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Sensitivity of amounts and distribution of tropical forest carbon credits depending on baseline rules

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ABSTRACT

One of the largest sources of global greenhouse gas emissions can be addressed through conservation of tropical forests by channeling funds to developing countries at a cost-savings for developed countries. However, questions remain to be resolved in negotiating a system for including reduced emissions from deforestation and forest degradation (REDD) in a post-Kyoto climate treaty. The approach to determine national baselines, or reference levels, for quantifying REDD has emerged as central to negotiations over a REDD mechanism in a post-Kyoto policy framework. The baseline approach is critical to the success of a REDD mechanism because it affects the quantity, credibility, and equity of credits generated from efforts to reduce forest carbon emissions. We compared outcomes of seven proposed baseline approaches as a function of country circumstances, using a retrospective analysis of FAO-FRA data on forest carbon emissions from deforestation. Depending upon the baseline approach used, the total credited emissions avoided ranged over two orders of magnitude for the same quantity of actual emissions reductions. There was also a wide range in the relative distribution of credits generated among the five country types we identified. Outcomes were especially variable for countries with high remaining forest and low rates of deforestation (HFLD). We suggest that the most credible approaches measure emissions avoided with respect to a business-as-usual baseline scenario linked to historic emissions data, and allow limited adjustments based on forest carbon stocks.

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1. Introduction

One of the largest sources of global greenhouse gas emissions can be addressed through conservation of the highest biodiversity ecosystem on earth, tropical forests, by channeling funds to developing countries at a cost-savings for developed countries. This four-dimensional win is the objective of including a framework for reducing emissions from deforestation and forest degradation (REDD) in a future climate treaty. And the multiple opportunities are why most delegates supported the concept of REDD in 2007 UNFCCC negotiations in Bali.

However, if REDD is to be included in future climate policy, there are still questions which must be resolved, including how to determine baseline emissions. A REDD baseline (used here as synonym of "reference level") defines an expected, or business-as-usual, emission of CO_2e (greenhouse gases measured as equivalent units of carbon dioxide) from deforestation and forest degradation in the absence of additional efforts to curb such emissions. To date, a number of methods for establishing national baselines have been proposed. The proposed methods differ a great deal in their approach, and in the likely outcomes, in terms of credits generated from REDD. Also, outcomes depend on country

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circumstances. Here we present a quantitative comparison of leading proposed methods for establishing national baselines as a function of country circumstances.

As with all other sectors of pollutant emissions trading, what would have happened cannot be directly measured once additional efforts to curb such emissions are implemented; thus, the approach to setting baselines is subject to debate and negotiation. The method for establishing REDD baselines as part of a post-Kyoto treaty will be determined by a deliberation about the best technical methods, and probably also by a political negotiation where a technically derived baseline can be adjusted as a function of "country circumstances."

The analysis we present here addresses a two-part question relevant to this debate and negotiation: what are the implications of different baseline methods for (a) the accuracy of emission estimates, and (b) the distribution, or equity, of offsets credits as a function of country circumstances? We unpackage these broad questions into two more specific questions we can analyze quantitatively:

1. *What types of countries can be identified as the basis for comparing baseline methods and understanding REDD country circumstances?*
2. *How many credited avoided emissions from deforestation does each proposal generate for each type of country, and how does that compare with actual avoided emissions?*

We address the first question with a quantitative classification of country types. To address the second question, we quantitatively compare seven existing proposals for setting baselines by analyzing how historical deforestation emissions would translate into a baseline for crediting avoided emissions during an initial performance period. We can do this with the benefit of hindsight: we analyze a retrospective scenario in which a REDD framework was instituted in year 2000, so that we can consider how different proposals for determining baselines would credit different country types, and how they compare to a known business-as-usual baseline (FAO reported emissions 2000–2005).

Our goal is to make a first approximation of the quantity of credits generated from different baseline proposals in order to spark more quantitative, substantive discussions about the differences between the proposals. It is beyond the scope of this analysis to represent the nuances and negotiations involved with many of the proposals—thus we base our calculations on some simple assumptions derived from our interpretation of the intent from source documents for each approach.

We conclude by drawing our results together for a discussion of strengths and weaknesses of alternative methods for calculating baselines, and offer our recommendations for refining baseline methods.

For our analyses we use FAO National Forest Resource Assessment (FRA) data. While this dataset has limitations and is subject to criticism (DeFries et al., 2007), it is the only global dataset available providing a 15+ year history of deforestation by country. FAO data are limited to net deforestation and do not report on emissions from forest degradation. Given lack of a global dataset on degradation, this paper only quantitatively assesses reduced emissions from deforestation (the first "D" in REDD). Degradation is an important contributor of greenhouse gas emissions and should be addressed in future efforts of this type to the extent of data availability.

1.1. *Country circumstances*

We review existing information on country circumstances with respect to deforestation, to frame the implications of baseline proposals for different types of countries. Four types of countries have been identified by da Fonseca et al. (2007) based on remaining forest cover and deforestation rate: (1) low forest cover and high rates of deforestation, (2) low forest cover and low rates of deforestation, (3) high forest cover and high rates of deforestation, and (4) high forest cover and low rates of deforestation (HFLD). To define these categories, the authors use cutoffs of 50% remaining forest and 0.22% forest loss per year. Remaining forest of 50% was selected as the simplest arbitrary cutoff. A cutoff of 0.22% per year was selected because it represents the global average rate of deforestation.

Forest transition models based on a number of studies (Mather, 1992; Drake, 1993; Grainger, 1995; Perz, 2007; Houghton and Hackler, 2000; Rudel, 2001; Andre, 1998; Mather and Needle, 1998; Staaland et al., 1998; Mather, 2001) link three of the types of countries identified by da Fonseca et al. in a time sequence as follows: HFLD countries (Fonseca Type 4) shift to increased rates of deforestation as development proceeds (Fonseca Type 3), but eventually reach a transition point where forest loss declines (Fonseca Type 2) and reverses due to forest regeneration (Fig. 1). A similar conceptual model of forest transition has been presented by The Coalition for Rainforest Nations and by the June 2008 UNFCCC REDD workshop in Tokyo to describe country circumstances with respect to REDD.

While the da Fonseca categories create a user-friendly template for understanding types of country circumstances with respect to REDD, it is not clear whether their arbitrary category cutoffs effectively characterize the constellation of country circumstances. For example, forest transition models raise the question as to whether Fonseca Type 1 is an appropriate category, or a scattering of outliers from other categories. In Section 2 we conduct an analysis to address this

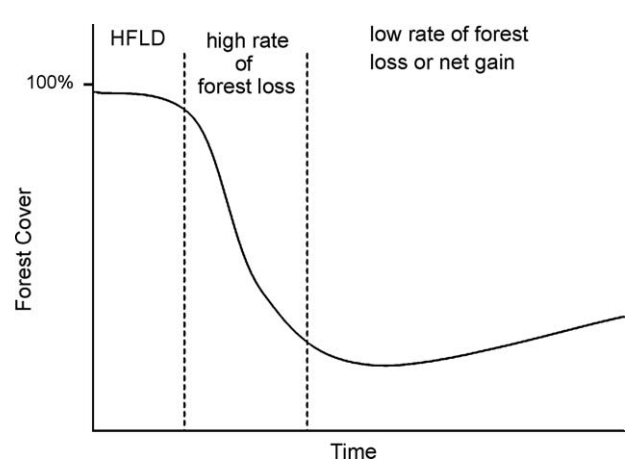

Fig. 1 – Generalized forest transition model.

question—and clarify a classification of country circumstances for REDD.

