PERSPECTIVE

REDD+ and climate: thinking beyond carbon

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Scientific research shows that deforestation can drive climate not only through changes in carbon stocks but also through biophysical feedbacks. These can alter the climate effectiveness of emission reductions and will thus have important implications for REDD+. Explored here are the implications for motivating tropical developing country participation, and for motivating efforts to measure integrated biophysical–carbon climate impacts of land use change. In the tropics, biophysical impacts of deforestation are found to enhance local warming, which suggests that REDD+ participants benefit from a locally concentrated good in the form of local climate impacts, in addition to the global public good in the form of emissions reductions. To capture the breadth of climate impacts of land use change, composite biophysical–carbon indices have been proposed, but are hampered by issues of scale and uncertainty. These issues must at least be acknowledged in policy discussions to allow land-based initiatives to move forward in a holistic manner.

REDD+, which refers to reducing emissions from **deforestation** and forest degradation, conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries, has emerged in recent years as an increasingly popular and much-debated policy option for controlling deforestation and lowering the atmospheric burden of CO_2. Thirty percent of the global land area is covered by forests, with deforestation between 2000 and 2005 occurring at a gross rate of 12.9 million ha^{-1} year^{-1}, mainly because of conversion to agriculture [1]. Although lower than the 16 million ha^{-1} year^{-1} in the 1990s, it is still considered 'alarmingly high' [2]. Forest area in developing regions is projected to continue decreasing by 200–490 million ha between 2000 and 2050 [3]. The tropics in particular represent a region of urgent concern. Tropical biomes are known as highly productive areas accounting for a major share of net primary productivity (although estimates of actual percentage differ from 32 to 36% [4–6] to 50% [7]. The Amazon alone contains 90–140 billion tons of carbon, which is approximately equivalent to anthropogenic carbon emissions over 9–14 years [8]. From the Amazon, 117,000 ± 30,000 MtCO$_2$ of carbon may be released to the atmosphere by 2050 in a business-as-usual scenario [1,9]. In total, carbon stocks in forest biomass in South America, Africa and south Asia have also decreased at a rate greater than 0.5% per year from 1990 to 2005 [1].

Given these trends, and recognizing the economic opportunity costs of forest land versus the implementation costs of preservation programs, more effective incentives are needed to counter deforestation [10]. REDD+ represents a relatively low-cost mitigation option with potentially significant carbon benefits in the short term [1,11], as well as several ecological, socioeconomic and aesthetic services and co-benefits [7].

Earlier proposed simply as 'Reducing Emissions from Deforestation in Developing Countries' by Papua New

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Key terms

REDD+: REDD refers to reducing emissions from deforestation and forest degradation. The '+' includes conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.

Deforestation: Defined in the UNFCCC as the *"direct human-induced conversion of forested land to nonforested land"* (FCCC/KP/CMP/2005/8/Add.3). The definition of 'forest' is more interesting: the UNFCCC definition of 'forests' contains very specific guidelines for minimum area (0.05–1.0 ha), crown cover (>10–30%) and height (2–5 m at maturity), but also broadly includes plantations as well as 'forests' that do not even contain trees (i.e., forests that are 'temporarily unstocked'; annex to Decision 16/CMP.1, FCCC/KP/CMP/2005/8/Add.3). Historically, this broadness of definition is due to post-Kyoto Protocol efforts of drafters to reconcile the different interpretations of what counts as 'forests'. However, it does suggest that climate feedbacks that might be associated with deforestation can occur even without a loss in 'forest area', by definition (e.g., conversion to a plantation or to a temporarily unstocked forest).

Biophysical factors: This category of non-GHG feedbacks on climate include surface properties such as albedo and net radiation, latent and sensible heat fluxes, and surface roughness. The impacts of biophysical–climate feedbacks are more spatially concentrated compared with the effects of GHGs.

