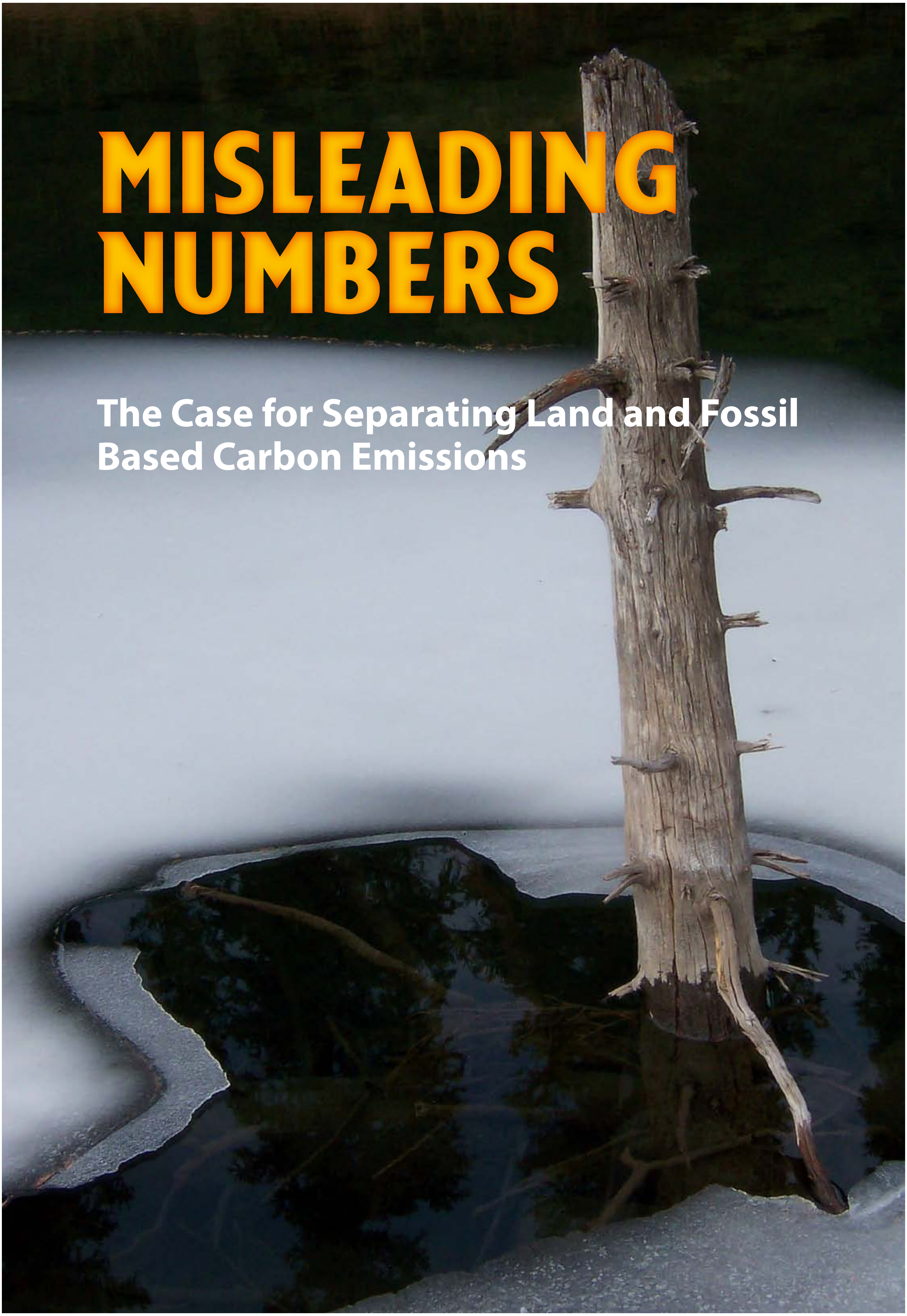
MISLEADING NUMBERS

The Case for Separating Land and Fossil Based Carbon Emissions



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ISBN: 978-1-906607-35-7

Coverphoto: Tree stump in frozen river
Photo: Mike Zebble (flickr.com)

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A publication by FERN
January 2014
www.fern.org

Acronyms

ADP	Ad-hoc working group of the Durban Platform on Enhanced Action
AFOLU	Agriculture, Forestry and Land Use
AR	Afforestation and Reforestation
CDM	Clean Development Mechanism
CIRAD	Centre for Agricultural Research for Development
EU ETS	European Union Emissions Trading System
FAO	Food and Agriculture Organisation
FRA	Forest Resource Assessment
GtC	Gigatonne Carbon
GHG	greenhouse gases
GIS	geographic information system
HWP	harvested wood products
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
LULUCF	Land Use, Land Use Change and Forestry
MODIS	Moderate Resolution Imaging Spectroradiometer
MRV	measurement, reporting and verification
NGO	non-governmental organisation
Pg C	petagramme carbon
Pg C-1	petagramme carbon changes per year
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SOC	soil organic carbon
TM	Thematic Mapper
UNFCC	United Nations Framework Convention on Climate Change
VERTIC	Verification Research, Training and Information Centre
WGBU	German Advisory Council on Global Change

Executive summary

The word 'carbon' appears with relentless ubiquity in the news and in government policy and legislation. It is discussed as if it were a simple, almost abstract and easily quantifiable substance. However, like many ubiquitous words or concepts, the term 'carbon' needs some unpicking.

There is a common assumption that different types of carbon stocks are uniform and interchangeable (fungible) within our climatic system. However, in terms of ecological impact, volume, and stability over time, the carbon released from fossil fuels is not equivalent to the carbon stored in trees, plants and soils in the terrestrial ecosystem.

Yet recent climate change mitigation schemes attempt to equate fossil carbon with terrestrial carbon, founded on the mistaken belief that the release of the former can be negated (or 'offset') by increasing (or even simply protecting) the storage potential of the latter.

Our ability to measure land use with remote aerial and satellite imaging, has improved immensely, in great part due to the demand for information to meet the requirements of climate mitigation regimes. However, as this paper shows, significant technical and budgetary limitations on our ability to measure emissions from land use remain.

Fossil fuel deposits take millions of years to form, yet modern civilisation is digging them up and burning them at an alarming rate. Photo Flickr.com / Eyeweed

To move from accurate measurement of tree cover to accurate estimation of carbon storage involves so many variables and proxies, (including estimates of soil carbon, levels of degradation, stocking rates and timber variety), that unacceptable margins of error remain.

This is due to several factors:

- Forest degradation is harder to detect than absolute loss, to the extent that recent attempts to quantify global land cover change have excluded degradation on the basis of lack of data;[1]
- Only above-ground biomass is easily monitored — most other carbon pools, such as those below ground, are ignored in carbon calculations (which generally leads to an underestimation of emissions from land use change);
- Compounding errors associated with methodology and data can lead to an overestimation of emissions;
- Inconsistencies in definitions, and methodological factors such as modelling (sampling) errors, cloud cover, interval length between mapping, and the spatial variation of above-ground carbon stocks all contribute to uncertainty in estimating emission reductions;[2]
- Significant error is introduced when extrapolating locally and regionally specific carbon data to other regions and forest types,[3] all of which contribute to estimates of emissions from land use change reporting uncertainty levels of around 50 per cent in most studies.

In short, accounting for land use carbon emissions is imprecise, costly and resource intensive, and the word 'accounting' — which implies real numbers — is misleading. In reality, terrestrial emissions and removals are estimated figures.

Currently, the belief that accounting for carbon in land is feasible means there is undue focus on emissions reductions in land. This is distracting climate policy making, away from fossil fuel emission reductions.

This does not mean that it is not important to reduce land-use change. But accepting the inherent levels of inaccuracy would widen the scope for different policy options to reduce forest loss. Improving knowledge of forest cover and loss still remains a critical element of reducing forest loss and managing forests sustainably. This paper shows that if policy makers would focus on forest loss, rather than on carbon emissions, this would translate more directly to policy incentives on the ground.

Opportunities exist, in a post-2012 climate mitigation treaty, to improve the rules and guidelines for land sector accounting. This requires that policy makers recognise the limitations in measuring land-based carbon. This would allow attention to focus on how to reduce emissions from fossil fuels whilst establishing incentives for sustainable land use.

1 Harris et al. 2012
2 Kleinn 2012; and Pelletier et al. 2011
3 Dixon et al. 1994; Spalding 2009

Introduction

Globally, greenhouse gas (GHG) emissions are continuing to grow, despite the increasing urgency of climate change, and despite repeated warnings from international institutions that the world is on the path to catastrophic climate change, with temperature increases of 4˚– 6˚C possible this century.[4] In addition to reducing fossil fuel emissions, mitigation efforts focus on emissions from land use change (largely deforestation and agriculture). This report therefore looks at the mitigation potential of the land use sector, and whether its inclusion in climate targets serves to increase levels of ambition, or whether forest and agricultural emissions in developing countries are being used by the global North to avoid or delay climate action.

Carbon pools are naturally in a state of dynamic equilibrium, maintaining a relatively steady level of atmospheric CO_2 over time. But climate change is being caused by an increase of GHG in the atmosphere, the principal gas being CO_2, caused primarily by the burning of permanent

A Center for International Forestry Research (CIFOR) study on above-ground and below-ground biomass in mangrove ecosystems in Kubu Raya, West Kalimantan, Indonesia.

