CLIMATE-RELEVANT LAND USE AND LAND COVER CHANGE POLICIES

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Observational and modeling studies clearly demonstrate that land-use and land-cover change (LULCC) (e.g., Fig. 1) plays an important biogeophysical and biogeochemical role in the climate system from the landscape to regional and even continental scales (Foley et al. 2005; Pielke et al. 2011; Brovkin et al. 2013; Luyssaert et al. 2014; Mahmood et al. 2014). The biogeochemical effect on the carbon budget is well recognized in both the scientific and policy-making communities. The biogeophysical effect on the water cycle and surface energy fluxes, and thus on the human role in affecting the climate system, is also well documented by the scientific community. Although the CO2-linked biogeochemical effects have some spatial heterogeneity, it is much less compared to LULCC-driven biogeophysical impacts and, overall, biogeochemical impacts on climate are more homogeneously distributed.

Hence, we suggest that the biogeophysical effects need to be better communicated among policy makers. In this vein, progress has been made through Land-Use and Climate, Identification of Robust Impacts (LUCID) modeling activities (de Noblet-Ducoudré et al. 2012) and the Coupled Model Intercomparison Project phase 5 (CMIP5) (Brovkin et al. 2013) and planned Coupled Model Intercomparison Project phase 6 (CMIP6) (Meehl et al. 2014). Without adequately considering the biogeophysical impacts of LULCC on climate, an appropriate response to the threats posed by human intervention into the climate system will not be sufficiently addressed (Lubowski et al. 2008).

Public policy plays an important role in shaping local- to national-scale land-use conversions and management practices (Miles and Kapos 2008; Pannell 2008). Global demand for food, fiber, and energy also affect national policies that drive regional LULCC (Mattison and Norris 2005) (Figs. 2 and 3). Specific examples include the global demand in beef resulted in deforestation in Australia, Brazil, and Colombia (McAlpine et al. 2009). Moreover, public policies affecting LULCC may have specific environmental or economic goals, but significant climate system consequences can occur.

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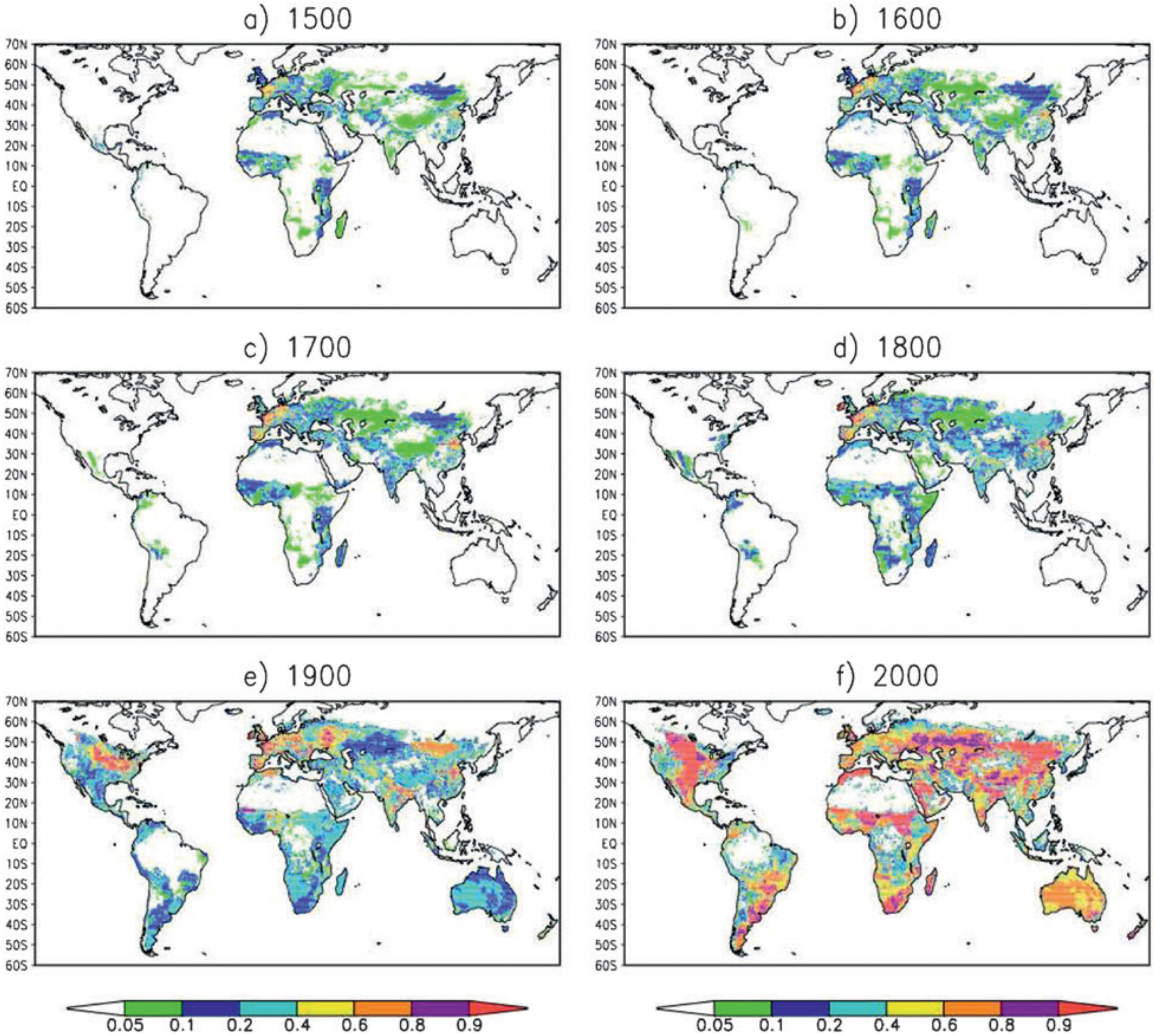