Guinea, representing the Coalition for Rainforest Nations [12], this initiative evolved into the 'REDD+' form (including forest degradation, conservation, sustainable management of forests and enhancement of forest carbon stocks) after the 13th COP to the UNFCCC in Bali, 2007. This broadening of scope was initially contentious. Brazil and the EU, fearing a proliferation of 'hot air' credits, opposed the inclusion of conservation [13]. During the August 2010 meeting in Bonn, Bolivia (supported by Saudi Arabia and Turkey) proposed not only removing conservation and enhancement of carbon stocks from the eligible activities, but also removing the word 'emissions' [12,14]. This was to incentivize the reduction of deforestation and degradation without having to use carbon as a metric [15]. Decision 1/CP.16 of the 2010 COP in Cancun, which contains the outcome from the Ad-hoc Working Group on Long-term Cooperative Action, recognizes all five elements of REDD+ as eligible activities.

However, the scope and framework of REDD+ have been criticized by some grassroot organizations and environmental groups. They claim that REDD+ promotes the commercialization of forests based purely on their carbon value and is, therefore, an incomplete approach to managing forest resources and ecosystem services. REDD+ has been touted as another form of 'CO_2lonialism of forests' [16] or of land grabbing and privatization of resources in the global south by industrialized countries or corporations who are perceived as delaying actions to reduce their own carbon footprints [101]. While it is acknowledged that reducing deforestation and degradation is desirable, critics contend that REDD+ is not the means to achieve this as there are other existing tools, such as the UN Convention on Biological Diversity; the UN Convention to Combat Desertification; and the UN Declaration of Rights of Indigenous Peoples, forest land entitlement for indigenous peoples, community-based forestry, national conservation programs [16].

Scientific literature on the climatic impacts of land cover change (many predating recent policy discussions on REDD+) do suggest that the REDD+ framework, and the overall carbon-based policy infrastructure, in general, is an incomplete approach to forest–climate interactions. Climate impacts of deforestation are not equivalent to the climate impacts of fossil fuel emissions due to the presence of biophysical feedbacks on climate associated with the land cover change. These biophysical feedbacks may either enhance or reduce the impacts of changes in carbon stocks.

The objective of this article is therefore to broaden the discourse on deforestation and REDD+ by bringing to light the noncarbon feedbacks of deforestation that have been shown to affect climate but that have yet to be acknowledged in the policy discussion in any significant way. This article explores the ways that biophysical feedbacks on climate are relevant to REDD+ policy. The following section highlights current scientific findings on biophysical–climate feedbacks that may have considerable impacts on the effectiveness of carbon-based mitigation initiatives. The subsequent sections discuss the primary implications of **biophysical factors** on REDD+ policy and on land use, land use change and forestry (LULUCF) initiatives in general. This article aims not to prescribe in detail the operational aspects of REDD+ but to encourage more holistic discussion in the LULUCF science–policy nexus.

The significance of biophysical–climate feedbacks

Describing the dynamics of biophysical–carbon climate coupling is a subject of active investigation in scientific circles, although it has yet to enter policy discussions. The current climate policy paradigm embodied in the text of the UNFCCC and the Kyoto Protocol has the control and stabilization of GHGs as the main objective. Article 3.3 of the Kyoto Protocol specifically cites the role of human-induced land use changes and forestry activities in meeting GHG emission reduction commitments. Thus, it is not surprising that current forestry-related climate response options focus solely on changes in carbon stocks.

This carbon-centric paradigm has thus far been appropriate for other sectors, such as the energy, transport and waste sectors, in which climate impacts are dominantly due to GHG emissions and in which fossil fuels as a resource are not multivalued in quite the same way as forests are. The forestry sector differs because of the social, cultural, biological and ecosystem services forest stands provide, apart from the climate service of carbon sequestration. If we now also recognize that LULUCF can drive climate through mechanisms other than changing concentrations of GHGs, then indeed, the carbon-centric paradigm becomes inadequate [17].

