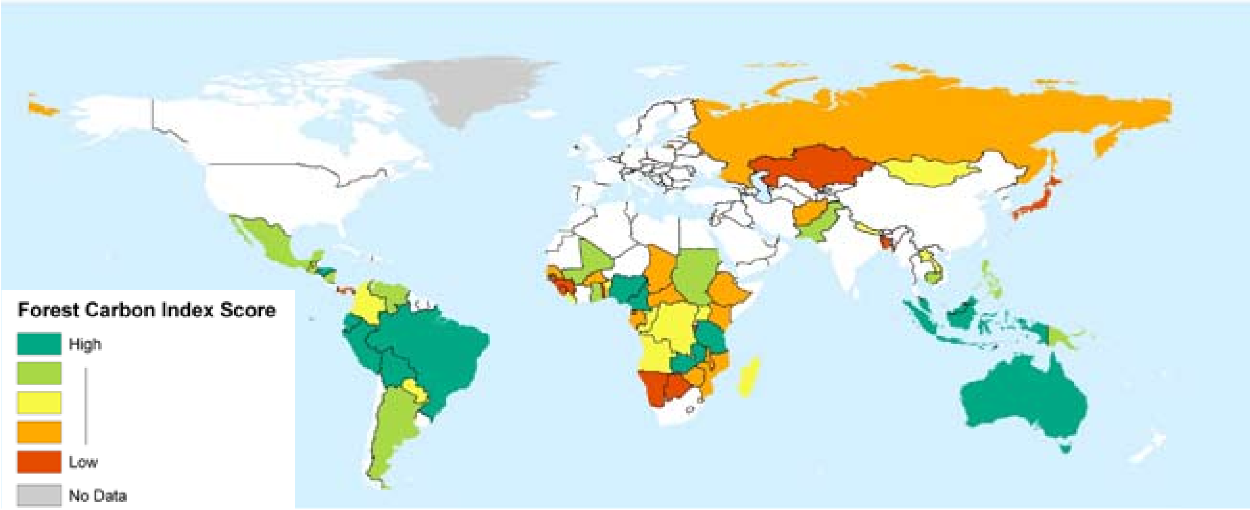
Country Rank	Country	Quantity (GtCO2-eq)	Percent of Quantity	Average Cost (\$/tCO2-eq)
1	Brazil	3.53	48%	\$15.41
2	Indonesia	0.87	12%	\$12.24
3	Malaysia	0.33	4%	\$16.63
4	Mexico	0.29	4%	\$17.58
5	Nigeria	0.25	3%	\$6.82
6	Bolivia	0.20	2%	\$14.74
7	Tanzania	0.15	2%	\$13.45
8	Ecuador	0.13	2%	\$12.11
9	Zambia	0.12	2%	\$14.86
10	Argentina	0.11	2%	\$13.36

Most countries will produce forest carbon credits at costs between \$12/tCO_2-eq and \$17/tCO_2-eq. Nigeria, however, has among the lowest average forest carbon costs due to the low opportunity costs of land and relatively high forest carbon contents. This will allow Nigeria to generate about 3 percent of the global quantity of forest carbon credits by 2020.

Without any risk adjustment, countries could generate 18.5 $GtCO_2$-eq during the first commitment period, more than doubling expected supplies. Countries with higher risk values, like Indonesia, Nigeria, Bolivia, Tanzania, Ecuador, and Zambia, will therefore have high incentives to quickly lower their country risk scores in order to generate even higher quantities of forest carbon.

A total of 62 countries will be able to participate in forest carbon markets to some extent during the first commitment period (Figure 27).

Figure 27. FCI Country Scores Based on Flows



Many countries will not be able to provide the majority of their potential supplies during the initial commitment period. Countries in the Congo Basin, in particular, will not be able to significantly reduce their deforestation rates between2013 and 2020 and will generate less than 10 percent of their potential supply of credits. The Amazon–Andes and Southeast Asian countries, by contrast, will be able to generate almost half of their potential credits over the eight years.

CHAPTER 4. ECONOMIC AND POLICY IMPLICATIONS

Up-and-coming forest carbon markets will create a massive new global commodity market that will be worth $13–18 billion per year from 2013 to 2020. Most revenue in this market will be captured by developing countries. If used appropriately, this revenue could help to alleviate poverty in some of the poorest regions of the world.

Indeed, for the top 10 scoring countries in the FCI (based on flows), our results suggest that every developing country will bring in over $100 million dollars in forest carbon revenues each year in the first commitment period (Table 9).

Table 9. Country Revenues from Forest Carbon

FCI Rank	Country	Total Costs (million $)	Total Investment (million $)	Total Costs as Percent of GDP	Investment as Percent of GDP
1	Brazil	$6,874	$8,836	0.4%	0.5%
2	Indonesia	$1,306	$2,163	0.2%	0.3%
3	Nigeria	$179	$623	0.1%	0.2%
4	Australia	$61	$223	0.0%	0.0%
5	Ecuador	$184	$323	0.2%	0.3%
6	Tanzania	$248	$367	0.6%	0.8%
7	Malaysia	$698	$813	0.2%	0.2%
8	Bolivia	$313	$423	0.8%	1.1%
9	Honduras	$159	$268	0.6%	1.0%
10	Zambia	$204	$298	1.4%	2.0%

At a minimum, countries will receive the payments to cover the total cost of generating forest carbon credits. If countries do not have to sell at the marginal cost of generating forest carbon credits, they could bring in even more revenue. In fact, if countries are able to sell credits at the market price of \$20/tCO_2-eq in 2020, they could maximize revenues from forest carbon.

Brazil, for example, could bring in $6.9–8.8 billion each year, and Indonesia could bring in $1.3–$2.2 billion each year. Even small countries like Zambia could bring in $204–298 million each year, which would increase its gross domestic product (GDP) by 1.4 to 2.0 percent. In fact, many of the major supplier countries would be able to increase their GDP by a nontrivial amount.