Fig. 1. LULCC during various time periods. Pastures and croplands are presented as fractions. Source of the data is http://luh.unh.edu. Refinement of the data has continued (e.g., much of central Australia is ungrazed or low-density grazing and shown as pasture). [Source: Pielke et al. (2011).]

Observational evidence confirms that policy-driven LULCC impacts convection, cloud cover, near-surface atmospheric moisture content, precipitation, temperatures, and long-term temperature trends in many parts of world, including the Amazonia, the northern Great Plains of the United States, India, and Southeast Asia (Marshall et al. 2004; Negri et al. 2004; Mahmood et al. 2006; Bonfils and Lobell 2007; Sen Roy et al. 2007, 2011; Kumagai et al. 2013). In some areas, precipitation has declined 12.7 mm yr^{-1} (Kumagai et al. 2013) and, depending on LULCC type and latitude, temperature changes were several degrees of warmer (Negri et al. 2004) or cooler (Bonfils and Lobell 2007). Observational data suggest that, in some cases, impacts of these LULCC can be felt far beyond the regions of changes (DeAngelis et al. 2010). Modeling research suggests that LULCC would modify temperature extremes (Avilla et al. 2012). Moreover, in some cases LULCC did not even deliver economic benefits (Gullison et al. 2007). It is reported that since the 1990s, 1.5 billion metric tons of carbon have been released annually to the atmosphere as a result of deforestation, which is about 20% of the total anthropogenic carbon emissions (Gullison et al. 2007).

An array of national LULCC policies, international trade, treaties, and protocols has direct effects on land use and land cover, with important biogeophysical and biogeochemical impacts on the climate system. However, these policies, agreements, and protocols are diverse and failed to adequately recognize these impacts. Here, we highlight the challenges associated with these diverse approaches and propose actions that can help to mitigate their adverse climatic impacts.

PROTOCOLS AND CHALLENGES. International protocols, such as the United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Convention to Combat Desertification (UNCCD) are well known for directly addressing the human role in the modification of the climate system. However, they only have an impact when the following actions occur: (i) donors embrace the goals and developing countries and donors work collaboratively to establish appropriate national capabilities and policies that are aligned with the treaty and (ii) developed countries define objectives in their national policies that align with the convention goals. Another challenge with these treaties and protocols is that they are typically sector specific. For example, the UNFCCC addresses emissions reductions through focused efforts on forestry and agriculture. The UNCCD addresses sustainable development in arid, semiarid, and dry subhumid areas and includes climate-specific objectives (Mattison and Norris 2005; Cowie et al. 2007).

