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Earth System Science 2010: Global Change, Climate and People

REDD Mitigation

C. Arcidiacono-Bársony^a, P. Ciais^a, N. Viovy^a, N. Vuichard^{a*}

^aLe Laboratoire des Sciences du Climat et l'Environnement (LSCE), Centre d'Etudes Orme des Merisiers, Gif sur Yvette 91191, France

Abstract

Tropical deforestation is a major driver of climate change accounting for ~12% of global anthropogenic CO₂ emissions. A mitigation strategy named Reduction Emission from Deforestation and forest Degradation (REDD) has been developed to tackle emissions due to forest loss in developing countries. REDD will be the core instrument in any post-2012 climate agreement according to the final document of the 15th UN Conference of the Parties. Nonetheless, REDD's implementation presents several political and scientific challenges. A review of current and future deforestation estimates in terms of forest surface change, carbon densities, and carbon fluxes is under preparation to aid the scientific community. REDD mitigation potential estimates and a case study have also been examined. Preliminary results of this review are presented.

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Keywords: Carbon Cycle; Deforestation; Mitigation; REDD; Scenario

1. Introduction

Ecosystem services provided by forests are widely acknowledged. These range from providing wood resources to supporting biodiversity to regulating regional rainfall and flood defense. Land-use-change (mainly deforestation), plays a major role in determining sources and sinks of carbon [1]. According to the 4th IPCC report [2], deforestation was responsible for ~ 17% of global anthropogenic CO₂ emissions. Subsequently, this share was lowered to ~ 12% relative to the year 2008. It was also pointed out the possibility of adding emissions from peatlands that correspond to ~ 3 % of the global CO₂ emissions [3].

The loss of forests amounts to more than 13 million ha per year in tropical countries [4]. The United Nations Framework Convention for Climate Change (UNFCCC) introduced a low cost mitigation mechanism in 2007, which aims at slowing down the rate at which remaining tropical forests are

* Corresponding author. Tel.: +33-016-908 -4108.

E-mail address: cristiana.arcidiacono@lsce.ipsl.fr.

degraded and deforested in developing countries [5]. This mechanism, called REDD -Reduction Emission from Deforestation and forest Degradation- will be central in any post Kyoto climate agreement, as established by the 15th UN Conference of the Parties in Copenhagen [6]. However, the Copenhagen conference has defined no clear targets or strategies, and left several challenges. This has urged the study of various systems of financial incentives (carbon credits) to the countries for preserving tropical forests [e.g. 7, 8]. In practice, incentives will be proportional to the amount of avoided emissions related to a so-called *business-as-usual* scenario (BAU), which corresponds to the deforestation baseline in absence of a reduction target during a reference period [7].

The allocation of carbon credits requires, in turn, accurate estimates of carbon stocks preserved from deforestation and a credible baseline scenario [9, 10]. Otherwise, no real decrease in the depletion of tropical forest carbon pools will occur despite the introduction of REDD [11]. In this context, global monitoring and its improvement are stimulated to acquire consistent and accurate information on carbon stocks [12]. Satellites allow to measure the forest cover, and identify possible disturbances (e.g. fires). In addition, radar imagery and new airborne approaches, such as LiDAR (Light Detection And Ranging), could be used to estimate forest biomass carbon density over large areas and assess levels of forest degradation [13, 14]. For instance, Asner *et al.* [12, 14] recently showed the capabilities of high resolution LiDAR-based maps of canopy height, from which biomass can be inferred, as a credible method to establish forest carbon stocks in the Amazon [14].

At present, avoided deforestation and degradation can only be calculated using the rate of change in forest cover and the amount of carbon stored in the forest (the carbon density), plus the delayed emissions from soils that can be pursued long after initial forest clearing. A literature review of this information is under preparation to highlight existing gaps and uncertainties of data in the tropics. Preliminary results from this review study are presented in this paper. Firstly, current changes in forest cover areas through different methods are compared, and uncertainties discussed. Subsequently, carbon densities and land use change induced fluxes are reviewed, while particular emphasis is given to differences in mitigation potential estimates for REDD. Eventually, an attempt to estimate this potential is considered by the way of a simple idealized case study.