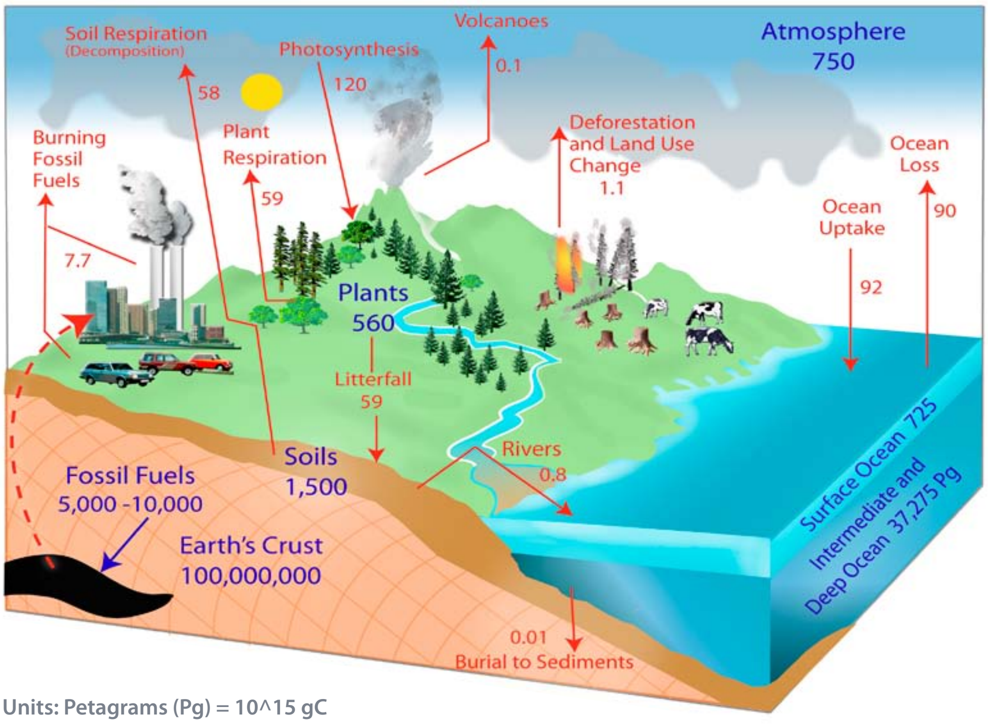
Photo by Sigit Deni Sasmito for Center for International Forestry Research (CIFOR)

4 The World Bank 2012; PwC 2012

carbon reservoirs: coal, oil and gas. Fossil fuel deposits take millions of years to form, yet modern civilisation is digging them up and burning them at an alarming rate. The world now combusts 400 years' worth of accumulated biological matter in the form of fossil fuels every year.[5] This carbon is released into the atmosphere, where it cycles between the above-ground carbon pools (land, ocean and atmosphere), disrupting the natural cycle by adding carbon to these active pools, which will not be safely locked away in underground fossil fuel reservoirs again for millennia.[6]

Land use change, through both natural causes and human impact, accounted for approximately 12 per cent of annual global CO_2 emissions over the past decade.[7] However, there are fundamental differences between 'terrestrial' and 'fossil' carbon pools and their impact on the climate. Emissions from fossil carbon are irreversible for all practical purposes as it will be millennia before fossil carbon released by human activity is removed from the terrestrial carbon cycle. Land-based carbon stocks such as forests, on the other hand, are highly reversible: their carbon is held for years or centuries at the most, and is easily returned to the atmosphere. In addition, while immense volumes of fossil carbon are held in the earth, there is a natural limit to the amount that can be held at any one time by terrestrial ecosystems.[8]

The carbon cycle shown in petagrams, designed by the GLOBE Carbon Cycle Project.



Units: Petagrams (Pg) = 10^15 gC

- Pools: PG
- Fluxes: Pg/year

Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35.313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.

5 Dukes 2003
6 From: http://globecarboncycle.unh.edu/CarbonCycleBackground.pdf
7 Van der Werf 2009; Friedlingstein 2010
8 Mackey et al. 2013

Box 1
The carbon cycle

In order to understand how carbon is cycled and how this affects atmospheric CO_2, it is necessary to understand where carbon is stored (pools), over what time scales, and the processes that transfer it from one pool to another (fluxes). Collectively, all of the major pools and fluxes of carbon on Earth comprise what we refer to as the 'global carbon cycle'. Carbon moves continually between the above-ground carbon pools: terrestrial ecosystems, the atmosphere and the oceans. Carbon pools that sequester carbon are sinks, and those which emit CO_2 are sources. Terrestrial carbon fluxes are climate-dependent and vary widely from region to region, as well as on an annual and even daily basis. The carbon balance of the terrestrial biosphere during the past half century has oscillated by more than one Gigatonne carbon (Gt C) between net carbon assimilation and dissimilation, solely due to climate variability. Sinks can turn into sources as a result of seasonal changes, where annual variability can be around 0.3 Gt C.[9] Given that terrestrial carbon stocks are by no means constant, this makes an estimation of fluxes very difficult: even slight climate changes can lead to sinks becoming sources.

Key terms related to the carbon cycle

***Terrestrial Ecosystems:* Terrestrial ecosystems contain carbon in the form of plants, animals, soils and micro-organisms (e.g. bacteria and fungi). Of these, plants and soils are by far the largest. 'Terrestrial carbon fluxes' is used to refer to the movement of carbon in or out of these ecosystems.**
***Carbon pools, stocks or reservoirs:* Carbon pool is often used interchangeably with stocks, to refer to where carbon is stored. There are three 'above ground' carbon pools: the atmosphere, the ocean and terrestrial ecosystems. Carbon is continually cycling between these carbon pools, to maintain equilibrium, and hence the land and ocean pools can be referred to as a 'buffer' rather than a stock. The only permanent stock (or reservoir) of carbon is the fossil carbon pool, where carbon is permanently stored underground.**
***Sinks:* A flux of carbon into an ecosystem is referred to as a sink.**
***Sources:* A flux of carbon out of an ecosystem is referred to as a source.**
***Fluxes:* The processes that transfer carbon from one pool to another. Carbon stocks are described in units of mass (g C), and a flux in units of mass/time (g C yr–1).**

Permafrost terraces interspersed with dwarf shrubs and sedge meadows.

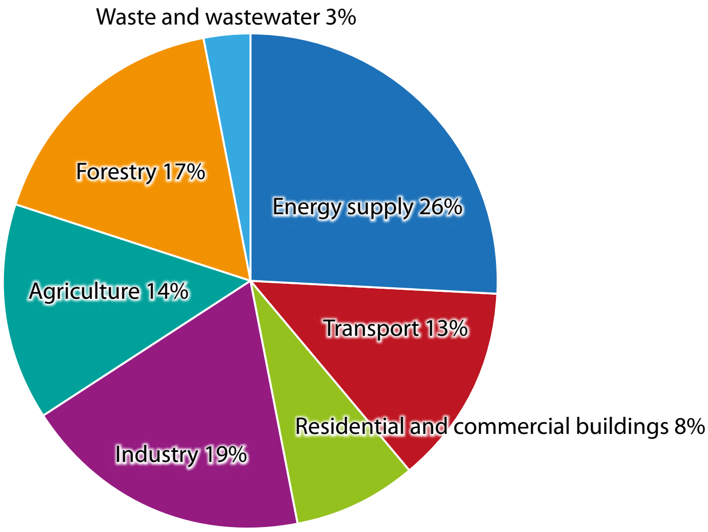
Photo: Fred Broerman / USFWSAlaska flickr.com

9 WGBU 1998

The clear danger is: if this fundamental difference between fossil and terrestrial carbon is not recognised, then carbon 'savings' from land use change may be used to justify the continued combustion of fossil fuels, substituting irreversible fossil fuel emissions with temporary terrestrial stores. The very real possibility that stored carbon will be released again after only a short time risks not a netting-off of carbon, but an increase of cumulative atmospheric GHG within a relatively short time frame.

In a paper published in *Nature Climate Change* in 2013, a global team of land carbon scientists tried to clarify the role of the land sector in the global carbon cycle. They showed that while reducing carbon loss from land use can contribute to reducing global GHG emissions, the maximum amount of this reduction is equivalent to only a small fraction of potential fossil fuel emissions, and is further limited by the natural carrying capacity of the terrestrial carbon stock.[10],[11] They explain that the carbon storage capacity of land can provide a valuable, cost-effective, short-term service in helping to reduce atmospheric CO_2, and slow the rate of anthropogenic climate change, bringing co-benefits for biodiversity and sustainable livelihoods. They also however point to strict, environmentally determined limits on the maximum amount of carbon that can be restored to land carbon stocks, and good reasons why this maximum will not be achieved (such as competing land use). They conclude that there is no effective mitigation option but to cut fossil fuel emissions deeply, and not to continue these emissions under the erroneous assumption that they can be offset in the long term by the uptake of CO_2 in land systems. Chart 1 shows the percentage of carbon that could be related to land use.

Chart 1: Global emissions by sector[12]



10 Mackey et al. 2013
11 It has been estimated that if all the carbon so far released by land use changes (mainly deforestation) could be restored through reforestation, this would reduce atmCO_2 at the end of the century by 40–70 ppm (Mackey et al. 2013). These estimates highlight the very modest scope for reforestation to reduce atmCO_2 compared with both the magnitude of fossil fuel CO_2 emissions and emissions from deforestation and degradation.
12 From: http://www.redd-monitor.org/2009/11/04/20-of-co2-emissions-from-deforestation-make-that-12/

Box 2
The limits of carbon measurement methods

It is not obvious that we can easily or usefully equate x amount of fossil carbon released with y amount of terrestrial carbon stored. But the comparison is made even harder when we examine the available methods for measuring the emissions from the two sources. Emissions from industrial processes and from the use of fossil fuels are localised and relatively stable over time. They can be estimated or measured at source and extrapolated with reasonable confidence, particularly in countries with data on energy supply and demand (i.e. most industrialised countries).[13] By contrast, terrestrial emissions are distributed over huge areas, with large inter-annual variations, making them difficult to measure and nearly impossible to extrapolate. There are serious challenges in quantifying the levels of carbon stocks in the terrestrial biosphere, in carbon fluxes, and the degree of human impact or influence over these.

The approach that the current climate change treaty (the Kyoto Protocol) takes to account for land use change and forestry activities fails to do justice to the uncertainties and differing timescales,[14] and it is unknown how the land use sector will be addressed in a new post-2015 climate treaty under the United Nations Framework Convention on Climate Change (UNFCCC).[15]

This report reviews historical and recent scientific literature on accounting for terrestrial emissions from land use change related to forests, to determine what the current claims of 'robust' and 'credible' accounting actually refer to, and to analyse the policy implications for meeting climate mitigation commitments in legislative frameworks in the European Union (EU) and the UNFCCC. Three critical elements of accounting are examined, which are combined to quantify emissions reductions and removals in the forest sector.

- Data collection and measurement – referred to as measurement, reporting and verification (MRV) in policy circles. The ability to measure forest cover, carbon density and land cover change largely determines the estimation of emissions from land use change;
- Establishment of a reference level (or base line) against which to measure change (in forest cover or emissions) as additional to the business as usual (BAU) scenario;
- How factors such as permanence (risk of reversal), leakage and uncertainty are dealt with.

Section One examines the scientific literature related to forest carbon accounting; section Two examines the current policy debate; and the conclusion analyses the implications of the scientific findings for policy discussions. The paper highlights the fundamental difference between fossil and terrestrial carbon, and concludes that reducing emissions in the land use sector cannot compensate for a lack of, or delays in, reductions in industrial emissions.