Although not specifically focused on climate, the Convention on Biodiversity (CBD) has clear climate-connected land-use implications due to strategic goals that include a target to dramatically reduce the rate of loss of native ecosystems (Peter 2004). Plans by the 2012 United Nations Conference on Sustainable Development (Rio+20) and the CBD to restore at least 15% of degraded landscapes globally to enhance ecosystem resilience and carbon stocks do not consider biogeophysical climate processes and feedbacks. While these treaties collectively can improve land use, land-use change, and forestry (LULUCF) practices, they will only have the desired positive effects if national policies and programs are aligned with LULUCF

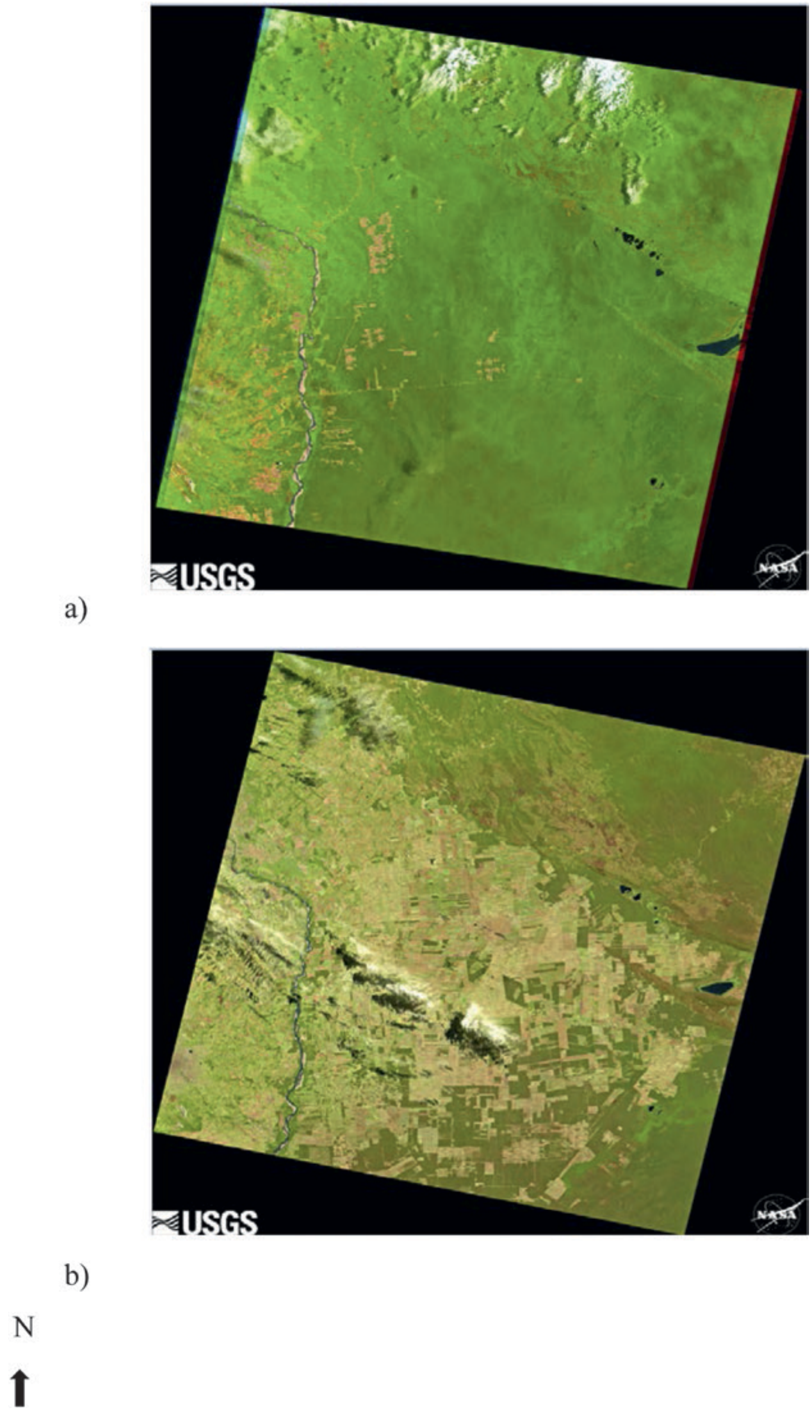

Fig. 2. LULCC in the Amazonian central Bolivia observed by Landsat satellite: (a) intact forests (green) prior to deforestation (light color) on 7 Nov 1986 and (b) after deforestation on 29 Aug 2013. Each image is 185 km × 185 km. The river on the western side of the images is the Rio Grande O Guapay, an upper tributary of the Amazon River.

