Written Statement by Kevin Robert Gurney[1] submitted to the Committee on Foreign Relations, Subcommittee on International Development and Foreign Assistance and International Environmental Protection, April 22, 2008

This statement presents an overview of tropical deforestation within global carbon cycle science and how this science intersects with current and future policy. It begins by setting the large-scale features of carbon exchange followed by a more specific treatment of tropical deforestation. This scientific understanding is then placed within the context of current international policy discussions on deforestation reduction credits and potential US policy with similar aims. I will review the relevant scientific knowledge in support of the proposed policy goals, highlighting uncertainties and scientific challenges.

THE CONTEXT

The Global Carbon Cycle

The current budget of carbon dioxide (CO_2) within the Earth's atmosphere continues to present challenges to quantification, particularly the portion that involves exchange between the terrestrial biosphere and the atmosphere. Table 1 presents the Intergovernmental Panel on Climate Change's (IPCC) recent review of the global carbon budget for the decade of the 1990s.[2][3] The most precise budget element is the increase in atmospheric carbon. This increase amounts to 3.2 billion tonnes of carbon each year or 3.2 'GtC/y'.[4] The emission of fossil fuel-derived carbon and that due to cement production is also relatively well-known at 6.4 GtC/y. Recent research into ocean exchange has improved that portion of the budget (an uptake of -2.2 GtC/y), leaving a final term in the budget: the net land-atmosphere exchange which amounts to global net uptake of -1.0 GtC/y. You will note that the confidence regarding the magnitude of these large net fluxes around the planet increases, with the last term having an uncertainty of over 50% (a one sigma uncertainty).

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[2] Denman, K.L. et al., Couplings Between Changes in the Climate System and Biogeochemistry in *Climate Change 2007, The Physical Science Basis*, contribution of Working Group I to the Fourth Assessment Report of the IPCC, 2007.

[3] "carbon" as opposed to "carbon dioxide (CO_2) " is the common unit used by biogeochemists in tracing the many parts of the earth system that influence atmospheric levels of CO_2. A unit of carbon is equivalent to a unit of CO_2 x (12/44).

[4] The atmosphere currently holds roughly 760 GtC of which roughly 200 have been added since the onset of industrialization.

Table 1. IPCC review of the global carbon budget in units of GtC/year with one sigma uncertainty estimates

	1980s		1990s		2000–2005c
	TAR	TAR revised[a]	TAR	AR4	AR4
Atmospheric Increase[b]	3.3 ± 0.1	3.3 ± 0.1	3.2 ± 0.1	3.2 ± 0.1	4.1 ± 0.1
Emissions (fossil + cement)[c]	5.4 ± 0.3	5.4 ± 0.3	6.4 ± 0.4	6.4 ± 0.4	7.2 ± 0.3
Net ocean-to-atmosphere flux[d]	–1.9 ± 0.6	–1.8 ± 0.8	–1.7 ± 0.5	–2.2 ± 0.4	–2.2 ± 0.5
Net land-to-atmosphere flux[e]	–0.2 ± 0.7	–0.3 ± 0.9	–1.4 ± 0.7	–1.0 ± 0.6	–0.9 ± 0.6
Partitioned as follows					
Land use change flux	1.7 (0.6 to 2.5)	1.4 (0.4 to 2.3)	n.a.	1.6 (0.5 to 2.7)	n.a.
Residual terrestrial sink	–1.9 (–3.8 to –0.3)	–1.7 (–3.4 to 0.2)	n.a.	–2.6 (–4.3 to –0.9)	n.a.

It is this last term, the net exchange between the global terrestrial biosphere and the atmosphere, that is of particular relevance to tropical deforestation, climate change and policies aimed at their amelioration.

The net land-atmosphere exchange is commonly defined as having two very important parts:

1) the "land-use change" flux

2) the "residual" flux

The first is an amount of carbon emission that is associated with readily observable phenomena at the surface and is nearly synonymous (in modern times) with tropical deforestation. This emission has an estimated magnitude for the 1990s of 1.6 GtC/y but with a large, uncertain range (0.5 to 2.7 GtC/y). This value is at the core of the oft-cited comment that tropical deforestation accounts for approximately 20% of global carbon emissions. However, it is worth noting that this is a poorly known quantity and more correctly ranges from 6% to 32% of global emissions.

