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Abstract

Despite accounting for 17-25% of anthropogenic emissions, deforestation was not included in the Kyoto Protocol. The UN Convention on Climate Change has recently decided to include it in future agreements and asked its scientific board to study methodological and scientific issues related to positive incentives to reduce emissions from deforestation. Here we present an empirically derived mechanism that offers a mix of incentives to developing countries to curb their emissions from deforestation while including important guaranties to the financing community. We use recent data both to model its effects on the 20 most forested developing countries and to produce empirical global cost curves of avoiding deforestation. Results show that at very low CO2 prices (~US$5.5/t) a successful mechanism could reduce 90% of global deforestation.

1. INTRODUCTION

Our species has converted 26.5% of Earth's terrestrial surface (*1*) into agriculture, ranching or urban areas and we currently appropriate 23.8-50% of Earth's terrestrial NPP (*2-4*). This conversion process, historically concentrated in the North, is now occurring with great rapidity in the most biodiverse and carbon rich ecosystems of the planet, tropical forests (*1*). Home to 50-66% of Earth's species *(5-6)*, these forests are being converted at a rate of between 5.6-12 million hectares per year *(7-9)*. The resulting 1-2 GtC/ emitted per year amount to 17-25% of anthropogenic GHG emissions *(10-12).* Recent research suggest that the role these forests play in regulating global climate might be bigger than previously thought *(13)* and will likely become even more important as alternative sinks become saturated *(14)* while they continue to act as sinks throughout a century of climate-change *(15).*

The financial rationale for deforestation in developing countries is clear, the alternative uses for land and timber provide higher short term returns than standing forests *(1, 16-17).* However, this is unlikely to be true when global benefits, such as carbon storage, climate regulation and biodiversity are included in a land use decision *(16-18*). This points to a failure of economic and institutional systems, caused by the "scale mismatch" *(19)* between natural and human systems. Recent studies show that compensating developing countries for even a small portion of the global benefits their forests provide might be sufficient to greatly reduce deforestation *(20).*

Paradoxically, for political and methodological reasons deforestation was the only major emissions source left out of the Kyoto Protocol. Therefore reductions in emissions from deforestation are not eligible for carbon credits, despite its potential to be one of the most cost effective ways of tackling climate change *(20).* After two years of scientific and methodological discussions, the Parties to the UNFCCC have recently affirmed the "urgent need to reduce emissions from deforestation", noted that it "requires stable and predictable availability of resources" and requested its scientific body to undertake a programme of work on methodological issues related to a range of policies approaches and positive incentives aimed at reducing emissions from deforestation *(21).*

Here we offer two contributions to this debate. Based on the ongoing political and academic discussions and on analyses based on recently available data, we present a compensation mechanism to provide combined incentives to developing countries to reduce or avoid emissions from land-use change. We then use recent data to simulate the operation of the mechanism in the top 20 developing countries by forest cover, predict the reductions in emissions for different level of incentives, test its adaptability and compare it with other candidate mechanisms. Finally we produce empirically estimated global cost curves of avoiding deforestation. These analyses strongly support the idea that reducing emissions from deforestation can provide one of the cheapest ways of combating global warming.

2. MECHANISM BACKGROUND

In the eleventh Conference of the Parties (COP 11) in December 2005 it was decided that the scientific board of the UNFCCC should examine the issue of positive incentives to reduce emissions from deforestation in developing countries *(21).* A group of scientists proposed the concept of "compensated reductions" *(22)* and based on that Brazil made the first official proposal of a RED mechanism *(23).* This mechanism would operate at the national level and linked compensation to a country's success in reducing recent deforestation rates. Its pioneering nature set the basis for all RED discussion, but it was soon pointed out *(24)* that targeting only a subset of countries (those countries with positive deforestation rates in the recent past) and connecting the incentive only to the annual deforested area (with no relation to total forest area) would likely compromise the effectiveness of the mechanism.

Attempts to address tropical deforestation in the past have systematically failed due to the "leakage" effect, i.e. a reduction of deforestation in a target area being compensated by an increase in other areas *(12,22-25).* The rapid and extensive growth in deforestation in South-east Asia after the 1998 logging ban in China *(26)* shows that deforestation also leaks across non-contiguous borders. A mechanism operating at the national level would solve the leakage within each country, a major drawback of project-based approaches *(12, 24-26)* and a major reason why these were not included in the Kyoto Protocol. But the threat of international leakage would remain.

This threat is particularly serious if an incentive mechanism rewarded only a subset of forested developing countries. An important challenge a RED mechanism has to address is that it needs to include countries in several stages of the conversion process. Deforestation is a multicausal issue *(27)* that has a complex relationship with development *(28)* and varies greatly both across countries and in time *(9).* Countries that are currently conserving their forest for some particular reasons might increase their rates in the near future. That this threat would be exacerbated by distorted incentives has been pointed out by many countries *(29).*

Some developing countries responded to this proposal by suggesting that additional provisions should offer incentives to developing countries that have been conserving their forests in the recent past *(23-24).* We *(25)* suggested a mechanism that would address this issue by i) connecting the incentive to be paid to all developing countries to the total reductions in emissions they achieve as a group at a given year and ii)distributing it to each country based on the reduction it achieved in comparison to its “expected emissions” (i.e. what it would emit assuming it deforested at the global average rate). A group of scientists from the Joint Research Center (JRC) of the EC suggested *(26)* a similar approach, but with the difference that countries would be divided in two groups. High deforesting countries (deforestation rates higher than a half or a third of global average) would receive their compensation based on past emissions and low deforesting countries would be tied to the threshold rate (half or a third of global average) as an assumed baseline.

3. OUR MECHANISM

Recent research has allowed us to use real world data to simulate the functioning of a RED mechanism and predict the response of individual countries to it. Through these simulations we were able to analyze the strengths and weakness of the mechanisms proposed so far, which in turn led to the development of the mechanism we present here. We believe it addresses the main issues related to RED, fits pragmatically into the international political framework and its design ensures maximum buy in by the participant countries.

It operates at the global level, transferring resources from the international community to developing countries by offering these a mix of incentives to reduce or avoid their emissions from deforestation. It directly connects the amount of incentive paid to global reductions in deforestation, eliminating the threat of leakage at all levels and guarantees the financier that it will “get what it pays for”. The importance of this guarantee in attracting finance to the mechanism can hardly be overstated.

It was designed to be i)comprehensive, by including countries in all stages of the conversion process (i.e. high, low or negative past or projected deforestation rates); ii) flexible, being capable of offering (or not) incentives to reduce deforestation and degradation and stimulate forest conservation and reforestation and afforestation activities; and iii)adjustable, both across countries and time.

It is open to any source of financial resources. The possible alternatives *(29)* can be classified as i) market oriented, where demand for credits is created (e.g. by expanding Annex 1 countries emission reduction targets) and these can be traded; ii) fund-oriented, where financing countries will provide the resources by taxing specific commodities or income; and iii) a mix of both. In all these options the resources will be transformed into incentives per avoided tonne of CO_2. Our mechanism is based on this last incentive and therefore works with all these options.

The mechanism transfers these resources to developing countries via a mix of incentives. The most important underlying causes of deforestation *(27)* are either decided or heavily influenced by the national governments (e.g. infrastructure expansion, property and use rights, tax and fiscal incentives) and are part of the long term development strategies of each country. A RED mechanism should seek to influence these and so the promise of sustained and predictable incentives is essential, as has been recently stated by many countries *(29).* However, if a RED mechanism is to be successful, incentives also need to reach local drivers of deforestation and agents capable of implementing conservation activities on the ground. These include local governments, indigenous groups and local communities and private companies that practice sustainable management. Due to very diverse national circumstances and to sovereignty issues it is unlikely that a RED mechanism will address the intra-national distribution of the incentives. However it has to be open and adaptable to these diverse circumstances and to the options to address them. The mechanism is presented in Box 1.

Box 1:

The mechanism operates at the global level, eliminating the threat of leakage at all levels and ensuring its financing community that incentives are paid to real reductions in global emissions from deforestation.

Each year *t* the reduction in emissions is the difference between the Global Baseline Emission and the actual Global Emissions in that year. If this difference is negative no incentive is paid. If it is positive then the Total Incentive paid is the product of the reduction by the base incentive per avoided tonne of CO2.

$$TI = (GBEt – GEt) \times \$k \qquad \text{Eq 1}$$

The second step is to distribute the Total Incentive among the developing countries in a way that offers them a mix of incentives to curb their emissions from deforestation. Each country can receive two kinds of incentives. The first is an incentive to reduce its emissions in comparison with its past emissions:

$$I1 = (PE – Et) \times \$k \qquad \text{Eq 2}$$

The second is an incentive to emit less than it would emit if it followed the global baseline emission rate[1]. That is, to emit less than it would be expected to emit if it had an average behavior:

$$I2 = (EE – Et) \times \$k \qquad \text{Eq 3}$$

The relative weight of these two incentives might be different. The Combined Incentive is:

[1] The fraction of forest carbon stocks emitted per year. For our 20 countries their average emissions rate (0,47%) is very close to their average deforestation rate (0,48%). The difference is due to differences in carbon content per hectare between countries.

$$CI = \alpha\, I1 + (1 - \alpha)I2 \qquad (0 \le \alpha \le 1) \qquad \text{Eq 4}$$

Given that the Total Incentive is given by Equation 1, the relative weights will have influence on the distribution of the incentives received among developing countries. As will be shown a careful choice of these weights is essential to the success of the mechanism.