2. Current Deforestation and forest Degradation

2.1. Trends in Forest Area

REDD baseline scenarios depend on historical deforestation trends [15]. A study carried out by [16] reported several time series data of tropical moist forest area in 63 countries between 1973 and 2000. The author of [16] questioned the reliability of any of these data to infer a long-term trend in tropical forest area given the large uncertainties associated to each estimate. Nevertheless, it was suggested that the best available data archive of historical deforestation area for REDD could be global Landsat imagery for 1990, 2000, and 2005, complemented by coarser resolution high frequency or radar data, for most developing countries [8].

The FAO (Food and Agricultural Organization of the United Nations) provides periodic reports of forest cover area in each country based upon field data from national statistics. These are not very accurate in tropical countries, and the assistance of remote sensing might be important to adjust estimates. Recently, trends in global forest area were reported by FAO over the 1990-2010 period [4]. These results show that globally the forest loss is dominated by deforestation occurring in Latin America. This accounts in fact for around 60% of the global tropical forest area loss, mainly localized in Brazil (48% of the total). Deforestation in Asia and Africa accounts globally for 30% and 5%, respectively over the same period

1990-2010. Indonesia alone totals 13% of global forest loss. These FAO estimates are net forest area change values, which include gross area losses by deforestation and forest degradation, but also forest recovery and increasing area of re-growing tropical forest. REDD programs will require only gross deforestation data. Hansen *et al.* [17], in this respect, provided for the first time global maps of gross forest cover loss (GFCL, i.e. conversion of forest cover to any non-forest cover) from 2000 to 2005 through a globally consistent methodology using satellite imagery. In this way, comparisons of GFCL among biomes, continents, and countries are allowed. The global average GFCL rate was estimated at $0.6\% \text{ yr}^{-1}$ relative to the forest area in 2000, but the 5 yr period is short to represent a long-term trend [17].

These different sources [4, 17] carry their own uncertainties and advantages. GFCL estimates through remote sensing [17] are valuable because of the consistent application of forest definition and methodology, but are stripped by the background necessary to inform about the carbon cycle [4]. This background might be supplied by FAO statistics. However, the forest area changes inferred from statistics and remote sensed products are not directly comparable, because relying on different spatial areas and forest definitions. The absence of their correlation was seen e.g. in [18], when plotting the annual change in forest area for 41 countries in 2000-2005 [19] versus relative satellite-derived annual forest loss [20]. Furthermore, information on afforestation, reforestation, and regrowth of secondary vegetation that might help, if properly integrated, to the direct comparison of the two sources [4, 17] often are not supplied by countries national statistics.

2.2. Biomass carbon Densities

Tropical forests store more than 320 GtC [21, 22]. This partly explains that CO_2 emissions from land use change in the tropics are particularly high [21]. As discussed by Gibbs *et al.* [21], the majority of carbon in tropical forests is found in above-ground live tissues. Remote sensing could thus be used potentially to infer forest structures and above-ground biomass (AGB), e.g. in [22, 23, 24].

Nonetheless, the mapping of tropical forest carbon stocks is a very difficult task especially when high accuracy is required across large areas, and for high biomass densities at which radar signals usually saturate [14, 21]. Houghton [25] investigated the uncertainties associated to different estimates of carbon stored in the vegetation biomass in tropical and boreal forests. The author found that the average and spatial distribution of biomass are practically unknown in the tropics. It was also observed that the uncertainty of the spatial distribution of soil carbon stock data is even more uncertain than the amount of carbon in the vegetation [25]. However, the fraction of the total change in carbon stocks not included in AGB -in coarse woody debris, soils, and wood products- amounts to 10÷35% according to land-use change measurements.

The carbon density in the forest biomass can be calculated only using ground-based forest carbon measurements [26]. Plenty of data sources and methods are already available [21, 27, 28]. The work of [21], for example, reported various carbon density estimates derived from field measurements from national forest inventories. At present, albeit efforts from FAO and research networks of inventory plots, e.g the RAINFOR network [29], in expanding the compilation of field measurements, there are no high quality field biomass estimates at a sufficient spatial extent -only one-millionth measured in the tropical region- to develop and validate maps of AGB across tropical regions.