13 Schlamadinger et al. 2007
14 WGBU 1998
15 La Viña et al. 2012

SECTION ONE

Quantifying carbon

In quantifying the amount of carbon held in or released from terrestrial ecosystems, there are two key challenges: the first is the practical and financial restrictions on collecting data about land use, from the air or on-site. The second is the imperfect models by which measurements of land use are converted to estimates of carbon stocks. Although technical advances have improved accuracy, small variations in methodology still produce widely variable estimates of carbon stock and fluxes. Finally, the value of any carbon-stock estimates to the battle against climate change must be judged against the incomparability of fossil and terrestrial carbon cycles (See box 1).

Land use change is widely considered the most difficult component to quantify in the global carbon budget.[16] The underlying data is often incomplete and may not be comparable across countries or regions due to different definitions of forest cover and land uses.[17] Perhaps the greatest area of debate, however, focuses on estimates of land use change in the tropics, with Spalding noting that "much of the discrepancy in results stems from different definitions of deforestation, which are often based on canopy cover thresholds, or from variations in what is included within or excluded from tropical forests".[18]

So is it possible to quantify emissions from land use change to any meaningful degree, and to what extent has the science improved in recent decades? This section summarises the findings of a number of scientific papers over the last ten years. These papers focus on the quantification of emissions and emission reductions from forests at a global scale, or from specific tropical forested regions.

16 Canadell et al. 2007; Harris et al. 2012
17 Grainger 2008; Spalding 2009; Wagonner 2009; Westholm et al. 2009
18 Spalding 2009

Quantification of global forest carbon fluxes: discrepancies and uncertainties

Methods for determining forest carbon fluxes can be broadly divided into 'top-down' (which involve direct measurement of atmospheric carbon fluxes) and 'bottom-up' approaches (which involve a combination of remote sensing and statistical sampling).[19]

Whilst a combination of top-down and bottom-up approaches would give the most realistic estimate of terrestrial carbon stocks and fluxes over time, top-down approaches are rarely employed, as methodologies are too onerous. Thus, all the studies reviewed here reflect the overall trend found in the literature, towards combining remote sensing (satellite or airborne images) with ground truthing (sample plots).[20] However, even in combination these two methods create large margins of uncertainty. The limitations of this approach are:

Remote sensing is generally low-resolution and only available for a limited historical period: The increased availability of satellite data such as MODIS or Landsat[21] has improved access to this collection method, and these are freely available and viable for global-scale enquiry (including third party verification).[22] This type of satellite data is however, quite low in resolution, a limiting factor for producing an accurate picture of land-cover processes and associated emissions estimates.[23] High-resolution

19 Spalding 2009
20 De Fries et al. 2007; Asner et al. 2010; Hansen et al. 2010; Hajek et al. 2011; Pelletier et al. 2011
21 MODIS (Moderate-resolution Imaging Spectroradiometer) is a satellite-mounted, remote-sensing instrument, capturing earth observation imagery at 250 m, 500 m and one km resolution. The Landsat Program, launched in 1972 provides the longest continuous space-based imagery, also at a moderate resolution. The Landsat Program is jointly managed by the US Geological Survey and NASA, and Landsat data are now available free of charge. The use of moderate resolution imagery raises questions such as how to apply the widely accepted FAO definition of forests as a minimum area of 0.5ha, with on average 250m data resolution.
22 Hansen et al. 2010
23 Pelletier et al. 2011

Unlike fossil carbon, carbon in trees is released when they are damaged or die as was the case in the 2005 megadrought in the Amazon Rainforest.
Image credit: NASA/JPL-Caltech

imagery, including Lidar,[24] remains expensive to obtain and is not available over the historical time series required to set reference levels (i.e. baseline scenarios to benchmark current and future emissions).

Only part of the forest carbon is measured: Carbon stocks in forests are classified into five different measurement pools: above-ground biomass; below-ground biomass (roots); dead wood; litter (humus layers of the soil surface); and soil organic carbon ((SOC), which includes all organic material in the soil to a depth of one metre, excluding roots). Most forest inventories look only at above-ground biomass, and therefore only show a small proportion of the overall picture. However, as full ground-based inventories are exceedingly resource-intensive and time-consuming, a more varied landscape requires more sample plots to get sufficient information.[25]

A lack of comparable historical data to provide a baseline: Uncertainty about the magnitude of terrestrial carbon fluxes is widely appreciated.[26] In 2008, Grainger noted that 'present global monitoring systems'[27] are too imprecise to detect whether or not there had been a decline in tropical forest area (between 1980 and 2005), although he did note increasing accuracy in observing trends. House et al.[28] noted that the lack of historical data is a widely recognised problem; defensible atmospheric measurements began in the 1950s, but global coverage did not follow until the 1970s, and it has remained imprecise.[29] To compensate for a lack of historical data, researchers often retrospectively project inventory data by using model simulations based on current data and assumptions about biophysical, climate, and anthropogenic processes over time. If inaccurate historical estimates are then used in models to extrapolate future carbon fluxes under different

24 Lidar (airborne light detection and ranging sensors) is an aircraft-mounted remote sensing technology that measures distance using radar and light, which can achieve high-resolution 3D imaging.
25 Houghton 2003

26 WGBU 1998; Houghton 2003; Grainger 2008, 2009, 2010
27 From data in Forest Resource Assessments (FRA) between 1980 and 2005, and a time series constructed from expert assessments of tropical moist forests.
28 House et al 2003
29 Grainger 2008

management and climate scenarios, the inaccuracies are further amplified.[30]

Converting measurement of forested areas to estimates of carbon stocks is fraught with error: While certainty levels of 80 per cent or more can be achieved for distinguishing between forest and non-forest,[31] data to determine carbon stocks and fluxes are only approximate, with compound errors contributing to uncertainty levels of 50 per cent or more in many cases.[32] Hence MRV, in the context of emissions, is more about estimation than measurement. While mapping and inventory-based approaches can model land cover, land cover change and biomass density, converting this to a carbon value is only ever an approximation.[33] Land-based carbon stocks vary temporally and spatially to such an extent that statistically reliable estimation is difficult.[34] Moving from an estimation of carbon fluxes (emissions and removals) to emissions reductions further increases the uncertainty. Only by focusing on trends (longer time periods and global or regional coverage) as opposed to quantification of emissions, can this uncertainty be reduced.

> 'When it comes to terrestrial carbon stocks and fluxes, the word "accounting" is misleading. Rather than accounting, which implies real numbers, we should be talking about estimated figures.'

The rest of this section examines in greater detail the uncertainties associated with quantifying land use carbon: in measuring forest cover change; and estimating the associated emissions reductions.

Problems with mapping forest area

Quantification of global CO_2 emissions from forest loss relies primarily on the accurate mapping of forest cover and quantification of forest loss. Traditionally this has been done via the compilation of national forest inventories, although recent advances in remote sensing are augmenting the inventory approach. Forest inventories, compiled by or for the forestry sector, have traditionally been focused on the harvesting value of forests, although they now increasingly include ecosystem and social data. Such inventories are carried out by national forest institutions, with perhaps ten-year intervals between national forest surveys,[35] using aerial photography or satellite imagery. Countries with large forest areas (such as Brazil) rely primarily on satellite observation.

Due to ongoing climate policy discussions, the information produced from large-scale forest monitoring now has a potential economic value. This has caused a renewed focus on global mapping of forest cover area and carbon fluxes, as well as efforts to reduce uncertainties by using more site-specific assessments. Many of the studies reviewed showed a great confidence in monitoring capabilities and an enthusiasm to 'address key scientific challenges' in order to remove policy roadblocks.[36] In the decade prior to 2010, the lack of data was identified as a key barrier, even where the information should have been relatively straightforward, such as forest area.[37] In 2008, Grainger warned that 'at present', global monitoring systems were too imprecise to detect changes in tropical forest area convincingly, and Westholm et al.[38] acknowledged that "despite past efforts, there is still a lack of international, acceptable, consistent and accurate data on global forest change and related carbon stocks". Yet Gibbs et al.[39] concluded that "the future of REDD and related climate policies need not be constrained by technical challenges", as they predicted that satellite-based estimates of forest cover and carbon stocks would become more accessible over the next few decades.

Problems with FAO data

Several studies illustrate the extent of the discrepancies and ambiguous or conflicting information that exists in official sources, such as national inventories used for UNFCCC reporting, and data from the Food and Agriculture Organisation (FAO). A 1990 revision of FAO data on global forest cover revealed a more than 10 per cent discrepancy in forest area, while national reports and FAO-published data from six out of seven nations were inconsistent as to whether forests were expanding or in decline.[40] Government monitoring institutions are designed to produce information aligned to government needs, rather than the data needs of scientists,[41] and the FAO themselves admit that the data

30 Spalding 2009
31 Houghton 2003; De Fries at al. 2007
32 eg Kalacska et al. 2008; Sanchez-Azofeifa et al. 2009; Van der Werf 2009; Pelletier et al. 2010, 2011
33 Pelletier et al. 2010
34 Ajani et al. 2013
35 Grainger 2010
36 Gibbs et al. 2007
37 Grainger 2008; Spalding 2009; Westholm et al. 2009; Macauley and Sedjo 2010
38 Westholm et al. 2009
39 Gibbs et al. 2007
40 See Grainger 2008 and 2009
41 Grainger 2010

is 'political,' as it is supplied by and must be approved by national governments. FAO data is also out of date, due to the nature of data provision, "requiring extrapolation to bring country data to a common reference date".[42] The use of FAO statistics without questioning the reliability of the data has been widespread in the scientific community, creating a general deficiency in research on global land use change.[43] The unreliability of FAO data is now increasingly acknowledged, with researchers cautioning against the use of FAO data in measuring changes in land use.[44]

Problems with remote sensing

Many researchers argue that inconsistencies from quantifying forest cover through national forest inventories could be improved by using remote sensing.[45] Remote sensing – in combination with ground truthing – has been shown to have high levels of accuracy (80–95 per cent) in estimating deforestation (i.e. conversion of forest to non-forest).[46] However, as carbon emissions depend not only on the area of forest cover change, but also on the associated biomass loss, remote sensing techniques have resulted in great variations in emissions data, as remote sensing is limited by incomplete information and resolution and detection problems, in particular the inability to detect degradation. The FAO[47] defines degradation as reducing the biomass density, biodiversity, canopy cover or other qualitative attributes of forest, in contrast to deforestation, which is forest clearance. Nevertheless, when available at a suitable resolution and spatial scale, some contend that remote sensing can be the cheapest method of surveying forests,[48] and is increasingly being used for 'live monitoring' of deforestation in specific areas to monitor compliance with consumer certification schemes.[49].