The last step is to make the sum of the incentives received by the countries equal to the Total Incentive. If its Combined Incentive is negative the country does not receive anything in that year. Each country that had a positive Combined Incentive receives a Final Incentive equals to its fraction of all positive Combined Incentive multiplied by the Total Incentive:

$$FI = (CI / \Sigma\, CI) \times TI \qquad (\text{For } CI>0) \qquad \text{EQ 5}$$

That is, if that country's Combined Incentives represented 10% of all countries' Combined Incentives, it receives 10% of the Total Incentive.

Table 1 estimates the effects of the mechanism for a base incentive equal to the CO2 market price of US$ 5,63. The underlying features and flexible aspects are discussed in the text.

Where: TI=Total Incentive;GBEt=Global Baseline Emissions in year t;GEt=Global emissions in year t; $k= base incentive per avoided tonne of CO2; I1= Incentive based on Past Behavior; PE= Country's Past Emissions ; Et= Country's Emissions in year t I2=Incentive based on expected behavior; EEi= Country's Expected Emissions ; CI = Combined Incentive; α = Relative weight Incentive 1; 1 - α = Relative weight Incentive 2; FI= Country's Final Incentive

The Combined Incentive makes the mechanism very comprehensive. It still offers incentives based on recent deforestation rates, so that high deforesting countries have enough incentive to reduce their deforestation rates. But it also includes an incentive for countries to keep their deforestation rates below the global average, making it attractive to countries that have been conserving their forest in the recent past. Both incentives are offered to all countries, making it unnecessary to classify them into "classes" or having different mechanisms for each stage of the conversion process. As deforestation rates are highly variable in time, these classifications might be problematic. As both incentives are simultaneously offered, a country with high deforestation rates will have an added incentive to go below the global average while low deforesting countries also receive more if they reduce even further their deforestation rates

If no country has a negative Combined Incentive, every country's Final Incentive will be equal to its Combined Incentive. If a country has a negative Combined Incentive, it will have a marginal impact on the incentive of the other countries in that year. That country's "excess" would be temporarily deducted from incentives received by the other countries (in the proportion given by Eq. 5). The marginal impact that this “bad behavior” by one country can have on the incentives received by other countries is very small *(30).* Nevertheless it introduces an interdependency between the developing countries. The likely consequence is an incentive for cooperation and knowledge sharing. Furthermore, it would make these countries more likely to accept (or maybe even to self-impose) some specific forms of market regulation that would help to reduce total deforestation. For instance a market ban on unsustainable forest products (or agricultural products from new deforested areas) has been suggested by some developing countries *(29),* would probably have support from the community financing the mechanism and would greatly reduce the incentives for increasing deforestation.

Virtually all proposals so far argue that a negative incentive should be considered a debit to be discounted from future incentives *(23-26, 29).* The argument is that such a feature would partially address the “permanency issue” (i.e. when the international financing community pays for the service of carbon storage but the carbon is emitted soon after). If this becomes the political consensus, this debit system can be inserted here. Some *(29)* argue for a “banking system” where even a country that receives a positive incentive would have a portion of this set aside to cover eventual future debits. This feature can be easily included by multiplying FI by some term β (say β=0.8, if 20% is the agreed discount).

In short, the mechanism allocates the resources from the international financing community, mediated by the behavior of all developing countries, to each country. It also supplies a mix of guarantees and incentives for reducing tropical deforestation. The question remains: How much can we reduce deforestation by such a mechanism, and at what cost?

4. SIMULATIONS

We tested the mechanism using recent data for the top 20 developing countries by forest area. These countries host 77% of total forests in developing countries. We also tested the effect of changes in the flexible aspects of the mechanism. For comparison we included the results of other candidate mechanisms.

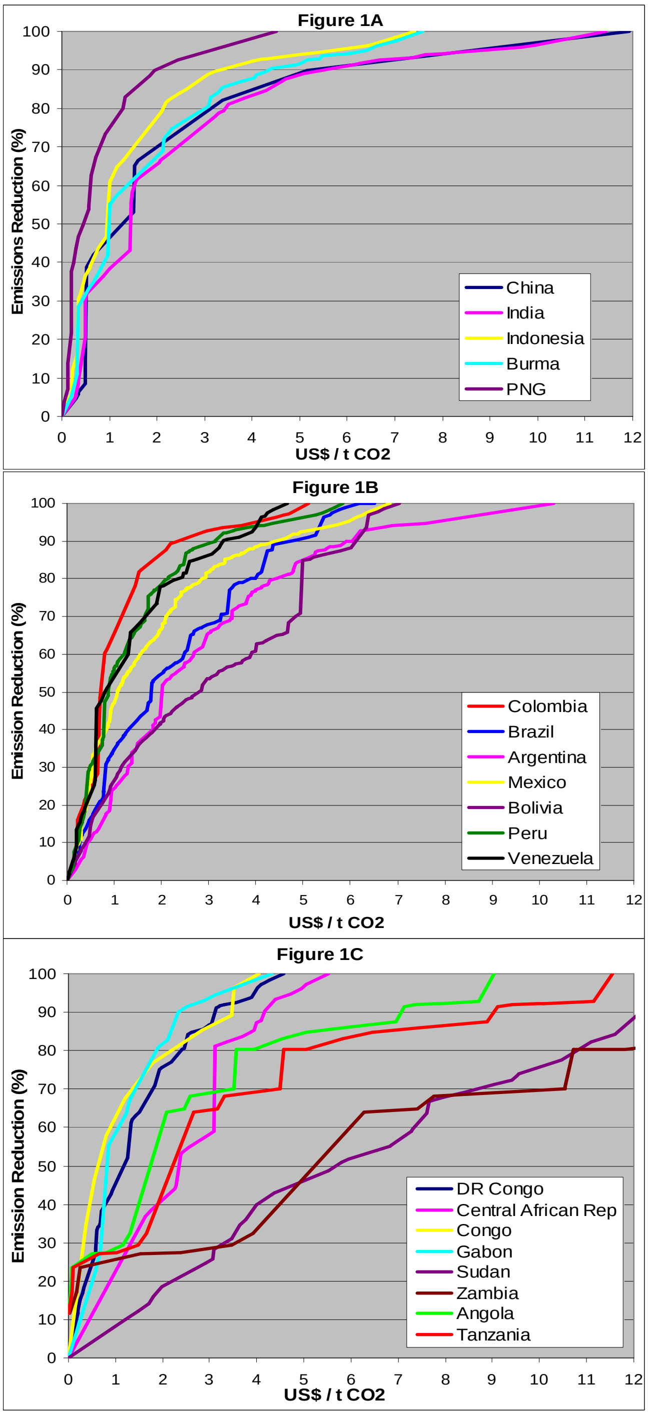
Data on forest area and past deforestation rates came from the latest global forest resource assessment from FAO *(9).* The same source (supplemented by other studies) and three global or regional biomass models *(31-33)* provided estimates for the carbon content per hectare for each country. Those were fed into the mechanism to estimate individual incentives offered for each country.

Subsequently we combined these with the mix of economic returns of alternative land uses. We used two different approaches to estimate these returns. First, recent field data on returns from alternative activities and converted areas from the top 8 developing countries by annual deforested area presented by the Stern Report *(20)* were used to estimate a general relationship between deforestation and opportunity costs that was then applied to the forest data of each of the 20 countries.

In the other approach we utilized a recent GIS-referenced global map of potential economic returns from agriculture and pasture *(34)* and overlaid on it two different GIS-referenced global databases of spatial distribution of deforestation *(35-36).* In this way we identified relative economic returns of recent deforested areas for 17 of our countries. These were used to generate an individual curve of opportunity costs for each country *(30).*

The outcome provided an estimate of the emission reductions as a function of the base incentive per avoided tonne for each country. These are showed on Figure 1. As can be seen, the estimates confirm the predictions that a large fraction of deforestation can be tackled with relatively low incentives. Even the sharp increase in costs for the last hectares still present values on the lower end of UNFCCC estimations of viable mitigation options (up to US$ 100 per t CO2).

Figure 1:



Reduction in National Emissions from Deforestation per Base Incentive. Figure 1 depicts the relationship between the base incentive per avoided tonne of CO2 and the associated percent reduction in emissions for countries from Asia and Oceania (1A), Latin America (1B) and Africa (1C). Based on potential opportunity costs and current carbon density (*30*).

Except for carbon-poor Sudan and Zambia all countries present a similar trend, with more than 80% of deforestation being avoided for base incentives of US$5 / t CO2 or less. These estimates confirm the many “low-hanging fruits” of reducing and avoiding deforestation.

Using the average CO_2 market price of the EU Emissions Trading Scheme, US$ 5,63 per tonne *(37),* as the base incentive for illustration, Table 1 presents the outcome of the mechanism, the reduction in emissions and the combined incentives of each country and a comparison between different weights and mechanisms. Supplementary Table 4 shows a more detailed calculation.