1.2. Baseline methods

The seven proposed methodologies for elaborating REDD baselines are: Combined Incentives, Compensated Reductions, Corridor Approach (V1 and V2), Joint Research Center, Stock Flow, and Terrestrial Carbon Group. We also include a ''simple historic'' baseline for comparison, in which no adjustments are made to a baseline calculated from historic mean emissions (1990–2000)—a simplified version of what has been proposed by Brazil (Brazil, 2006). Table 1 summarizes these proposals and the sections below highlight the main distinguishing features of each. The formulas used to calculate credits generated by each proposal are provided under methods in Section 3.

1.2.1. Compensated Reductions

This proposal was submitted in 2005 to the UNFCCC at COP 11 by Costa Rica and Papua New Guinea on behalf of the Coalition of Rainforest Nations (Coalition, 2005). The proposal was later refined by Environmental Defense and the Instituto de Pesquisa Ambiental da Amazonia (IPAM) who named it ''Compensated Reductions'' and submitted to SBSTA in February 2007.

This mechanism was designed to provide positive incentives to support voluntary policy approaches that result in gross emissions reductions from deforestation in developing countries as measured against an historical emissions rate. The historical emissions rate should be determined by assessing data related to rates of deforestation and estimating the carbon stock implications using relevant IPCC Guidance over a historical period that should be no shorter than 5 years. The baseline (referred to as reference rate) could be updated periodically and, ideally, adjusted downward. The Compensated Reductions proposal states that national circumstances should be taken into consideration when negotiating adjustments to baselines and incorporates various mechanisms for accommodating countries with historically low emission rates. Those include the creation of a global stabilization fund or a growth budget option under which countries could negotiate a baseline that is higher than their historical baseline rate in order to allow some room for economic development.

1.2.2. Joint Research Center (JRC)

The Joint Research Center Proposal (JRC) was developed by Mollicone et al. (2007). As in Compensated Reductions, the JRC proposal makes considerations for countries with historically low rates of forest conversion. See Skutsch et al. (2007) for a more detailed comparative discussion of Compensated Reductions and JRC proposals. The JRC method divides countries based on their conditions; specifically, high-conversion and low-conversion rates. For countries with rates more than half of the global average, the baseline is established using the historical rates from 1990 to 2005. Countries qualified as high-conversion must reduce below this baseline for credits to be issued. Countries qualified as low-conversion (those with rates less than half of the global average) must keep conversion rates below half of the global average to receive compensation. In addressing degradation, the JRC method divides forest type into three categories: intact forest (untouched primary forest), non-intact forest (that which shows signs of human intervention/degradation), and non-forest (deforested).

Unfortunately, our analysis is not able to differentiate between intact vs. non-intact forest because this distinction is not available through FAO-FRA global data.

1.2.3. Terrestrial Carbon Group

This proposal links avoided forest carbon emissions credits to actions that conserve forests under some threat of deforestation (Terrestrial Carbon Group, 2008). A portion of forest resources are put into a reserve and reflect areas that do not represent a risk of future deforestation or development (termed ''protected terrestrial carbon''). The remaining areas are eligible for carbon credit generation, so long as they are carefully managed (termed ''tradable terrestrial carbon''). Annual tradable carbon is defined as 1/50th of tradable stocks, or an emission rate of 2% annually; however the time period over which tradable stocks can be made available as credits, can be adjusted as a function of country circumstances. The annual tradable carbon and pay-out period was adjusted for the purposes of this analysis after communications with the authors (see methods in Section 3). The issue of permanence is addressed by a requirement that as credits are sold, specified land must move from tradable to protected status.

1.2.4. Corridor Approach

The Corridor Approach was outlined in a joint submission to SBSTA in 2006 by Joanneum Research, Union of Concerned Scientists, Woods Hole Research Center, and the Instituto de Pesquisa Ambiental da Amazonia (Joanneum Research et al., 2006). The unique feature of this approach is its proposed use of corridors (a range between upper and lower reference levels) to address issues of inter-annual variability in levels of deforestation. In this proposal, a country would establish an upper and lower reference level for baseline emissions based on an historical baseline period. If a country brings its emissions below the lower reference level, credits are generated. There are two ways to address emissions above and within the corridor. In variant 1, if a country's emissions rise above the upper reference level, a debit against future credit is initiated. For emissions within the corridor, credits would accrue but not be eligible for sale until emissions fall below the lower boundary. In variant 2, no debits accrue for emissions above the upper reference level. Emissions within the corridor would be discounted, with the discount rate decreasing as emissions levels are closer to the lower reference level.

1.2.5. Combined Incentives

The Combined Incentives approach was proposed by the Centre for Social and Economic Research on the Global Environment (Strassburg et al., 2008). This mechanism associates the amount of incentives offered by the international community to the actual reduction in global emissions from deforestation. The credits allocated to an individual country are determined by a formula that combines a measure of individual country performance against their own historic emissions baseline, and performance against a global emissions baseline. The relative weighting of these two variables is

Table 1 – Proposals for negotiated baseline methodologies.

Proposal	Historical or projected?	Historical time period used	Includes degradation?	Debits	Recalculated over time?	Provisions for country circumstances
Combined Incentives (Strassburg et al., 2008)	Historical	Not specified	Yes	Proposes no debits, although would allow a debit system to be incorporated if there is political consensus for debiting.	Global diminishing baseline could be established.	The use of the global emission rate offers higher payments for countries with low emissions rates.
Compensated Reductions (ED and IPAM, 2007)	Historical	5–10 years	Yes	"Once in, always in" clause—banking of some credits could be used to ensure this.	Adjusted downwards over time.	Includes a stabilization fund and/or allows countries to negotiate a "growth cap".
Corridor Approach (JR et al., 2006)	Historical	5–15 years	Yes	Variant 1: countries are debited for surpassing the upper reference level, variant 2: no debits accrue.	No	No
Joint Research Centre (Mollicone, et al., 2007)	Historical, and projection for HFLD countries.	1990–2005	Yes–divides forests into intact and non-intact forests	No penalties for exceeding the baseline.	Adjusted downwards over time.	Global average used for countries with high forest cover but low emission rates.
Stock Flow (WHRC and IPAM, 2008)	Historical, and projection based on global patterns.	Not specified	Yes	If a country exceeds its historical emissions rate, the country's dividends will be reduced accordingly. If these costs exceed the country's dividend revenue then they will receive no payment and a debit is carried over to be discounted from future revenues.	Not specified.	Dividends are provided for maintaining carbons stocks.
Terrestrial Carbon Group (TCG, 2008)	Neither, but informed by historic rates and projection of threats.	20–30 years	Yes	If emissions have increased over the crediting period, the difference is converted into an amount to be debited in future credit periods.	The National Terrestrial Carbon Budget can be adjusted due to unexpected events such as war or insurgency.	A variety of alternatives are mentioned based on country circumstances.

left open to negotiation. If the resulting value is negative, then the country is assigned zero credits. This can happen when the rate of national forest carbon stock emissions is substantially higher than the global baseline.

1.2.6. *The Stock Flow approach*

The Stock Flow approach was developed by the Woods Hole Research Center (WHRC) and the Amazon Institute for Environmental Research (IPAM) and submitted to the UNFCCC in September 2008. As with Combined Incentives, total global REDD credits generated are pegged to global forest carbon emissions reductions. Credits are allocated to countries as a function of both reduced emissions from deforestation (as compared with historical rate), and as dividends for maintaining carbon stocks (as a proportion of global forest carbon stocks). The relative weighting of these two variables is left open to negotiation.

2. Classification of country types

In this section we address the first question presented in Section 1:

What types of countries can be identified as the basis for comparing baseline methods and understanding country circumstances?

Many of the proposals reviewed above are designed with reference to multiple country types (especially HFLD) and an assumed transition process in which deforestation is associated with development. Given the importance of carefully defining country types for answering the questions discussed in Section 1, and the relatively arbitrary classification of countries employed by earlier studies, we conducted a quantitative analysis of "natural" groupings of countries according to the key variables identified by da Fonseca et al. (2007).