Despite being an improvement over inventory-based FAO data, there are still significant limitations when using remote sensing. In 2009, Wagonner summarised the results of a variety of global, national and local efforts to map deforestation, finding results that varied by 100 per cent between satellite-based remote sensing and ground-based inventories, and between high- and low-resolution satellite monitoring.[50] Similar variations were found in remote-sensed values for carbon[51] and above-ground biomass.[52] Substantial errors were identified in the quantification of emissions from land cover change arising from remote-sensing-based mapping in Panama.[53] The researchers found that cloud cover and long interval times between mapping means that moderate-resolution imagery might only be available once every few years. The resulting necessity to use a mosaic of multi-year imagery compounded errors, easily resulting in an overestimation of emissions.[54]

It is well documented that very high-resolution monitoring reduces uncertainty,[55] but this comes with increasing costs and capacity requirements. Hansen et al. demonstrated that new data streams, freely available imagery and improved methods allow for operational monitoring of global forest cover change. Noting the barriers formed by coarse resolution mapping, as discussed above, Hansen's team combined coarse data for global coverage with 30 metre resolution data for sample plots. The researchers concluded that remote sensing offers a viable way to monitor forest loss at a global scale (the team found the boreal forest is the biome with the highest forest cover loss), but cannot capture significant regional variations in forest land use, natural and human-induced drivers, nor detect degradation and reforestation.[56]

Problems with estimating carbon stocks and fluxes

The transition from a measurement of forest cover to an estimate of the carbon stock it contains is not easy. Beyond the difficulties described above, of determining rates of land use change, there remain many knowledge gaps regarding carbon fluxes, the location of carbon sinks and sources, and the processes driving them.[57] Key challenges in carbon flux estimates stem from a lack of data, and the hazards of aggregating country-level data — constructed using different underlying methodologies and definitions — into one statistic.[58] In addition to forest area, several other variables are multiplied to estimate

42 FRA 1990 (FAO Forestry Paper 112)
43 Grainger 2010
44 De Fries et al. 2002 in Spalding 2009; Grainger 2008; Hansen et al. 2010; Baccini et al. 2012
45 De Fries et al. 2007; Gibbs et al. 2007
46 De Fries et al. 2007
47 FAO 1982
48 Zhang et al. 2009
49 Remote sensing and live monitoring are becoming more and more accurate. Nonetheless, it should be noted that 'accurate' could still mean anywhere between 20-50 per cent uncertainty. That may be fine for the purpose of monitoring deforestation, and company activity concerning clearing and deforestation. It is no accurate enough for quantifying emissions reductions to offset them.

50 Kalacska et al. 2008; Sanchez-Azofeifa 2009
51 Dong et al. 2003, in Waggoner 2009
52 Waggoner 2009. In both cases MODIS and Landsat TM overestimate above-ground biomass compared with US Forest Inventory Analysis (FIA).
53 Pelletier et al 2010, 2011
54 Pelletier et al. 2011 described this as the snapshot effect, which significantly constrains estimates, making it difficult to distinguish between net and gross emissions (because land cover processes cannot be tracked appropriately).
55 Asner et al. 2010; Hansen et al. 2010; Pelletier et al. 2011
56 Hansen et al. 2010
57 Spalding 2009
58 Spalding 2009

carbon stock attributes, in particular timber volume and density (biomass). In fact large-area forest monitoring systems usually cover between 100 and 250 variables,[59] and the spatial and temporal variability in carbon storage is substantial.[60]

Conversion from tree volume to carbon content is a large source of uncertainty, with Pelletier et al. finding the uncertainty in biomass conversion factors to be one of the major sources of error in estimating emission reductions.[61] When carbon is calculated by multiplying area by density, documented discrepancies (such as those in forested areas referred to above) range "up to a multi-billion ton difference in the global stock of carbon in trees".[62] For example, seven different estimates of Amazon carbon stock range from 39Pg C[63] to 93Pg C[64] – with the 54Pg C discrepancy in Amazonian rainforests alone representing approximately 16 per cent of the global carbon stock in forests. Because many variables are multiplied together to estimate an attribute like carbon stock, inaccuracies in any one will have an amplified impact on the accuracy of the end result. A 10 per cent error in biomass-per-timber volume can lever a discrepancy equivalent to millions of hectares of forest cover. Variables that are small in absolute values can have great leverage on results. It is the variables that are the most difficult or expensive to measure that, ironically, require the greatest improvement in accuracy, and "labouring to improve the certainty of the least uncertain components wastes effort, as more precise measurements of, say, accessible stands cannot remedy inaccuracies from biased sampling of regional forests".[65]

Smith gives an example of the difficulty of determining biomass found in a single forested hectare, finding a threefold difference in the Mutinondo Wilderness Area in Zambia.[66] Kleinn concurs, saying that it is not possible to produce a true value of a carbon stock on a given forest plot – not for above-ground biomass, and even less so for the other carbon pools. "These uncertainly determined values are then used for all sorts of extrapolations and for remote-based sensing regionalisation [the use of remote sensors on satellites]".[67] The Intergovernmental Panel on Climate Change (IPCC) provides guidelines on estimating emissions, using biomass default values. Methods used essentially combine measurements of changes in forest area with estimates of changes in carbon stocks, to estimate emissions from deforestation over large regions – employing biome average datasets of carbon stocks and applying 'best guesses' to combine or modify multiple biome averages.[68] An analysis of the role of forests in the global carbon budget[69] recommended that regionally specific carbon data should not be extrapolated to other regions and forest types. Nonetheless, Westholm et al. find these biome average results to be an important starting point for a country to assess the relative magnitude of forest-related emissions.[70] Ultimately, actual carbon emissions from deforestation will be determined by the biomass on a particular site. Often these biomass levels may not conform to average values, which can have a significant impact on carbon estimates, particularly in areas with high rates of deforestation and forest degradation.

Using a Panama-based example, Pelletier et al. illustrate a range of uncertainties in estimating forest carbon density and quantifying emissions from land use change. The researchers demonstrate model sensitivity for determining carbon stocks, with different allometric equations producing different results for the same input data. Using five above-ground tree carbon stock estimates they found a difference in terms of annual CO_2 emissions of more than 100 per cent between the highest and lowest estimates (due to the choice of methods for estimating biomass), finding that actual emissions reductions in developing countries could be obscured by their associated uncertainties.[71] The study showed that the combination of errors drawn from allometric equations (biomass conversion factors) and sampling can be as large as 20–50 per cent of the above-ground biomass estimate. This study was carried out for above-ground biomass only; including a range of estimates for the other carbon pools would further increase the uncertainty of the analysis.[72]

A study to determine emissions from above-ground carbon stocks in the Peruvian Amazon combined LiDAR with satellite imaging and field plots to map above-ground carbon stocks and emissions at very high resolutions (0.1ha). The researchers found that using LiDAR combined with field calibration plots delivers greater accuracy in the ability to detect a wider range of land use changes (degra-

59 Kleinn 2012
60 Asner et al. 2010
61 Pelletier et al 2010
62 Waggoner 2009
63 Pg C refers to Petagrams of Carbon, with a Pg = 10^15 grams. While Pg refers to a stock of carbon, Pg C-yr refers to a flux measured over one year.
64 Hansen et al. 2010
65 Waggoner 2009
66 Smith 2003, in Waggoner 2009
67 Kleinn 2012

68 De Fries et al. 2007; Gibbs et al. in 2007
69 Spalding 2009
70 Westholme at al. 2009
71 With a 54.5 per cent variation in the estimate of emissions from land cover change, none of the modelled scenarios (with the exception of a 50 per cent reduction in emissions) achieved reductions outside the margins of error (Pelletier et al. 2011).
72 Pelletier et al. 2010, 2011

The only permanent stock of carbon is the fossil carbon pool. Above ground carbon is liable to be released through deforestation.
Photo: Flickr.com Curt Carnemark / World Bank

dation and re-growth),[73] but a key obstacle is the high cost of the operation and the small geographic coverage. By combining airborne radar with strategic use of satellite data, they suggest this approach could be scaled up to large areas at low cost, providing high-resolution estimation of forest carbon stocks and emissions. This study found 30 per cent less in above ground biomass than would have been the case if applying IPCC default values.[74]

Discrepancies in remote sensing data are thought to be improved via plot sampling, or ground truthing. In reality, the inaccessibility of tropical forests makes it difficult to do effective ground truthing to determine if the remote-sensed value is accurate. Capacity constraints (technical and financial) are also a limiting factor to conducting field missions. Features such as cloud cover, mountains and slopes significantly limit remote sensing.[75] The main potential of remote sensing is perhaps as a validation tool and a tool for monitoring forest conversion, rather than as a tool for producing the actual estimate of above-ground biomass, particularly in the tropics, where field measurements are most needed.[76] Waggoner perhaps sums up the above discussion best when he talks about deforestation rates to be understood as estimates and not absolute truth or facts.[77] The largest point of consensus from the above literature is the need for a global monitoring programme, and improved monitoring of forests at the global and national scales.[78]

Improvements in the science?

Science has improved over recent years, with the publication of many studies employing 'state of the art' remote sensing methods to estimate the emissions from deforestation at a global scale. Yet closer inspection finds a wide discrepancy in estimates (up to threefold between studies published in consecutive years).[79] In some cases the discrepancies have been explained, in others consensus is down to coincidence. Do these studies indicate a marked

73 Asner et al. (2010) detected a 47 per cent increase in regional emissions from degradation (which was offset by an 18 per cent uptake in secondary regrowth).
74 Asner et al. 2010
75 Spalding 2009
76 Mayaux et al. 2005; Patenaude et al. 2005
77 Waggoner 2009
78 Grainger 2008; Spalding 2009; Macauley and Sedjo 2010
79 Ranging from 0.81PgC (Harris et al. 2012) to 2.8PgC (Pan et al. 2011) per year, for overlapping data periods in the early 2000s.

improvement in measuring forest carbon emissions, and are they sufficiently robust for intended policy uses?

Van der Werf et al. recalculated the initial IPCC estimates that deforestation contributes 20 per cent to annual global GHG emissions,[80] and found that in 2008 the relative contribution of CO_2 emissions from deforestation was smaller, around 12 per cent.[81] This was in part due to an increase in fossil fuel emissions, thereby reducing the proportion of emissions from deforestation, but it was also due to updated satellite-based estimations of deforestation rates,[82] as well as reductions in deforestation in the tropics.[83] This lower estimate of the contribution of forest loss to climate change has several policy implications, the most important being a reminder that "reducing fossil fuel emissions remains the key element for stabilising atmospheric CO_2 concentrations".[84] However, the uncertainty ranges in the underlying data remain large (up to 50 per cent), and emissions from peat land are not included in the estimate.