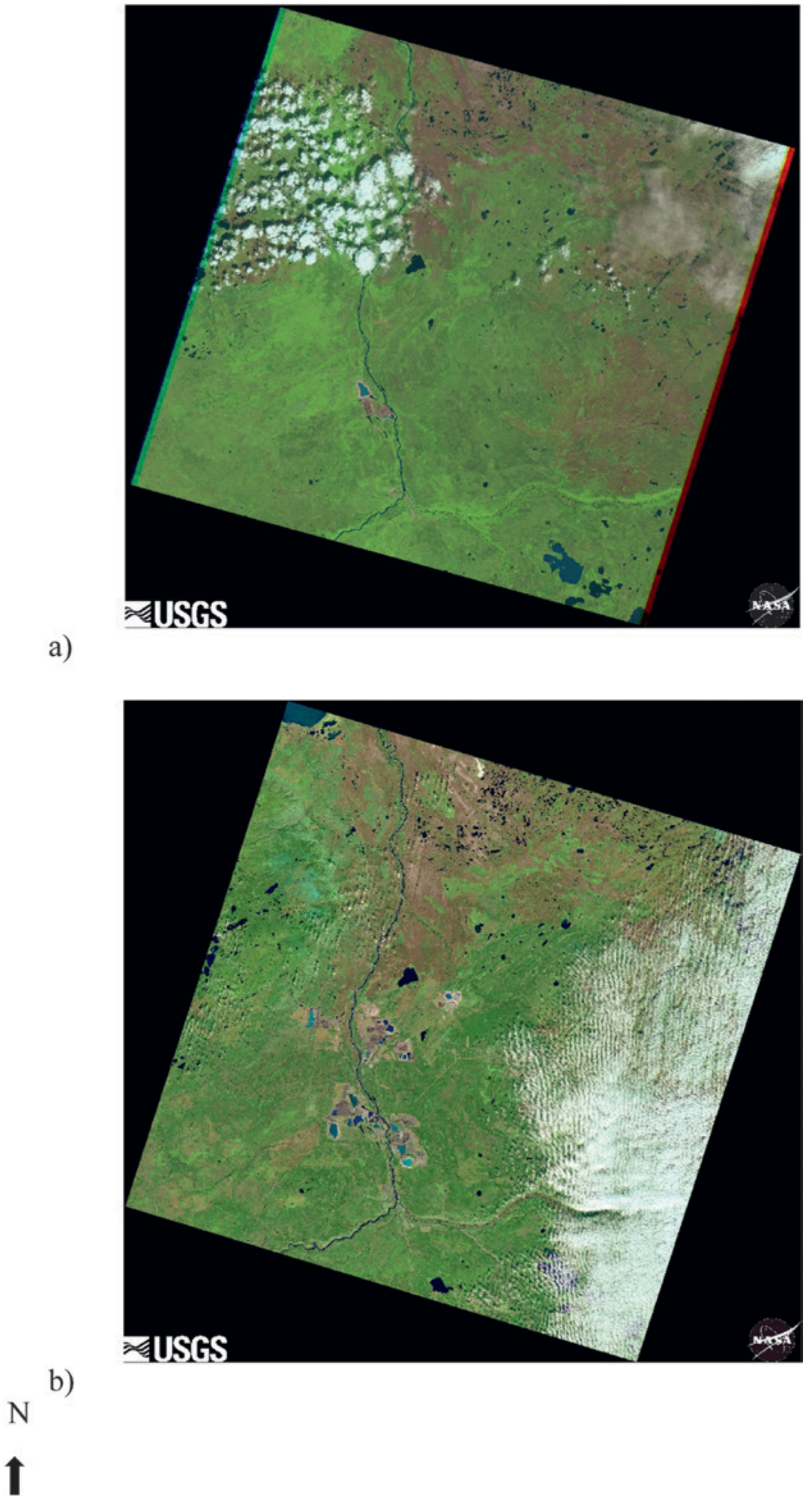

Fig. 3. LULCC in Fort McMurray, Alberta, Canada, region showing the growth of tar sands/oil and gas mining. Fort McMurray is in the bottom center of the image (on the fork of the rivers) and the mining areas are all to the north. Land-use expansion of 50 miles is due to the energy policy. The images are from (a) *Landsat-5* on 24 Jul 1984 and (b) *Landsat-8* on 28 Sep 2014. Each image is 185 km × 185 km.