Land cover influences climate through both biophysical and biogeochemical pathways. Biophysical factors include properties such as **albedo** and net surface radiation, the surface energy budget, sensible heat flux (which refers to the land-atmosphere transfer of heat), **latent heat flux** and surface roughness (which affects air flow and mixing). Biogeochemical factors, as the name suggests, refer to the biosphere–atmosphere flow and interactions of chemical compounds, including (specifically in this article's context), carbon and other GHGs. Biophysical factors and biogeochemical factors operate at different, almost opposite, temporal and spatial scales. CO_2 emissions become well mixed in the atmospheric commons and are global in impact, although this impact lags in time. In contrast, biophysical impacts are generally location specific, locally stronger and temporally immediate. For example, CO_2 released from forest burning circulates in the atmosphere and may even be partially absorbed by another land or ocean sink. It would be difficult to attribute warming at any particular place and time to the CO_2 emissions from that particular instance of forest burning. The biophysical impacts, however, are more proximate – changes in surface properties and fluxes occur as a direct result of the change in land cover.

Although the carbon-induced warming of tropical deforestation is generally stronger over a larger scale than the biophysical impacts [18,19], the latter still play an important role (as seen in modeling studies [11,17,18–31]). The net biophysical effect depends on the location and particular type of land use or land cover change. Deforestation results in reduced latent heat flux through reduced forest canopy evapotranspiration. In the tropics, modeling studies suggest that this reduction in latent heat flux aggravates the carbon-induced warming [18,19,26,32–34]. This is not the case for higher latitudes, however, where the exposure of snow-covered ground results in increased reflection of incoming solar radiation compared with reflection by 'dark' tree cover. This albedo effect seems to dominate over that of the reduced latent heat flux, acting as a cooling feedback and running counter to the carbon impacts [18,19,30,31,35].

Countries currently involved in REDD+ readiness projects or pilot programs are predominantly in the tropics and sub-tropics and hence the alteration of latent heat flux and the resulting enhanced warming and perturbed precipitation are additional variables to consider when determining the overall climate impacts of forest cover changes. Because biophysical feedbacks operate at smaller scales, the warming and changes in precipitation due to deforestation are significantly stronger where the loss of tree cover actually occurs, or in areas near or downwind of the deforestation site (e.g., as discussed in [26,36–39], among others).

Whether there are consistent remote, teleconnected responses (causal connections or correlations between meteorological or other environmental phenomena that occur at long distances apart) in the extratropics due to biophysical feedbacks is still under investigation. The albedo effect of boreal deforestation has been simulated to cause a global net cooling on the order of 0.8 K in one recent study using an integrated climate and carbon model [18]. Statistically significant impacts of deforestation in the Amazon and central Africa on precipitation in North America, and southeast Asia on China and the Balkan Peninsula, have been found by another study through the use of general circulation models [40]. Amazonian deforestation may also result in large-scale circulation changes in the mid to high latitudes in the northern hemisphere that will bring less wintertime rain over the northeast Atlantic [41]. However, other research has found it difficult to differentiate the impact of land cover change from natural variability and isolate statistically significant responses in hydroclimatic variables in the extratropics [42].

In any case, biophysical feedbacks constitute inherently important processes in local to regional land–climate feedbacks that cannot be ignored or divorced from the carbon impacts if we consider the ultimate goal of initiatives such as REDD+ to be the mitigation of overall adverse climate change, rather than just the mitigation of GHGs. Biophysical impacts are not merely 'co-benefits' of REDD+; rather, they represent natural mechanisms through which changes in land cover affect climate and, therefore, together with the carbon impacts, underscore the efficacy of REDD+ and other LULUCF initiatives. Thus, the presence of biophysical–climate feedbacks has major implications on REDD+ policy: first in terms of motivating developing country participation; and second in terms of motivating the discussion and development of a more holistic climate metric for LULUCF sector.