Such large transfers of wealth will have the potential not only to boost the economies of many developing countries, but could also advance other international goals, such as direct poverty alleviation, national security, and biodiversity protection. To ensure that forest carbon markets have the greatest positive impact, policy mechanisms will be need to be appropriately designed to manage country risks, and safeguards will be needed to protect against broad risks in a fledgling market.

Co-Benefits from the new Carbon Market

The large transfer of wealth from rich to poor countries for forest carbon credits will help to tackle a major source of global greenhouse gas emissions, but it could also advance several other important international objectives. Beyond climate change mitigation, some of the potential co-benefits of forest carbon include reducing poverty, improving national security, and protecting tropical biodiversity.

Reducing poverty: Poverty and deforestation are closely linked phenomena. New forest carbon policy can channel revenue to communities in forested areas to manage and protect standing forests. This revenue can serve as an alternative livelihood to subsistence agriculture in forested areas.

Improving national security: Poor forest governance has a long history of exacerbating conflict and unrest. Illegally harvested timber has been used to fund armed activities in the Democratic Republic of Congo, Cambodia, and Myanmar.[51] Successful forest carbon markets will require improved forest governance. By clarifying land rights, resolving land disputes, and improving programs to monitor and enforce land laws, forest-related conflicts will decline.

Protecting tropical biodiversity: Tropical forests hold over half of all species on the planet today.[52] At the current rate of deforestation, 5 to 10 percent of tropical forest species will be lost per decade.[53] Trees are the basic building blocks of forest habitat, and so financial incentives to keep trees standing will also contribute to protecting the home of many of the world's species.

These co-benefits make forest carbon an even more attractive investment because of the clear social and environmental benefits beyond those associated with climate change. In order to maximize these co-benefits, however, international and domestic policies will have to be appropriately designed to ensure that new revenue streams reach the poorest communities, improve governance structures, and help to protect the highest diversity areas of forests.

Policy Mechanisms

The forest carbon market will be a major new commodity market that will require carefully designed policy mechanisms to ensure that it runs effectively. Risk factors will play an important role in determining which countries can functionally participate in forest carbon markets, and when. In the absence of risk factors, many of the countries that provide the best opportunities for investments in forest carbon are in the Congo Basin. But when risk is taken into account, these countries quickly look like less promising. The vastly different levels of risk across countries with large profit potentials indicate the possible need for a phased entry into the carbon markets for countries with high risk.

Many countries, including Norway and the Coalition of Rainforest Nations, have issued support for a phased approach to implementing a market for forest carbon credits. This approach would accommodate varying country circumstances and would entail three phases:

Phase I: Strategy development, readiness and capacity building, and demonstration activities

Phase II: Implementation of policies and measures

Phase III: Payment for performance

These phases collectively encourage progression toward a performance-based implementation of country-level forest carbon programs that generate emissions reductions that can be monitored, reported, and verified.[54]

Phase I will serve to build the institutional capacity within countries to run a national forest carbon program. This will be the period during which countries plan the strategy and timing for implementing a national forest carbon program. Some limited project-level demonstration activities may occur either for countries to become familiar with managing forest carbon directly or working with the private sector to manage forest carbon. Funds for Phase I will come mostly from the World Bank's Forest Carbon Partnership Facility and from the existing voluntary market for forest carbon.

Phase II will begin the implementation of a national forest carbon program, including creating and passing necessary legislation. It will also require establishing specific offices within the national government to oversee the operation of the national forest carbon program. And finally, it will require investing in the appropriate technologies to monitor forests through satellite systems or on-the-ground patrols. Financing for Phase II activities could come from special capacity-building funds created by domestic and international legislation. For example, the recent U.S. bill passed in the House (H.R. 2454, the American Clean Energy and Security Act) sets aside 5 percent of revenues made from auctioning emissions credits toward international forest carbon activities. This revenue is meant to fund the types of readiness and capacity-building activities in Phase II as well as to achieve 720 $MtCO_2$-eq in measurable emissions reductions.

Phase III pertains to the long-term forest carbon markets, in which payments are made for performance. Performance-based forest carbon activities could be funded through global trade in carbon credits or through the establishment of special forest carbon funds that pool money from developed countries.

FCI scores indicate that several countries are already well positioned to be early movers in such a phased approach and are ready to move directly to Phase II. Peru, Bolivia, and Colombia, placing 3rd, 4th, and 5th in the Forest Carbon Index ranking based on stocks (Table 5), have the combination of high profit potential and low risk that position them to be the earliest movers in the forest carbon markets. While they may not be the largest suppliers due to relatively small flows, they could bring tons to the market faster than many countries with high deforestation rates. Brazil, which has a high level of readiness and has moved forward with national-level policy through its Amazon Fund, is almost ready for Phase III.

Countries such as Indonesia, Malaysia and Mexico, placing 2nd, 3rd, and 4th in the FCI ranking based on flows, have significant future potential to supply forest carbon based on high deforestation rates, but will struggle to bring tons to market quickly as a result of relatively high levels of country risk. These will need to be priority countries for building governance and readiness capacity. With sufficient support, these countries could be ideal "second movers" in the market.

Phased entry into the carbon markets will allow developing countries sufficient time to ensure that country governance is stable and strong, they have implemented policies and measures to operate a national forest carbon program, and they have the institutional capacity to manage a forest carbon program. This approach will slow the supply of forest carbon credits in the near-term, but it will serve to stabilize the forest carbon market in the long-term and ensure that investors have confidence that they are making sound investments.

Most capacity building will need to occur in developing countries, but developed countries will also need to build institutional capacity. Developed countries should consider establishing financial intermediaries that could serve four principal functions:

- Finance emission reductions from Brazil and other nations that may choose not participate in U.S. carbon markets
- Engage nations that require capacity building or fail to attract private capital
- Aggregate forest carbon offset demand and supply
- Ensure the environmental integrity of offsets[55]

Brazil's current position within the negotiations is to not sell forest carbon credits to developed countries that could be used as offsets. Instead, Brazil wants to establish a fund mechanism where developed countries would pool resources and give lump sum contributions to Brazil's Amazon Fund. Private capital could not be used toward such a fund unless a government aggregator could pool the private capital into a fund. In the case of the United States, a government-run financial intermediary cold also manage the additional funds obtained from the allowance auction to purchase supplemental forest carbon credits from countries like Brazil.