The residual flux, as it's name implies, is the uptake necessary to balance the well-constrained total budget. It is a phenomenon of considerable scientific research and profound importance to climate change and climate change policy.[5] It is a very uncertain flux ranging from -4.3 to -0.9 GtC/y and it's magnitude is directly tied to the estimated magnitude of tropical deforestation. Were the estimated tropical deforestation to increase, the residual uptake would also increase (a larger net uptake value) in order to maintain the same total global budget.

A series of hypotheses have been posited to explain this residual flux and include a combination of CO_2 fertilization, nitrogen fertilization, climate variability/change, and human management with the mixture differing from place to place. It must be remembered that all net terrestrial biosphere fluxes are the balance of *very large* gross fluxes of over 100 GtC/y, due to the seasonal 'give and take' of photosynthesis

[5] The mechanisms responsible for the residual flux and their evolution in the future is a first-order uncertainty in climate change projections.

and respiration. Hence, isolating this residual flux is akin to searching for a "needle in the haystack".

The separation of the net land-atmosphere exchange (into parts 1. and 2. above) is, in some ways, an intellectual convenience. Many of the processes in 2) above are thought to occur simultaneously with those in 1). For example, there is research that suggests net carbon uptake is occurring in mature, intact tropical forests. The implication is that countries with large tropical forests may have both deforestation and net uptake (CO_2 fertilization, N fertilization, etc) occurring within national boundaries.

This distinction goes beyond simple academic curiosity. The atmosphere "sees" the total net flux – this is what drives the additional greenhouse gas forcing due to this large component of the atmospheric carbon budget. A portion of climate change forcing is due to deforestation. However, it appears that there are countervailing processes ameliorating the full carbon impact of the deforestation emissions.

In addition to carbon emissions from tropical deforestation and the resulting addition to atmospheric CO_2, tropical forests have a number of key interactions with the climate system that are poorly understood but recognized as being important at the large scale. For example, tropical forests act as crucial mediators of radiation transfer and water exchange between the tropical land regions and the atmosphere. Recent research has shown that large-scale deforestation/afforestation can have a cooling/warming influence of measurable magnitude relative to projected climate change.[6] Furthermore, the impact of afforestation in the tropics is one of cooling while high latitude afforestation exacerbates climate warming.

There is also research that indicates potential feedbacks between climate and forest function.[7] For example, changes in forest cover could cause changes in local climate, particularly drying and warming, resulting in a shift towards savannah or grassland ecosystems. This shift would transfer potentially large amounts of carbon to the atmosphere and act as a positive feedback between climate change and tropical forest integrity.

It is important to keep in mind that this is a view of tropical forests that is necessarily from the climate science perspective. Tropical forests have additional importance when viewed from ecological, social, and economic perspectives. Policy options may include these other perspectives.

Tropical Deforestation

The current estimates for tropical deforestation at the regional scale are arrived at through a variety of techniques such as satellite remote sensing, ground surveys, aircraft, flux towers, model estimation and inverse approaches. Many of these are used in combination, with each having particular strengths and weaknesses. When

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[6] See recent research by Bala, G. et al., Proceedings of the National Academy of Sciences, 104 (16): 655-6555.

[7] See Oyama M.D. and C. Nobre (2003), Geophysical Research Letters, 30 (23).

ordered by their carbon emissions magnitude (for the decade of the 1990s), the IPCC estimates the large tropical regions as follows:

Tropical Asia:	0.8 GtC/y (0.4 to 1.1)
Tropical America:	0.7 GtC/y (0.4 to 0.9)
Tropical Africa:	0.3 GtC/y (0.2 to 0.4)

When viewed next to the decade of the 1980s, all regions have exhibited increases in total deforestation carbon emission, though uncertainty is large. When examined as a year-to-year phenomenon, large-scale deforestation emissions exhibit considerable variability. For example, the Brazilian space agency has estimated the year-to-year variations in deforestation emissions to be as high as 30%.[8]

At the individual country-level, the importance of deforestation as a share of total national emissions varies substantially among tropical countries. Table 2 lists many of the top greenhouse gas (GHG) emitting countries with the land-use, land-use change share quantified separately. Tropical countries are shown in red.