2.1. *Methods*

We applied multivariate statistics to the same two key variables used by da Fonseca: percent remaining forest and rate of deforestation. We used a method called cluster analysis which identifies "natural" groupings in data to generate categories. Specifically, we used Ward's linkage to calculate Euclidean distance in *n*-dimensional space (Everitt, 1980).

We calculated the two variables as (1) proportion of originally forested area remaining as derived from FAO 2005 National Forest Resource Assessment (FRA) data, and (2) rate of forest change using FAO 2005 data for quantity of forest lost, and using original area of forest cover from WRI to calculate rates (Bryant et al., 1997). These variables were calculated for the 56 tropical forest countries around the globe with available data and with originally forested area $> 20{,}000\ km^2$. We excluded countries with original forest area less than $20{,}000\ km^2$ because we observed that countries below this threshold had highly variable forest loss dynamics which obscured the broader trends from larger countries that make up the bulk of global tropical forests.

2.2. *Results*

Five distinct categories emerged from the cluster analysis dendrogram in Fig. 2. The well-structured nature of the dendrogram (long initial branches before spreading out into lots of little branches) is an expression of non-random natural groupings of countries according to these two variables. We selected five classes because (i) this expressed the major branching pattern, (ii) this offered a reasonable number of groups for our analysis, and (iii) further splitting would result in isolation of very small country groups (i.e. two countries in a group). We display the distribution of countries with respect to the two variables used in the cluster analysis, along with a third variable of original forest area (bubble size), in Fig. 3. The clusters are numbered according to a gradient from highest remaining forest (1) to lowest remaining forest (5) with the exception of clusters 2 and 3 which have virtually the same range of percent remaining forest, but differ in rate of deforestation.

The most striking feature of Fig. 3 is the lack of countries in the lower left-hand corner, that is with high deforestation

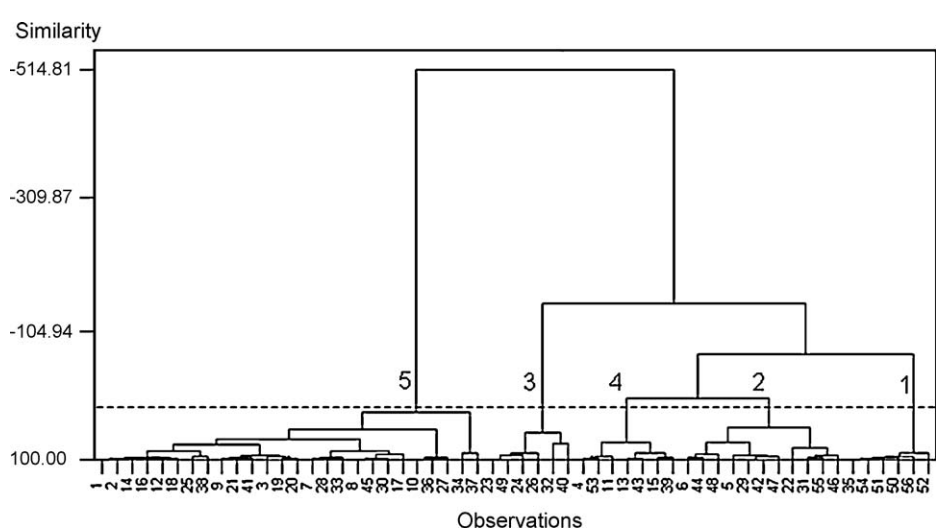

Fig. 2 – The cluster analysis dendrogram was cut at the dotted line to generate five distinct clusters. Note that the numbers assigned to clusters are not derived from relationships in the dendrogram.

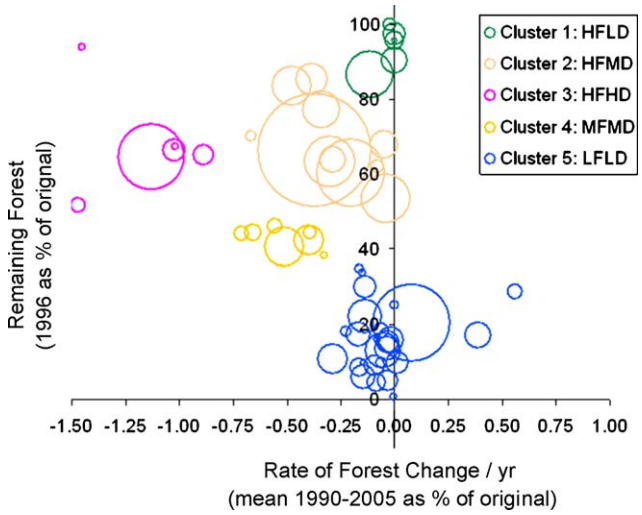

Fig. 3 – Countries are color coded by groups generated using cluster analysis, and graphed according to the two variables used in the cluster analysis. A third variable, original area of forest cover, was used to determine the size of the circle for each country. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

(above 0.3% forest loss) and below a threshold of about 40% remaining forest. This observation is consistent with the lack of ''low forest high deforestation'' countries posited by the forest transition theory discussed above. The importance of the 40% remaining forest threshold is confirmed by the dendrogram, where the largest difference between clusters is between cluster 5 and all other clusters.

In Table 2 we assign names (and acronyms) to each cluster and summarize dominant geographic distributions. The geographic distribution of each cluster is mapped in Fig. 4. We also looked at change in the rate of deforestation (1990–2000 as compared with 2001–2005) in Fig. 5, where negative numbers indicate decreases in rate of forest loss.

Our analysis identified the core ''high forest low deforestation'' (HFLD) countries as cluster 1, which tend to occur in Latin America. Our analysis identified two other clusters with percent remaining forest above 50%: cluster 2, which has relatively high remaining forest and medium to low rates of deforestation (HFMD), and cluster 3, which has the highest rates of deforestation and relatively high remaining forest (HFHD). In contrast to what we might expect from the forest transition model displayed in Fig. 1, countries in clusters 1 and 2 are not tending to show increasing rates of deforestation—rather they have relatively stable rates of deforestation, suggesting that they are not transitioning towards cluster 3. Cluster 3, predominantly located in Southeast Asia, has not only high rates of deforestation, but is tending to show increasing rates, although the change in rates is highly variable (some show strong decreasing rates). Cluster 4 has rates of forest loss intermediate between cluster 2 and 3, and remaining forest just below 50% (MFMD); however, the rates of forest loss are declining as predicted by the forest transition model. Finally, countries in cluster 5 (LFLD) have lost most of their forest, and have relatively low rates of deforestation (relative to original forest area), in some cases with net reforestation, as predicted by the forest transition model.

3. Comparison of alternative baseline approaches

With the benefit of objectively defined country types from the previous section, we are in a position to consider the second question presented in Section 1:

How much credited emissions avoided does each proposal generate for each type of country, and how does that compare with actual emissions avoided?

We address this question with a quantitative comparison of the seven existing proposals described above by developing a hypothetical retrospective scenario in which a REDD framework was instituted in year 2000. In this scenario, our ''business-as-usual'' reference scenario is actually known: reported emissions during the period 2000–2005. In our scenario, all countries succeeded in implementing 10% reductions from this actual business-as-usual emissions level—thus 10% of countries' FAO-FRA reported deforestation emissions during 2000–2005 represent ''actual'' reduced emissions from deforestation. We can then compare these ''actual'' reduced emissions with credited emissions by different proposals (based on our interpretation of them). Credited emissions are derived from data on historical emissions (FAO-FRA 1990–2000) and in some cases additional data, with modifications depending upon each proposal's methods. Since our intent is not to single out individual countries but to consider broader patterns, we lump countries into five ''meta-countries'' to represent each of the ''country circumstances'' types we identify in the previous section.