In 2012, two studies employed state-of-the-art remote sensing to estimate emissions from deforestation "with unprecedented accuracy and spatial resolution".[85] Curiously these studies, published six months apart, appeared to differ by a factor of three in their estimates of emissions from tropical deforestation, with Baccini et al. reporting 2.22 Pg C-yr over the period 2000–2010, and Harris et al. reporting 0.81 Pg C^{-yr} between 2000 and 2005 – a difference of 1.41 Pg C^{-yr} – which has been described as a "cause for concern in climate policy circles".[86] A subsequent effort to harmonise the two estimates concluded that there is in fact agreement between the two vastly different sets of results. When accounting for the same carbon pools over the same time frame (2005–2007) both research teams agreed that emissions from gross deforestation in tropical regions contributed 3.0 Gt CO_2 y (0.8 Pg C^{-yr}(+/- 0.3 Pg C^{-yr}).[87,88] Limiting data to one carbon pool may have helped to reach consensus, although it would not be unimaginable that a strong political agenda for reducing uncertainties has overruled the less convenient scientific findings.

80 In 2007, the Intergovernmental Panel on Climate Change (IPCC) came up with a 'best estimate' of net carbon emissions from tropical land use change in the 1990s of 1.6 ± 0.6 C of carbon per year. That amounts to about 20 per cent of greenhouse gas emissions from human activity during the 1990s.
81 Van der Werfe et al 2009
82 from Hansen et al. 2008 and Achard et al. 2008
83 Friedlingstein et al. 2010
84 Van der Werf et al. 2009
85 Baccini et al. 2012 and Harris et al. 2012
86 Zarin 2012
87 The 3Gt figure is equivalent to 0.8 Pg. Emissions in climate policy circles are usually expressed in Gt; but in land use policy are expressed in Pg
88 Meridian Institute 2012

Uncertainties remain

This consensus on emissions from gross deforestation (excluding soil carbon, peat and degradation), despite different underlying data sets, spatial scales and models, shows a significant evolution in accounting for emissions from deforestation. However, there are large uncertainties associated with this estimate, with Harris et al. attaching a 30 per cent margin of error, and Baccini et al. not reporting on uncertainties.[89] In addition, the omission of degradation from the Harris et al. study again highlights a significant shortfall with remote sensing techniques, when carbon stocks in degraded forests can be 70 per cent lower than background forest levels.[90] Of greatest concern, however, is the significant divergence between the two studies with regard to where emissions are occurring, with Harris et al. estimating twice the level of emissions for Sub-Saharan Africa and half the level for South and South-East Asia as Baccini et al. The Meridian policy brief concludes that "about half of our consensus is likely due to the use of similar data sets on forest area change in Brazil. The other half of our consensus is more coincidental, as it results from differences in sub-Saharan Africa and South and Southeast Asia between the two analyses that cancel each other out".[91]

While the studies discussed above show an impressive evolution in the science of monitoring global deforestation rates and associated emissions, the basic disagreement between leading global studies regarding rates of deforestation in Africa and South and South East Asia reminds us of the high level of unknowns in biological carbon flows. As Harris et al. note, "emissions from land-use change… are the most uncertain component of the global carbon cycle".[92] Recent research at national scales and discreet geographical regions continue to reveal the extent of uncertainties that remain in the quantification of emissions from land use change, and many studies exclude carbon pools other than above ground biomass and degradation as the uncertainties are so high.

Further limitations

Very few developing countries include soil carbon data or degradation in their estimates, increasing uncertainties further and leading to a probable under-reporting of emissions. Losses of soil carbon in forest conversion are significant[93] and are generally unaccounted or under-

89 Baccini et al. 2012; Harris et al. 2012
90 Asner et al. 2010
91 Meridian Institute 2012
92 Harris et al. 2012
93 Guo and Gifford 2002

accounted for in estimates of carbon emissions from land use change: even though, globally, soil organic matter contains more than three times as much carbon as either the atmosphere or terrestrial vegetation.[94] Large unknowns remain in relation to soil organic carbon fluxes which are very difficult to quantify,[95] further increasing uncertainty ranges in the estimation of emissions from deforestation. Most publications on carbon fluxes have omitted the carbon stocks in the soil, the below ground biomass (roots) and the associated flora. According to IPCC guidelines, the inventory of a conversion of forests to cropland or pasture need only consider the top 30 centimetres of the mineral soil. For most vegetation types, this is inadequate, e.g. in the case of erosion or deeper roots.[96]

The inability to detect degradation is a clear limitation of methods relying heavily on satellite-based data, without validation to reported land use change activities. This is compounded by a lack of clear definitions for degradation in terms of measurable indicators. Although research on quantifying forest degradation is ongoing, operational methods are not ready for implementation at the global scale.[97] The contribution of degradation to emissions from forest loss is significant. Estimates range from 47 per cent in the Brazilian Amazon[98] to 132 per cent in African forests.[99] Asner et al. found carbon stocks in degraded forests to be 70 per cent lower than background forest levels, yet these degraded forests would still be classified as forests.[100] Due to the difficulty of identifying and quantifying degradation, proxy approaches have been suggested to allow an estimation of degradation while using spatially explicit data.[101] While the associated uncertainty with proxy-based approaches is high, the costs remain low, representing a pragmatic approach to monitoring land use change. The matrix approach suggested by Bucki et al. uses land use change categories to identify carbon loss based on change in forest area, employing an area-based approach which focuses on activity data – facilitating identification of the agents of forest loss, rather than focusing on decreasing uncertainty levels in emissions estimations.[102]

The contribution of uncertainties from forest carbon density in the quantification of emissions from land-cover change is well known, and derives from both regional variations in forest carbon density (caused by temperature, elevation, precipitation, etc.), and errors propagated through estimation methods. Asner et al. revealed highly skewed distribution of forest carbon, using Lidar analysis, agreeing that samples of forest carbon storage obtained with field plots cannot account for spatial variation in carbon stocks.[103] Pelletier et al. categorise the major errors leading to uncertainties as inventory protocol, the conversion of tree volume to biomass, and the uncertainties in accounting for carbon pools other than above-ground carbon (dead wood and litter, soil carbon, below-ground carbon).[104] A meta-analysis by Zeigler of over 250 studies reporting above- and below-ground carbon estimates for different land use types found great uncertainty in the net total ecosystem carbon changes from different land use transitions. It concluded that knowledge of carbon changes can only be improved through extensive supplementary fieldwork, as remote sensing cannot pick up on site-specific differences, certain land use changes such as degradation, or different carbon pools (in particular soil organic carbon).[105] Ziegler et al. and Pelletier et al. conclude that more field studies are needed to provide better data of above- and below-ground carbon stocks. This would be a task for national forest research institutions by means of permanent observation plots, as exists in many developed countries, but further investment is needed in such national institutions in many forested countries.[106]

In 2013, Asner at al. used (air-borne) Lidar to create high-fidelity mapping which achieved approximately 10 per cent uncertainty levels at 1-ha resolution. Uncertainty levels increased when scaling up to nation-wide coverage, leading to persistent uncertainties about the per-hectare reliability of carbon stock monitoring (and hence reliability of carbon payments).[107]

Non-permanence

The issue of non-permanence in the context of climate mitigation in the land use sector is commonly understood as the propensity for reversal from terrestrial carbon stocks. This is caused by both human-induced and climatic factors (forest clearing, as well as the sensitivity of terrestrial carbon stocks to drought, fire and other factors). This can lead to a reversal of emissions that have previously been sequestered in land-based stocks, and accounted against a country's climate mitigation targets. There is no real parallel to this potential reversibility in emissions from

94 Schmidt et al. 2011
95 Schmidt et al. 2011; Ziegler et al. 2012
96 WGBU 1998
97 Hansen et al. 2010
98 Asner et al. 2010
99 Gaston et al. 1998
100 Asner et al. 2010
101 De Fries et al. 2007; Bucki et al. 2012
102 Bucki et al.2012

103 Asner et al.2010
104 Pelletier et al. 2010
105 Ziegler 2012
106 Ziegler 2012; Pelletier 2010, 2011
107 Asner at al. 2013

fossil fuel use where a reduction in emissions from fossil fuel use remains permanent, even if the actions causing the reduction stop (those emissions avoided are not subsequently released). Non-permanence in accounting for emissions from the land use sector is generally understood in a 100-year timeframe, yet if carbon is to be usefully stored for climate mitigation purposes, it must remain stored for geological timescales – not just 100 years, but for more than 10,000 years.[108]

However, the risk of reversal from the terrestrial carbon sink, where net sinks become net sources of GHG emissions, dwarfs the accounting uncertainties described above, due to the scale of terrestrial carbon stores (with 240–500 Pg C in living biomass alone, excluding soil and other carbon pools) see box 1.

The sensitivity of terrestrial sinks to a warming climate is a cause for great concern, with the probability for sink reversal hotly debated amongst climate scientists. In 2000 Cox et al. published a study in Nature that presented results from a fully coupled, three-dimensional carbon–climate model. The findings showed that under a 'business as usual' scenario, the terrestrial biosphere acts as an overall carbon sink until about 2050, but turns into a source thereafter, increasing the rate of global warming. A subsequent study from a team led by Cox suggested that faster plant growth due to higher concentrations of CO_2 may offset increased emissions from forest die-off in the tropics – concluding that overall forests are expected to continue to accumulate carbon.[109] However the paper did not incorporate the effects of deforestation and forest degradation, which can increase the incidence of drought, fire and tree mortality, with many studies indicating the likelihood that additional climate change would have substantial impacts on tropical forests and would reinforce their contributions to global climate change.[110] Choat et al. found that all forests worldwide are at 'equally high risk' of die-off from drought conditions, due to vulnerability to water reduction in forests from all biomes. With drought conditions increasing around the globe due to climate change and deforestation, the research suggests large swathes of the world's forests may be approaching a tipping point.[111] Other studies show higher-than-expected incidence of die-off from drought in the Amazon rainforest, with slow recovery of canopy structure and function, potentially leading to loss of carbon storage and changes in rainfall patterns.[112] In boreal forests, insect outbreaks are causing major ecosystem disturbances, which can result in large forest areas becoming sources of carbon to the atmosphere for decades, impacting on carbon stocks for up to 100 years after beetle outbreaks.[113]

On the other side of the debate, Gullison et al. published findings which projected that tropical forests would continue to act as sinks (albeit declining sinks) throughout the century.[114] Pan et al. argued that globally forest sinks are not in decline, and documented a large and persistent sink in the world's forests. However, this study found significant regional differences, with the temperate forest increasing by 17 per cent while the tropical forest sink was decreasing by 23 per cent (despite a 50 per cent decrease in carbon stocks in Canadian boreal forests in the study period due to wildfire and insect breakout). The study included 'regrowth' forests, which offset decline in carbon stocks due to deforestation.[115] The methodology however, left much room for error, with monitoring occurring only in Africa and South America, and carbon stocks assumed for South-East Asia based on the mean rate of change for Africa and South America.