Developed countries will also need financial intermediaries to manage funds that are dedicated to capacity building or to funding conservation of stocks in countries with high risk of international leakage. This financial intermediary would be tasked with ensuring that benchmarks are met within developing countries to pass through the phased approach. The financial intermediary would also provide technical support to developing countries for managing their offset markets, or preparing for future offset markets.

A government aggregator could also make bulk purchases on behalf of developed country companies and could reduce costs and achieve greater emission reductions for every dollar spent. If the developed countries could pay the marginal cost of credits rather than the expected $20 market price, they could save almost $40 billion from 2013-2020 according to FCI results. It is unlikely an aggregator could negotiate down to marginal cost pricing, but it could aggregate demand and use its large purchase power to negotiate down the price to purchase credits between the marginal cost and the market price of credits.

Finally, a government-based forest carbon offset aggregator would be well positioned to ensure the environmental integrity of offsets entering the United States. With the government verifying emissions reductions and monitoring implementation, moreover, U.S. companies could avoid exposure to the reputation and business risks associated with tropical forest-sector investments in far-away regions about which they may have very little information.

These financial intermediaries could be run by a coalition of developed countries like the European Union, or a single country like the United States.

Safeguards

A new, large commodity market in forest carbon holds several significant risks that must be protected against. These risks are largely foreseeable, and so proactive policymakers can safeguard against the evident risks to ensure the market functions optimally.

There are two general categories of risks that will require the attention of policymakers as international and domestic policies are being forged: risks that threaten the success of forest carbon markets, and risks that come as a result of the success of carbon markets. Both types of risk should be effectively managed in order to maintain the political will to continue forest carbon markets into the future.

The most significant risk that could prevent the forest carbon markets from functioning effectively is the problem of *leakage.* Leakage, in which payments to decrease deforestation in one area simply drive deforestation to another area, is very likely to occur if there is an insufficient flow of payments to protect forests or if there is insufficient country participation.

The FCI projects that new forest carbon markets will protect 973,000 km^2 of forests that previously were not protected, an area almost the size of Bolivia. This could reduce emissions from deforestation by almost half, but only if absolutely no leakage occurs. Given that huge quantities of forest carbon stocks have high opportunity costs that are comparable to the prices they will receive, it is unlikely that forest carbon markets will perfectly protect the exact parcels of forest that would have been deforested. And even if the correct parcels were chosen, there would be many opportunities to profitably clear forests in nearby areas. Without proper monitoring and enforcement of forests in all countries, leakage potential could be quite high.

To address leakage through domestic and international climate change legislation, the most effective option will be to emphasize a rapid transition to performance-based national-level forest carbon programs, a *sectoral approach*. If payments are only made for performance, such that countries only receive funds after they have reduced their deforestation rates, within-country leakage would be eliminated. This approach leaves the responsibility of managing forest carbon stocks to each participating developing country but will ensure the environmental integrity of the program, and therefore the legitimacy of the market.

In addition to national, performance-based approaches to forest carbon, international forest carbon credits may be discounted against domestic emissions reductions. Under the provisions of U.S. House Bill 2454, beginning in 2017 international forest carbon emissions reductions will be valued at four-fifths the quantity of domestic emissions reductions in order to provide incentives for domestic emissions reductions in the long-term. This discounting will essentially serve as a quantity buffer that allows for a leakage margin of 20 percent on each ton purchased.

The international community will also need to begin considering paying countries with low or no deforestation to protect against international leakage. If deforestation stops completely in the countries where it exists today, demand for agriculture and timber will drive deforestation to other countries. Congo Basin countries are especially vulnerable to international leakage due to the low level of governance over their forests despite relatively low historical deforestation rates. High-forest, low-deforestation countries such as those in the Congo Basin could receive special funds that would not cover the full opportunity costs of protecting their stocks of forests, but instead could go toward monitoring and enforcement capacity within their national and subnational governments to ensure the forest stocks remain protected.

The leakage problem is further complicated when we begin to think about leakage across different ecosystems. An overly narrow focus on forest conservation for carbon only ignores the many ecological, cultural, and economic functions of forests. For example, if Brazil only protects high-carbon forests, then there will be an increased pressure to the clear the savannas known as the *cerrado,* which have much lower carbon content than the forests of the Amazon. The cerrado is one of the most biologically rich ecosystems in the world, so this cross-ecosystem leakage could threaten biodiversity in any ecosystem that is not carbon rich. Policy instruments should therefore encourage the continued protection of valuable ecosystems outside of the sphere of policies to conserve forest carbon, and should dedicate some additional financial resources to these objectives.

Even successful forest carbon markets will hold certain risks that will be important for policymakers to manage by creating simple safeguards. The most important risk involves the interaction of forest carbon markets and global food security. Successfully reducing deforestation rates will prevent agricultural lands from further expanding into existing forested areas. Since one of the major drivers of deforestation is agriculture, limiting the supply of land available for agriculture in the face of a growing demand for food will likely cause the price of food to increase dramatically.

Future forest carbon policy must also dedicate resources to increasing food productivity on existing agricultural lands. The interconnectedness of markets like agriculture and timber that require large areas of land, although not directly related to forest carbon, also requires policies that manage those markets to be linked. Nations should consider explicitly adopting comprehensive terrestrial accounting to manage forest carbon, food, timber, and fuel markets simultaneously, rather than having distinct and disjointed laws on each. New legislation could create funds to invest more money in research and development of breakthrough technologies that will improve the productivity of these fertile agricultural lands.