Table 1: RED-DC Mechanism Equilibrium Projections

Country	Forest Area (10^6 ha)	Initial Deforestation (%)	Equilibrium Reduction (%)	Combined Incentive (10^6 US$ y^{-1})				
				α=0.5	α=1	α=0	JRC (1/2)	JRC (1/3)
Brazil	478	0.55	97.5	5,996	6,497	5,495	5,877	6,150
China	197	-1.7*	100.0*	594	0	1,187	553	386
DR Congo	134	0.3	100.0	1,763	1,379	2,147	1,247	1,305
Indonesia	88	1.85	94.5	1,935	3,200	(669)†	2,895	3,029
Peru	69	0.1	99.8	512	(180)†	844	393	274
India	68	-0.6*	100.0*	212	0	425	198	138
Sudan	68	0.8	48.7	102	179	(26)†	162	169
Mexico	64	0.45	93.4	619	607	632	549	574
Colombia	61	0.1	100.0	518	(183)†	853	397	277
Angola	59	0.2	87.1	307	174	440	194	164
Bolivia	59	0.45	86.7	522	510	533	462	483
Venezuela	48	0.6	100.0	854	960	748	869	909
Zambia	42	0.95	53.4	63	121	(6)†	110	115
Tanzania	35	1.05	82.1	266	401	(130)†	363	380
Argentina	33	0.4	88.4	191	174	207	158	165
Myanmar	32	1.35	93.5	536	824	248	746	780
Papua New Guinea	29	0.5	100.0	486	502	470	454	476
Central African Republic	23	0.1	100.0	180	(63)†	296	138	(96)†
Congo	22	0.1	100.0	243	(86)†	400	186	130
Gabon	22	0.1	100.0	220	(77)†	362	169	118
TOTAL	**1,631**	**(Mean = 0.48)**	**94.4**	**16,118**	**15,528**	**15,287**	**16,118**	**16,022**
Emission Reduction (%)				94.4	90.9	71.5	94.4‡	94.0‡
Participant Countries				20	15	16	20	19
Incentives to High Def Countries in relation to Low Def Countries (Equal Forest Area)				+74%	+270%	-6%	+147%	+192%

RED Mechanism equilibrium projections for a base incentive of US$ 5.63. The particular case when α=1 is similar to the mechanism proposed by Brazil (*23*). Using α=0 is similar to the mechanism we previously proposed (*25*) . JRC is the mechanism proposed by the Joint Research Center (*26*). * China and India have negative deforestation rates. As the default version of this mechanism does not include reforestation, their initial deforestation rate is considered equal to zero. Their equilibrium reduction is their hypothetical reduction if they had a positive deforestation rate, based on their opportunity costs curves (*30*) and the base incentive of US5,63; † These Combined Incentives are smaller than the total opportunity costs these country would incur (*30*) and therefore insufficient to make them join the mechanism; ‡ The reduction obtained by the JRC mechanism would be smaller than these for the base incentive of US$ 5,63, as their marginal incentive is smaller. But these would be the reductions achieved for the total incentive listed in the cells immediately above.

The projections presented in Table 1 show the effect that different weights in the Combined Incentive (Box 1) have on the distribution of the incentives and consequently on the behavior of countries. Among our 20 countries, the total forest area is equally divided by high (above global average) and low deforesting countries.

The first extreme example where the incentive is entirely based on recent past behavior ($\alpha = 1$) strongly favors countries with high past deforestation, whose combined incentive is 270% higher than those of low deforesting countries. As a result, five of these would not join the agreement for base incentives up to US$ 5,63 per tonne of CO_2. The resulting reductions in emissions would probably be smaller than those presented in Table 1, where countries that do not join simply maintain their past behavior. Without appropriate incentives and in a context of reduced supply of deforestation-related products, a leak of deforestation to these countries would be very likely. Although the mechanism is protected and this leakage would be accounted for, the final reduction in emissions would be smaller. This extreme example is very similar to the Brazilian proposal *(23).* The difference is that the Brazilian proposal does not have the first global step of this mechanism and so a considerable amount of incentives could be paid to the high deforesting countries without any guarantee that the leakage of deforestation to other countries would not compromise the reduction in the first group.

The other extreme example leads to similar but inverse results. If the compensation is entirely based on the expected emissions calculated from the global average rate ($\alpha = 0$), some high deforesting countries do not receive enough incentive to “join the game” (receiving 6% less than the low deforesting countries). As a result four of them would not join the mechanism, with serious consequences for its effectiveness. This extreme option, similar to the mechanism we previously suggested *(25),* might present some advantages on the “fairness” side, but these are compromised by a lack of effectiveness.

The intermediate case presented, where both incentives have the same weight ($\alpha = 0.5$) has clear advantages over the other options. The Combined Incentive of high deforesting countries is still higher (+74%) than those of low deforesting ones, but this bias is much less pronounced than the other cases. And this bias might be necessary, at least over an initial period, as they would have to make “more effort” to change recent past behavior.

The projections indicate that for an incentive of US$ 5,63 per tonne of CO2 all 20 countries would join and reduce their emissions by an aggregate rate of 94,5%.

The mechanism proposed by the JCR team *(26)* would also have the participation of all countries when using the ½ global baseline threshold. Their emissions reduction would be smaller for the same base incentive, but the same per total incentive. Both their options, however, present a strong bias towards high deforesting countries, whose Combined Incentives are 147% or 192% higher than those of low deforesting countries. A country that has a deforestation rate equal to half or one third the global average would have to reduce it even further to receive any incentive. And due to its smaller flexibility it would be difficult to reduce this bias over time.

5. UNDERLYING FEATURES AND FLEXIBILITY

Deforestation varies considerably across time *(9,12).* Basing a long-term mechanism on a snapshot of five or ten years at a given point in time is unfair and potentially ineffective. Making country by country adjustments based on opportunity costs and future national deforestation scenarios would be highly subjective and possibly impractical. For instance, opportunity costs can change dramatically with simple governmental decisions.

In recognition of this our mechanism provides all countries the same treatment of combined incentives. Our analysis based both on current and potential opportunity costs showed that it is capable of attracting countries with very diverse deforestation profiles. And although initially a higher fraction of the incentives might go to high deforesting countries, this bias is less pronounced than in alternative mechanisms. It makes sense that countries with higher current deforestation rates need more incentives to join the mechanism now. But taking the case of Indonesia as an example, it is hard to justify paying it approximately US$ 3 billions per year (reducing the amount received by low deforesting countries) if its emissions reduction would be the same if it received US$1.9 billions per year. And it is even harder to justify why this current high deforestation should continue to be the base for a long term mechanism.

This brings us to one of the most interesting features of this Combined Incentives mechanism. It is possible to move from an initial configuration where current deforestation has the necessary (for all countries to join) high weight to another where the incentive is increasingly based on the total forest (carbon stock) of each country. Total forest carbon stock is the best measure for the service of carbon storage, and its connection with total forest area a better measure for the total potential foregone benefits from alternative land uses. All it takes to make this transition is an adjustment in the weight of the Combined Incentives, simply by lowering the value of α *(38)*.

There are still some interesting features included in the simple formula of the proposed mechanism. It relates the financial incentive to actual GHG emissions from deforestation, instead of relating it to the deforestation rate itself. As deforestation or partial conversion of a hectare can be done in several different ways resulting in a different volume of GHG emissions *(39)*, relating the compensation paid to the final emission provides an incentive for adopting the least damaging practice. It also provides a strong incentive for prioritizing carbon-rich vegetation (as long as safeguards are in place to maintain biodiversity), an issue of particular importance in vast areas undergoing conversion to palm-tree plantations. If it is not practical or desirable, then this term becomes constant and equal to the carbon content of each hectare.

Forest degradation might be of the same order of magnitude as deforestation *(40).* For this reason it has been included in the official RED discussions *(29).* Afforestation and reforestation activities might play an important role in medium and long term CO2 sequestration *(12).* Our mechanism by default already includes emissions from degradation, as it is based on total emissions from land-use change. Reforestation and afforestation are not included in the default version, as they are currently covered by the Clean Development Mechanism. However the success of the CDM approach regarding these two activities is frequently questioned and it might be desirable to unify forestry activities under a single mechanism. This mechanism can easily account for these activities simply by considering them as negative emissions on the current emissions terms (GEt in Eq 1 and Et in Eqs 2 and 3).

The proposed mechanism has been developed in the context of the discussions taking place within the UNFCCC. Carbon storage and sequestration, however, are not the only global services provided by forests. Biodiversity provides a well known variety of direct services *(1).* To focus on just one, a recent review showed that 47% of the small molecules used in cancer treatment in the US are either natural products or were directly derived from them *(41)* and the role of these in the pharmaceutical sector has been reaffirmed *(42).* Furthermore there are feedbacks between biodiversity services and the carbon related ones *(1,12),* with some evidence that increased biodiversity might lead to increased biomass *(43).* Much clearer is the fact that biodiversity increases the resiliency of ecosystems in the face of change *(44-46)* and this, in the context of unavoidable climate change *(12)* is a key feature. An ideal mechanism (i.e. one that would maximize global welfare) should take these other global benefits into account in order to target more precisely and effectively areas of higher global value. A biodiversity premium can be inserted in the mechanism, simply by adding an extra weight to emissions from more biodiversity rich areas *(47).*

Finally, some parties have proposed the inclusion of a “diminishing baseline” *(29)* to reflect the reduction in deforestation that would occur in the absence of a mechanism. Trying to establish these baselines on a country by country basis would likely be a very subjective and sensitive issue. Here it is possible to establish a global diminishing baseline that would lead to a uniform reduction across all countries (simply by diminishing the GBEt in Eq 1). If it is decided that it is more appropriate to do it on a country by country basis, the corresponding term on Eq. 2 (PE) should be the one reduced over time (which would lead to the corresponding reduction in GBE on equation 1, as GBE = Σ PE). A diminishing baseline is connected to the issue of “hot-air” (a carbon credit given to a reduction that would happen anyway). An interesting feature here is that if the global baseline emissions term is adjusted to reflect the business as usual global emission in that year, then the mechanism does not produce “hot air”. It might be the case that some individual countries receive compensation for “virtual reductions”, but this would be exactly compensated by some other countries having a baseline lower than what their business as usual emissions would be on that year. The aggregate sum is zero, making the mechanism hot air-proof.