Table 2 – Characteristics of country types.

Name	Description	Forest cover	Annual rate forest loss	Dominant location	Forest carbon stocks (as percentage of tropical total)
HFLD	Highest forest cover, low rate of deforestation	85–100%	0.0–0.1%	Latin America	10.5%
HFMD	High forest cover, medium to low rate of deforestation	50–85%	0.04–0.8%	Latin America	63.7%
HFHD	High forest cover, high rate of deforestation	50–95%	0.8–1.5%	SE Asia	5.2%
MFMD	Medium forest cover, medium rate of deforestation	35–50%	0.3–0.8%	Scattered	5.0%
LFLD	Low forest cover, low rate of deforestation	1–35%	0–0.3%	Africa	15.5%

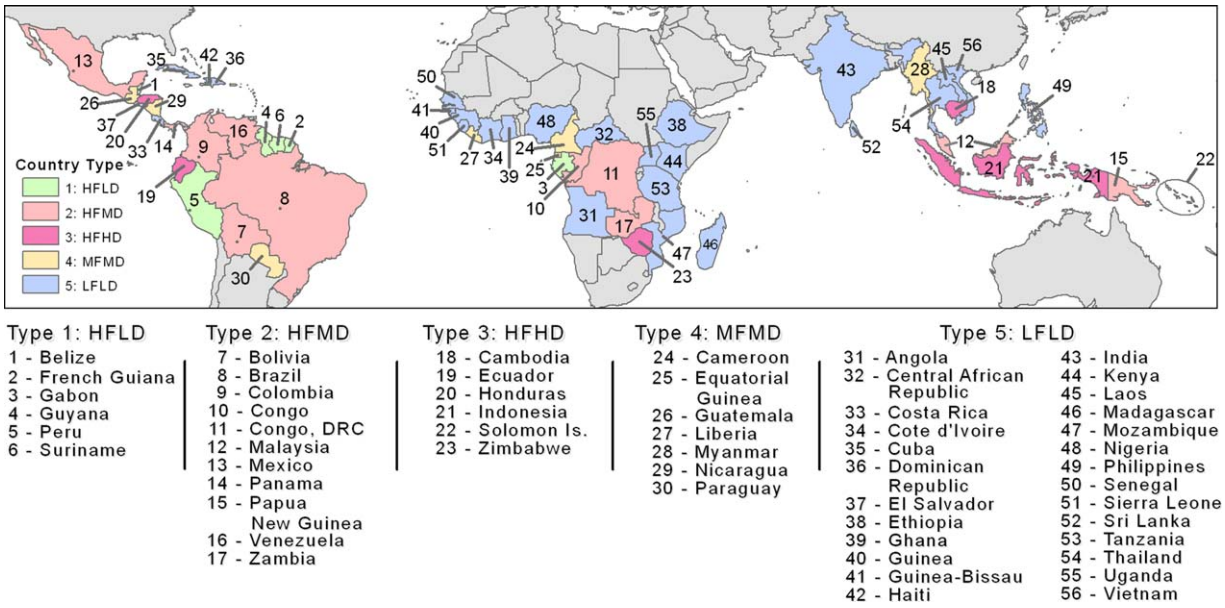

Fig. 4 – The geographic distribution of countries sorted into clusters (country types) are mapped across the tropics. Most cluster 1 and 2 countries, characterized by high remaining forest and low deforestation rates (HFLD) or medium deforestation rates (HFMD), are found in Latin America. Most cluster 3 countries, characterized by high remaining forest and high rates of deforestation (HFHD), are found in Southeast Asia. Cluster 4 countries, characterized by medium percent remaining forest and medium to high rates of deforestation (MFMD), are globally scattered. Most cluster 5 countries, characterized by low percent remaining forest and low rates of deforestation or net reforestation (LFLD), are found in Africa.

As described in Section 1, it is beyond the scope of this analysis to represent the nuances and negotiations involved with many of the proposals. Thus we base our calculations on some simple assumptions derived from our interpretation of the intent of each approach as described in source documents, and where possible from direct communications with authors.

3.1. *Methods*

Forest biomass carbon density estimates (metric tons CO_2 equivalent per hectare in aboveground biomass) were calculated for each meta-country (sum of all countries in each country type) as the area-weighted averages of carbon density from FAO-FRA reported national estimates of biomass carbon.

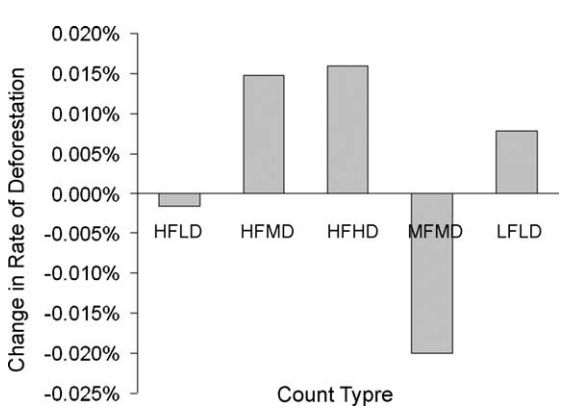

Fig. 5 – Change in rate of forest cover change compares the rate of forest cover change during 1990–2000 period with the rate during 2001–2005 for each country category. Land area of all countries in each country type was lumped together to calculate combined values for rate change.

To calculate the business-as-usual reference scenario, and "actual" reduced emissions scenario, we simply summed the values as described above from all countries in each country type to generate a "meta-country" value for each country type. For example, the "actual" reduced emissions from deforestation for the HFLD "meta-country" is the sum of the six values of FAO-FRA reported country emissions during the period 2000–2005 from the six HFLD countries identified in Section 2, multiplied by 0.1 (for a 10% emissions reduction).

Negotiated reference emissions levels for the 2000–2005 commitment period were determined for each of the proposals analyzed as follows (referencing FAO-FRA data for all historic data):

3.1.1. *Simple historic*

All meta-countries were assigned their respective historical emissions (1990–2000) for their commitment period baselines.

3.1.2. *Compensated Reductions*

Meta-countries with low (less than 0.1%) historical deforestation rates (cluster 1) were assigned a baseline level for economies in transition as the historical emissions (1990–2000) plus 10% of historical emissions. This seemed to us a reasonable negotiated outcome based on the approach described in this proposal. All other meta-countries (clusters 2, 3, 4 and 5) were assigned the historical emissions for their commitment period baselines.

3.1.3. Joint Research Center

Meta-countries with historical (1990–2000) deforestation rates (% per year) greater than or equal to half of the historical (1990–2000) global deforestation rate (Clusters 2, 3, 4 and 5) were assigned baselines equal to the meta-country historical (1990–2000) deforestation rate × 2000 forest cover area × area-weighted average carbon stocks per unit area. Meta-countries with historical deforestation rates less than half of the historical global deforestation rate (cluster 1) were assigned baselines equal to half of the global historical rate × 2000 forest cover area × area-weighted average carbon stocks per unit area. These methods are all following the approach as described in this proposal.

A "global" deforestation rate of 0.58 was calculated as mean annual rate from 1990 to 2000 across all tropical countries included in this analysis, using FAO-FRA. Our analysis was restricted to "forest" as reported by FAO-FRA (could not differentiate between intact vs. non-intact due to limitations of global data).