A new commodity market that will be valued at billions of dollars per year will undoubtedly have rippling effects across the economic markets. The ever-growing demand for agriculture and timber products will present risks to forest carbon markets through leakage, and an increasingly successful forest carbon market will drive up the prices in agriculture and timber markets. These potential negative impacts should not be cause to turn away from forest carbon, since forest carbon markets hold the greatest opportunity to simultaneously mitigate climate change, provide sustainable development revenue to poor communities, conserve tropical forests, improve national security, and protect biodiversity. Nevertheless, it will be up to policymakers to ensure that the most vulnerable are protected from such a large new market.

CHAPTER 5. CONCLUSIONS

The FCI illuminates the likely geography of forest carbon asset supply to determine which areas have the potential to generate forest carbon credits. It also estimates forest carbon market conditions—including prices, quantities, and revenues, both locally and nationally—by considering opportunity costs, carbon mitigation potentials, investment risks, and government readiness.

The potential geography of forest carbon supplies based on forest carbon stocks shows that cost-effective forest carbon exists across the globe. Combining country risk and profit potentials to create FCI scores allows for relative comparisons of countries and locations within countries on their ability to generate forest carbon.

Countries in the tropics have the most cost-effective forest carbon stocks. In particular, countries in the Amazon–Andes, Congo Basin, and Southeast Asian islands have the least-cost forest carbon stocks, although high levels of risk in the Congo Basin reduce the value of investments in that region. Brazil emerges as the best country for forest carbon investing given its huge profit potential for forest carbon and low risk. Indeed, Brazil has already established the Amazon Fund, a national plan for reducing its deforestation that now only needs to receive sufficient financing.

While Brazil is currently politically opposed to the sale of offset credits to reduce costs of climate change policies in developed countries, Brazil may change their political position in the negotiations, or may compromise by selling forest carbon emissions credits as supplemental emission reductions. Either way, Brazil is positioned to have the most immediate potential for supplying forest carbon in the near term. Peru and Bolivia also have the potential to be early movers, although their total potential supply is far less than that of Brazil due to low deforestation rates.

While many tropical countries have cost-effective stocks, a number of them do not have large historical deforestation rates, so their potential forest carbon supplies are limited because they would only be paid to reduce their historical deforestation rate. Countries in the Congo Basin, which have historically low deforestation, are especially affected, despite poor forest governance and high vulnerability to future deforestation if international leakage occurs. Peru, Colombia, and Guyana also have low historical deforestation despite high FCI scores based on stocks. This suggests that these countries could be initial suppliers of forest carbon but would have limited long-term supply potential unless they are paid to protect some of their stocks.

Instead, countries with very high historical deforestation rates and large forest areas will be the major suppliers of forest credits in the long-term. Indonesia and Brazil will be the two major suppliers of credits in the first commitment period, supplying 60 percent of the total quantity. As the market develops and countries improve their governance and market readiness, countries like Malaysia, Mexico, and Nigeria will hold great potential to become big players in the forest carbon market.

The FCI demonstrates that tropical forests will be a huge part of the immediate climate change solution. Forest conservation and regrowth will mitigate almost 1 $GtCO_2$-eq of greenhouse gas emissions each year from 2013 to 2020 at an average cost of \$13/tCO_2-eq. Over these 8 years, 973,000 km^2 of forests will be protected—an area almost the size of Bolivia.

The FCI also demonstrates that a new forest carbon commodity market could be large and would have a significant economic impact on many participating countries. The forest carbon market will be worth almost \$20 billion per year from 2013 to 2020, and will increase the GDP of many developing countries by as much as 1 to 2 percent.

The large financial flows to tropical developing countries have the potential not only to mitigate climate change, but also to protect tropical forests with high biodiversity, reduce rural poverty, and improve national security. If the rules of the market are appropriately designed, these co-benefits can be maximized so that a broad set of international objectives are achieved through the forest carbon market.

Domestic and international climate change policies that support a phased approach for country participation will help achieve strong forest carbon markets. Having countries invest first in capacity building will protect the markets from being flooded by high-risk forest carbon. As countries implement national forest carbon programs and build readiness and capacity to reduce deforestation, they can finally advance to a phase in which they are paid for actual emissions reductions.

Policymakers can also implement certain safeguards in domestic and international climate change legislation to protect against specific risks in the markets. The two most important safeguards will be to minimize leakage by promoting country-level, sectoral approaches to forest carbon activities, in which payments are made for performance of emissions reductions below a national baseline of deforestation. Policymakers may also consider setting up special funds for high-forest, low-deforestation countries that are at high risk of international leakage.

A second important safeguard will be to protect food production, and in some cases it will be appropriate to dedicate funds toward comprehensive land-use planning. To ensure that the increasing demand for food is met, forest carbon markets should be designed to not shift significant areas of agriculturally productive land into forests. Instead, new forests should be grown only on agriculturally marginal lands.

A new market in forest carbon will have the potential to change the way humans manage lands across the globe. By paying for the value of standing forests, this market will not only have direct environmental and social benefits, but will also shape the way humans view services provided by nature.

ENDNOTES

1. FAO (2006).
2. Geist and Lambin (2001).
3. Soloman et al. (2007); Houghton 2008.
4. Meridian Institute (2009).
5. UNFCCC (1998).
6. Chomitz (2006).
7. UNFCCC (1998).
8. International Energy Agency (2008).
9. PEACE (2007).
10. Emissions from deforestation in Indonesia are five times those from all other sectors combined: land-use change and forestry account for 2,563 MtCO2e, whereas the total emissions from all other sectors are only 451 MtCO2e (Houghton 2003).
11. See http://ec.europa.eu/environment/forests/deforestation.htm.
12. A total of 25 countries had submitted R-PINs to the World Bank at the time this report was written.
13. Busch et al. (2009); Grieg-Gran (2006).
14. See Annex 3: Options for Setting Reference Levels (RLs) (Meridian Institute 2009).
15. McKinsey & Company (2009).
16. Kindermann et al. (2008a); Benítez et al. (2004, 2007).
17. Meridian Institute (2009, Appendix 2, Table 2.3) reviews the literature up to 2008.
18. Myers (2007, 10–11) reviews the literature through 2007.
19. Murray et al. (2009).
20. See Appendix 1 for a detailed methodology of the selection of price constraints.
21. These price caps are all in 2009 dollars, not adjusted for inflation.
22. Accessibility model created by Michael Jennings (unpublished).
23. See Appendix 2 for an illustration of producer-surplus estimates in our model.
24. The land-cover map used is the GLC2000 developed by JRC (2003). See Appendix 3 for GLC2000 classifications.
25. Davies and Nori (2008).
26. See Benítez et al. (2007) for original model.
27. Existing carbon content is taken from a model developed by Kindermann et al. (2008b).