6. GLOBAL AND TOTAL COSTS OF RED

We weighted the national estimates of our 20 countries to produce a global relation between the base incentive offered and the associated reduction in emissions from deforestation. The resulting data points from both our approaches were plotted on Figure 2.

Given the fact that our "field approach" was based on data from field studies in eight countries and that our "GIS approach" is the result of combining global models of agricultural rents with remote sensing and expert opinion on deforestation patterns, the fit between them is remarkable. Even more so when considering that the costs of viable mitigation options studied by the UNFCCC is US$ 0-100 per tonne of CO_2. Figure 2 also shows the outcome of our mechanism for the market price (US$ 5,63) of CO_2.

Figure 2: Global Reduction in Emissions from deforestation per base incentive

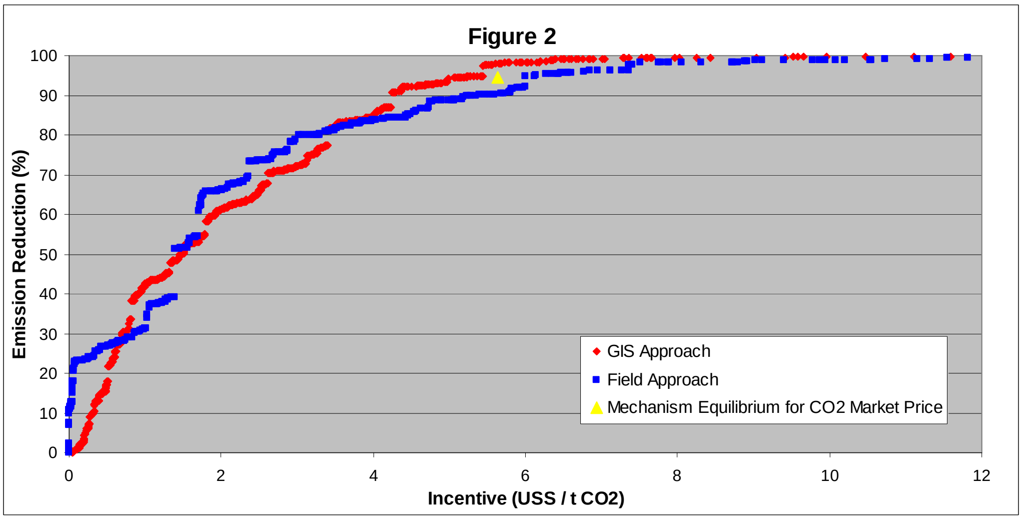


Figure 2 depicts the global reduction in emissions from deforestation for our two approaches. National curves were averaged by national annual emissions *(30).* The figure also shows the reduction resulting from a base incentive of US$5,63 applied to our mechanism (α =0.5). All countries would join and reduce their aggregate emissions by ~94%.

We then integrated the data plots based on a mechanism offering a fixed incentive per avoided tonne of CO_2 (as all the mechanism analyzed here) and added transaction, forest management and forest protection costs to produce a global cost curve of a RED mechanism (Figure 3) *(30).* For our reduction of 94.5% the total costs would be US$ 29.6 billions, of which US$ 20.9 billions are incentives, US$ 1.1 billions transaction costs and US$ 7.6 billions forest management and protection costs.

An important observation is that the relation between the cost of RED and its consequent reduction in emissions does not vary either due to a change in the base incentive per avoided tonne or to a uniform change in the carbon content per hectare across all countries. The reduction achieved is a function of i)the opportunity costs per hectare and ii) the product of the base incentive and the emissions per hectare. In other words, if the goal is a reduction of 90% of emissions and new estimates (e.g. the inclusion of soil carbon) double the carbon content per hectare for all countries, the incentive per tonne necessary to achieve the goal is halved and the final costs remain unchanged.

Figure 3: Total Costs of Reducing Emissions from Deforestation

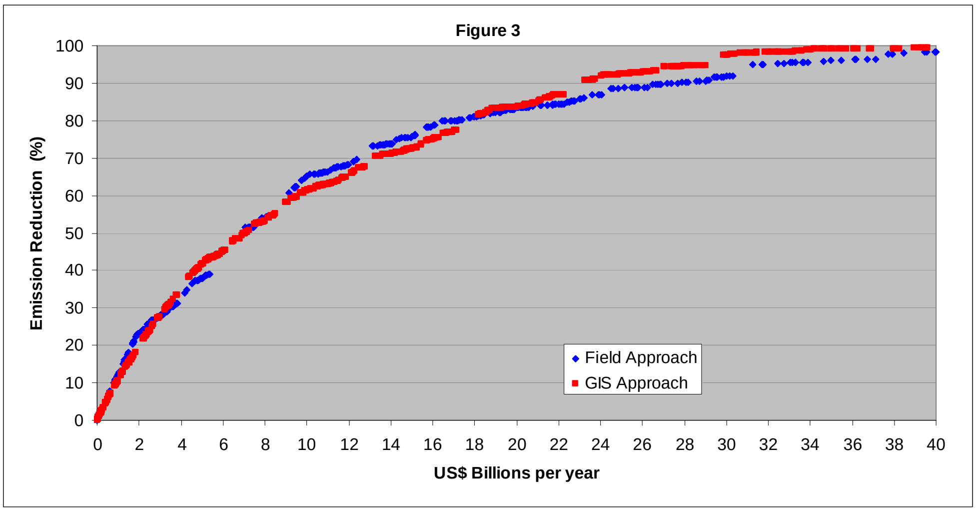


Figure 3 depicts the total (incentives, transaction, management and protection) costs of reducing emissions from deforestation for our two approaches. These results are not influenced by changes in carbon density or base incentives, as one compensates the other (*30*). About 90% of emissions from deforestation can be reduced or avoided at a total cost of US$ 25 billions per year.

7. CONCLUSIONS

Our estimates confirm the general agreement that RED can be a very cost effective option for mitigating climate change. Incentives in the order of US$ 20 billions per year could curb 90% of global emissions from deforestation. The associated cost per tonne of CO2 would be equal to the current market price, which is expected to increase sharply in the near future, and on the very low side of the UNFCCC estimates of mitigation options (up to US$ 100 per t of CO2). The annual amount of CO2 emissions reduced (3.2-6.4 Gt CO2) would be four to eight times the annual target of the Kyoto Protocol.

As our analysis showed, however, the way these incentives are distributed is crucial to the success of the RED enterprise. The mechanism we presented addresses some of the most important challenges a RED mechanism would face. In particular it includes countries from all stages of the conversion process, offers a mix of incentives to both reduce deforestation rates and emissions per deforested hectare and directly connects the total incentive paid to global reductions in emissions. In addition its flexibility allows several financing options, the fine tuning of incentives across countries and time, and the inclusion or not of incentives to reforestation, biodiversity conservation and other ecosystem types.

By providing substantial reductions in GHGs emissions at a very low cost, this RED mechanism would be a powerful and cost effective tool to address what is now considered the biggest threat humankind has ever faced (*48*). The purely economic benefits in terms of avoided damage *(20)* far exceed its costs.

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APPENDIX

1. METHODS

In order to be able to model the response of each country to our incentive mechanism we need several variables. Two of these, forest area and deforestation rates, are available on the last FRA from FAO (*1*) and listed on columns 2 and 3 of Table 1 on the main text. Although neither of these variables is free of uncertainties and criticism (*2-3*), the FRA is the standard source. Forest area was taken directly from the FAO study, while the deforestation rate is the average of the deforestation rates for 1990-2000 and 2000-2005. Gabon was the only country without deforestation data and we used the conservative estimate of a study focused on that country *(4).* When we extrapolate the resulting 7.7 million deforested hectares per year to the remaining 23% of forest cover (using the average deforestation rate of 0,48% p.a.) we have a total estimate of 10.1 million hectares deforested each year. This value is inside the interval found in the literature for 1990s of 5.6 to 12 (*1, 5-6*) million ha per year.

Two other key variables necessary to estimate the individual response were obtained through more complex approaches. These are detailed on the next two sections.