Table 2. Ranked GHG emissions for the year 2000 with the LULUCF component isolated[9]

	2000 GHG emissions with LULUCF (MtC eq)$^{\alpha}$	LULUCF (MtC eq)$^{\beta}$	Percent LULUCF
USA	1779.7	-110.0	6%
China	1336	-12.9	1%
EU (25)	1280.8	-5.7	0.4%
Indonesia	834.5	699.5	84%
Brazil	604.4	374.5	62%
Russia	538.4	14.7	3%
India	490.5	-11.0	2.2%
Japan	365.1	1.2	0.3%
Malaysia	237	190.8	81%
Canada	201.9	17.6	9%
Mexico	165.8	26.4	16%
South Korea	143.7	0.4	0.3%
Ukraine$^{\chi}$	141	0.0	0.0%
Myanmar	138.6	116.1	84%
Australia	135.3	1.2	0.9%
Iran	122	2.3	1.9%
South Africa	113.1	0.5	0.4%
Venezuela	104	39.3	38%
Turkey	102.8	5.7	5.5%
Dem. Rep Congo	100.7	86.6	86%
Zambia	69.1	64.3	93%

$^{\alpha}$ "MtC eq" – million metric tons of carbon equivalent

$^{\beta}$ negative numbers indicate net uptake

$^{\chi}$ No CH_4 or N_2O

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[8] Instituto Nacional de Pesquisas Espaciais (INPE) (2005) Monitoring deforestation in the Amazon from space, available at www.obt.inpe.br/prodes/

[9] This data comes from World Resources Institute's Climate Analysis Indicators Tool (http://cait.wri.org). While the absolute magnitudes contain uncertainty, the purpose here is to establish relative magnitudes and an ordinal relationship

The majority of the tropical countries have deforestation (which is nearly identical to LULUCF in these countries) as the dominant source of overall greenhouse gas emissions to the atmosphere. These numerical facts indicate why tropical deforestation has emerged as a top priority within the climate policy regime: deforestation is large in the absolute global sense and it is often the dominant form of greenhouse gas emissions for many developing countries.

Current Policy Consideration

The current emphasis within the international climate change policy realm is on constructing a post-2012 commitment structure in which all countries, including those in the developing world, would enter into some form of emission mitigation agreement. Because of the preceding analysis, the renewed interest in incorporating the developing world in future agreements, and the many dimensions of tropical forests, tropical deforestation has figured prominently in this discussion and is now taking a central role in international negotiations. Furthermore, because of lengthy discussion of deforestation in the negotiations around the first commitment period of the Kyoto Protocol, there is broad interest in structuring deforestation mitigation targets at the national level as opposed to the project or plot-scale.[10]

A number of proposals have been put forth on how to structure deforestation emission reduction targets. All of these proposals, with one exception (to be discussed later), require determining some form of baseline for deforestation against which a target can be compared. These baselines can be constructed as historical averages or as projections into the future along a "business as usual" trajectory. Therefore, effort at reducing deforestation, below either the historical or projected baselines, constitute legitimate reduction effort.

Many of the proposals also recognize the need to create incentives for deforestation reductions and have varying degrees of financial reward for selling credits when countries exceed certain mitigation thresholds. The supply of financing for these reductions are expected to come under a trading regime in which countries that face high mitigation costs purchase lower cost deforestation credits and thereby meet emission reduction goals.

Similarly, Senate Bill 2191 (America's Climate Security Act of 2007), proposes mechanisms whereby the United States would allow a certain percentage of domestic mitigation to be met by "carrying out forest carbon activities in countries other than the United States."

Both the international proposals and S.2191 intersect in critical ways with the current scientific knowledge on deforestation and the carbon cycle.

[10] Papua New Guinea and Costa Rica proposed to include addressing emissions from deforestation under the Climate Convention using a national emissions approach.

CRITICAL SCIENTIFIC ISSUES

Measurement Uncertainties

A recent study attempted a review of deforestation uncertainties when combining a cluster of measurement techniques at the national level.[11] The authors conclude that current quantification of deforestation credits at scales approaching the national level (the estimate was prepared for the Brazilian Amazon), to be **almost 50%** (2 sigma interval). This uncertainty accounted for current satellite capabilities, above-ground biomass, dead biomass and below-ground biomass estimation. The authors note that though seemingly large, this level of uncertainty is not fundamentally different from those recognized for the non-CO_2 greenhouse gases, methane, and nitrous oxide, within current Annex I accounting.