3.1.4. Terrestrial carbon

The following variables were calculated:

- E_h: 10 year historic mean total forest carbon emissions, 1990–2000.
- C_{total}: total terrestrial forest carbon stocks in meta-country X at beginning of initial performance period (year 2000).
- y: proportion of total terrestrial forest carbon that is "tradable." The proportion of terrestrial forest carbon that is "protected" is thus $(1 - y)$.
- C_{trade}: tradable forest carbon stocks in meta-country X at beginning of initial performance period (year 2000): $C_{total} \times y$.
- T: years over which "tradable" terrestrial forest carbon can be traded in annual increments.
- C_{yr}: maximum credits available to be traded per year: C_{trade}/T.

The following rules were applied:

- Set y equal to 75% of original forest carbon (original forest area × carbon density × 0.75).
- Set C_{yr} as the same as E_h and back-calculate T. If T is more than 75 years using C_{yr} based on average annual historic emissions, recalculate C_{yr} based on T of 75. Thus $T \leq 75$.

"Protected terrestrial carbon" was calculated for all meta-countries as 25% of "current" forest carbon stocks; thus the remainder (75%) was "tradable terrestrial carbon." Forest carbon stocks were calculated as year 2000 FAO-FRA forest area multiplied by FOA-FRA country-specific carbon density values. The figure of 25% was selected considering the following points:

- 19.6% of humid tropical forests have some protection status, derived as all protected sites within the World Database on Protected Areas, including protected areas within IUCN management categories I–VI and those not assigned to an IUCN management category, such as forest reserves. These protected areas experienced a 0.16% rate of forest loss per year between 2000 and 2005 (a conservative estimate based on MODIS analysis) (Campbell et al., 2008).
- The amount of land designated as "protected terrestrial carbon" as a function of inaccessibility due to biophysical or economic constraints is open to interpretation and thus depends greatly on negotiations; however, we assume that "REDD supply" countries will be resistant to giving up much additional stocks without opportunity for compensation as part of "tradable terrestrial carbon." Thus we allocated about 5% due to inaccessibility across all country types. It could be argued that countries with high remaining forest (HFLD, HFMD, and HFHD) would have higher proportions of inaccessible forests due to remoteness, as compared with MFMD and LFLD countries; however, it could alternatively be argued that large portions of the forests remaining outside protected areas in MFMD and LFLD countries are remaining because of biophysical or economic constraints to conversion.

We assume that all of the 10% avoided emissions is certified under TCG proposal for each meta-country. While this is logical since we have assumed that the reductions actually happened, in reality, the ability of countries to certify emissions may reduce credits generated. All of the quantitative parameters described above were determined in consultation with proposal authors.

3.1.5. Corridor Approach

All meta-countries were assigned upper and lower bound reference levels equivalent to their respective historical average annual emissions (1990–2000) ±20%, which reflects observed variability in 5-year average Amazonian deforestation rates (see results in next section). For this analysis, the performance in emissions reductions calculated represents credits immediately redeemable. For variant 2 we applied a linear function discount factor to credits within the corridor, ranging from 0% (at the lower bound) to 100% (at the upper bound).

3.1.6. Combined Incentives

Three values were calculated:

- E_n: "national" emissions; carbon stocks per unit area of meta-country X × average annual forest area lost from 1990 to 2000.
- E_g: "global" emissions allocation; carbon stocks of meta-country type X × global rate of deforestation emissions (0.53%).
- E_a: "actual" annual emissions under 10% REDD scenario; 0.9 × FAO-FRA reported average annual emissions during 2000–2005 performance period.

Annual Credits (C_a) for avoided emissions were calculated as:

$$C_a = ((E_n^* \, alpha) + (E_g^*(1 - alpha))) - E_a$$

where *alpha* is a weighting factor for influence of "national" emissions vs. "global" emissions allocation. This weighting factor is intended to vary over time, but the proposal authors suggested that for the purposes of this scenario it begin at 0.9 ("national" emissions accounts for 90% of credit determination, while "global" allocation accounts for 10%).

If the resulting value is negative, then the meta-country is assigned zero credits. Negative calculations can result when global emissions allocation is lower than actual annual emissions during performance period.

3.1.7. *Stock Flow*

Three values were calculated:

- E_n: "national" emissions; carbon stocks per unit area of meta-country X × average annual forest area lost from 1990 to 2000.
- E_g: "global" emissions allocation; meta-country X proportion of global (tropical) carbon stocks × total avoided emissions credits generated globally (tropical).
- E_a: "actual" annual emissions under 10% REDD scenario; 0.9 × FAO-FRA reported average annual emissions during 2000–2005 performance period.

Annual Credits (C_a) for avoided emissions were calculated as:

$$C_a = (E_n - E_a) \times 0.5 + (E_g \times 0.5)$$

In the above equation, *alpha* was set to 0.5 for the first performance period, after consultation with the proposal author.

3.2. *Results*

3.2.1. *Inter-annual variability in deforestation: empirically deriving a "corridor" for the Corridor Approach*

We used annual deforestation data (INPE) from the nine Brazilian Amazonia states to assess the variability of deforestation rates, to provide a reference for deriving a "corridor" for the Corridor Approach. This was an appealing context for analyzing such variability because it is the only tropical forest region where a 15-year dataset reporting annual deforestation is available across a region including nine Brazilian states that are (i) of a size scale similar to many countries, and (ii) represent a broad range of "country circumstances" with respect to the two variables we used in our classification. Over three 5-year periods 1991–1995, 1996–2000 and 2001–2005, the maximum annual deforestation (km^2/year) averaged 1.68 times the 5-year average. Likewise, the minimum annual deforestation (km^2/year) averaged 0.60 times the 5-year average. These values include the state of Amapa which showed substantially higher variability than other states, associated with very low amounts of deforestation which makes inter-annual shifts, as a percentage of the mean, very large. Excluding the state of Amapa as an outlier, the maximum and minimum current annual deforestation averaged 1.49 and 0.67 times, respectively, the corresponding 5-year average.

Longer timeframes for assessing deforestation should reduce variation, and alternately we assessed variability of 5-year average annual deforestation, which conforms more closely to expected 5-year performance periods and REDD monitoring frequency. Maximum and minimum average annual deforestation calculated from three 5-year periods, 1991–1995, 1996–2000 and 2001–2005, averaged 1.29 and 0.77 times, respectively, the corresponding 15-year (1991–2005) average annual deforestation. Again, excluding the state of Amapa, maximum and minimum 5-year average annual deforestation averaged 1.19 and 0.83 times, respectively, the 15-year average.

In summary, annual deforestation ranges on average ±30–70% of 5-year average annual deforestation, and 5-year average annual deforestation ranges on average ±17–29% of 15-year average annual deforestation.

3.2.2. *Outcomes of 10% REDD performance scenario*

Proposed methods for calculating and negotiating baselines are faced with a difficult trade-off between credibility during a given performance period on the one hand, and providing incentives to resist increased pressure to deforest for those with significant carbon stocks and historically low expected emissions (resulting from leakage and/or perverse incentives) on the other hand.