New approaches would be necessary to extend field plot networks and fill the gaps between forest inventory plot measurements and satellite observations. Novel airborne mapping methods can assist in developing carbon stock estimates in tropical forests [30]. An AGB biomass map across tropical Africa [24] represents a first initial success obtained from combining space-borne surface reflectance data in the visible and IR domains (MODIS) with several field measurements during the period 2000–2003.

Conversely, Asner *et al.* [14] combined strategically satellite data and airborne LiDAR to yield high resolution forest carbon stocks and emission in the Peruvian Amazon. At present, ESA and NASA are planning their biomass missions to measure AGB at high spatial resolution with new designed satellites [14, 23, 31, 32]. Results from these missions are expected to meet REDD requirements to develop carbon credits with less uncertainties.

2.3. Carbon Fluxes from Current Deforestation

Anthropogenic land-use changes alter the balance between the CO₂ released into the atmosphere and that absorbed by the ecosystem. The corresponding loss of carbon from land occurs with a flow that is very difficult to estimate; methods for flux estimation from land use change are detailed for instance in [28]. Land use change related flux depends on various parameters ranging from the type and fate of vegetation to the dynamics of soil carbon after clearing [33]. The different accounting of these parameters is responsible for broad differences encountered in historical reviews of net carbon fluxes from land use change [31, 33, 34]. Additionally, periodic updates of rates in deforestation by FAO through revised methodologies, yet without harmonization of data, affect deforestation CO₂ flux estimates largely, e.g. [35]. In 2008, the CO₂ emission from deforestation was ~1.2 GtC yr⁻¹, i.e. ~ 12% of total human induced emissions (updated from 17%) within the range of 6 ÷ 17% if including its uncertainty [3]. Houghton suggested that about 80% uncertainty in the estimate of carbon flux derives from a 50% uncertainty in the average biomass density [25]. The relative uncertainty is very large and hinders accuracy in establishing a baseline upon which to account for REDD carbon credits.

3. REDD Mitigation Potential

Land use change causes substantial global emissions and for 30 developing countries is the main source of CO₂ net exchange. This means that these countries might be eligible to receive UNFCC REDD incentives. However, future CO₂ emissions from land use change are very uncertain due to the lack of knowledge on future trends in tropical forest clearing, degradation rates, and the errors associated with current estimates of carbon stocks in the different compartments, and the related fluxes.

The REDD mitigation potential can be defined as the foreseen reduction in greenhouse gas emissions through the slowdown or halt of deforestation associated to the UNFCC REDD program. Figure 1 shows various estimates of REDD mitigation potential obtained using different socio-economical and biophysical models [36-41]. Their range of uncertainty (Fig. 1) depends on the socio-economic storyline chosen in the specific study.

In the work of Sathaye *et al.* [36], deforestation rates under BAU scenarios are expected to be very high in Africa and South America determining a loss of 600 million ha by the year 2050. Alternatively, the adoption of mitigation programmes via forest protection could generate global carbon gains ranging from ~ 27 to 87 GtC by 2100 as simulated by a global dynamic partial equilibrium model (GCOMAP). Soares-Filo *et al.* [37] used this spatial-explicit model in conjunction with demographic and economic databases to study carbon emissions in Amazon. They projected the disappearance of 40% Amazon forests accompanied by the release of approximately 32 ± 8 GtC to the atmosphere by 2050. The potential of avoiding emissions instead amounts to 8.0 ± 2.8 GtC by 2050.