'Concentrated goods' for developing countries

One major implication of the role of biophysical–climate feedbacks on REDD+ policy discussion involves motivating tropical developing country participation. Because climate models suggest that the combined biophysical and carbon feedbacks on climate

Key terms

Albedo: The extent to which a surface reflects incoming solar radiation. It is usually expressed as the percentage or fraction of radiation reflected. Forest-cover albedo is low compared with snow-covered ground, which explains why boreal deforestation may have a cooling effect. Different landscapes have varied surface reflectivity depending on factors such as type of land cover (e.g., urban vs vegetation), types of vegetation (e.g., trees vs shrubs vs grassland), type of soil and soil moisture.

Latent heat flux: The land–atmosphere flux of energy through ground evaporation, canopy evaporation and canopy transpiration. Forests typically have high latent heat fluxes compared with bare land. Latent heat flux is a component of the surface energy budget. Thus, latent heat flux is typically quantified in W/m^2. Reductions in latent heat flux are usually associated with warming.

are considerably greater in locales experiencing deforestation, they constitute a 'concentrated climate good' for developing countries. Thus, the mitigation of both global and local climate change would then be the main benefit and motivation for enhancing developing country participation – not that national governments require much additional persuasion to join REDD+. The number of partner countries of the UN-REDD National Programmes recently increased to 44, with 16 directly receiving support for National Programme activities for the development and implementation of REDD+, even if the financing mechanisms for REDD+ carbon offsets have not been resolved [102]. Currently, there are also 36 REDD+ countries, 15 donor governments and 11 carbon fund participants involved in the Forest Carbon Partnership Facility [103]. Clearly, there is interest in REDD+ and efforts are mobilizing on the ground.

The recognition that deforestation imparts local biophysical climate impacts in addition to the global carbon impacts can also address criticism from those who identify REDD+ as another form of carbon colonialism. REDD+ evolved as a country-driven initiative, purely on a voluntary basis. This is precisely because developing countries acknowledged the magnitude of the impact deforestation has on climate, and felt that it was necessary to address the drivers of this problem, but also recognized that additional incentives were required. The inclusion of the biophysical benefits of climate regulation strengthens this position. The motivation for participating in REDD+ from a developing country perspective would not, or should not, be the income from supplying carbon credits. Rather, it would be the desire of developing countries to reduce the adverse impacts of deforestation in their own localities since it is they who will suffer most. It is the developing country that will have more to gain in the form of overall climate benefits, both biophysical and carbon, rather than the Annex I investor (principally from a developed country), who buys only carbon credits. The income from carbon credits becomes simply an additional incentive in light of these local climate impacts. Presumably, having more at stake should be enough reason for developing country governments to prepare REDD+ strategies and ensure that they are implemented appropriately. Thus, a carefully implemented REDD+ mechanism with the rigorous governance, socioeconomic and cultural safeguards may well find a niche complementing, not hindering, other tools for protecting forests that have thus far not been entirely successful on their own especially in the developing world.

Annex I country investment in REDD+ can then be regarded as support for developing country mitigation and adaptation, rather than as a form of carbon colonialism, even if it is attached to a carbon market. As for the argument that allowing industrialized countries to purchase REDD+ carbon credits only delays action on their part, this is an issue that is perhaps better resolved by other policies or initiatives such as tightening caps on emissions or domestic technology improvement, rather than by disallowing REDD+ in the countries that will benefit from REDD+ policies.

There is an important caveat to make here, however. Although the concentrated climate good provides additional incentive for governments of tropical developing countries to participate in REDD+, this must be weighed against the interests of other stakeholders, especially if the stakeholders involved are diverse groups with different and even competing interests. The grassroots organizations that are critical of REDD+ are clear examples of groups that may have differing but potentially legitimate opinions and concerns. Many indigenous peoples and forest-dependent communities live in poverty, and it has been argued that REDD+ can potentially impinge upon their economic welfare by *"giving priority to conservation rather than development"* [43]. Agricultural expansion in the face of increasing populations is one of the main drivers of deforestation; thus, food security will also be a competing, but equally important, issue.