1.1 EMISSIONS PER HECTARE

Estimating the amount of GHG emitted from deforestation is a complex task and the results vary considerably. In addition to uncertainties in the deforestation rates are those in the emissions per deforested hectare (EpH). A recent review by some of the leading scientists in the field (*2*) states that the latter are related to the uncertainties in several steps of the process, such as land cover dynamics after deforestation, the mode of clearing (e.g. slash and burn versus clean cut), the fate of the cleared carbon and the response of soil carbon. In addition to these factors other studies note that CO2 is not the only GHG emitted in the process, with relevant quantities of the much more powerful (in terms of warming potential) methane being associate with deforestation *(7-8*). Here we will assume that the conversion of one hectare emits the amount of carbon stored in its above and below ground biomass. Ignoring the fraction of carbon that can be stored in the subsequent land cover, the fraction not immediately released into the atmosphere or the one trapped in long term wood products tend to overestimate the emissions. On the other hand, ignoring carbon emissions from soil and other GHG emissions lead to an underestimation. In the Brazilian Amazon it is likely that the last two factors dominate the first two (*8*). As will be seen, when compared to other studies our estimates for the EpH are on the conservative side.

The latest FRA from FAO provides estimates of the total carbon stock in forests for 16 of our 20 countries. Dividing these stocks by the forest area of each country gives the average carbon content per hectare listed on column 2 of ST1.

These estimates, however, are admittedly imprecise (*1*). Furthermore, basing the analysis solely on such average values present an additional problem. Carbon stocks vary greatly within each country and current and future deforestation might be concentrated in regions with carbon density considerably higher or lower than the national average. For instance, FAO average carbon content for Brazilian forests is 103 t C ha-1, but deforestation is concentrated in the Amazon region where carbon concentrations are generally above 150 t C ha-1 (*8*).

To reduce these uncertainties we also followed a different approach. Potter (*9*) presented a global map of biomass distribution. In order to find the average carbon content related to the areas more relevant to RED, we used GIS techniques to combine the spatial distribution of recent (2000-2005) deforestation given by the VCC-MODIS product (*10*) with the Millennium Ecosystem Assessment map of deforestation hotspots (*11*). We then overlaid this combined map (some 50,000 points centred on 5 minute grid cells) with the Potter (*9*) biomass data in order to select the grid cells more relevant to RED and made a country by country average. As Potter (*9*) only provided estimates for above ground biomass, we used the ratio between total and above ground biomass from our FAO data (1.28) to convert Potter (*9*) values to total biomass. This ratio falls between similar values used by Fearnside (*8*) (1.34) and Achard et al. (*12*) (1.20). The resulting estimates are listed on column 3 of ST1.

ST1

Country	FAO (t C /ha)	GIS (base data from Potter) (t C /ha)	GIS (base data from NASA Regional Models) (t C/ha)	Average GIS (t C/ha)	Final Estimate (t C/ha)	Final Estimate (t CO2 /ha)
Brazil	103	142		142	123	450
China	31	94		94	62	229
DR Congo	173	154	165	160	167	611
Indonesia	67	152	115	134	100	367
Peru		127		127	127	467
India	35	102	89	95	65	239
Sudan	23	62	24	43	33	121
Mexico		109		109	109	399
Colombia	133	158		158	146	534
Angola	82				82	300
Bolivia	90	126		126	108	395
Venezuela		162		162	162	596
Zambia	27				27	100
Tanzania	64				64	234
Argentina	73	72		72	72	265
Myanmar	98	105	91	98	98	360
Papua New Guinea		165		165	165	606
Central African Republic	123	154	139	147	135	495
Congo	231	116	162	139	185	677
Gabon	167	122	232	177	172	632

We also overlaid this combined map over two regional maps produced by NASA for Southeast Asia and Tropical Africa (*13-14*). The resulting estimates, also corrected for above-below ground biomass ratio (column 4 ST1), were averaged with the estimates from Potter's (*9*) map to produce our average GIS estimate (column 5 ST1). These values were then averaged with FAO estimates to produce our final estimates for the Emissions per Hectare parameter for each country (column 6 and 7 of ST1).

As can be seen by the comparison with the review presented by Ramakutty et al (*2*), our estimates for the EpH term are on the lower bound of the estimates available in the literature and therefore will lead to a more conservative estimate for equilibrium reductions in emissions (as the incentive per hectare is smaller).

Our resulting estimate of GHG emissions from deforestation for our 20 countries is 827 Mt of C per year. When extrapolated to the remaining 23% of forests in developing countries the total estimate is 1073 Mt of C per year. Related estimates in the literature range from 900 to 2200 Mt C. The latest study review by Ramankutty et al *(2)* provides an estimate of 1100 MtC *(5).*

1.2 OPPORTUNITY COSTS

We also used two distinct approaches to estimate the opportunity costs of avoiding deforestation.

The first one was based on the estimates presented by the Stern Review on the Economics of Climate Change (*15*). That study synthesized field information on the economic returns of the activities to which land is converted in the top eight countries by annual deforested area (responsible for 46% of annual deforestation). In addition, and crucially, the study also presented estimates for the area converted to each activity in each country.

We assumed that the average behavior of these countries represents the behavior of the average developing country. Although this is admittedly a simplification, we believe it to be a reasonable one as i) these countries are responsible for nearly half of the annual deforested area (so the extrapolation to the other half is not overly unrealistic and ii) as these countries are the top eight deforesting countries it is fair to assume that their economic returns for doing so are at least equal to (more likely higher than) the average of developing countries.

Supplementary Table 2 lists the land fraction and returns for each of the 24 alternative uses. The land proportion was estimated by summing up the area corresponding to each use from all eight countries and dividing it by the total annual deforested area in all of them. Returns also include part of the income from one-off timber harvesting and are expressed as a Net Present Value (30 years, 10% discount rate). Activities that provided the same return per hectare were grouped together.

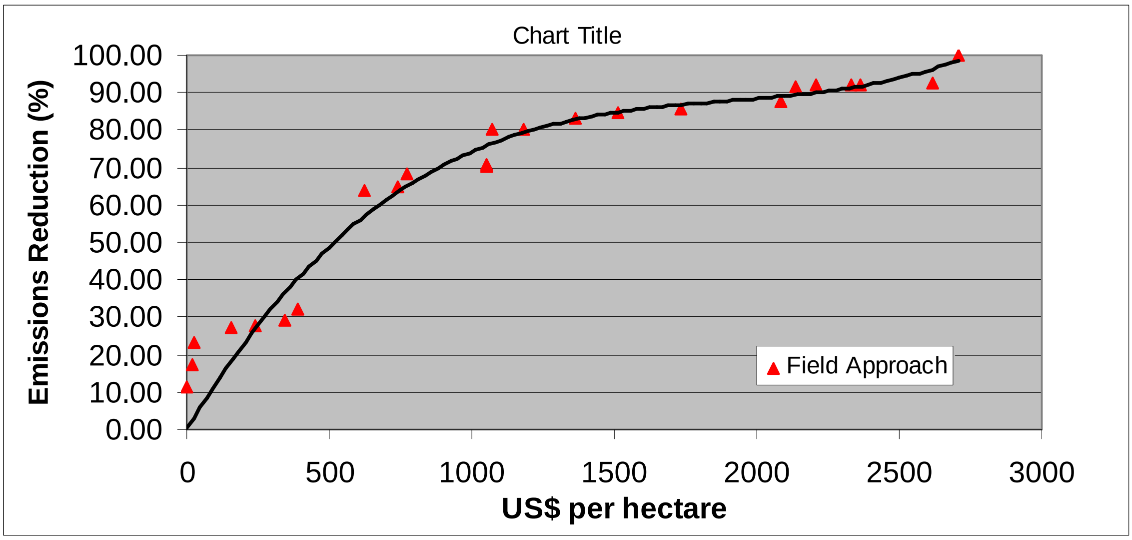
ST2

Alternative Land Use	Returns (USS/ha)	% Land Used	Cumulative %
Beef cattle small scale/Manioc/Rice	2	11.55	11.55
Cassava monoculture	18	5.75	17.30
Rice Fallow	26	6.20	23.50
Dairy	154	3.51	27.02
Perennials (Bananas, sugarcane pineapples)	239	0.50	27.52
Annual food crops long fallow	346	1.75	29.27
Beef Cattle	390	3.06	32.33
Beef cattle medium/large scale	626	31.67	63.99
Cocoa without marketed fruit	740	0.87	64.87
Annual food crops short fallow	774	3.40	68.27
Small-scale maize and cassava	1,052	1.86	70.13
Cassava monoculture	1,053	0.45	70.59
Smallholder rubber	1,071	9.77	80.35
Oil palm and rubber	1,180	0.08	80.43
Cocoa with marketed fruit	1,365	2.62	83.06
Smallholder oil palm/Low-yield independent	1,515	1.65	84.71
Smallholder subsistence crops	1,737	1.13	85.84
Supported growers	2,085	1.77	87.61
Soybeans	2,135	3.82	91.43
High yield independent	2,205	0.49	91.92
Oil palm supported growers	2,330	0.21	92.13
Oil palm Independent grower	2,363	0.06	92.19
Tree plantations	2,614	0.50	92.70
Oil palm Large scale/government	2,705	7.30	100.00

For each return value on column two, column four presents the fraction of the land converted to uses that provide smaller or equal returns per hectare. The relation between these two columns is plotted on Supplementary Figure 1. Also on SF1 is the best-fit curve (R^2=0.99) for the 24 data points.

As will be discussed in the next section, the per hectare incentive needed to stimulate a reduction in deforestation is equal to the economic returns provided by that hectare. This curve (henceforth the "field estimate") can therefore be understood as a cost function for a RED mechanism, relating the reduction in deforestation rates (*y*) that can be achieved for different incentives per hectare (*x*).