28. Cramer et al. (1999).

29. FAO (2005).

30. CIESIN (2002).

31. See Appendices 4 and 5 for data sources.

32. See Appendix 6 for a review of forest carbon stock estimates.

33. Houghton (2005).

34. Data from Batjes (1996).

35. We use agricultural rents from Naidoo and Iwamura (2007), who estimate gross economic rents on the basis of existing land uses of 42 different crops and 6 livestock types and their respective crop productivity, livestock density, and global prices.

36. For a full discussion of discount rate estimation, see Appendix 7.

37. We use timber rents from a model developed by Kindermann et al. (2006) and updated by Gusti (unpublished) that is based on standing timber volumes and timber prices.

38. For a full discussion of all the land-use options, see Appendix 8.

39. Antinori and Sathaye (2007).

40. From a sample of 10 projects analyzed by Antinori and Sathaye (2007).

41. Fagan, M. and R. DeFries. (Forthcoming)

42. The expected profits are actually far lower and are based on existing deforestation rates and the quantity of credits necessary to reduce deforestation rates to zero.

43. World Bank. 2008a.

44. World Bank. 2008a.

45. World Bank. 2008b.

46. In addition, 51 intergovernmental, international, and regional organizations using Earth observation or involved in related issues have been recognized as participating organizations. GEO was an initiative of the 2002 World Summit on Sustainable Development and by the Group of Eight meeting at Evian, France, in 2003.

47. See Appendix 10 for a complete list of countries' risk factors.

48. See Appendix 10 for a complete list of countries' FCI scores.

49. FAO (2005).

50. See Appendix 10 for a complete list of countries' average costs, total costs, and profit potentials

51. FAO (2005).

52. World Resources Institute (2009). www.wri.org/publication/content/8190.

53. The Nature Conservancy (2009). www.nature.org/rainforests/explore/facts.html.

54. Meridian Institute (2009).

55. Purvis et al. 2009.

56. Waggoner. 2009

APPENDICES

Appendix 1. Price Constraint Selection

The price of forest carbon will depend on whether we are assuming forest carbon credits to be permanent or temporary. The majority of credits sold on the carbon markets today are permanent and therefore valued at their net present value. If forest carbon is sold as temporary credits, they will cost a fraction of the price of permanent ones. For example, the price of one-year temporary credits will be equivalent to their annual rental value.

Price estimates of future carbon credits are based on prices derived from expected policy and market outcomes, not the shadow price of carbon representing climate damages as estimated by Nordhaus' DICE model, for example (Nordhaus 1993). Since the only policy available to date with price estimates is the American Clean Energy and Security Act (H.R. 2454), we used this as the foundational policy for our price estimates.

We evaluated two principal studies on H.R. 2454 to formulate reasonable estimates of credit prices in 2020 and 2030 (Table A.1), an Energy Information Agency (EIA) study and an Environmental Protection Agency (EPA) study.

Table A.1. Price Estimates of Emissions Allowances

Model Summary			Price (US$/tCO2-eq)	
			2020	**2030**
EIA	Emissions Allowance	Basic	31.7	64.8
		High Offsets	20.5	41.9
	International Offset	Basic	25.4	22.6
		High Offsets	16.4	33.5
EPA	Emissions Allowance	ADAGE	16	27
		IGEM	16	26
	International Offset	ADAGE	13	21
		IGEM	13	21
Average	Emissions Allowance		21	40
	International Offset		-19	32
FCI	Price Constraint		20	40