The near-term credibility of baseline approaches can be compared by assessing how accurately they will reflect business-as-usual emissions, so that REDD credits accurately represent the amount of reductions that take place over a specified time period. This comparison, for total emissions reduction credits generated across all country types, is presented in Fig. 6. Three of the proposals (Combined Incentives, Compensated Reductions, and Stock Flow) generated total emissions equal or close (within 10%) to what would be generated from a simple historic baseline. These proposals generated 22–27% fewer credited emissions reductions than actual emissions reductions in our scenario, so we refer to

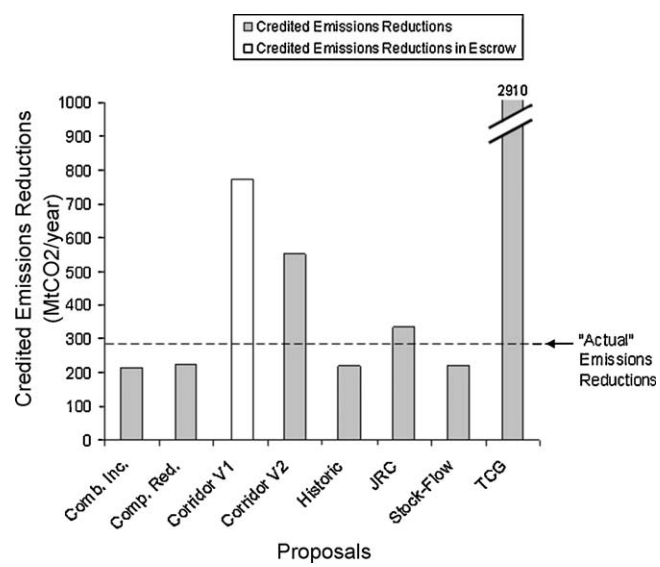

Fig. 6 – The estimated total emissions reductions credits generated by each of the seven proposals, as well as the "simple historic" approach, are compared using the results of our 10% REDD scenario. Three of the proposals (Combined Incentives, Compensated Reductions, and Stock Flow) generated total emissions close to (within 10% of) those generated from a simple historic baseline, resulting in conservative quantities of credits. The remaining four "liberal" proposals generated credits above actual emissions reductions, although Corridor V1 credits were in escrow until additional reductions are made.

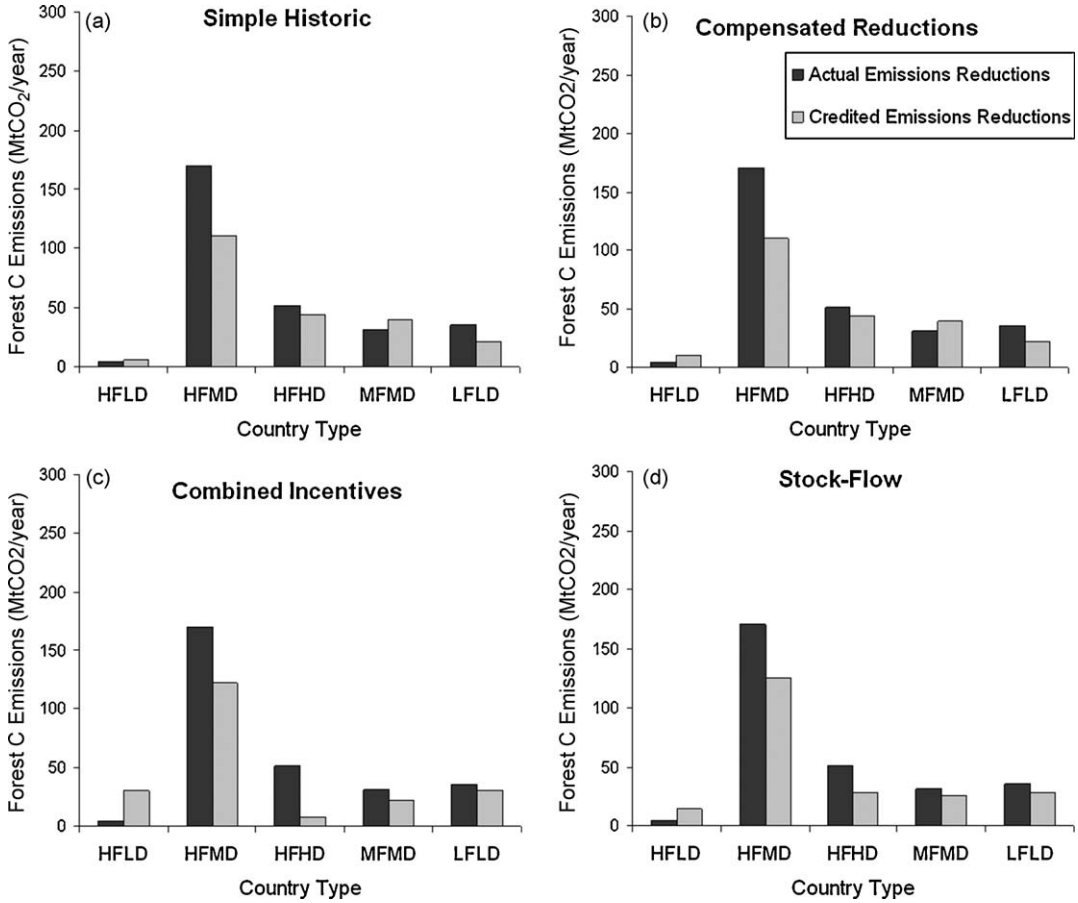

Fig. 7 – Estimated quantity of credited emissions during the first 5-year performance period are displayed by country type for three proposals (b–d) with total credited emissions close to (within 10%) of emissions that would be credited using a simple historic baseline (a). These three proposals differ principally in how a similar quantity of total emissions credits should be distributed among the five country types.

these as ''conservative proposals.'' Credited emissions were conservative for these three proposals because FAO reported forest carbon emissions have been increasing, and these proposals are close to, or pegged to, the ''simple historic'' global baseline. FAO-FRA reported annual emissions from all 56 countries during the 2000–2005 period as higher (by 2.5%) than during the 1990–2000 period. Thus, baselines derived from 1990 to 2000 emissions slightly underestimated the actual business-as-usual emissions during 2000–2005.

One proposal (Corridor V1) generated no credits during the first performance period, but generated over twice the actual emissions avoided as credits in escrow (redeemable if further reductions were achieved). The remaining three proposals (Corridor V2, JRC, TCG) generated more credits than the actual emissions avoided. We will refer to these four as ''liberal proposals.'' JRC generated slightly more credits than emissions avoided, while credits generated by Corridor V2 were about twice the number of emissions avoided. In the case of TCG, the quantity of credits generated was ten times the quantity of emissions avoided during the first performance period of our scenario (Fig. 6).

In Figs. 7 and 8 we compare results by country type for each proposal. Our modeled outcomes for ''simple historic,'' ''Combined Incentives'', ''Compensated Reductions'', and ''Stock Flow'' differed principally in how a similar quantity of total emissions credits were distributed among the five country types. A simple historic baseline resulted in credits in excess of actual emissions avoided for HFLD and MFMD countries, since as a group these country types had lower reported emissions during 2000–2005 than during 1990–2000. The opposite was true for HFMD, HFHD, and LFLD countries.

The remaining three conservative proposals in Fig. 7 adjusted credits generated from the reference scenario of simple historic allocations. ''Combined Incentives'' generated the largest quantity of additional credits for HFLD countries (which has the highest ratio of stocks to deforestation rate), and in contrast the smallest quantity of credits to HFHD countries (which has the highest rate of deforestation with respect to forest carbon stocks). The ''Stock Flow'' approach made a similar, but not as large, re-allocation. The ''Compensated Reductions'' proposal made the mildest adjustment, simply increasing credits to HFLD country category by 10%; however, this is a simple assumption we made since the guidelines of this proposal were not specific.