It is also important to note that this estimate does not explicitly include the difficulties associated with forest degradation and the spatial variability of biomass. Forest degradation is the loss of biomass and carbon within a forest system while still maintaining a sufficient forest canopy such that an area does not fall into a deforested category. Degradation is notoriously difficult to measure remotely and is estimated to constitute, for example, 2-25% of deforestation in the Brazilian Amazon. The variability of biomass is also a poorly quantified component of tropical forest inventories and similarly could increase this uncertainty should variation occur at the regional scale.

The same study attempted to estimate future improvements in this uncertainty estimate and came to the conclusion that expected improvements in remote sensing and an anticipated halving of uncertainty in ground-level survey data would bring this uncertainty down to **16%**. Once again, however, degradation and the spatial variability of biomass could potentially increase this uncertainty depending upon how much degradation occurs.

Baselines

Many of the current international proposals under consideration in addition to S.2191, borrow the precedent established in the first commitment period of the Kyoto Protocol for industrial emissions: recommending deforestation reductions relative to a historical baseline. Some proposals suggest that deforestation mitigation be measured against a projected business as usual trajectory. From a scientific perspective, the biggest challenge is the establishment of a historical level of deforestation emissions given the fact that data availability and quality decreases as one moves back through the decade of the 90s and the 80s. The uncertainty associated with establishing a historical baseline can have implications for the functioning of an international trading regime. Should a baseline be set at a level mistakenly higher than actual deforestation levels, deforestation levels could potentially increase while at the same time offering up undeserved credits and leading to a net increase in atmospheric CO_2. Should a level be set lower than actual

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[11] Persson U. and C. Azar (2007), *Mitig Adapt Strat Glob Change*, **12**:1277-1304.

deforestation, developing countries could find themselves having to purchase credits to cover their shortfall.

Isolating Deforestation or Not?

Many of the techniques used to assess tropical deforestation are better suited, or result in less uncertainty, when used to estimate the total net flux between regional forest and the atmosphere. Inverse techniques, flux towers, and modeling efforts are less robust at isolating the deforestation component of the total net land-atmosphere exchange. Furthermore, as highlighted in the opening section of this paper, assessment of the total net land-atmosphere flux avails of the large-scale mass constraint of the global budget.

Furthermore, the recognition that there is significant net uptake occurring in intact mature tropical forests will raise the possibility that developing tropical countries may wish to include that uptake in a national baseline estimate or target. There is precedent within the Kyoto Protocol for such net accounting and there is no reason to believe that it will not be an expectation for accounting in the tropical forest regions.

This will raise a series of additional scientific/technical questions, however. An attempt to fulfill a "full carbon accounting" system requires significant institutional and technical capacity in addition to placing pressure on fundamental improvements in understanding the current residual flux.

Unforeseen Events/Interannual Variability

Related to the previous issue of whether to isolate deforestation reductions as the creditable component or include other forest processes, is the issue of what constitutes a direct anthropogenic deforestation activity. For example, observational evidence indicates that strong El Nino/Southern Oscillation (ENSO) events are associated with biospheric carbon loss in many tropical land regions. In the 1997/1998 ENSO event, much of this carbon loss in Tropical Asia was associated with fire. Estimates indicate that roughly 0.8 to 2.6 GtC/year were emitted during the ENSO period due to fires, initiated by human activity, that in normal years would not cause significant carbon emissions. In the dry ENSO time period, these normally controllable fires grew to significant size, burning through deep peat forest land. This event also highlights the fact that both deforestation and the total net tropical land-atmosphere flux has significant variability. These variations can occur on timescales of a few years and remain a topic of considerable scientific research, as alluded to in the introductory section of this paper.

Permanence, Additionality, Leakage, Verification

Both the international and domestic policy discussions raise a series of methodological issues that have direct scientific implications. All recognize the need for any biospheric crediting mechanism to attend to each of these important issues. They were discussed at length during the negotiations leading up to the finalization of the Marrakech Accords and have continued to be important issues as the negotiations consider a post-2012 policy and U.S. domestic legislation considers including tropical deforestation credits as a component of national greenhouse gas mitigation targets. A short definition of each is as follows:

Permanence: the need to maintain and continuously guarantee the integrity of sequestered or set-aside carbon stocks.

Additionality: the need to ascertain what is considered an activity (altered deforestation trajectory, sequestering carbon activity, etc) additional to what would have occurred without climate policy.