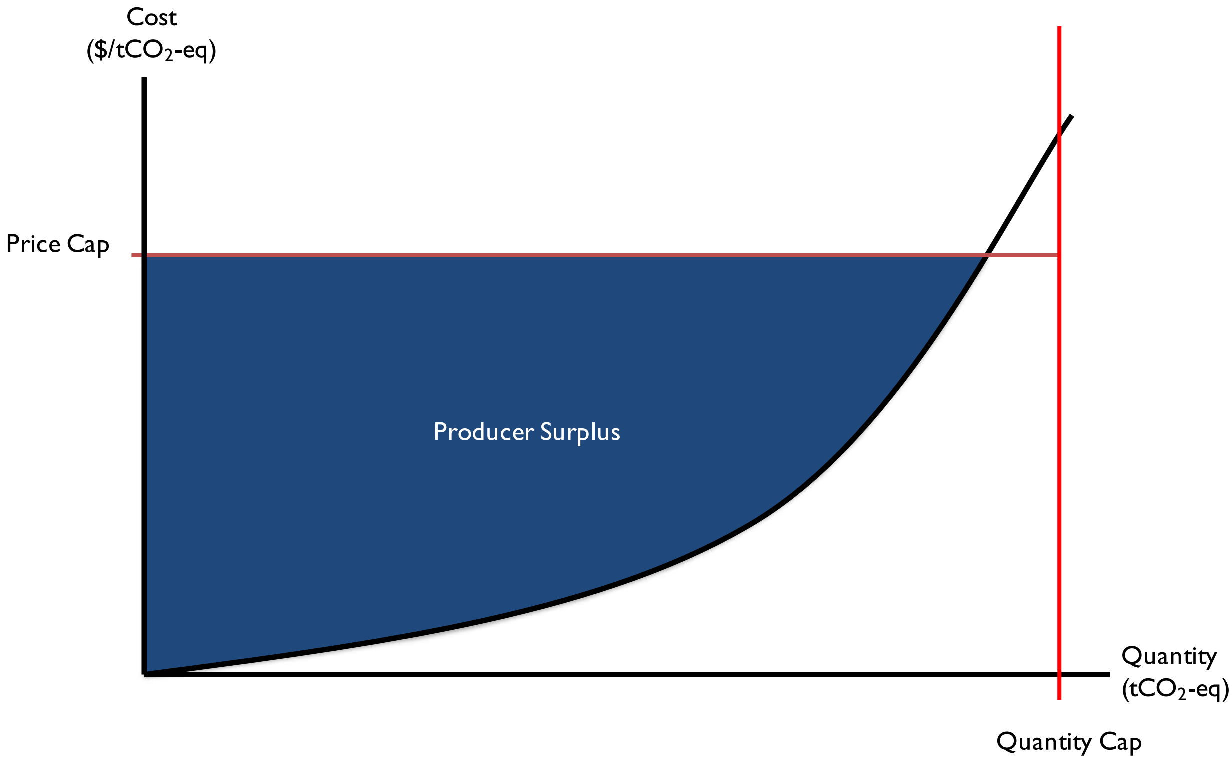
Both the EIA and EPA studies modeled the price of emissions allowances and international offsets separately; EIA modeled multiple market scenarios, whereas EPA used different models (ADAGE versus IGEM). From the EIA study, we chose the two policy scenarios with the most likely scenarios: the basic case and the high-offsets case. Across these various models, the average emissions allowance price was \$21/tCO_2-eq in 2020 and \$40/tCO_2-eq in 2030. The average international offset price was \$19/tCO_2-eq in 2020 and \$32/tCO_2-eq in 2030. Although international forest carbon offsets will largely compete with other international offsets, the absolute backstop price for forest carbon may be closer to the emissions allowance price. Therefore, when we chose our final price constraints for the FCI, we chose \$20/tCO_2-eq in 2020 and \$40/tCO_2-eq in 2030.

All values above these price estimates for both A/R and REDD were excluded in each scenario.

Appendix 2. Producer Surplus Estimation

Producer surplus is the metric used to compare forest carbon asset generation across countries. It can be thought of as the sum of all marginal economic profits along a supply curve, capped at the market price of carbon credits. The area shaded in blue in Figure A.2 illustrates the concept of producer surplus.

Figure A.2. Theoretical Illustration of Producer Surplus



Appendix 3. Global Land-Cover Classifications

Global land-cover classifications used in the FCI were based on the Joint Research Centre's GLC2000 database. Discrepancies among the GLC2000 and other land cover data are widely acknowledged and arise from differences in definition of forested land and limitations in measurement techniques.[56] As forest measures improve, enhanced data can be readily incorporated in the FCI.

The following tables show the land classifications that were included in grid cells that we classified as suitable for either A/R or REDD.

Table A.3.1. Land Classifications from GLC2000 Used for A/R

A/R
Shrub cover, closed–open, evergreen (class 13)
Shrub cover, closed–open, deciduous (class 14)
Herbaceous cover, closed–open (class 15)
Sparse herbaceous or sparse shrub cover (class 16)
Regularly flooded shrub and/or herbaceous cover (class 17)
Cultivated and managed areas (class 18)
Mosaic: cropland / tree cover / other natural vegetation (class 19)
Mosaic: cropland / shrub and/or grass cover (class 20)

Table A.3.2. Land Classifications from GLC2000 Used for REDD

REDD
Tree cover, broadleaved, evergreen (class 2)
Tree cover, broadleaved, deciduous, closed (class 4)
Tree cover, broadleaved, deciduous, open (class 5)
Tree cover, needle-leaved, evergreen (class 6)
Tree cover, needle-leaved, deciduous (class 7)
Tree cover, mixed-leaf type (class 8)
Tree cover, regularly flooded, fresh water (class 9)
Tree cover, regularly flooded, saline water (class 10)
Mosaic: tree cover/ other natural vegetation

Appendix 4. Datasets Used in REDD Analysis

The REDD analysis combines five different data sources to calculate quantities and costs; these are listed in the following table.

Table A.4. Datasets Used in REDD Analysis

Dataset	Purpose	Source
Forest area	Delineates grid cells identified as forest using GLC2000	JRC (2003)
Above-ground carbon in forests	Estimates above-ground forest carbon content(in tC/ha)	Kindermann et al. (2008b)
Value of forested lands (two datasets)	Estimates opportunity costs of avoiding land conversion from forests to agriculture (in $/ha)	Naidoo and Iwamura (2007) Kindermann et al. (2006)
Additionality mask	Estimates human accessibility to forested grid cells	Jennings (unpublished)

Appendix 5. Datasets Used in A/R Analysis

The A/R analysis combines three datasets to calculate A/R quantities and costs, as shown in the following table.

Table A.5. Datasets Used in A/R Analysis

Dataset	Purpose	Source
Nonforest area suitable for A/R	Delineates grid cells for A/R analysis using GLC2000	JRC (2003)
Potential forest carbon content	Models potential forest carbon content after one rotation (in tC/ha)	Kindermann et al. (unpublished)
Current agricultural NPV	Estimates opportunity costs of converting agricultural land into forests	Naidoo and Iwamura (2007)

Appendix 6. Carbon Stock Estimates

Based on a review of the literature on global estimates of forest carbon, we found six studies with adequate scope and methodological appropriateness against which to compare the FCI forest carbon stock estimates. The global forest carbon stock estimates from these studies are listed in the following table.