While deforestation and climate studies such as those summarized in the previous section can provide a global- or large-scale perspective, they cannot capture all these complexities of REDD+ project design because of limits in scale and scope. Not all the ecosystem services can be represented at the scale that is most relevant and useful to the community, and cultural and socioeconomic services are not captured at all in global climate models. The recognition of local climate benefits from REDD+ does not preclude the need to protect other stakeholder interests that might be adversely affected by the particular REDD+ project. Each country's unique institutional infrastructure determines who influences the process of REDD+ project design and who benefits from the actual implementation. Thus, it is important to engage all pertinent stakeholders in a more constructive dialogue with the objective of identifying losses versus gains/co-benefits, and developing contextualized, substantial and holistic safeguards.

Where the recognition of local biophysical climate impacts might not be particularly helpful is in convincing developed countries – often remote from where REDD+ projects are implemented – to finance REDD+. Given what is currently known from scientific studies, the climate benefit to the latter may not be as great as in the localities implementing the project.

If it can be robustly demonstrated that deforestation in the tropics will have far-reaching consequences, then this would create more motivation for Annex I countries in the extratropics to invest in reversing deforestation trends in non-Annex I countries. Barring this, it is presumably the 'global public good' in the form of reduced carbon emissions that would be relevant to Annex I countries rather than the concentrated climate good in the REDD+ project areas. This is where the carbon market may present an advantage. While a performance- or results-based system (as discussed in COP 17) would be more consistent with the science, it is uncertain if the level of Annex I support will be adequate in the absence of a carbon market. If REDD+ is attached to a carbon market, then Annex I countries' need for credits to meet target emissions reductions can become a source of additional investments in REDD+. Admittedly, how significant a source this will be depends on factors such as the price of CERs, the availability of credits through other mechanisms and the strength of emission caps. But without carbon credits, it is difficult to predict the level of Annex I commitments to a common REDD+ fund.

Is a climate metric feasible?

Looking at the long term, how can this discussion of biophysical feedbacks transform the REDD+ framework beyond advocating that developing countries should have a bigger stake in a carbon-based mechanism for reasons other than carbon? A second major implication of biophysical feedbacks is in motivating discussions, at a science–policy interface, on the possibility of developing more inclusive policies and metrics.

The policy emphasis on carbon-based metrics arose from the proven direct radiative impact of GHGs on the atmosphere, which drives global climate change. Biophysical feedbacks have likewise been shown to affect radiative balance (e.g., through albedo). This has helped bring them into the climate discussion, although their scope is broader than this, including nonradiative aspects (e.g., changes in evapotranspiration and surface roughness) [21]. The question now is whether forestry-based initiatives (and all land use/land cover changes for that matter) require a different metric; one that is already climate based (i.e., using temperature and/or precipitation) rather than carbon based. Changes in forest cover automatically affect surface albedo, evapotranspiration and surface roughness. This means that so as long as there is still deforestation, even if slowed by REDD+ activities, there will still be biophysical impacts that influence the effectiveness of local to regional climate regulation. This is an inherent property of any type of land use change that cannot be addressed by the safeguards considered in Decision 1.CP16. From this perspective, it would seem that Bolivia was on the right track with its proposal to have REDD focus on simply reducing deforestation and degradation and sustainable management of forests, without reference to emissions or to carbon stocks.

How, then, should negotiations for a post-Kyoto climate framework move forward with defining the rules governing the LULUCF sector? Should it be 'de-linked' or integrated with other sectors for which carbon accounting is more appropriate [44]? If full integration is the objective, then a common and integrated metric would be needed. What metric would this be? Current popular metrics such global warming potentials cannot capture what is actually felt on the ground as a result of both biophysical and carbon impacts of how human activities are shaping the Earth's landscapes [28].

Measures of temperature and precipitation sensitivity to land use change that integrate both carbon and biophysical impacts would, theoretically, constitute a more appropriate metric. A projected baseline would be required – the avoided warming and the magnitude of the avoided change in precipitation could be calculated, for example, given the area of forest preserved relative to projections of deforestation and given the sensitivities per unit area.