Leakage: the movement of deforestation from an area or country with a deforestation mitigation target to an area or country without such a limit. National targets are a recognized improvement over project or plot-level efforts but may still exhibit leakage should policies not apply across the tropical forest countries.

Verification: given the current measurement and monitoring challenges, what viable verification opportunities are there for deforestation?

Degradation: An important, but difficult to quantify, portion of tropical forest demise.

CONCLUSIONS

The quantification of tropical deforestation carbon emissions is intricately tied to the global carbon cycle due to the fact that it remains closely linked to the overall net land-atmosphere flux. The scientific understanding of tropical deforestation carbon emissions over scales larger than the plot level continues to evolve. Research has shown that in addition to tropical deforestation emissions, tropical forest regions are also likely sequestering carbon in intact, mature forests. This has significant implications for policy approaches that link reduced deforestation to an international carbon market.

Measurement and monitoring uncertainties remain substantial and have been estimated to be almost 50% at the scale of the Brazilian Amazon. Degradation and the spatial variability of biomass content may further increase this estimation uncertainty. Though there is an expectation that this uncertainty will fall due to improvements in satellite remote sensing capabilities and better ground surveys, whether or not these uncertainty reductions are sufficient to support policy goals remains difficult to assess.

A series of additional difficulties persist in the scientific discussions on this topic. These include the ability to establish unbiased baselines, the difficulties of large interannual variability and unforeseen events, biospheric carbon permanence, additionality, leakage, verification, and the challenges of including forest degradation.

Whether or not current scientific knowledge is sufficient to support the policy goals being discussed for international policy and U.S. legislation, rests to a great degree on the implicit policy priorities. If the net radiative forcing of emission mitigation, be they industrial or biospheric, is paramount, the current science on the net impact of deforestation on the atmosphere may be too limited and too uncertain to adequately support the aims of current proposals. If tropical forest preservation is a priority, the potential co-benefit of lowered greenhouse gas emissions may not require a high level of scientific certainty and emphasis should be placed on those aspects that assess the phenomenon of deforestation with less emphasis on the net associated greenhouse has emissions.

Appendix A: The "Preservation Pathway" Approach

A recent proposal attempts to avoid some of the aforementioned technical difficulties, particularly those associated with estimating baselines.[12] The approach, called "Preservation Pathway" combines the desire for forest preservation with the need to reduce emissions associated with forest loss by focusing on the relative rate of change of forest cover as the criteria by which countries gain access to trading preserved forest carbon stocks. This approach avoids the technically challenging task of quantifying historical or future deforestation emission baselines. Rather, it places emphasis on improving quantification of contemporary stocks and the relative decline in deforestation rates necessary to preserve those stocks. This approach places emphasis on the complete emissions trajectory necessary to attain an agreed-upon preserved forest and as such, meets both forest conservation and climate goals simultaneously.

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[12] Gurney, K.R. and L. Raymond (2008), *Carbon Balance and Management*, **3** (2), doi:10.1186/1750-0680-3-2. A copy is included as an attachment.

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Commentary

Targeting deforestation rates in climate change policy: a "Preservation Pathway" approach

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Abstract

We present a new methodological approach to incorporating deforestation within the international climate change negotiating regime. The approach, called "Preservation Pathway" combines the desire for forest preservation with the need to reduce emissions associated with forest loss by focusing on the relative rate of change of forest cover as the criteria by which countries gain access to trading preserved forest carbon stocks. This approach avoids the technically challenging task of quantifying historical or future deforestation emission baselines. Rather, it places emphasis on improving quantification of contemporary stocks and the relative decline in deforestation rates necessary to preserve those stocks. This approach places emphasis on the complete emissions trajectory necessary to attain an agreed-upon preserved forest and as such, meets both forest conservation and climate goals simultaneously.

Introduction

With the entry into force of the Kyoto Protocol in February of 2005, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have begun to consider how and when developing countries might adopt greenhouse gas emissions reduction commitments [1]. Consideration of developing country participation in the Kyoto framework will need to recognize that the majority of emissions from many developing countries arise from non-industrial emitting activities including deforestation [2,3].