SF1



Our second approach is based on a recently available global map of economic rents from agricultural lands. Naidoo and Iwamura (*16*) integrate information on crop productivity, livestock density, and prices to generate their map. As their focus was on current returns they also based the analysis on the area occupied by each crop on the mid 1990s. As a consequence, however, large wilderness areas such as the Amazon and Congo basins produced low or no returns. Following our request, they kindly provided us with a map of agricultural rents without considering the area actually occupied by each crop. Instead, this map of "potential agricultural rents" showed the rent of the most valuable crop that could be produced in each cell. As we believe that this map is more representative of the opportunity costs of a RED mechanism, we used it as the basis for our second approach.

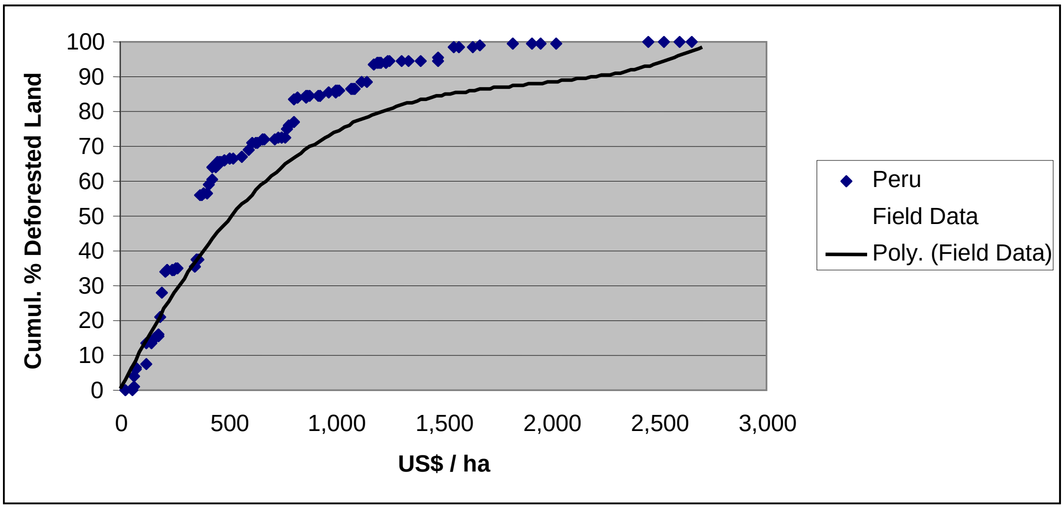
As Naidoo and Iwamura (*16*) have used crop prices (and not profits) we needed to adjust the data to be compatible with the one from our first approach (and with current RED discussions) that focus on incentive to counteracts returns from alternative activities, not their income. We used the profit margin of 15% adopted by the Stern Review (*15*) in the cases where they needed to convert income to returns

As with our second approach to estimating carbon content, we needed to focus on areas more relevant to a RED-DC mechanism. We therefore used a GIS to overlay the same combined distribution of recent and projected deforestation areas (some 51,000 points centred on 5 minute grid cells) and extract the corresponding agricultural return values. We used this GIS-derived data for 17 of our 20 countries to generate individual country curves of costs of avoiding deforestation[2].

As an illustration, ST3 presents the summary of the data obtained for Peru. As in the case of our Field Estimate, we plotted the relation between each economic return (column 2 ST3) and the corresponding cumulative area converted up to that point (column 5 ST3). The results are plotted on SF2. We also included our Field Estimate on the graph for comparison.

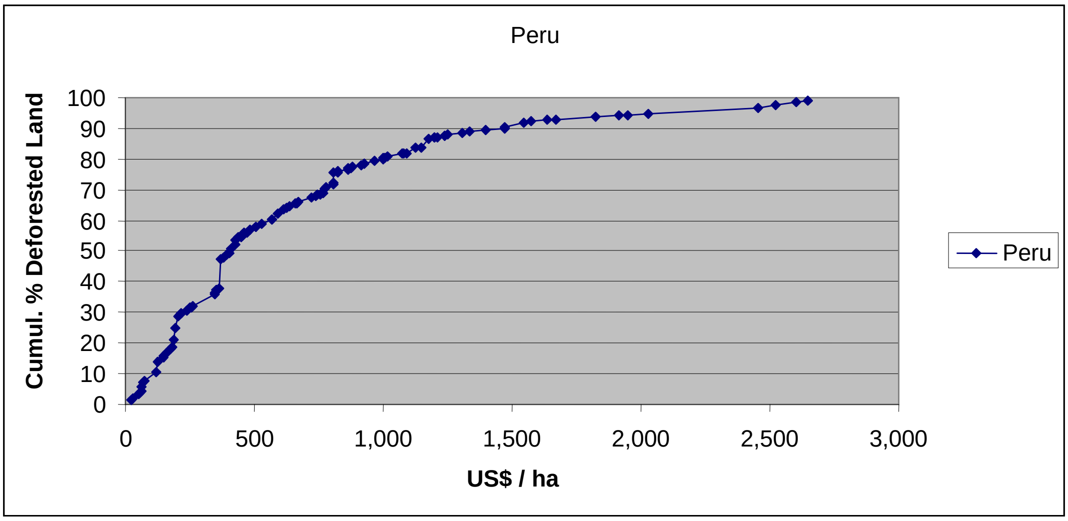
SF2

[2] Three countries (Angola, Zambia and Tanzania) were not covered by either MODIS-VCC or MEA hotspots.



We then averaged the general field curve from our first approach with the values for the GIS deforestation points in each country to generate our final cost curves of avoiding deforestation for each of the 20 countries (SF3).

SF3



1.3 THE EQUILIBRIUM

The basic assumption in our estimation of the response of each country to the mechanism is that a country will convert a hectare if the return of doing so is higher than the incentive it receives to conserve it. If the incentive is higher, the hectare is conserved. An underlying assumption is that when the mechanism is in place no country will decide to convert more than it had done previously.

Each country's reduction in emissions is equal to the fraction of emissions from the area that used to be converted to activities that generate lower returns than the incentive per hectare now offered by the mechanism. This marginal incentive can be found by:

From Equation 5:

$FIi = (CIi / \Sigma CI) \times TI$ (For CI>0) EQ 5

But as we are assuming that no country will receive a negative CI, the sum of all country's combined incentives is equal to the total incentive and the final incentive is equal to Combined Incentive :

$FIi=CIi \{[\alpha . PEi + (1 – \alpha) EEi] – Eti\} . \$k$

This can be rewritten as

$FIi=CIi \{[\alpha PEi + (1 – \alpha) EEi] – (x_{it} . EpH_{it}\} . \$k$ Eq 6

Where
x_{it} = Hectares Deforest by country i in year t
EpH_{it}= Emissions per Hectare of Country i on year t

As discussed in the main text, by linking the incentive offered to the actual reduction in GHG emissions, the mechanism provides two kinds of incentives. One is the incentive to reduce the number of deforested hectares and the other to reduce the emissions per hectare deforested.

To simplify the analysis, we will here assume that the emissions per hectare term is fixed. Therefore the only variable the country can choose each year is the number of deforested hectares (*x*). The marginal incentive is then the impact that one additional deforested hectare has on the total incentive a country receives.

Differentiating Eq 6 in relation to *x:*

$\delta CIi/ \delta x = - EpH_{it} . \$k$

Not surprisingly, and in line with the goals of the mechanism, the incentive a country receives for each additional hectare conserved is equal to the amount of CO2 that would be emitted multiplied by the base incentive per avoided tonne.

Therefore for each of our 20 countries we divided the per hectare cost (x-axis SF3) by that country's CO2 Emissions per Hectare term (7^{th} column ST1) to generate the relation between the base incentive offered (\$k) and the corresponding percentage reduction in emissions from deforestation for each given country. The 20 curves are presented on Figure 1 of the main text.

There is an important last step. A country will only join the mechanism and reduce its emissions to the equilibrium rate if the total incentive it receives is higher than the total opportunity costs it would incur. One way of thinking about these costs is that they related to the area that would no longer be converted. But this would mean that countries with current low deforestation rates would always join the mechanism as their "current" opportunity costs are very low. This goes against the rationale of the mechanism. Countries from the Congo Basin, for instance, could decide to build highways into the heart of the forest and incentives that only cover their very low deforested areas would not suffice to counteract their potential gains. Therefore we decided for a mix approach. Countries with high deforesting rates had their total opportunity costs based on their current deforested areas. For countries with low deforestation rates we used the global average rate (here equals to 0,48%) to calculate their potential deforested area and this became the base for their total opportunity costs. Note that this has no influence on the equilibrium reduction or on the amount of incentive received. It is only used to check if a country would join the mechanism.