Efforts have been made in this field – Gotangco Castillo and Gurney, for example, attempted to quantify climate sensitivities due to both biophysical and carbon changes per unit area of forest removed in a global climate model [45]. West *et al.* propose metrics based on heat and moisture loading into the atmosphere due to land cover change using observations and a land-surface model [46].

For the purposes of creating credits tradable with other countries, metrics based on global means or some other noncontext-specific variables (e.g., equivalent tons of CO_2) would be relevant to all Parties and simpler to use. However, with a climate metric, in particular, it becomes inappropriate to attempt a global averaging and accounting because it is local impacts that communities have to contend with. Mitigation and adaptation needs are context specific. In addition, variances in temperature, and more so precipitation, can be wide, depending on location and context, even within the tropics. A global averaging would mask these variations and give a deceptive picture of change. Currently, the use of a carbon metric sidesteps this issue to an extent – we can focus on reducing carbon emissions as much as possible while modelers work towards reducing uncertainties in projections of possible future climates. A climate metric will be, precisely, a measure of overall temperature and precipitation changes and will therefore have to deal with this issue of scale directly.

A climate metric would not be entirely dissimilar from a carbon metric, however, as it would also share in its counterfactual nature. If climate credits are to be created and traded then it is imperative to ensure that these credits 'exist', although they are based on mere estimates or projections of climate changes that did not come to be. This is analogous to the notion of computing for additional avoided GHG emissions. The use of models would not suffice unless they could be shown to adequately represent reality. Even if ensembles were used to bracket possible temperature changes in response to forest loss or gain, this will likely be a relatively wide range if the spread of current estimates of model climate sensitivities (2.1–4.4°C [47]) are any indication.

In addition, there are different types of forest conversion – for example, forests to grasslands/grazing, to agriculture, to roads or urban areas, to plantations (although plantations are also considered as 'forests' by definition) – which would need to be considered. This will require estimating a range of plausible sensitivities cutting across all the possible directions of land cover change in different regions. A simplifying solution might be to assign a conservative estimate for temperature change per unit forest area per type of conversion, but this will still require rigorous modeling and observational data analyses. Precipitation presents an even greater challenge since models do not even agree on the direction of change in some regions.

Moving forward with a compromise?

Given the difficulties presented by a climate metric, it may not be feasible to implement at this time. Instead, a compromise may be found in the following options for translating biophysical impacts into a form that can be merged with carbon accounting.

Pielke *et al.* [28] and Marland *et al.* [17] discuss the option of quantifying biophysical impacts in terms of radiative forcing or energy units normalized over the affected area. Expressed as such, either they are further converted into equivalent carbon units, or accounting could instead be performed in terms of energy flows. This option is limited in applicability, however. Radiative forcing may capture the radiative effect of changes in albedo but it cannot adequately capture changes in the partitioning of net surface radiation into surface sensible and latent heat fluxes that affect surface temperatures.

Marland *et al.* [17] and Anderson *et al.* [48] also suggest using the net biophysical impacts to derive simple region-specific credit/discount coefficients to apply to a project's carbon credits as a first-order adjustment. This option will have to address questions of scale in order to be politically viable. Admittedly, a significant increase in temperature in a given area is a change that will entail costs and must be mitigated and/or adapted to, whether driven locally by biophysical considerations or globally by GHGs. However, the latter entails additional impacts outside of project boundaries, such as melting ice shelves and glaciers, sea-level rise, large-scale changes in convection, moisture transport and precipitation. Therefore, the challenge is how to modify carbon credits that are global in consequence by coefficients based on local climate regulation of land use change through biophysical pathways that may not affect the global picture significantly.

A first step to this compromise may be to initially consider for a composite metric only the biophysical impacts that have been found to have more robust teleconnections or global impacts. Examples include the albedo effect of large-scale deforestation [18] and the changes to global moisture transport and fluxes from deforestation in the Amazon [41,49]. Other more local biophysical impacts – such as changes in surface roughness that are more difficult to accommodate in a coefficient – may be left as additional co-benefits to be specified and safeguarded; however, this is only for the time being, until scientific research has developed a more appropriate method of integration that recognizes biophysical pathways as processes directly affecting climate rather than as ancillary goals (as the name 'co-benefits' sometimes suggests). This approach limits the range of biophysical feedbacks that can be factored into carbon credits, and may benefit certain regions (i.e., the Amazon Basin) more than others, but might be a more conceptually and scientifically consistent starting point.