Agreement on the current Kyoto rules were preceded by considerable debate on whether or not deforestation should be included in the emission reduction arithmetic for the first commitment period spanning the years 2008 to 2012 [4-6]. Some argued that nations designating a portion of forest off-limits to deforestation should accrue carbon credits equivalent to the difference between a projection of business as usual deforestation and the protected forest [7,8]. This would achieve much-needed conservation goals while also recognizing the atmospheric benefit of "avoiding" deforestation emissions. Objections were raised to this approach, however, and centered on difficulties such as "leakage" (the displacement of deforestation activity outside the designated preserved forest and stimulated by the preserving activity) and "permanence" (the potentially transitory nature of biospheric carbon due to factors such as pest outbreak or fire) and the likelihood that those credits would be used by developed nations to meet their fossil fuel CO_2 emissions reductions leading to, at best, a zero sum game from a long-term atmospheric point of view and, at worst, an increase in near-term net greenhouse gas emissions [9-11]. Though deforestation was ultimately not included in the rules for the first commitment period, Parties have indicated a willingness to consider deforestation policy in future negotiating [12]. The negotiations that took place in Bali Indonesia in December of 2007 has reaffirmed this intent and methodological and conceptual work is underway among governments, NGOs, and the scientific community [13].

Discussion

Thus far, proposals to limit deforestation within the UNFCCC process have followed the model established for limiting fossil fuel/industrial emissions, relying on percentage reduction targets of current deforestation rates relative to an historical or "business-as-usual" baseline [12,14-16]. It is not clear, however, if the baseline/emission reduction model is an appropriate one for the problem of deforestation. To begin with, emissions limits effectively allocate the atmosphere's sink capacity to absorb GHGs – a globally distributed, unowned part of the "global commons" and beyond the control of any individual nation or private actor. Forests and soils, by contrast, are already subject to widely recognized claims of exclusive national control. It seems unlikely, therefore, that a policy designed for an open access resource would be the most appropriate for resources subject to strong existing national claims.

In addition, deforestation is distinctive from fossil fuel/industrial emissions in that the quantity and quality of the unextracted resource (standing forest) is itself associated with social, biological, as well as economic value. For example, the very existence of unextracted coal or oil at particular locations is generally not of direct social or biological concern. In the case of deforestation, however, significant social and biological implications arise when large contiguous forests are reduced to remnant status because forests provide a host of benefits in their unextracted form. These implications extend beyond CO_2 emissions to include reducing biodiversity, critical habitat, and undiscovered medicinal flora, while potentially compromising the future of local communities dependent upon sustained forest resources.

The analogy between fossil fuel/industrial and deforestation emissions also faces technical difficulties: determining levels of net carbon emissions from forest loss for a base period and a target period is far more difficult than measuring CO_2 output from fossil fuel consumption and is currently burdened by significant uncertainties [17-19]. Estimates of net carbon exchange in the tropics disagree by factors of two or more and recent work suggests that the differences are likely due to a variety of factors including assumptions about land-use history, land-cover dynamics, and the fate of cleared forest materials [20]. There is an expectation that net carbon exchange estimation in deforesting regions will improve with new remote sensors and renewed international cooperation, but issues of cost, limited historical data, and the challenge of in situ observations remain [21].

In addition, by defaulting to percentage reductions from historical baselines, the analogy fails to recognize the broader set of suggested and actual emissions allocation rules within the global climate change policy process. While percentage reductions from historical baselines were the basis of the Kyoto agreement, many other ideas were proposed and considered during the negotiation process. In actuality, scholars have promulgated a remarkable diversity of rules for distributing emissions entitlements, including schemes based on equal per capita shares, equal shares per unit of energy or economic output, or an auction [22]. Negotiators and policymakers have subsequently considered and utilized many such principles, including in recent allocation contexts like the EU Emissions Trading System [23].

Finally, lowering the deforestation rate may only delay the complete removal of virgin forest rather than preventing it. Only when the deforestation rate approaches zero or forest stands are designated as immune from deforestation pressure, will forest preservation occur. While deforestation rates can of course be adjusted over time in future agreements, that uncertainty leaves forests in some jeopardy. Under this scenario, it is not difficult to imagine a country running out of primary forest before it runs out of incremental deforestation reduction targets.