Among liberal proposals, the JRC proposal differed moderately from conservative proposals by having both a larger increased allocation to HFLD countries, and in not downwardly adjusting other country types (e.g. HFHD) to avoid

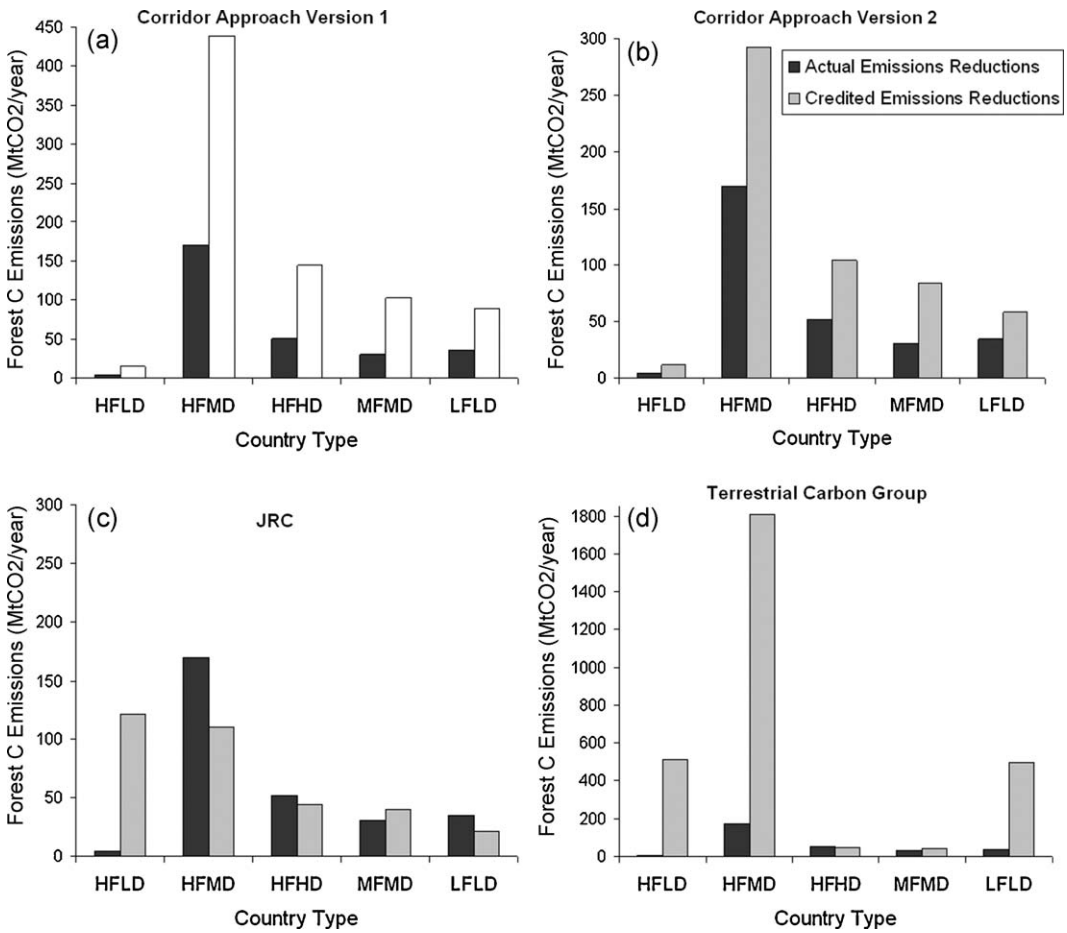

Fig. 8 – Estimated quantity of credited emissions during the first 5-year performance period are displayed by country type for four proposals, all of which have total credited emissions not close to (±50% or more) of emissions that would be credited using a simple historic baseline (3a). These proposals differ both on the quantity of total.

generating credits in excess of pan-tropical avoided emissions. The "Corridor V1" and "Corridor V2" proposals generated additional credits beyond "actual" emissions reductions across the board, but in the case of "Corridor V1" these credits were in escrow, and not available for exchange until further emissions reductions were achieved. The "TCG" proposal generated very high additional credits for the three country categories that had relatively lower deforestation rates (HFLD, HFMD, and LFLD). The TCG proposal does have specific guidelines to avoid generating credits in excess of emissions avoided over the long term, but allows for substantial allocation of expected future avoided emissions during the initial performance period.

4. Discussion and conclusions

4.1. *REDD country circumstances*

We derived five natural groups, or types, of tropical countries based on two key variables relevant to REDD with global datasets (deforestation rate and remaining forest). These REDD country types allow us to compare methods for establishing national REDD baselines with respect to country circumstances. Lumping individual countries into country types also helps buffer inconsistencies in collection of FAO-FRA data—the only available global dataset on deforestation for this analysis.

REDD country types represent a progression of forest loss, from nearly all original forests remaining (Type 1: HFLD) to less than 40% of original forest area remaining (Type 5: LFLD); however, Types 2 and 3 share medium to high levels of remaining forest and differ instead in rate of deforestation (about three times higher on average in Type 3 countries).

Country type 1 represents the core "high forest low deforestation" (HFLD) countries discussed in many baseline proposals, although we note that a subset of countries with "high forest and medium deforestation" (type 2—HFMD) also have relatively low rates of deforestation. These countries present the most dramatic example of the conundrum faced in the design of a REDD mechanism: how is the credibility of REDD offsets maintained while avoiding the perverse incentive to increase rates of deforestation for those countries that do not currently have elevated deforestation? Many HFMD countries, and all countries with high remaining forest and high rates of deforestation (type 3—HFHD) would be expected to reap the greatest benefits from a REDD framework, simply because there is substantial opportunity for avoided emissions. Countries with medium remaining forest and medium

rates of deforestation (Type 4—MFMD) have experienced more past deforestation, and continue to actively deforest, but still retain about 40% of their original forest that could be eligible for REDD incentives. MFMD countries tend to have decreasing rates of deforestation in transition towards Type 5 (low forest, low deforestation—LFLD), and credible REDD baselines should account for this trend in countries where it occurs. LFLD countries are characterized by low rates of deforestation (and in some cases net reforestation) if rates are defined with respect to original forest area as we defined them. Many LFLD countries are primarily eligible for land-based carbon sequestration through reforestation and/or improved management of agricultural landscapes; however REDD opportunities may yet exist in LFLD countries, and can be particularly critical with respect to biodiversity since remaining forests may provide the last remaining fragments of a given forest type.

Trends in the change of deforestation rates were consistent with the conceptual ''forest transition curve'' model discussed in Section 1 for HFMD, HFHD, and MFMD country categories: deforestation rates are tending to increase for countries with 50–95% remaining forest cover, in contrast with countries with 35–50% remaining forests which tend to have decreasing rates of deforestation. However, the trends for countries at either end of the forest loss continuum are not consistent with the ''forest transition curve'' conceptual model: the very low rate of deforestation in HFLD countries has actually been decreasing slightly according to FAO data. At the other end of the continuum, LFLD countries, as a group, show increasing rates of net deforestation, despite limited remaining forest. The forest transition curve predicts that HFLD countries would be showing at least slight increases in deforestation rates, while LFLD countries would be showing declining rates of deforestation. These exceptions to the conceptual forest transition model suggest that there are important differences between the forest transition patterns that today's developed countries passed through (from which the forest transition curve was derived) and the experience of developing countries today.

This cautionary note is consistent with findings from regional and country-specific analyses in the academic literature. Studies on forest transition processes in a number of developing tropical countries of Latin America, Africa, and Southeast Asia (Rudel, 2001, 2002; Foster and Rosenzweig, 2003; Klooster, 2003; Bray and Klepeis, 2005; Perz, 2007) identify a variety of distinct and regionalized processes that often are not consistent with the generalized forest transition curve. In contrast, the bulk of evidence for the forest transition theory is derived from examples of such transitions reported in numerous advanced industrial countries including the United States (Houghton and Hackler, 2000; Rudel, 2001) and various European countries (Andre, 1998; Mather and Needle, 1998; Staaland et al., 1998; Mather, 2001).

Thus, both our analysis of trends in FAO-FRA data with respect to the country types we derived, and our review of the literature, raise concerns about applying the generalized forest transition curve to non-Annex 1 countries as part of REDD policy development. In particular, it should not be assumed that HFLD countries will have increasing rates of deforestation, or that LFLD countries will have decreasing rates.