objectives. Unfortunately, there is no consistency at national levels to achieve this alignment. In the United States, for example, farm, energy, and conservation policies have clear land-use implications, but the policies themselves do not necessarily embrace climate. According to a recent survey only 35 of 50 states of the United States adopted a state-level climate mitigation plan. The approaches and priorities are diverse with different LULCC and climate outcomes (Rittenhouse and Rissman 2012). Even small differences in the definition of forest by the Food and Agriculture Organization of the United Nations (FAO) and a sovereign country can result in large discrepancies in estimates of forest extent and deforestation (Romijn et al. 2013) and subsequent policy response with climate consequence.

Despite the recognition of both the biogeophysical and biogeochemical climate impacts of LULCC by the scientific community, a major weakness of international protocols is that they do not directly address biogeophysical impacts. Most protocols only focus on the reduction of carbon emissions (biogeochemical impacts) resulting from LULCC and potential adaptation and mitigation strategies. On the other hand, planned afforestation to increase carbon sequestration may inadvertently modify local and regional climate by altering surface albedo, heat, moisture, momentum, and turbulent fluxes. In other words, some of the protocols are geographic-region and time- and spatial-scale dependent. Hence, the current approach does not bring the climate impacts of LULCC to the attention of policy makers and the general public in its entirety and makes these protocols inefficient and ineffective in dealing with the biogeophysical and biogeochemical impacts of climate.

RECOMMENDATIONS. In short, these diverse national and international policies and the subsequent shaping and/or reshaping of land use and land cover complicates efforts to mitigate the LULCC impacts on climate. Hence, several key steps need to be adopted to help reduce unintended impacts of LULCC on climate. They are as follows:

1) *Translating of international treaties and protocols into national policies and actions that deliver positive climate outcomes.*

   International policies are primarily focused on forests and their role in the carbon cycle. National policies, whether government based or market driven, tend to focus on the primary resource-based economic sectors (e.g., agriculture, forestry, grazing, energy). Brazil's soy moratorium is a voluntary market-based program to curtail soy expansion on lands deforested since 2006 (Gibbs et al. 2015). The moratorium resulted in reduced deforestation in the Brazilian Amazon. This is a clear case where agricultural land-use policy aligned with Reducing Emissions from Deforestation and Forest Degradation+ (REDD+) and UNFCCC objectives with mutually beneficial results.

   The relationships between national and international policies are obviously important. As with the approval of many other international treaties or protocols (e.g., trade agreements), incentives that lead to the reduction of negative impacts of LULCC on climate and that include clear economic benefits should be identified as priority actions at the national level.

   An additional concern is the impact of changes in governing bodies on national policies. Governing changes can shift policies for better or worse LULCC and climate outcomes. For example, there is evidence that changes in majority parties in Brazil have had weakening effects on deforestation control (Rodrigues-Filho et al. 2015).

   International bodies should approach various nations through established communication channels and encourage dialogue and initiatives to address this challenge (recommendation 1). In response, national legislative bodies will need to recognize this issue and propose and approve necessary laws that would allow nations to have cohesive actions that are consistent with their priorities. This could be achieved by using existing platforms of international treaty negotiations. Individual countries will need to develop national policies to resolve this issue (translation of international treaties and protocols into national policies and actions) with consideration of their current socioeconomic environment.

   Policy implementation and its impacts can be determined by periodic assessment of the trajectory of the resulting LULCC and changes in the structure and spatial scale of the landscape (further details are provided in recommendation 3). It needs to be recognized that the biogeophysical impacts vary from region to region; for example, changes in tropical forest cover will have different climate consequences compared to changes in temperate or boreal forests. Hence, region-specific rules and actions need to be adopted.

   Developing countries may need additional help in the process of translation of treaties and protocols. International bodies such as the United Nations and linked entities or developed countries may offer help to overcome difficulties in devising workable and effective policies and their implementation so that these mismatches are removed.