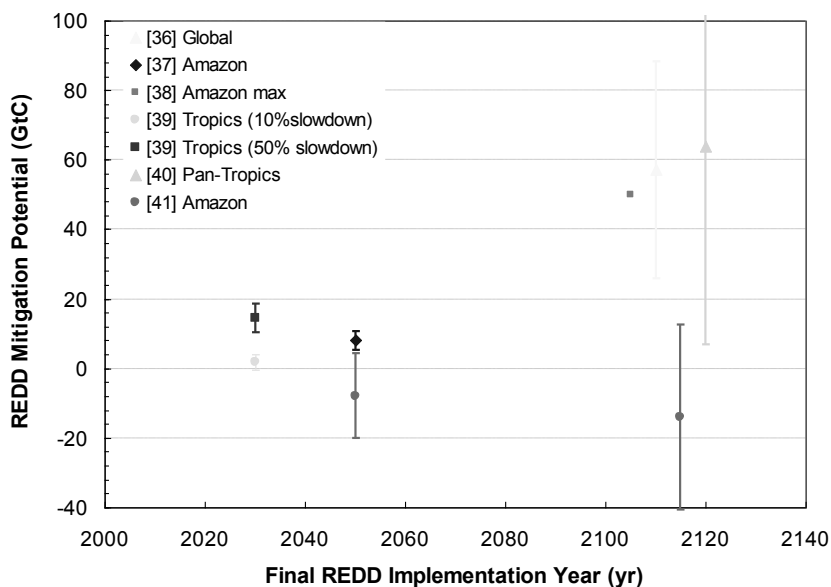


Fig. 1. Various REDD mitigation potentials without [36–39] and with [40, 41] the climate change effects included. Data from [36] spans scenarios from deforestation to no deforestation. The REDD estimates for the end of the century are shown slightly shifted for a clarity purpose.

The Lund-Potsdam-Jena dynamic global vegetation model (LPJ) allowed the simulation of forest stock variations induced by climate change in the pan-tropical region under the SRES A2 emission and climate change scenario [40]. Two extreme land use change scenarios were prescribed to the model from 2012 and 2050/2100: *intensive deforestation* and *total forest protection* (i.e. a REDD extended to every forest). The simulated carbon losses from intensive deforestation ranged from -35 to -134 GtC by the end of the 21st century. Conversely, total forest protection avoids losses that range from 7 to 121 GtC over the same period (Fig. 1). Tropical carbon stocks would be affected by climate change differently depending on the analysed region. The authors in [40] suggested that elements such as climate change, water availability, and CO_2 fertilization are the main drivers in determining carbon changes and should be fully accounted for in REDD strategies.

Following this study, interactions of climate change with deforestation and fire were investigated by [41] to establish if a positive feedback might be triggered by forest area loss. The LPJ model was used with feedbacks from deforestation and accidental fires to simulate possible changes in the carbon cycling of the Amazon Basin. It was simulated that deforestation and fire, when no CO_2 increase or climate change is accounted, release from 7 to 20 GtC by mid-century. However, the introduction of interactions between climate and CO_2 change (increasing forest dieback from drought but increasing C sinks from CO_2 fertilization) and deforestation tend to, either compensate for carbon losses (e.g. CO_2 fertilization offsets the deforestation C losses), or aggravate them (mortality induced by drought adds to deforestation C losses). Therefore, carbon stock changes might be positive or negative within the range of -20 to $+4$ GtC (Fig. 1) between the years 2012 and 2050 [41]. As shown in figure 1, the range of simulated C stock changes becomes even larger by 2100, from $+13$ to -41 GtC, according to different climate/ CO_2

projections and assumed rate of deforestation, including its interaction with fire. Overall, deforestation, fire and climate change in synergy are estimated by [41] to cause a decrease in carbon stock by 26 up to 36 GtC compared to present day values.

Busch *et al.* [7] analysed seven different REDD incentive options to assess reduction in CO₂ emissions from land use change in different regions. The resulting emissions from deforestation, with and without the REDD incentives implemented are approximately independent from the particular design option and amount to an emission saving of 1.4 ÷ 1.1 MtC yr⁻¹ worldwide, with REDD. However, these findings are strongly region dependent. Asia and Latin America show very fast reductions in emissions via REDD that amount to ~ 0.7 MtC yr⁻¹ and 0.8 MtC yr⁻¹, respectively. Gains are very small in Africa (at most 0.08 MtC yr⁻¹).

To sum up, the only work on a global level is that of Sathaye *et al.* [36], while most projections shown and discussed in this study refer to tropical countries (Fig. 1). These vary notably and present large uncertainties especially by the end of the century. The literature is not conflicting suggesting that REDD projects could introduce carbon gains when accumulated over time during the next century, and represent important mitigation opportunities. However, one risk for the full success of REDD might lie in positive feedbacks of climate change and increased fire disturbance [40, 41, 42].