Some geographic trends were apparent from our classification of countries based on remaining forest and deforestation rates: Latin America has a higher proportion of HFLD and HFMD countries; tropical regions of Africa and central Asia have higher proportions of LFLD countries; and southeast Asia is predominantly HFHD and HFMD countries. While these trends are noticeable, geographic regionality is by no means a proxy for REDD country circumstances. All country types are represented in each of the regions (with the exception of Asia which has no HFLD countries).

4.2. *Comparison of baseline proposals*

Depending upon the baseline method used, the total credited emissions avoided ranged over two orders of magnitude for the same quantity of actual emissions reductions. This is a massive difference, and highlights the important implications of the details of baseline methods in determining how a REDD mechanism will function. The range of credited emissions among methods was greatest for HFLD countries, and applies similarly to the subset of HFMD countries with relatively low deforestation rates. This range in outcomes is due to the different approaches proposals take to addressing the challenging issues that particularly confront REDD in these countries, such as credibility, perverse incentives, equity, and leakage. Our analysis focuses on the issue of credibility, and how it relates to equity.

The two proposals (corridor and TCG) that generated substantially more overall credits than actual avoided emissions in our scenario are attempting to aggressively address longer term issues that confront a REDD mechanism (e.g. equity, leakage, and permanence). Each proposal presents creative solutions to specific baseline concerns that we did not explicitly assess here. Despite these strengths, we expect that these proposals will face a credibility gap in the link between credited emissions avoided and actual emissions avoided during a given performance period. We also raise a concern that a large proportion of payments generated from the TCG proposal for countries with relatively low deforestation rates and high remaining forest would not function as an incentive to change behavior within a given performance period, since substantial payments would be made even if substantial increases from historic rates of deforestation occurred. The Joint Research Council proposal generated only a slightly higher number of total credits than total actual emissions, so faces a similar but almost negligible credibility issue.

For REDD payments to successfully function as incentives to reduce emissions, we suspect that they should be (a) closely linked in quantity to actual emissions avoided against a credible, historically derived baseline, and (b) closely linked in time and space to actions taken on the ground by local stakeholders that reduce emissions.

The two proposals that peg global REDD credits generated with global emissions (Combined Incentives and Stock Flow) have the advantage of being designed to avoid a credibility problem at the scale of global REDD credits. These proposals address potential leakage and equity issues by re-distributing the pie of global REDD credits, rather than increasing the size of the pie. These proposals do encounter a problem of reduced payments, and thus incentives, for countries with high deforestation rates (e.g. HFHD). These conclusions may apply similarly to the Compensated Reductions proposal, given the

assumptions we made for this analysis; however, this is an open-ended proposal that does not make an explicit link to global emissions or deductions for countries with high rates.

These three proposals (Combined Incentives, Stock Flow, and Compensated Reductions) generated conservative outcomes overall (~25% lower avoided emissions credits), since historic mean deforestation rates did not capture the global trend of increasing deforestation rates. Thus, the historical mean global baseline underestimated the actual deforestation emissions that occurred during 2000–2005 by 2.5%. While more sophisticated techniques could reduce this error, the "business-as-usual" future simply cannot be perfectly predicted. Prediction error could be reduced, for example, by applying linear regression models to historic data, in order to capture trends; however, this is not feasible using FAO-FRA data given its coarse temporal resolution. More sophisticated forward-looking modeling methods, involving analysis of deforestation drivers and spatially explicit data (e.g. Soares-Filho et al., 2006), offer the potential for yet more refined estimations of "business as usual" baselines, at least within a 10-year time horizon (Brown et al., 2007). However, there is a trade-off with employing increasingly complex models for the purposes of deriving national baselines: as model complexity increases and as inputs other than actual emissions are used, so increases opportunities to game the system in negotiations over country-specific baselines.

Some have argued that the fundamental inability to generate perfect baselines is a reason to dispense with them (Pirard and Karsenty, in press). We suggest that this would be like throwing the baby out with the bathwater, as long as baselines are tightly linked overall to global historic emissions. Even the simple 1990–2000 historic mean baseline was a highly accurate predictor of 2000–2005 emissions (2.5% error), and conservative due to increasing emissions. Thus, historic mean global emissions offer a credible basis for generating emissions offsets for a cap-and-trade mechanism. The more challenging question is how to allocate emissions reductions among countries to effectively and efficiently incentivize performance below country baselines while addressing concerns about equity.

Among the two conservative and methodologically explicit proposals (Combined Incentives and Stock Flow), Combined Incentives tends to make larger adjustments to national baselines from their historic level as a function of variation from mean global emissions rates. Such adjustments involve a delicate trade-off. As national baselines are adjusted towards a global average, countries with low rates of deforestation have increased incentive to engage in a REDD mechanism, yet countries with higher deforestation rates have decreased incentive to engage change behavior.

The Stock Flow approach maintains the strongest linkage between emissions credits generated and actual emissions avoided at the national level while offering an explicit method to structure negotiations about equity adjustments as a function of stocks. Among the conservative approaches, the Stock Flow approach appears to maintain the largest incentive for rapidly deforesting countries to change behavior while encouraging low deforestation countries with the highest potential deforestation to stabilize emissions. In other words, we think the Stock Flow approach strikes a good balance, if we assume that adjustment of baselines is the best method for addressing equity. There may be other avenues to explore for addressing equity issues outside of baselines.

We do not expect that the general conclusions from our analysis of comparative implications of different proposals would change if data were available on emissions from forest degradation, since all proposals we considered support including degradation in a REDD mechanism. However, inclusion of degradation in this analysis would influence the relative and absolute outcomes for different county types. The total magnitude of historic emissions would substantially increase for most countries, since emissions from degradation are likely to be of a similar magnitude as from deforestation (Asner et al., 2005; Putz et al., 2008). Emissions from degradation may add proportionally more to historic emissions levels of countries with lower emissions and high remaining forests, simply because there are proportionally more opportunities for degradation emissions in such countries. Thus, including degradation may alleviate some of the equity and perverse incentives concerns associated with countries with relatively low rates of deforestation and high remaining forests.

4.3. *Summary of conclusions for negotiators*

(1) Careful consideration should be given to the implications of proposed baseline methods details. In our analysis, the total credited emissions avoided ranged over two orders of magnitude for the same quantity of actual emissions reductions, depending upon the baseline method used.
(2) A simple mean historic rate of deforestation was an accurate predictor (2.5% error) of global deforestation rate during the next 5-year period, offering an intuitive, simple, and credible reference for measuring emissions avoided.
(3) For REDD payments to successfully function as incentives to reduce emissions, we suspect that they should be (a) closely linked in quantity to actual emissions avoided against a historically derived baseline, and (b) closely linked in time and space to actions taken on the ground by local stakeholders where emissions are expected to occur.
(4) Adjustments of national baselines to address equity concerns (e.g. towards a global average) involve a delicate trade-off. In order for the global credibility of REDD offset credits to be maintained, incentives for countries with higher past deforestation must be reduced in order to increase payments to countries with lower deforestation rates. Thus, such adjustments from national historic emissions baselines should be limited. The Stock Flow proposal offers a good balance between credible offsets and a structured approach to address equity issues through adjustments linked to forest carbon stocks. Avenues outside of baseline adjustment should also be explored for addressing equity.
(5) Assumptions behind generalized forest transition models, derived from the experience of developed countries, should be questioned when applied to developing countries. For example, contrary to the prediction of generalized forest transition models, countries with high remaining forest and low deforestation (HFLD) as a group are not experiencing increasing rates of deforestation, while

countries with low remaining forest and low rates of deforestation relative to original forest area (LFLD) are not, as a group, experiencing decreasing rates of deforestation.

(6) While geographic trends in REDD country circumstances are noticeable, geographic regionality is by no means a proxy for REDD country circumstances. The full range of country circumstances, according to our classification, are represented in almost all of the regions.

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