A comprehensive analysis based on thirteen coupled climate–carbon cycle models found that, despite large uncertainties (e.g. around the tipping point of sinks), all models simulated a relative weakening of both the land and ocean carbon sinks in the warmer climate of the future.[116] Ultimately, the non-fungibility between fossil and terrestrial carbon consists of differences in timescales, reversibility, scale and measurement. The release of fossil carbon into the atmosphere is not reversible in any meaningful timescale. Atmospheric carbon sequestered by the biosphere is highly reversible, both from human activities, and through the impacts of climate change itself.

108 Mackey et al. 2013
109 Cox et al. 2013
110 Fearnside 2004; Davidson et al. 2011
111 Choat et al. 2012
112 Davidson et al. 2011; Asner et al. 2012; Saatchi et al. 2012; Chambers et al. 2013
113 Kurz et al. 2008; Edburg et al. 2011
114 Gullison et al. 2007
115 Pan et al. 2011
116 Friedlingstein et al. 2013

SECTION TWO

'Accounting' for land-based carbon: the policy challenge

The amount of land sector carbon accounting that is included in carbon mitigation has varied, though the trend has been to allow ever more land sector emissions into the calculations of net emissions. Although this imposes some rigour and structure upon accounting within the sector, the fundamental problems remain: it is of limited accuracy and requires a false assumption of equivalence. No international agreement has resolved these problems.

LULUCF within the Kyoto Protocol

The Kyoto Protocol (KP) was agreed at the UNFCCC Conference of the Parties (COP) 3 in Kyoto in 1997. It set quantified and legally binding commitments to limit or reduce GHG emissions. Under the Protocol, industrialised countries (Annex I) were required to reduce their emissions by at least five per cent below 1990 levels within the first commitment period (2008–2012). LULUCF is included in the KP through Article 3.3 (on afforestation, reforestation and deforestation activities), Article 3.4 (additional voluntary activities in land management) and Article 3.7 (accounting rules). Reporting to the UNFCCC via National GHG Inventories (a requirement for all countries who are a Party to the Convention) is divided into five economic sectors.[117] One of these is the land use sector, which is the only sector where GHG removals, as well as emissions, occur.[118] Accounting under the KP (as compared to reporting under the Convention) required the negotiation of a more stringent set of accounting rules. The presence of removals in the land use sector meant that different accounting rules were needed for the LULUCF sector under the KP than for other sectors, leading to increased complexity in rule-setting.

Negotiations on the inclusion of the land use sector within the KP was contentious, with many arguing that, due to accounting complexities, accounting for terrestrial sinks could become a distraction from reducing emissions from fossil fuel use. Others felt that incentives were needed to reduce deforestation, responsible for a significant amount of GHG emissions. Houghton observed that "the net annual flux of carbon between terrestrial ecosystems and the atmosphere is small, between 0 and 1.4 Pg C per year, and thus (arguably) not worth measuring or counting for the KP".[119] The small fraction of sinks compared to emissions from fossil fuel use was observed by several other researchers.[120] On the other hand, LULUCF removals could be large compared to emission reduction commitments in the first commitment period of the KP (around five per cent for most countries), with climate scientists identifying a large residual carbon uptake (2.3 Gt C/year) in the terrestrial biosphere.[121] This information had an important influence on negotiations on accounting for land use change in industrial countries. There was concern that some industrialised countries might be able to meet their Kyoto commitments solely or largely through claiming a significant portion of this residual carbon uptake within their national boundaries.[122] This would relieve them of the need to make serious efforts to reduce fossil fuel emissions, yet many countries would not agree to legally binding climate obligations until they secured agreement that biological sinks created during the calculation period could be included in the emission reduction levels assigned to each country. The German advisory body on climate change (the WGBU) noted at the time that "this approach harbours some danger", because the difficulties associated with verifying emissions from terrestrial carbon undermine the verifiability of overall reduction targets. They also noted that the need for complicated accounting methodologies leads to "the possibility for abuse".[123]

117 The five economic sectors for mitigation were defined as energy, industrial processes, waste, agriculture and land use. The 2006 guidelines have restructured this into four sectors, changing land use (LULUCF) to AFOLU with the integration of agriculture.
118 Due to biomass growth, Schlamadinger et al. 2007

119 Houghton 2001
120 Falkowski et al. 2000; Noble et al. 2001
121 Schlamadinger et al. 2007
122 Schlamadinger et al. 2007
123 WGBU 1998

The N'hambita project in Mozambique claims to be able to offset fossil carbon emissions, but there is no guarantee that trees planted will still be standing in a decade.

Kyoto Protocol Phase One. Subsequent negotiations of the rules for quantifying LULUCF emissions for the first commitment period of the KP (2008–2012) remained contentious.[124] This was in part due to the fact that overall emission reduction targets for Parties to the KP were set before LULUCF rules were agreed. LULUCF was subsequently seen as a way to offset emissions, with some Parties arguing that accounting for land use activities would require a renegotiation of targets as additional removals would decrease the efforts needed to meet the targets set under the KP. These targets were not increased to accommodate the inclusion of LULUCF, and the LULUCF rules have resulted in significant under-reporting of emissions and over-stating of removals (LULUCF loopholes) for a variety of reasons. Schlamadinger et al. described the framework for implementation of LULUCF in the first commitment period as "a negotiated solution produced by an evolving political process that had to deal with considerable scientific uncertainty",[125] and Daviet et al. listed asymmetrical accounting (accounting sequestration but not emissions) and lack of transparency (Annex 1 countries withholding reference-level data) as some of the ongoing issues in LULUCF accounting.[126] According to the United Nations Environment Programme (UNEP), the loopholes for weak LULUCF rules could amount to 0.6 Gt CO_2 annually.[127]

Kyoto Protocol Phase Two. Negotiations on LULUCF rules for the second commitment period of the KP, which were concluded at COP 17 in Durban in 2012, remain contentious. Under the Durban rules for LULUCF, mandatory accounting has been extended from deforestation to include forest management, thereby extending the scope of coverage for accounting from the land use sector. This is seen as a significant improvement: the move to mandatory accounting for forest management means that accounting for conversion of natural forests to plantation forests will be required.[128] However, many believe that the new rules do not close the fundamental 'LULUCF loopholes'. Other changes are the inclusion of harvested wood products (HWP); a minimum 'background level' of emissions before natural disturbances on managed lands can be excluded; and wetland drainage and rewetting has been included as a new voluntary activity.

124 Daviet et al. 2009
125 Schlamadinger 2007

126 Daviet et al. 2009
127 UNEP 2011
128 La Viña et al. 2012; Mackey et al. 2013

Box 4
Summary of LULUCF rules for first commitment period (2008–2012)

The Marrakesh Accords (concluded at COP 7) specified the voluntary activities that parties may elect to comply with the KP commitments during the first commitment period, together with the adoption of a clear definition of Article 3.3 and 3.4 activities and a definition of 'forest'. The Marrakesh Accords as they pertain to LULUCF establish:

Mandatory accounting

- carbon stock changes and non-CO_2 emissions between 2008 and 2012 on new forest areas (afforestation and reforestation (AR) created since 1990 or deforested (D) since 1990 (conversion of forest to non-forest));

Optional accounting

- forest management (subject to a cap in uptake);[129]
- cropland, grazing land and revegetation relative to 1990 baseline;
- afforestation and reforestation projects in non-Annex B countries agreed under the terms of the Clean Development Mechanism (CDM), up to a limit of one per cent of the Annex B countries' total emissions in 1990.

Net–net accounting

- emissions and removals during the first commitment period from cropland management, grazing land management, and revegetation are compared with emissions and removals from these activities during a previous period (base year or base period). Not used for forest management.

Gross–net accounting

- considers emissions and removals for deforestation during the commitment period only, without comparison to the emissions and removals of a previous time period (Australia managed to insert an exception into this article that allows Annex 1 parties with net emissions in 1990 from land use change and forestry to use a net–net approach, by adding land use emissions to their base year emissions, thereby diminishing the commitment to reduce energy-related emissions).[130]

Box 5
The EU and LULUCF

Inside the EU, net removals from LULUCF account for nine per cent of total GHG emissions. Partially accounted under the KP, this sector has traditionally been left out of the main EU policy frameworks for existing climate-related commitments (i.e. the EU Climate and Energy Package which sets a 20 per cent emissions reduction target by 2020) due to the recognition of serious difficulties in accounting for the emissions from this sector. In 2009, the European Council and Parliament requested the Commission to assess the options to include LULUCF in the EU's climate change commitments.[131] In 2010, an expert group on LULUCF was launched, which examined a number of potential approaches to LULUCF within the EU.

In March 2013, the EU passed its own legislation on LULUCF, which entered into force in May 2013.[132] This legislation sets out an EU-wide accounting framework for LULUCF, but does not set mitigation targets for the LULUCF sector. The accounting rules build on the Durban LULUCF rules – mandatory accounting for deforestation, afforestation/reforestation and forest management, with voluntary accounting for wetland drainage and re-wetting – but go further than the UNFCCC decision by phasing in accounting for cropland and grazing land management from 2016, with mandatory accounting for these activities from 2021.