Allocations of credits starting from a deforestation baseline also risks rewarding countries that have already engaged in substantial harvesting and unfairly punishing countries that have yet to start harvesting their forests at a similar rate. A recent proposal by Danilo Mollicone and colleagues suggests referencing national rates to the global mean deforestation rate, offering a method by which both high and low deforesting countries are offered more equitable incentives [16]. Though a step in the right direction, credit bestowed for preserved forest in one commitment period does not eliminate the possibility that the preserved forest will be removed without penalty in the next. Incremental improvements in the deforestation rate without reference to a fixed goal associated with preserved forest offers only temporary protection. A policy approach that links a rate reduction to a specific quantity of standing stock responds to the unique nature of forests as a contributor to atmospheric CO_2 and a multi-valued resource in their own right.

These difficulties with the fossil fuel/industrial emissions analogy suggest an opportunity to consider a different approach to deforestation policy. Instead of negotiating deforestation targets relative to historical levels, countries might consider a national target related to the amount of untouched forest they are willing to preserve and the necessary change in deforestation rates required to get there. Such an approach, which attempts to strike a compromise between conservation and emission reduction goals, can be called a "Preservation Pathway".

For example, many developing countries have experienced increasing rates of deforestation during the last two decades [24]. This represents a positive growth rate in deforestation (equivalent to the second derivative of forest stocks with respect to time or the slope of the deforestation rate) and means that, should nothing change, the date at which the entire original forest removal occurs arrives earlier and earlier as time progresses (Figure 1, example country A). Agreeing to a specific level of preservation would require such a country to transition from an increasing to a declining deforestation rate and follow a trajectory that ensures the preserved amount (Figure 1, example country B).

An important advantage to this approach is that the ability to determine whether a deforestation rate is increasing, level, or decreasing is a relative measure and, as such, can be ascertained reasonably well with a combination of remote-sensing and ground-based measurements. It removes some of the pressure to determine a target level of deforestation that in turn requires absolute estimation of deforestation rates relative to a similarly estimated base year or period. In contrast, the Preservation Pathway approach relies on the ability to estimate relative rates of performance. For example, strategic satellite remote-sensing efforts have achieved good levels of accuracy in assessing the amount of canopy change over time in forested regions [25]. However, translating that into absolute quantities of carbon emitted remains difficult due to the inability of satellites to view near-ground vegetation and below-ground carbon [18]. In situ observations, inverse estimation, and numerical simulation similarly face difficulties in absolute estimation [26,27]. Therefore, determining the percentage change of forest disturbance over a five year period is likely a more robust measure compared to knowing the absolute quantity of carbon emitted over similar periods of time.

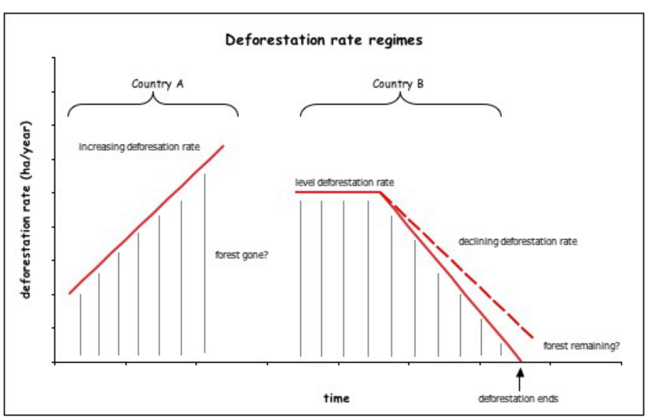

Figure 1
Preservation Pathways Schematic. Deforestation rate regime schematic showing examples with two different theoretical countries. Example country A exhibits an increasing deforestation rate with accelerating near-term loss of original forest. Example country B exhibits a constant, then declining deforestation rate with the possibility of preserving a portion of original forest.

The issue of forest degradation – the act of vegetation destruction that is either under the threshold of what is considered deforestation and/or cannot be assessed from remote sensing platforms – remains a challenge for this and all current proposed methodologies. Degradation can raise difficulties if a country has a declining deforestation rate but is simultaneously increasing forest degradation. In order to account for such a circumstance, degradation would have to be estimated with best available methods but like the assessment of forest cover, only in a relative sense, This removes the pressure for absolute historical quantification and places it on the relative trajectory of degradation.