Note, however, that both the options presented here differ from a true climate metric in the sense that biophysical and carbon impacts are first calculated separately and then combined. This does not fully capture nonlinear effects, compared with directly measuring impacts on temperature and precipitation. In terms of methodology, measuring biophysical impacts separately to factor into carbon credits *ad hoc* may not be significantly easier than directly quantifying local climate response to land cover changes. When observational data is used, it is difficult to divorce carbon-induced changes from biophysical ones in the overall measurements of temperature and precipitation. When climate models are employed, both the biophysical and climate sensitivities can already be derived from the same simulation.

A major advantage, however, of a composite biophysical–carbon index compared with a direct climate metric is the potential to reconcile it and integrate it with today's carbon-based policy framework. This would perhaps make it more political palatable to UNFCCC Parties compared with a REDD+ program that is completely de-linked (although NGOs and grassroots organizations that oppose REDD+ on a fundamental level might prefer the de-linking). While the immediate next step is simply the inclusion of biophysical–carbon impacts in science–policy discussions, this option of exploring a composite biophysical–carbon index represents a transitional step towards a more direct and integrated measure of climate impacts.

Conclusion

An understanding of the full range of biosphere–climate feedbacks is critical to both improving climate projections and operationalizing climate objectives through more effective policies. On the one hand, available science is telling us that there are more facets to biosphere and climate dynamics than the present policy infrastructure accounts for. On the other hand, more research is needed to give concrete and unequivocal recommendations on the role of the agriculture, forestry and land use sector in future climate and development policy beyond just carbon considerations. Clearly, however, the biophysical dimension of land–climate interactions represents not simply a co-benefit but actual processes that will influence the extent to which that goal of avoiding adverse climate change is achieved.

To support land use/land cover change and climate policy, what is required now from scientific research is a comprehensive effort that combines modeling land cover change types and pathways (including an investigation of factors that may affect sensitivities of biophysical–carbon climate feedbacks), and the analysis of observational records to determine how much greater or lesser the combined biophysical and carbon impacts are compared with just carbon impacts. Continued scientific research will improve our understanding of biosphere–atmosphere feedbacks, and provide the best available technologies and methodologies for monitoring and measurement.

Admittedly, there are more cultural and socioeconomic complexities to REDD+ project design and implementation that are not captured fully by climate modeling studies. However, the realization that developing countries have more at stake can serve to motivate and empower them to ensure careful study and implementation of REDD+ in their own localities, with the involvement of all pertinent stakeholder groups and substantial and rigorous safeguards in place.

Research will also benefit from input from the policy arena. Despite the biophysical contributions to climate being relatively well established by the scientific literature, policy discussions and negotiations have yet to acknowledge these in any significant way. However, it is crucial that policy discussions at least begin to consider the noncarbon climate feedbacks as inherent in REDD+ in order to craft more cost-effective mechanisms. This is the immediate next step, which may guide the agenda for further research in the science–policy nexus. A clear policy mandate that recognizes the need to explore noncarbon climate impacts (with a view towards eventually developing a climate metric, or at the very least a composite biophysical–carbon index) will provide impetus for research and feedback as to what technical areas require strengthening to enable climate discussions to move forward in a holistic manner.

Future perspective

Given the current difficulties and intricacies of accounting for a metric as conceptually tractable as equivalent tons CO_2, it is unlikely that science–policy discussions would shift to considering composite biophysical–carbon or integrated climate metrics any time soon. Coming negotiations would prioritize operationalizing REDD+ fully rather than stalling implementation to re-evaluate metrics. However, the relevant texts of COP16 and COP17 stress 'results-based' actions. It is as yet unclear exactly what indicators for 'results' are to be quantified and monitored, but this presents an opportunity for future discussions of REDD+ results and co-benefits to at least explicitly acknowledge and incorporate the noncarbon climate benefits.