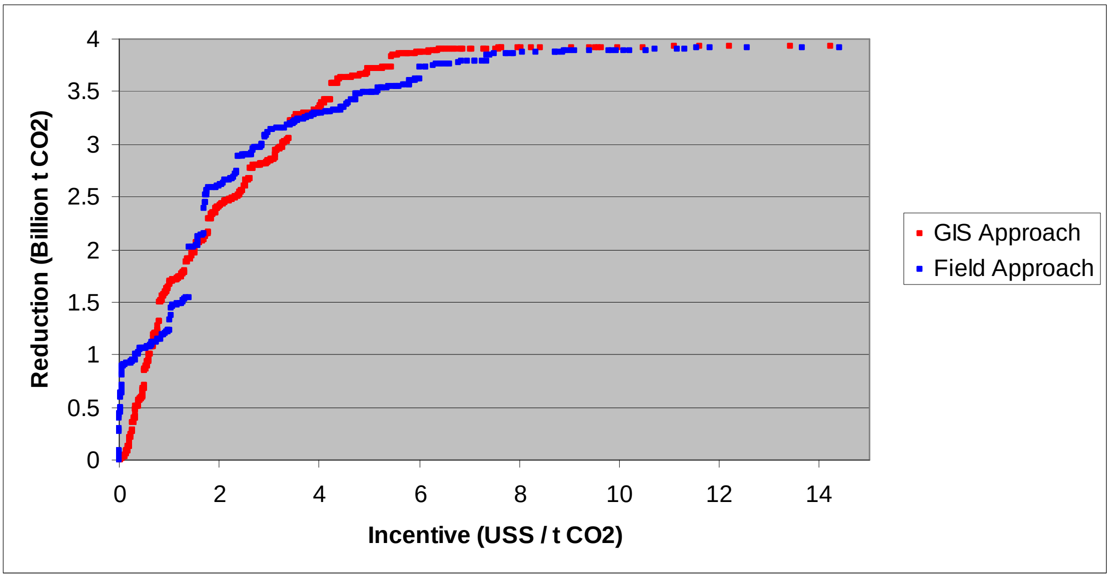
The total incentive a country would receive at its equilibrium point is given by equation 3. Here the relative weight α comes into play for the first time. Although it has no role in determining the equilibrium rate, it has a major role in determining whether a country joins the mechanism. In columns 5 to 7 of Table 1 in the main text we present the total incentive paid to each country for different values of α (for a base incentive of US$ 5,32 / t CO2). As can be seen, a high α increases the payoff to countries with high deforestation rates and means some low deforesting countries would not join the mechanism. The opposite occurs when a low α is chosen, with some high deforesting countries ignoring the mechanism. An intermediate value of α attracts all 20 countries to the mechanism. Finally, for any given α a higher base incentive increases the payoff to all countries, eventually attracting more participants even with more extreme values of α. The opposite occurs when the base incentive is reduced.

In reality it is unlikely that each developing country would switch to the equilibrium deforestation rate as soon as the mechanism is in place. Although deforestation rates tend to react quite quickly to economic incentives, it might take some time for certain countries to achieve this rate. This might be particularly true where a large portion of deforestation comes from illegal activities. In order to have a positive sum on Equation 4, high deforesting countries need to reduced their emissions below a certain threshold (α PEi + (1 – α) EEi) before they receive their first credit. As governments can be remarkably myopic an initial "debit free" period might be agreed, so that a negative CI only becomes a debit after a certain period of time. Using an initial α=1 for high deforesting countries and gradually reducing it over time also solves this potential myopia problem.

1.4 GLOBAL AND TOTAL COSTS OF AVOIDING DEFORESTATION

There are two stages involved in estimating the global costs of RED. The first is to produce a relation between the base incentive per avoided tonne and the consequent reduction in emissions at the global level. For each country and each approach we took its relation between incentive per avoided tonne and the associated percent reduction in deforested land (from SF2) and multiplied this last variable by its annual emissions from deforestation (5^{th} column, ST4). We then have a relation between incentive per tonne and the corresponding reduction in emissions for each country. Summing all these and extrapolating the total emissions to the remaining 23% of forests in developing countries gives us a total annual emission of 3.9 GtCO2. The resulting global relation between incentives per avoided tonne of CO2 and the consequent avoided emissions (in tonnes of CO2) is shown on SF4.

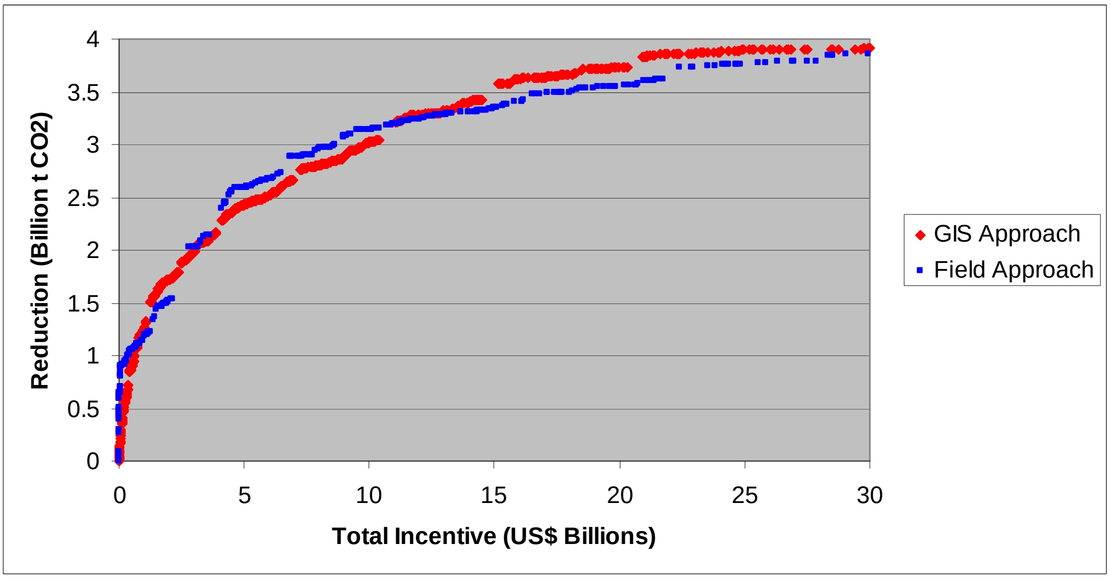
SF4



Given the fact that both approaches are entirely distinct, the curves are notably close. Dividing the y-axis by the total avoided tonnes gives us a relation between the incentives offered and the resulting percent reduction in emissions. It is plotted in Figure 2 of the main text.

As the same incentive is paid to all reduced emissions, the total incentive cost is the product of the incentive per reduced tonne of CO2 and its correspondent avoided emissions. SF 5 plots the reduction in emissions from deforestation achieved as a function of the total incentives paid for both our Field and GIS approaches.

SF5



Finally, in addition to the incentive payments a RED initiative would have transaction costs and the costs of protecting and managing the forests. It could be argued that the last two should be borne by the developing countries themselves, but we believe that this would contradict the rationale of RED. As incentives would be paid so countries do not convert their forests to alternative uses, then they should include the extra costs a country would incur for conserving the forests that otherwise would be converted.

The Stern review (15) cites that Costa Rica's Payments for Environment Services scheme is required by law to spend no more than 7% of its budget on administering the scheme and the rest on the payments. And that a similar scheme in Mexico has these costs capped at 4%. As a global system would likely incur in economies of scales, we believe the average of these two values, or 5,5% is a conservative estimate. This percentage will be added to the total costs.

James et al. (17) present the results of a comprehensive review of conservation costs worldwide. If we average (by forest area) the cost of protection and management of forests in Latin America, Sub Saharan Africa, Developing Asia and the Pacific we find a value of US$ 3,8 per hectare per year (adjusted for 2005 US$). It is unrealistic to assume that countries can predict the exact patch of forest that would be deforested in a given year, protect it and as a consequence no deforestation would occur on the rest of its forests. On the other hand it would be an exaggeration to assume that to reduce 10% of its deforestation rates developing countries should protect and manage 100% of their forests. A reasonable intermediate solution is to associate the costs to the reduction in deforestation rates, so that to reduce its deforestation rates by 80% a country would need to protect 80% of its forests. So based on the total forest area in developing countries of 2,1 billion hectares, total management and protection costs will be the product of the percent reduction by US$ 8 billion.

The graph showing the total costs of RED and the associated reduction in emissions is shown in Figure 3 in the main text.

2. LIMITATIONS AND SIMPLIFICATIONS

2.1 DATA ON EMISSIONS PER HECTARE

We combined diverse sources in order to choose the most representative value for each country in regards to a RED mechanism. Our estimates carry the uncertainties of the studies used as sources. In comparison with other studies they are on the conservative side. Higher values for this variable would:

- i) lead to higher reductions in emissions for the same base incentive (pushing upwards the curves on Figures 1 and 2). The higher reductions in column 4 of Table 1 would increase the incentive received by the country that had its EpH increased, without affecting other countries' incentives.
- ii) not affect the relation between total costs and percent reduction in emissions (Figure 3). As a consequence the mechanism would be "cheaper", as the same total cost would reduce higher quantities of CO_2.

2.2 DATA ON DEFORESTATION AREA

We used the standard FAO data for forest area and deforestation rates. Our extrapolated estimate of 10.1 million hectares deforested per year is inside the range of values found in the literature. An increase (or decrease) in the annual deforestation rates would:

- i) Have no influence on the equilibrium reduction in emissions for the same base incentive (column 4 Table 1); increase (or decrease) the incentive received by the country for the same equilibrium reduction in emissions (columns 5-9 Table 1); have a positive (or negative) marginal effect on other countries by increasing (or decreasing) the average emissions rate thus increasing (or decreasing) their expected emissions terms;

ii) increase (or decrease) proportionally the costs of reducing the same percentage of emissions (Figure 3), as more (or less) hectares would now have to be compensated, but would not affect the reduction per base incentive (Figures 1 and 2) nor the total costs for the same amount of CO2 avoided.