The regulation remains separate from the main EU policy framework for implementing existing climate-related commitments, the EU ETS and the Effort Sharing Decision (ESD).[133] This means that LULUCF will not be accounted for when reporting against the EU's existing target of a 20 per cent emissions reduction by 2020. The decision does not set a target for emissions reductions in the LULUCF sector, in part due to concerns about the robustness of accounting rules at the national level (the reason that the land use sector remained outside the EU climate commitments in the first place). The European Commission (EC) will consider proposing GHG targets for agriculture and forestry sectors "once the accounting rules have proven their worth".[134]

129 Gross–net accounting for forest management under Article 3.4 was subjected to a cap equal to 15 per cent of projected removals, or three per cent of base year emissions, whichever was less.
130 WGBU 1998

131 Article 9 of Decision 406/2009/EC.
132 Decision No 529/2013/EU .http://ec.europa.eu/clima/policies/forests/lulucf/documentation_en.htm
133 The EU ETS covers about half of EU emissions and mainly covers electricity generation, heavy industry and aviation. The ESD covers the domestic and transport sectors, which are considered inappropriate for emissions trading.
134 DG Climate Action – http://ec.europa.eu/clima/policies/forests/lulucf/index_en.htm

REDD+

REDD+ was agreed at the UNFCCC as part of the 2010 Cancun Agreements, to "slow, halt and reverse forest cover and carbon loss".[135] The concept of REDD+ was first proposed to the UNFCCC in 2005, following the exclusion of avoided deforestation from the CDM due to concerns that large variations in accounting for reduced emissions from avoided deforestation would undermine the environmental integrity of the KP, given irresolvable issues of leakage, permanence and additionality. Land use activities in the CDM were restricted to afforestation/reforestation, with the issuing of temporary credits to account for non-permanence. The original proposal attracted a great deal of support, due largely to the proposal to account for avoided deforestation at the national level. National accounting negates the risk of project leakage, i.e. avoided deforestation in one area relocating to another area of the country. This does not address concerns of international leakage, however, or issues of permanence and additionally.

'Reducing emissions in the land use sector cannot compensate for a lack of reduction in industrial emissions.'

REDD+ is proposed as a performance-based mechanism where developing countries are incentivised to reduce deforestation and forest degradation, conserve forests and enhance existing forest carbon stocks. Negotiations are ongoing as to what constitutes 'results-based actions' for payments, with a divergence in opinions about whether results are defined as tons of CO_2 quantified against a reference level, or based on a broader package of social and environmental considerations. Some experts have raised concerns about the effectiveness of financial incentives for complex structural problems such as deforestation.[136]

The quantification of emissions reductions for REDD+ has three elements: the form of accounting (MRV); the use of a baseline to establish additionality; and adjustments to the baseline to reflect differences in national circumstances (adjustment factors), and as a way of dealing with permanence, leakage and uncertainty (discounting, conservative accounting).

Up until COP 19, technical discussions about MRV and reference levels have remained the major focus for REDD+ negotiators, with the level of verification (international or domestic) proving a deeply divisive issue. The debate hinged on the level of certainty required before reductions can be counted in climate mitigation targets, or offset against emissions reductions in fossil fuel use,[137] with a compromise eventually being agreed that keeps verification in line with developing country commitments under the Convention.

Establishing a meaningful baseline. Whether forest or land sector accounting could ever be credible depends very much on what is measured and what it is compared to. Measuring performance in terms of results defined as tonnes of CO_2 necessitates establishing an emissions reference level, in order to determine whether the emissions reductions differ from a business-as-usual (BAU) scenario, i.e. what future deforestation *would have occurred* in the absence of incentives from REDD+. A variety of options have been put forward for determining reference levels, from historical (based on ten-year data sets), to modelled projections to account for future variables. Economist Alain Karsenty and colleagues referred to this as "the thorny problem of the baseline", which he says remains unresolved for REDD+ as all the proposals fail to circumvent the 'counterfactual scenario' of what would have happened in the absence of the policy incentives. They concluded that no approach can reliably determine future deforestation rates, and baselines will to a large extent be politically determined, as was seen during negotiations on LULUCF.[138]

Is carbon the most useful metric to measure? As previously discussed, carbon flux is not easy to measure, and the cause of changes to fluxes cannot always easily be identified. A country might claim emission reductions based on reduced deforestation that in fact had nothing to do with their policy initiatives under REDD+ or similar incentive mechanisms — they may simply be benefiting from an unexpected 'windfall' caused by other socio-economic factors. By rewarding good luck, rather than well-constructed policy initiatives, the approach may be a disincentive to well-formulated forestry protection programmes.[139] Some suggest that a more pragmatic approach would be to circumvent the baseline issue by defining performance criteria that go beyond quantified emission reductions.[140] La Viña et al. have questioned whether REDD+ will ultimately "go the path that LULUCF

135 UNFCCC Decision 1/CP.16.
136 Karsenty et al. 2012

137 See the FERN Forest Watch Special, January 2013 for a fuller explanation of this: http://www.fern.org/doha
138 Alain Karsenty et al.2012
139 Pirard 2008
140 Karsenty et al. 2012

The most effective form of climate change mitigation is to avoid carbon emissions from all sources. Photo: Alexrk2 / Wikimedia Commons

did under the KP of entertaining drawn-out negotiations towards a strict, rules-based accounting regime".[141]

As negotiations on REDD+ continue to unfold, many governments and NGOs argue for a broader definition of performance. They suggest an approach that defines results in terms of improved policies and actions that address the drivers of forest loss,[142] rather than a narrow focus on emissions reductions as the sole determinant of performance. While some governments argue that the 'safeguards' (as agreed to at COP 16 in Cancun) will ensure that REDD+ will target environmental and social outcomes in spite of an incentive structure focused on carbon, others voice concern over the narrow carbon focus. Some suggest aligning results-based payments with other success criteria, such as the implementation of polices and measures to improve governance, respect international obligations on human and indigenous peoples' rights, and address the drivers of forest loss. They argue this would incentivise actions that most effectively reduce forest loss. Meanwhile, a growing movement of environmental and indigenous peoples' organisations, as well as governments such as Bolivia, reject the REDD+ mechanism entirely, saying it is based on the commodification of forests, rather than respect for the rights of forest peoples, and will not curb forest loss.

Accounting for LULUCF: 2020 and beyond

Negotiations on a post-Kyoto climate mitigation treaty offer an opportunity to re-assess the role of LULUCF accounting in calculating carbon emissions.

The Durban Platform on Enhanced Action (ADP) was established at COP 17 in Durban in 2011, and sets a framework for negotiating "a new protocol, another legal instrument, or an agreed outcome with legal force, applicable to all" by 2015, to enter into force by 2020. How the new agreement will strengthen the multilateral rules-based regime under the Convention — in particular how the principles of the Convention will be applied in the new agreement — is a key focus for initial discussions under the ADP. Work under the ADP has been divided into Workstream 1 (post-2020 agreement) and Workstream 2 (pre-2020 ambition).

Negotiations under the ADP present an opportunity to re-evaluate the way the land sector is accounted for, to ensure the inclusion of the land sector and forests in mitigation actions does not undermine action in other sectors. As early as 2007, Schlamadinger et al. referred to a future

141 La Viña et al. 2012
142 See, for example REDD+: An incentive structure for long-term performance, published by a group of NGOs including Rainforest Foundation Norway, FERN, ClientEarth and Greenpeace: http://www.fern.org/REDDincentive

climate agreement under the UNFCCC that will specifically refer "not only to emissions by sources but also to removals by sinks".[143] The relatively limited scope of LULUCF activities agreed to under the KP means that the non-permanence risk associated with LULUCF activities remained small.[144] The possibility of further expanding these activities in a new treaty increases the risk of mitigation targets in a new agreement becoming unverifiable, lowering ambition at exactly the time when steep declines in emissions are needed from all sectors.

The question of how land use issues will be taken up in ADP negotiations remains an open one. Some analysts have suggested that LULUCF, REDD+ and agriculture are treated coherently as one sector, although the inclusion of agriculture in mitigation efforts is particularly controversial. La Viña et al., writing about the treatment of the land sector under the ADP, suggest that a mandatory accounting system for the whole land use sector that includes emissions and removals from forest, cropland, grazing land, wetland, and peat land management "would likely ensure the highest level of environmental integrity". However, they do not evaluate the drawbacks of this, the primary ones being the potential for the inclusion of land sector emissions to make emissions reductions in fossil fuels unverifiable, and the potential risk to food security posed by the inclusion of agriculture in mitigation.[145] The role of agriculture in mitigation is currently minimal (cropland and grazing land management are included as voluntary activities under the KP). This is in part due to the large role agriculture plays in adaptation and food security, and concerns that this will be compromised if agriculture were included in mitigation.

In 2007, Schlamadinger et al. pointed out that negotiation of rules for the post-2012 commitment period opened the door to different approaches to LULUCF rules than the one adopted for the first commitment period.[146] In the same vein, current accounting rules and frameworks are one possible approach of many. How the land sector is included in the new mitigation framework will determine the level of ambition and mitigation potential under a post-2020 emissions reductions treaty, and impact on crucial issues of land-tenure security and food sovereignty for a significant part of the world's population.

Box 6
IPCC Tiers

The IPCC, in its 2003 LULUCF Good Practice Guidelines, suggests three hierarchical 'tiers' of data for emission and carbon stock change factors with increasing levels of data requirements and analytical complexity.

- **Tier 1 – IPCC default values of carbon stocks detailed per ecological zone and per continent. These values have a large uncertainty range (70 per cent) even for above-ground biomass;[147]**
- **Tier 2 – Country-specific data and forest biomass estimated at finer scales;**
- **Tier 3 – Higher spatial resolution, using numerical models and/or actual detailed field estimates with periodical measurements of changes in forest biomass on permanent plots.**

In addition to the three tiers for emissions data, the IPCC suggests three non-hierarchical 'approaches' for obtaining activity data:

- **Approach 1 – only identifying the total area for each land category;**
- **Approach 2 – tracking aggregated land use changes between categories;**
- **Approach 3 – tracking land use changes on a spatially explicit basis.**

143 Schlamadinger et al. 2007
144 Schlamadinger et al. 2007
145 La Viña et al. 2012
146 Schlamadinger 2007

147 IPCC 2006

Conclusions

Radically cutting carbon emissions is key to averting catastrophic climate change. But meaningful action is being jeopardised by confusion about the nature of the global carbon cycle and how emissions reductions are calculated. The central problem is the lumping together of two very different sources of carbon emissions, one caused by burning fossil fuels, the other originating in the terrestrial ecosystem – from carbon stored in trees, plants, soils and micro-organisms. This approach is fundamentally flawed for the following reasons:

Monitoring deforestation to any degree is costly and time consuming

Whilst monitoring deforestation via satellite data has advanced to the point that it is globally operational at low cost and it is possible to distinguish between forest and non-forest with up to 95 per cent accuracy,[148] limitations remain regarding certain topographies and regions, and data processing errors are still possible. Even in the best case scenario, it remains necessary to build capacity and institutions at the national level (in tropical forested countries in particular), to ensure forest inventories to verify satellite data.