2) *Updating international protocols to reflect advancement in climate–LULCC science for effective policies.*

   It is critical that international protocols stay current as new scientific knowledge of climatic impacts of LULCC comes to light [e.g., the increased recognition of biogeophysical impacts of LULCC by the Intergovernmental Panel on Climate Change (IPCC 2013)]. Increased surveillance and monitoring from ground-based measurements and satellite observations (further discussed below) can provide objective evidence of the connections between LULCC and climate (e.g., localized warming and drying). More aggressive acquisitions of high-resolution satellite imagery, for example, are resulting in more timely evidence of the impacts of land change events on both human and natural systems (Roy et al. 2014). State-of-the-art mesoscale models using more accurate representations of surface conditions (e.g., land-cover properties, topography) along with realistic scenarios can help understand the outcomes of policy options (Lawrence and Vandecar 2015). These actual and scenario-based assessments need to be communicated and subsequently translated into the national policies for effective mitigation and adaptation strategies. Again, this can be achieved by continued collaboration among various international bodies and national entities and by using established protocols and procedures.

3) *Continuing to invest in the measurement, database development, reporting, and verification activities associated with LULCC, LULCC-relevant climate monitoring, and emissions reductions linked to land-use practices.*

In this era of limited government funding for new initiatives, we need to start with leveraging current and largely successful approaches such as satellite observation of LULCC. Specifically, for example, continuation of Landsat, *Terra*, *Aqua*, Sentinel, and other similar satellite missions by various nations and space agency policies that allow free access to Earth observation data are needed for international transparency for monitoring LULCC (De Sy et al. 2012; Herold and Johns 2007). These activities should include database development and easy access to quality-assured data. Spaceborne observation and monitoring platforms could be particularly useful for developing nations where historical data may not be available (Herold et al. 2011). We recognize that processing and analysis of the data still require resources and budgetary support. However, the level of funding needed for these steps is relatively small even in an already constrained national budget. As shown in Brazil's approach to the reduction in deforestation, monitoring transparency and appropriate policies can lead to significant lowering of adverse impacts of LULCCs (Instituto Nacional de Pesquisas Especias 2013).

In addition to utilizing data from existing in situ and spaceborne climate monitoring platforms, new in situ monitoring networks need to be established in regions where rapid LULCC is currently underway. This effort could be undertaken in selected areas such as the Amazonia, Costa Rican cloud forests, Southeast Asian tropical forests, and near rapidly growing urban and agricultural areas and then expanded to other regions. This effort could consider collaborating with existing coordinated national and international efforts [e.g., Flux Network (FLUXNET; Baldocchi et al. 2001)]. Mitigation of the diverse range of effects on climate from LULCC can also begin with existing local policies and practices of land management devised for conservation efforts. For example, in the United States and China, there are certain government policies [e.g., Grain for Green Project (Fan et al. 2014)] that encourage farmers from selected regions to adopt conservation practices that may also reduce biogeophysical and biogeochemical effects on climate. Wherever needed, these policies could be further expanded so that specific emissions reduction policies can be adopted and implemented. It is also critical that the local-level implementation requires simple and straightforward policies (Höhne et al. 2007).

4) *Reducing deforestation and forest degradation in developing countries under REDD+ is an important step. However, developed countries that are not covered under this protocol need to be included.*

Again, existing international platforms can be used to initiate the discussions. Negotiation of actual individual national-level actions, to be adopted by developed countries, can begin subsequently. A major requirement underpinning the implementation of these protocols is an a priori assessment of the LULCCs that will result from their implementation. This assessment should include i) an analysis of the extent, type, and intensity of the resulting changes; ii) what are the likely biogeophysical and biogeochemical feedbacks on the climate system at different spatial scales; and iii) what are the risks and consequences for the regional environment and communities. This assessment should follow similar rigor to that applied for greenhouse gas accounting.

Another important aspect of REDD+ implementation is that all relevant parties need to be aware of potential and unintended danger of "recentralization" of forest governance (Phelps et al. 2010). This awareness is particularly critical for developing nations because many of them have spent many decades overcoming the legacy of centralized colonial and postcolonial governance in all aspects of national life. This decentralization effort is still ongoing or is in the process of taking root in governance for many of these countries. Hence, REDD+ implementation should not interfere, disrupt, or set examples that are counterproductive to decentralization efforts.

We suggest that these steps will make current national policies and international protocols and conventions more effective. This, in turn, would reduce negative climatic impacts arising from LULCC, whether planned or inadvertent.

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