The Preservation Pathway approach is consistent conceptually with how nations treat other terrestrial resources like oil, gas, and coal. It is consistent with a nation's internationally recognized right to consume or protect natural resources located within (or even proximate to) its borders, while encouraging a positive commitment to conserve some of these resources for environmental reasons. In this regard, it reframes developing country contributions with respect to deforestation as a laudable service to the world community, rather than simply a reduction in bad behavior. Such a reframing may be vital to making any such arrangement more politically palatable.

At the same time, it is unreasonable to expect good feelings alone to encourage developing nation's to undertake such commitments. Only when the value of standing forest begins to approach the value of the cleared land for a Soya plantation, one might say, is real progress on this issue likely to occur. Thus, financial incentives are a vital component of any deforestation policy, and this approach will likely require the translation of conserved forests into units of carbon such that value on the international market can be achieved. However, rather than rely on the ability to compute absolute deforestation rates with incremental targets and base year calculations, a post-2012 deforestation trading system could allow countries to sell carbon credits associated with the standing stock of the agreed-upon "preserved forest" once they have transitioned from a positive to negative deforestation growth rate. More specifically, the credits could be based on a combination of the agreed-upon amount of aboveground carbon in the virgin forest to be left intact and the rapidity with which the deforestation rate approaches zero. Though the standing *stock* of carbon in the preserved forest presents some of the same measurement challenges noted for historical baselines, it is different in that it requires an assessment of current conditions only that can be carefully measured and verified (and improved over time). Proposed approaches that require a quantification of baseline or historical deforestation carbon fluxes require a quantification of emission *rates* at past times, a particularly difficult task given the paucity and unreliability of past deforestation rates.

For example, a deforesting country wishing to sell carbon credits in this scheme must establish a target amount of preserved forest within their national boundary. They must further outline the deforestation pathway that ensures the preservation of that forest amount. In order to sell carbon credits at full market value a country would have to meet two objectives: 1) deforestation rates must be declining, and 2) the relative rate of decline from one commitment period to the next (averaged over five year periods) is sufficient to preserve the specified amount of original forest. The quantity of credits awarded would be based on a determination of the amount of carbon in the preserved forest employing standard practices and independent verification (which would also ensure that the preserved forest is not undergoing degradation).

To avoid a flood of credits at the outset of the Preservation Pathway journey, they could be "metered out" over the course of the years prior to achieving the final preservation/zero deforestation point and could scale with the rapidity of deforestation rate reductions or agreed-upon national circumstances. This slow release of credits allows the trading system to maintain integrity and limit price volatility should the estimate of total standing stock of carbon in the preserved forest undergo adjustment (due to improved monitoring, for example), by altering the amount of credits remaining once a country is proceeding down the negotiated path. Should either of the two criteria be violated once begun, the credit value could be discounted or eliminated on an annual basis until the appropriate Preservation Pathway is again achieved. Liability for countries that significantly violate their deforestation rate reduction (such as a reversal from a declining to increasing rate) must be included and could be tied to future trading eligibility.

The future rules could also include emissions targets for developed countries in the post-2012 time period that only allow a fixed fraction of deforestation carbon credits for each reduction performed domestically. This would encourage a market for deforestation credits while continuing to apply pressure for domestic action in the developed world, further diversifying global efforts to reduce greenhouse gas concentrations and making them more robust.

Finally, social, biodiversity and equity criteria could be linked to the crediting system to promote the preservation of continuous versus fragmented forest tracts or particularly valuable forested areas that may contain especially diverse regions or support vulnerable local communities. Research on weighted economic incentives like "agglomeration bonuses" suggests they can be effective policy tools in creating larger and more ecologically sound conservation areas [28]. In a similar manner, a country that chooses a path that leaves a large portion of original forest intact and reduces deforestation rates rapidly with adherence to agreed upon criteria based on equity, social and biodiversity concerns could accrue credits of higher value to sell on rapidly expanding national and international carbon markets.

Conclusion

The Preservation Pathway approach to including deforestation within international climate change policymaking combines some of the objectives of "avoided deforestation" with objectives that reflect the atmospheric impact of forest removal. It recognizes the value of preserved carbon stocks while incorporating incentives to reduce current deforestation rates and hence, limit the atmospheric burden of carbon dioxide. It creates a more manageable climate policy entry point for many countries in that some of the technical barriers associated with absolute calculations are avoided while emphasizing the long-term goal of changing regimes or pathways of forest loss.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

KRG conceived of and wrote initial draft. LR contributed significant components to final paper. All authors read and approved the final manuscript.

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