Table A.6. Global Estimates of Forest Carbon Stocks

	Study	Global* Forest Carbon Stocks ($MtCO_2$-eq)
1	Olson et al. (1983); Gibbs (2006)	726,483
2	Houghton (1999); DeFries et al. (2002)	983,747
3	IPCC (2006)	1,145,348
4	Brown (1997); Achard et al. (2002, 2004)	777,834
5	Gibbs and Brown (2007a, 2007b)	373,838
6	FAO (2006)	693,815
7	Kindermann et al. (2008b)	856,511
	Average**	837,206
	FCI forest stock estimate	762,634

**Based on 61 countries included in Table 3 of Gibbs et al. (2007).*

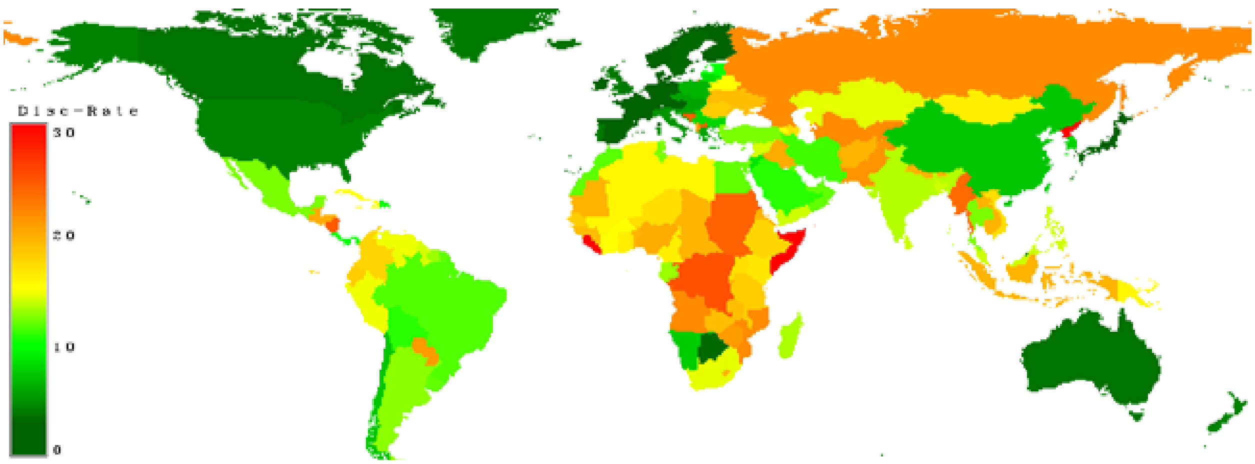
***To calculate the average global forest stock across all six studies, we first took the average country estimates from studies 1–6 and totaled all countries to find a global estimate. We took the weighted average with this value and the global estimate of Kindermann et al. (2008b). Each study was weighted equally.*

Appendix 7. Discount Rates

Selection of discount rates is always contentious. But for a spatially explicit model that attempts to calculate the present value of the opportunity cost of land, the results will be highly sensitive to the differences in discount rates in different locations. In order to account for these differences, we used country-level estimates of discount rates created by Benítez et al. (2004). They estimate the discount rates by correlating empirically derived discount rates from a subsample of countries with a risk index with global country coverage. They then are able to extrapolate discount rates for all countries with risk index values.

The figure below shows their estimated discount rates (figure taken from Kindermann et al. 2008a).

Figure A.7. Country Level Discount Rates from Kindermann et al. (2008a)



Since there is some question as to the accuracy of these country-specific estimates, we elected to cluster the countries into three categories: Organisation for Economic Co-operation and Development (OECD) countries, least-developed countries, and all other countries. We calculated the average discount rate in each category and applied that average to all countries within the category. This approach allows us to present a simpler model that better reflects the level of accuracy of our data, and it eliminates outlier estimates (like Botswana).

Averaged discount rates: OECD, 4 percent; least-developed countries, 20 percent; other, 15 percent.

Appendix 8. Options and Assumptions in Opportunity Cost Calculations

Temporary versus Permanent Credits

Calculating the opportunity costs of land depends on our policy assumptions. We identified three potential ways to calculate opportunity costs of land:

1. Forest carbon credits are temporary, renewed annually
a. Opportunity costs are annual land rents
b. Non-permanence does not need to be accounted for
c. No discount rate needs to be chosen

2. Forest carbon credits are temporary, renewed after a fixed interval of years (e.g., every five years)
a. Opportunity costs are the net present value (NPV) of rents over a fixed interval of years
b. Non-permanence may or may not be accounted for, depending on the interval length
c. Must choose a discount rate

3. Forest carbon credits are permanent
a. Opportunity costs are the NPV of rents over an infinite interval of years
b. Must discount for non-permanence risk
c. Must choose a discount rate

We opted for the third assumption, which would allow forest carbon credits to be fungible with all other carbon credits. While this approach incorporates the methodological burdens of non-permanence risk and discount rates, we believe it to be the most likely market outcome, and therefore we elected to make our best attempt at accurately modeling it.

Drivers of Deforestation

Opportunity costs of conserving existing forested land (REDD) depend on different drivers of deforestation. In any given location, you may have:

1. Forest logged, cleared, and then converted to agriculture
Opportunity costs are the value of harvestable standing volume of wood in year 1, plus the discounted present value of agricultural rents in all subsequent years.

2. Forest cleared, and then converted to agriculture
Opportunity costs are the NPV of agricultural rents.

3. Forest logged, left fallow
Opportunity costs are the value of harvestable standing volume of wood in year 1. No further rent is claimed, but deforestation could occur quickly in such an area.

4. Forest cleared and burned for charcoal
Informal market that cannot be captured easily.

5. Forest degraded for fuel wood
Informal market that cannot be captured easily.
Due to data limitations, we only modeled the first two scenarios, where forest is either cleared and converted directly to agriculture, or cleared first for timber, then converted to agriculture.