2.3 DATA ON OPPORTUNITY COSTS

Probably the most uncertain of the variables used, although the remarkable fit between both approaches offer some mutual support. An increase in opportunity costs would:

i) educe the equilibrium reduction for the same base incentive (Column 4 Table 1); have no effect on the behavior of other countries;

ii) Decrease the reduction in emissions for the same base incentive (Figures 1 and 2) and for the same total incentive (Figure 3).

2.4 A “BAD BEHAVIOUR”

We assumed that no country would emit more than its incentive threshold [A PE + (1-A)(EE)]. If a country *b* emits more, it will have a marginal negative effect on the other countries’ final incentives. The final incentive of each other country *i* would be reduced by the product between the “bad” country’s excess and each country’s fraction of all Combined Incentives:

$$\text{Impact on } FI_i = \{Et_b - [(\alpha)(PE_b) + (1-\alpha)(EE_b)]\} * \$k * (CI_i / \Sigma\, CI)$$

If a system of debit is adopted this negative effective will be compensated when the “bad” country receives its next credit. If a banking system is adopted, the other countries might receive the compensation on the same year (if there is enough credit on country *i*’s “account”) and not be affected at all.

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ST3

Peru – GIS Approach

	Return (US$ ha^{-1} y^{-1})	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	22.54	1	0.0	0.0	0.0
	27.32	3	0.1	0.1	0.2
	52.74	1	0.0	0.0	0.2
	59.22	1	0.0	0.0	0.3
	61.84	15	0.7	0.7	1.0
	64.16	59	2.8	2.8	3.8
	68.68	48	2.3	2.3	6.0
	72.78	9	0.4	0.4	6.5
	116.98	22	1.0	1.0	7.5
	122.65	124	5.9	5.9	13.4
	146.69	1	0.0	0.0	13.4
	148.78	7	0.3	0.3	13.8
	158.22	29	1.4	1.4	15.1
	177.67	11	0.5	0.5	15.6
	180.30	7	0.3	0.3	16.0
	185.51	105	5.0	5.0	20.9
	192.47	149	7.0	7.0	28.0
	206.05	131	6.2	6.2	34.2
	216.41	2	0.1	0.1	34.3
	218.35	3	0.1	0.1	34.4
	238.14	2	0.1	0.1	34.5
	239.85	3	0.1	0.1	34.6
	250.78	1	0.0	0.0	34.7
	257.56	2	0.1	0.1	34.8
	262.25	9	0.4	0.4	35.2
	344.20	2	0.1	0.1	35.3
	348.08	6	0.3	0.3	35.6
	350.94	36	1.7	1.7	37.3
	351.67	1	0.0	0.0	37.3
	364.76	4	0.2	0.2	37.5
	367.95	393	18.6	18.6	56.1
	378.79	1	0.0	0.0	56.1
	390.87	8	0.4	0.4	56.5
	404.54	1	0.0	0.0	56.6
	408.12	53	2.5	2.5	59.1
	423.43	34	1.6	1.6	60.7
	426.15	71	3.4	3.4	64.0
	440.07	3	0.1	0.1	64.2
	446.12	2	0.1	0.1	64.3
	452.14	1	0.0	0.0	64.3
	453.31	24	1.1	1.1	65.5
	461.41	1	0.0	0.0	65.5

468.98	2	0.1	0.1	65.6
480.36	6	0.3	0.3	65.9
485.69	1	0.0	0.0	65.9
506.07	7	0.3	0.3	66.3
506.30	8	0.4	0.4	66.6
527.67	2	0.1	0.1	66.7
566.64	2	0.1	0.1	66.8
568.54	7	0.3	0.3	67.2
593.63	40	1.9	1.9	69.0
615.90	38	1.8	1.8	70.8
626.34	1	0.0	0.0	70.9
635.82	1	0.0	0.0	70.9
659.36	19	0.9	0.9	71.8
664.52	1	0.0	0.0	71.9
671.14	1	0.0	0.0	71.9
720.29	1	0.0	0.0	72.0
736.10	8	0.4	0.4	72.4
746.21	3	0.1	0.1	72.5
753.92	1	0.0	0.0	72.5
767.53	2	0.1	0.1	72.6
772.07	48	2.3	2.3	74.9
779.14	18	0.9	0.9	75.8
808.36	24	1.1	1.1	76.9
809.08	1	0.0	0.0	76.9
809.49	144	6.8	6.8	83.7
822.07	4	0.2	0.2	83.9
825.68	1	0.0	0.0	84.0
863.17	1	0.0	0.0	84.0
865.42	5	0.2	0.2	84.3
874.25	1	0.0	0.0	84.3
880.87	2	0.1	0.1	84.4
917.06	1	0.0	0.0	84.5
923.87	1	0.0	0.0	84.5
927.23	1	0.0	0.0	84.5
964.65	17	0.8	0.8	85.3
1,000.18	3	0.1	0.1	85.5
1,000.83	8	0.4	0.4	85.9
1,007.38	1	0.0	0.0	85.9
1,017.80	5	0.2	0.2	86.2
1,071.47	3	0.1	0.1	86.3
1,081.77	1	0.0	0.0	86.3
1,090.60	3	0.1	0.1	86.5
1,123.00	46	2.2	2.2	88.7
1,148.00	1	0.0	0.0	88.7
1,177.44	106	5.0	5.0	93.7
1,196.16	1	0.0	0.0	93.8
1,200.99	4	0.2	0.2	94.0

	1,212.13	1	0.0	0.0	94.0
	1,236.73	2	0.1	0.1	94.1
	1,238.32	4	0.2	0.2	94.3
	1,248.08	2	0.1	0.1	94.4
	1,304.87	2	0.1	0.1	94.5
	1,336.91	2	0.1	0.1	94.6
	1,398.21	1	0.0	0.0	94.6
	1,471.80	1	0.0	0.0	94.7
	1,473.94	20	0.9	0.9	95.6
	1,545.39	56	2.6	2.6	98.3
	1,576.29	4	0.2	0.2	98.4
	1,638.11	6	0.3	0.3	98.7
	1,669.02	1	0.0	0.0	98.8
	1,824.88	15	0.7	0.7	99.5
	1,913.33	1	0.0	0.0	99.5
	1,951.60	2	0.1	0.1	99.6
	2,028.13	2	0.1	0.1	99.7
	2,452.99	1	0.0	0.0	99.8
	2,525.27	1	0.0	0.0	99.8
	2,600.17	3	0.1	0.1	100.0
	2,649.23	1	0.0	0.0	100.0
	Total	2,116	100.0	100.0	

ST4

Country	Forest Area (10^6 ha)	Initial Deforestation (%)	EpH (tCO2/ha)	Past Emissions (10^6tC)	Expected Emissions (10^6tC)	Equilibrium Reduction %	Equilibrium Emissions (10^3tC)	Combined Incentive (10^6 US$) y^{-1}				
								α=0.5	α=1	α=0	JRC (1/2)	JRC (1/3)
Brazil	478	0.55	123	1,184	1,006	97.5	29,590	5,996	6,497	5,495	5,877	6,150
China	197	-1.7	62	0	211	100.0	0	594	0	1,187	553	386
DR Congo	134	0.3	167	245	381	100.0	0	1,763	1,379	2,147	1,247	1,305
Indonesia	88	1.85	100	601	152	94.5	33,081	1,935	3,200	669	2,895	3,029
Peru	69	0.1	127	32	150	99.8	55	512	180	844	393	274
India	68	-0.6	65	0	75	100.0	0	212	0	425	198	138
Sudan	68	0.8	33	65	38	48.7	33,434	102	179	26	162	169
Mexico	64	0.45	109	115	120	93.4	7,614	619	607	632	549	574
Colombia	61	0.1	146	32	151	100.0	0	518	183	853	397	277
Angola	59	0.2	82	35	83	87.1	4,566	307	174	440	194	164
Bolivia	59	0.45	108	105	109	86.7	13,902	522	510	533	462	483
Venezuela	48	0.6	162	171	133	100.0	0	854	960	748	869	909
Zambia	42	0.95	27	40	20	53.4	18,765	63	121	6	110	115
Tanzania	35	1.05	64	87	39	82.1	15,533	266	401	130	363	380
Argentina	33	0.4	72	35	41	88.4	4,061	191	174	207	158	165
Myanmar	32	1.35	98	157	54	93.5	10,178	536	824	248	746	780
Papua New Guinea	29	0.5	165	89	83	100.0	0	486	502	470	454	476
Central African Republic	23	0.1	135	11	53	100.0	0	180	63	296	138	96
Congo	22	0.1	185	15	71	100.0	0	243	86	400	186	130
Gabon	22	0.1	172	14	64	100.0	0	220	77	362	169	118
TOTAL	1,631	(Mean = 0.48)		3,034	3,034	94.4	170,779	16,118	15,528	15,287	16,118	16,022
Emission Reduction (%)								94.4	90.9	71.5	94.4	94.0
Participant Countries								20	15	16	20	19
Incentives to High Def Countries in relation to Low Def Countries (Equal Forest Area)								+74%	+270%	-6%	+147%	+192%