In parallel, scientific research will continue to better characterize biosphere–atmosphere dynamics. More robust results on potential teleconnections and large-scale impacts will be of particular importance if we are to eventually develop holistic yet simplified metrics to describe the impacts of land use change on climate.

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Executive summary

Background

- REDD+, an emerging popular incentive to counter high deforestation trends and gain carbon benefits in the short term, has been criticized as a form of 'carbon colonialism' and as being inadequate to the multidimensionality of the forestry sector.
- Scientific literature on the climatic impacts of land cover change (some predating policy discussions on REDD+) suggest that a carbon stock-based policy infrastructure is an incomplete approach to forest–climate interactions. This is because deforestation also entails biophysical feedbacks on climate.

The significance of biophysical–climate feedbacks

- Biophysical factors include properties such as albedo or surface reflectivity, sensible heat flux, latent heat flux and surface roughness. CO_2 emissions become well mixed in the atmospheric commons and are global in impact, although this impact may lag in time. In contrast, biophysical impacts are generally location specific, locally stronger and temporally immediate.
- Deforestation results in reduced canopy evapotranspiration. In the tropics, modeling studies suggest that this reduction in latent heat flux aggravates the carbon warming and perturbs precipitation patterns. This is contrast to deforestation in boreal regions that may lead to albedo-triggered cooling. Thus, biophysical mechanisms represent additional variables to consider when determining the overall climate impacts of forest cover changes.
- The presence of biophysical–climate feedbacks therefore has major implications on REDD+ policy: first, in terms of motivating developing country participation; and second, in terms of motivating the discussion and development of a more holistic climate metric for the land use, land use change and forestry (LULUCF) sector.

'Concentrated goods' for developing countries

- While Annex I countries benefit from the global public good in the form of reduced carbon emissions, REDD+ hosts in the tropics benefit from the additional concentrated climate good in the form of biophysical impacts as well. This can address criticism from those who identify REDD+ as another form of carbon colonialism.

Is a climate metric feasible?

- Recognition of biophysical feedbacks can also motivate discussions, at a science–policy interface, on the possibility of developing more inclusive policies and metrics. Current metrics such global warming potentials cannot capture what is actually felt on the ground as a result of both biophysical and carbon impacts of how human activities are shaping the Earth's landscapes.
- Questions that need to be addressed include whether forestry (or land in general) initiatives require a different metric; one that is already climate based (i.e., using temperature and/or precipitation) rather than carbon-based, and whether the LULUCF sector should be de-linked from other sectors.

Moving forward with a compromise?

- Biophysical impacts, however, are difficult to capture with current carbon-based metrics. It has been proposed to use net biophysical impacts as region-specific credit/discount coefficients to apply to a project's carbon credits as a first-order adjustment. The problem is how to modify carbon credits that are global in consequence by coefficients based on local climate regulation.
- A compromise may be to initially consider for a composite metric only the biophysical impacts that have been found to potentially have teleconnections or global impact. Examples include the albedo effect of large-scale boreal deforestation and the changes to global moisture transport and fluxes from deforestation in the Amazon. The main advantage of a composite biophysical–carbon index is in the potential to reconcile it with the current carbon-based policy framework, as opposed to a true climate metric, which would, for example, try to directly quantify the impacts of land use change on temperature and precipitation.

Conclusion

- A two-way dialogue between the science and policy communities is needed: while more comprehensive scientific research is required to support LULUCF policies, policy discussions should at least acknowledge the significance biophysical–climate feedbacks.
- A clear policy mandate that recognizes the need to explore noncarbon climate impacts (with a view towards eventually developing a climate metric, or at the very least a composite biophysical–carbon index) will provide impetus for research and feedback as to what technical areas require strengthening to enable climate discussions to move forward in a holistic manner.

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