Appendix 9. Datasets for Remote Sensing Capacity Indicator

http://www.ceos.org (accessed July 2008)

http://earthobservations.org (accessed July 2008)

http://servirtest.nsstc.nasa.gov/about.html (accessed July 2008)

Appendix 10. Country Data Tables

Country	Average Cost ($)	Total Cost ($)	Profit Potential ($)	Risk Index	FCI Score (Stocks)	FCI Score (Flows)
Afghanistan	9.66	19,882,811	22,319,509	0.09	0.66	0.72
Angola	13.98	389,071,383	153,602,177	0.10	0.90	0.80
Argentina	13.36	1,941,252,477	281,118,252	0.55	0.79	0.83
Australia	5.54	484,918,697	1,301,600,703	0.87	0.81	0.89
Bangladesh	6.26	103,443	226,811	0.39	0.55	0.53
Benin	13.64	209,987,121	116,253,411	0.29	0.80	0.79
Bolivia	14.74	2,503,202,467	884,177,798	0.36	0.94	0.88
Botswana	16.75	19,931,972	3,860,721	0.54	0.63	0.65
Brazil	15.41	54,988,043,086	15,701,890,650	0.54	1.00	1.00
Brunei	0.50	5,568	219,173	0.34	0.71	0.52
Burkina Faso	9.99	21,949,525	31,895,821	0.20	0.71	0.74
Burundi	14.58	19,707,801	7,329,351	0.10	0.64	0.67
Cambodia	13.05	1,013,322,353	567,979,263	0.23	0.82	0.86
Cameroon	12.21	794,286,251	639,045,250	0.18	0.90	0.86
Cent. Afr. Rep.	15.31	165,071,557	38,735,573	0.11	0.91	0.74
Chad	8.70	10,912,661	29,847,348	0.05	0.69	0.73
Colombia	15.91	774,240,253	109,061,644	0.49	0.93	0.79
Congo, Rep.	12.66	125,548,252	82,351,826	0.16	0.92	0.78
Congo, D.R.	16.77	671,852,125	118,682,194	0.03	0.91	0.79
Ecuador	12.11	1,474,362,692	1,109,443,340	0.36	0.88	0.89
Eq. Guinea	17.00	24,068,485	4,394,627	0.07	0.74	0.65
Ethiopia	12.65	126,970,278	67,945,318	0.22	0.74	0.77
Gabon	17.29	134,898,417	21,220,107	0.19	0.91	0.72
Ghana	13.36	994,293,743	548,165,947	0.45	0.85	0.86
Guatemala	15.37	707,020,128	224,902,622	0.39	0.85	0.82

Country	Average Cost ($)	Total Cost ($)	Profit Potential ($)	Risk Index	FCI Score (Stocks)	FCI Score (Flows)
Guinea	15.33	46,669,359	15,078,505	0.07	0.80	0.70
Guinea-Bissau	17.94	16,681,555	2,199,990	0.17	0.74	0.62
Honduras	12.69	1,269,027,815	874,071,544	0.42	0.84	0.88
Indonesia	12.24	10,446,941,971	6,856,374,492	0.41	0.92	0.96
Japan	19.63	62,263,259	1,183,924	0.88	0.83	0.60
Kazakhstan	17.48	27,159,492	3,912,805	0.37	0.72	0.65
Kenya	15.17	193,662,107	63,731,580	0.50	0.81	0.77
Laos	12.91	148,794,129	90,852,133	0.13	0.78	0.78
Liberia	16.94	434,288,759	69,703,814	0.15	0.76	0.77
Madagascar	13.49	318,003,109	166,262,332	0.25	0.89	0.81
Malawi	13.61	79,109,673	38,105,345	0.28	0.75	0.74
Malaysia	16.63	5,584,431,044	918,965,491	0.62	0.90	0.88
Mali	8.21	74,235,286	279,708,374	0.34	0.74	0.83
Mexico	17.58	5,205,865,548	624,951,850	0.61	0.85	0.86
Mongolia	14.88	414,174,381	141,060,573	0.60	0.84	0.80
Mozambique	14.81	207,158,894	39,855,472	0.35	0.88	0.75
Myanmar	9.00	0	0	0.00	0.00	0.00
Namibia	9.44	1,081,628	1,209,520	0.57	0.55	0.60
Nepal	15.40	561,749,122	177,284,377	0.31	0.82	0.81
Nicaragua	14.20	972,055,222	418,436,725	0.46	0.87	0.85
Nigeria	6.82	1,429,772,336	3,557,162,197	0.35	0.90	0.94
North Korea	17.53	0	0	0.00	0.00	0.00
Pakistan	14.76	602,424,076	210,355,930	0.43	0.77	0.82
Panama	19.16	88,794,653	3,891,909	0.63	0.81	0.65
Papua New Guinea	13.54	916,773,677	337,600,403	0.45	0.87	0.84
Paraguay	14.25	1,273,005,205	176,890,895	0.39	0.86	0.81

Country	Average Cost ($)	Total Cost ($)	Profit Potential ($)	Risk Index	FCI Score (Stocks)	FCI Score (Flows)
Peru	12.39	1,247,782,730	744,866,994	0.54	0.95	0.87
Philippines	12.92	280,051,927	186,151,887	0.39	0.74	0.81
Russia	18.33	705,273,096	67,460,725	0.44	0.92	0.77
Senegal	14.46	62,766,794	28,618,779	0.27	0.69	0.73
Sierra Leone	14.55	42,832,229	18,241,030	0.19	0.73	0.71
Somalia	14.70	0	0	0.00	0.00	0.00
Sudan	10.12	470,558,027	381,760,014	0.13	0.81	0.84
Tanzania	13.45	1,981,940,667	953,026,303	0.33	0.88	0.88
Togo	15.72	46,881,425	10,536,933	0.12	0.74	0.69
Uganda	12.43	199,381,494	159,855,165	0.34	0.77	0.80
Venezuela	12.63	921,542,974	568,006,713	0.12	0.85	0.86
Zambia	14.86	1,628,748,036	756,730,948	0.31	0.88	0.87
Zimbabwe	15.51	158,938,648	43,007,365	0.09	0.71	0.75
	Average	*Total*	*Total*	*Average*	*Average*	*Average*
World	*13.43*	*105,735,723,895*	*41,053,382,471*	*0.32*	*0.77*	*0.74*

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