Monitoring land sector emissions remains highly uncertain

Monitoring land use changes other than deforestation (degradation, reforestation, etc.) remains challenging, and large-scale monitoring is not possible with levels of accuracy comparable to monitoring fossil emissions. Degradation in some cases contributes to as much as half of the emissions associated with forest loss: it is also a major precursor to deforestation. Estimating emissions from land use change is based first and foremost on land use change data, which even with the most recent estimates is generally associated with levels of uncertainty of around 50 per cent. This, together with the high risk of terrestrial carbon release, significantly hampers the ability to verify emission reduction commitments if terrestrial and fossil carbon are put in the same accounting framework.

Although huge resources have been made available in recent years, and much progress has been achieved in the field of remote sensing, no overall major breakthrough has been achieved.

Focusing on emissions risks taking attention away from required policy and legal reforms

Creating an incentive mechanism reliant on quantified emissions reductions focuses attention on technical issues and MRV at the expense of addressing broader governance reforms.[149] There is broad consensus that focusing on the underlying causes of forest destruction, such as poor forest governance, disregard for ecosystems and lack of clarity around land tenure rights, is the essential first step to reducing forest loss. Incentivising these activities will require on-going support and monitoring of progress across a range of actions in order to ensure the efficient allocation of resources.

Monitoring emissions to allow participation in a performance based mechanism is costly and unfairly discriminating

Levels of uncertainty associated with tier 1 levels of reporting reduce the potential to earn money from a performance-based mechanism such as REDD+. Pelletier

148 De Fries et al. 2007; Pekkarinen et al. 2009

149 Simula 2010; Karsenty et al. 2012

Whilst energy companies are looking for more ways to find and transport energy such as this pipeline from north to south Alaska, the Wuppertal Institute are recommending that fossil fuel use and extraction is limited. Photo: Flickr.com / rodadas.net (alvaro & alicia)

et al. concluded that a country such as Panama should invest in better monitoring to increase accuracy and thereby increase income from carbon credits. Potvin et al. noted that such investments as risky if incentives are provided via a carbon market, given falling carbon prices. They estimate a cost of almost US $5 million per year for a country such as Panama to participate in REDD+ (to cover the opportunity and protection costs as well as administration and transaction costs), which is close to 25 per cent above the break-even opportunity cost alone.

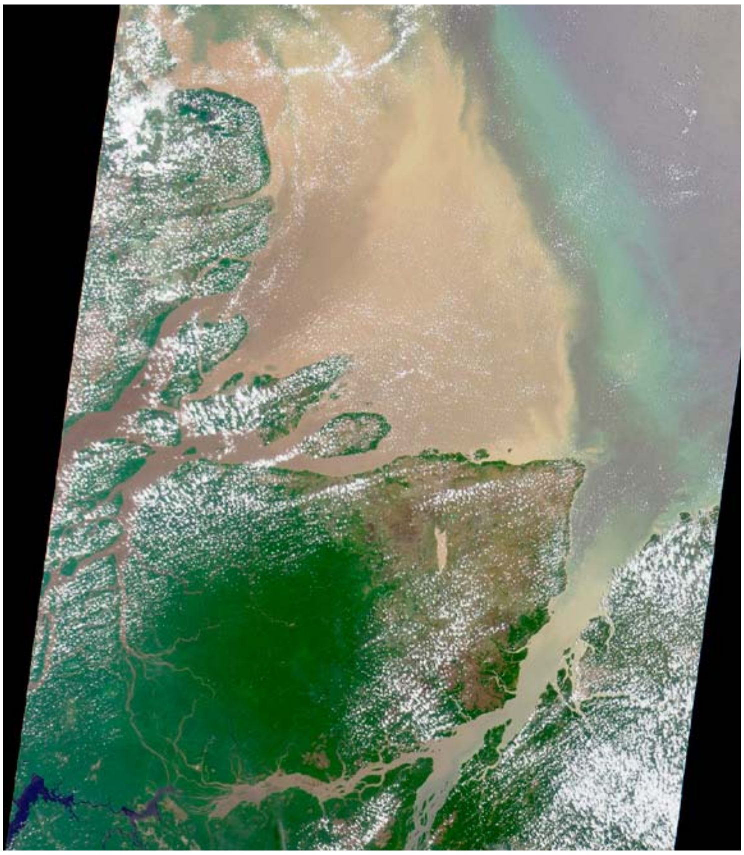
Focusing on emissions linked to drivers of deforestation rather then measuring carbon may be a more effective way to reduce forest loss

The key policy question is what level of certainty, or accuracy, in accounting is 'good enough'. Bucki et al. suggest that stringent monitoring requirements would prevent the least developed countries from accessing financial incentives from a performance mechanism such as REDD+, leading to displacement of deforestation to these areas. The authors propose developing a simpler approach to measuring emissions, which directly addresses the drivers of forest loss and degradation as a more effective way to actually reduce emissions in the near term. This simplified approach to monitoring would allow for different incentive schemes (price per hectare or per ton of carbon, baseline adjustments, biodiversity premiums, payments for ecosystem services) and should therefore be set for different contexts, to reflect the situations of individual countries and the relative benefits of reducing deforestation in terms of mitigation, adaptation, food security, poverty alleviation and biodiversity. Daviet et al. make a similar proposal in the case of LULUCF, suggesting that more information on policies and measures is needed to verify that 'credits' being claimed are real and verifiable. The authors suggest that the information on policies and measures being enacted verifies actions are taking place to address deforestation, which will likely result in a reduction in emissions.

Increasing reliance on remote sensing may lead to over-reliance on remote sensing and Northern expertise at the expense of developing capacity for national forest inventories

Developed countries rely heavily on forest inventory and management data rather than remote sensing for LULUCF accounting. Inventories of GHG emissions help countries understand where most significant land use emissions come from, and developing this at the national level (rather than relying on global assessments) improves national and local capacity, and develops country-owned data and knowledge, which in turn strengthens forestry departments and feeds into improved management decisions.[150] While the advances in remote sensing to monitor deforestation are of great value, successful forest monitoring systems need to be embedded into permanent national institutions and be accompanied by research, to build long-term capacity. Institution development within forested countries and capacity building in national forest monitoring will ultimately be more demanding than statistical analysis and image processing.

Hajek et al. observe that while recent advances in technology are one of the key enablers of REDD+, they note that the required technology and technical expertise represent a barrier to entry for actors with lower capacity, especially indigenous peoples. Increased technology to enable monitoring, therefore, does not address the need to build capacity in terms of governance of the forest resource and community forest management.



Satellite photo of the mouth of the Amazon river.
Photo: Image courtesy NASA/GSFC/JPL; MISR Team

Keeping fossil and terrestrial carbon accounting separate is fundamental to environmental integrity

Ajani et al. point out that the incorporation of the land sector into GHG inventories means fundamentally different characteristics between fossil and terrestrial carbon have been lost in aggregation, and recommend disaggregating land use carbon from fossilised carbon stocks. The WGBU warn that 'as few sinks as possible should be permitted for accounting, as each credited sink considerably hampers the verifiability of the reduction commitments.'

Schlamadinger et al.[151] suggested that a contrasting approach (to existing LULUCF rules) could utilise completely separate targets for different sectors, one for LULUCF and another (or others) for non-LULUCF emissions: "Exceeding a target in one sector need not be permitted to 'count' toward meeting the target in another sector. Equally distinct from the approach of the Kyoto Protocol would be an approach that does not require quantification of improvements in LULUCF, whether through reductions in emissions or increases in terrestrial carbon stocks. Such an approach might be entirely based on 'policies and measures'".[152]

In 2013, the Wuppertal Institute recommended what they call "a paradigm shift for international climate policy",[153] suggesting a reconsideration of the quantity-based approach that climate policy has so far been based on, as adopting quantity commitments is risky for governments as key emission drivers such as economic and population growth are largely beyond their influence. The Institute suggests that countries explore 'policy based commitments' that are more in line with what governments can actually deliver. They suggest scaling up certain climate-friendly technologies, improving energy efficiency, and limiting fossil fuel use and fossil fuel extraction as possible types of commitments.

150 Kleinn 2012
151 Schlamadinger et al 2007
152 Schlamadinger et al. 2007
153 Sterk et al. 2013

Recommendations

Focus on policies to reduce deforestation, in particular social and rights-based aspects. This would lead to more clearly verifiable and implementable results (with governments having greater control over policy development and implementation, and very little over emissions reductions).

Include forest degradation when accounting for forest loss: From a climate mitigation perspective, excluding degradation misses out a large proportion of the emissions from forest loss. Given how difficult it is to measure terrestrial emissions with a reasonable degree of certainty, simplified MRV approaches could be utilised which use spatially explicit activity data and emissions factors; proxy indicators to monitor degradation; and policies and measures to verify national efforts to address forest loss. Make the inherent uncertainties in resultant emissions estimates explicit, so that degradation and deforestation can be equally targeted.

Don't create a 'net approach' to mitigation targets: Attempting to offset energy emissions with terrestrial sequestration, lacks scientific credibility and undermines emissions reductions. Fossil fuel reservoirs are permanent compared to the temporary and cyclical nature of the terrestrial carbon pool. There is a high propensity for reversal from biotic carbon due to human activities (land use change) resulting in fragmented forest landscapes which are more vulnerable to drought, fires and insect outbreaks; and climate change is leading to global terrestrial carbon stores shifting from a net sink to a net source of emissions.

Account for industrial emissions and emissions from the land sector separately and with separate targets: This allows the development of appropriate methodologies for quantifying emissions from land use change, focused on areas of scientific progress (monitoring of deforestation) without restrictions caused by the need to provide 'fungibility' between fossil and terrestrial emissions.

Base incentives for performance-based mechanisms (such as REDD+) on simple performance indicators (i.e.: deforestation): Proxy indicators should be used for degradation and other land use change activities. Verification through policies and measures related to forest governance indicators will provide confidence that policies to reduce emissions from land use change are being designed and implemented.

There is no option but to cut fossil fuel emissions: Our final recommendation concurs with Mackey et al.'s[154] observation that while forest conservation can avoid or reduce future carbon emissions, it does not in any meaningful sense offset continuing emissions from other sources. The authors conclude that "the most effective form of climate change mitigation is to avoid carbon emissions from all sources. This means that there is no option but to cut fossil fuel emissions, and not to continue these emissions under the erroneous assumption that they can be offset in the long term by the uptake of CO_2 in land systems."

154 Mackey et al.'s 2013

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A publication by FERN
January 2014

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