3. Future Scenarios with and without REDD

3.1 IPCC Land Use Change Projections

The Intergovernmental Panel for Climate Change (IPCC) modeled emissions under a range of different scenarios, namely the SRES scenarios [433]. The possibility that any single emission path will occur as described in these scenarios remains highly uncertain. Most SRES deforestation flux scenarios storyline were optimistic. That is a fast decrease in CO₂ emissions and an increase in the net global forest cover were projected [43].

New benchmark scenarios (RCPs), labeled in terms of ultimate levels of radiative forcing, have recently been made available for the next IPCC report: 8.5 W/m² (MESSAGE model) [44]; 6.0 W/m² (AIM) [45]; 4.5 W/m² (MiniCAM) [46]; 2.6 W/m² (IMAGE) [47]. These RCPs scenarios are not climate policy prescriptive as they were chosen only to give a span of the radiative forcing and ease the mapping of various climates or pathways [48]. Nevertheless, these RCPs include a significant amount of REDD, (deforestation reduction) to reach the target radiative forcing during the 21st century.

3.2 A REDD Case Study

A simple study is presented to analyze a range of future potential REDD contributions to the abatement of CO₂ emissions. Firstly, only five countries among the seven main contributor countries to the land use change flux were considered: Brazil, Indonesia, Democratic Republic of the Congo, Nigeria, Bolivia, and Colombia. Their total forest area [19] was used as a proxy to establish CO₂ emissions as in the work of [9]. The total net forest area was assumed to decline monotonically at a fixed average historical rate of 1.2 million ha yr⁻¹ to have the baseline for REDD interventions. Finally, the total deforestation rate was arbitrarily decreased by 1%, 3%, 5%, 10%, 20%, and 50% annually after the reference post-Kyoto protocol year, 2012, to have six REDD contrasted potential implementations.

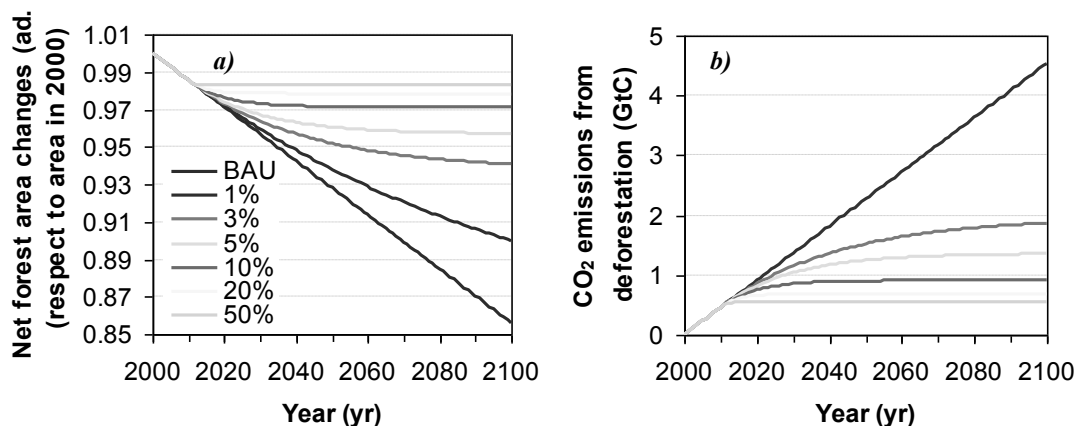


Fig. 2. (a) Scenarios of net changes in the total forest area of Brasil, Indonesia, Democratic Republic of the Congo, Nigeria, Bolivia, and Colombia: at a constant rate of deforestation (BAU), and at annual deforestation rate reductions from 2012 onwards of 1%, 3%, 5%, 10%, 20%, and 50%. (b) Corresponding CO₂ emissions for each scenario of forest cover change.

These scenarios for a range of contrasted REDD implementation rates are illustrated in figure 2(a) as net forest area changes with respect to the total forest area in 2000. Their corresponding CO₂ emissions (figure 2(b)) were calculated using the rate of change in the forest area multiplied by the average carbon density, which are supplied by [19]. It was assumed a 50% loss of the AGB carbon during deforestation to obtain the conversion factors to flux [28]. By 2100, the cumulative CO₂ deforestation emissions from these five countries is estimated to be ~5 GtC if deforestation continues as BAU. This contribution is expected to lower by 40% to ~3 GtC already at 1% slowdown, and further by 60% to ~2 GtC at 3% slowdown of the total deforestation rate. Alternatively, the annual deforestation rate reduction of 5% and 10% could abate the emission to ~1 GtC. Both 20%, and 50% deforestation slowdowns allow almost a 90% emission reduction, and result in ~0.5 GtC emission. All findings in this case study fall at the higher end of Poulter's findings [41] in § 3.

Tentatively, the above results were introduced into the medium-high global CO₂ emission scenario SRES A2 for land use [48]. SRES did not include UNFCC mitigation strategies, thus CO₂ emission reductions from REDD were considered as additional to those expected by SRES A2. Figure 3 shows a fast decrease in CO₂ emissions introducing the REDD slowdown in the annual rate of deforestation. Deforestation emissions range from 0.2 to 0.6 GtC using the six REDD options already by mid-century. Subsequently, deforestation emissions are almost offset by the end of the century.

In future, other possible sources of forest data and approaches could be used in the REDD case study. More work is necessary to consider the underlying uncertainties in current findings. This for example could be done analyzing the effect of carbon conversion into the various pools, and the inclusion of other positive/negative feedbacks.

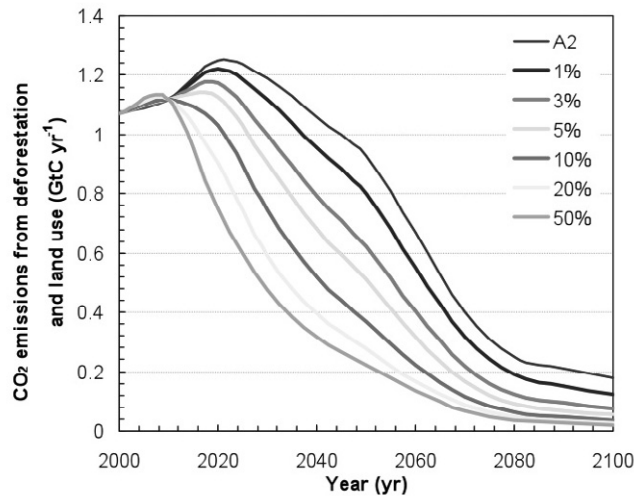


Fig. 3. Annual CO₂ emissions from land use change under the SRES A2 scenario (blue) [48]. REDD scenarios with the annual deforestation rate reduced by 1% (purple), 3% (pink), 5% (azure), 10% (red), 20% (yellow) and 50% (green) from 2012 onwards.

4. Conclusions

A novel climate mitigation strategy, REDD, is under discussion at UNFCCC to be included in the next post-Kyoto climate change agreement. The main concern for an efficient REDD mechanism is the accurate estimation of the avoided carbon reduction in tropical forests. In this respect, current and future deforestation in terms of forest surface changes, carbon densities and relative CO₂ emission estimates were studied.

The REDD related studies found in the literature show that data are still limited and have large uncertainties. This applies in particular to national historical rates of deforestation, which are important for tracing REDD country baselines. In addition, Hansen *et al.* [17] illustrated the capability of quantifying global forest cover loss through satellite observations. Regarding carbon densities, spatially extensive field biomass estimates are still needed [13, 21]. New capabilities and improved earth observation data (e.g. from LiDAR) are expected to lead, in the near future, a more complete forest change assessment than in [17], and a direct measurement of carbon changes for flux estimations [12].

The REDD mitigation potential estimated has been reviewed. This shows that different estimates of foreseen carbon saving vary notably, but have a relative positive perspective for mitigation. However, the possibility of increased fire events, and climate-induced feedbacks might counterbalance heavily the sequestration benefits from deforestation reduction as discussed in [40, 41]. Finally, a simple case has been presented to study six future REDD implementations. In this case, the forest area of five tropical countries was analysed using the approach of [9] to illustrate possible benefits (in terms of carbon flux reduction) from six contrasted deforestation rate slowdowns. It was found a fast reduction in CO₂ emissions with this approach. In future, a dynamic global vegetation model (ORCHIDEE) will be used to

investigate the uncertainties of these findings, and to estimate the permissible land use emissions for a given set of future atmospheric CO₂ stabilization targets.

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