Regreening and land-use: the missing piece of the climate solution

A climate policy brief, commissioned by Restore UK

CONSULTATION DRAFT

"On socio-economics, the goal is to create a regreening industry, much like the fledgling renewables sector: generating revenues and profits, creating jobs, and bringing demonstrable increases in the prosperity and quality of life of citizens and communities on the lands where regreening takes place. In parallel, it must also be fully aligned with sustainable development goals, particularly the imperatives to comply with the highest social and environmental standards."

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Executive Summary

The case for a re-assessment of land-use carbon mitigation

This policy brief makes the case for a re-assessment of the role of land-use within climate mitigation policy, which at present is assumed to comprise no more than 8-12% of carbon mitigation, with the remaining 88-92% attributed to fossil fuel emissions.

However, when IPCC and other scientific data are unpacked and presented on a gross rather than net basis, land-use is seen as potentially contributing 30% of carbon mitigation, if ambitious and focused regreening[i] efforts are prioritised and supported.

The brief signposts a range of regreening strategies, in five key areas:

- Reducing emissions in tropical, temperate and boreal regions, through measures to curb the loss and degradation of forests and other terrestrial ecosystems;
- More proactive and effective protection of global lands so as to maintain existing CO_2 sequestration;
- Increasing new CO_2 sequestration capacity ('negative emissions') through large-scale restorations, such as the recovery of degraded forests and peatlands;
- Reducing reliance on natural forests as sources of timber and wood products, by increasing the capacity and output of plantations, woodlots and other forms of sustainable tree farming;
- Sustainable intensification of agriculture (including agroforestry), in both smallholder and large-scale contexts, on already cultivated or ecologically marginal lands.

While the brief argues that regreening offers great opportunities for more mitigation, this does not imply that efforts to achieve fossil fuel emissions reductions should be reined back or reallocated. The pathways are entirely complementary, and there is no need for trade-offs between the two.

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[i] *Regreening* is a broad umbrella term to describe activities that add to the world's existing biomass. Biomass consists of trees, plants, grasses, shrubs and other woody vegetation. Regreening approaches include: *forest and other land restoration; reforestation; afforestation; natural forest, grassland and wetland ecosystem recovery and regeneration.* Regreening can also refer to a range of food and wood farming practices, notably *agroforestry* and *plantation forestry.*

The addition of biomass comprises three components: the conservation of trees and other vegetation that would otherwise be removed from a landscape; additional growth of existing biomass; and the establishment of new trees and other vegetation. A regreening strategy could therefore involve reducing logging and conversion of land to other uses, encouraging the annual incremental growth of trees and planting new biomass or allowing degraded biomass to naturally regenerate.

Policy and finance reform

In the policy and finance contexts, the overall aim is to stimulate discussion and innovative, cross-sectoral approaches on land use, through an exploration of some of the options. Within these, several priorities emerge:

- Reform of greenhouse gas accounting is called for, so that gross anthropogenic emissions, particularly from carbon, are routinely reported;
- Land-based sequestration should be recognised as a distinct mitigation category, within the suite of pathways that seek to secure 'negative emissions' (atmospheric CO_2 removals);
- The formation of a group of Annex 1 and non-Annex 1 countries to act as land-use champions within the UN system could help catalyse much-needed momentum;
- In the short term, immediate progress could be made via transparent reporting of gross land-use emissions and sequestration within Intended Nationally Determined Contributions (INDCs);
- There is a need to approach regreening finance as a form of public-private sector infrastructure investment, driven by an ambition to achieve significant results.

Part I: Land-use mitigation and climate policy

1. The neglect of land-use mitigation

Land-use has thus far been allocated a relatively minor role within climate policy, as illustrated in current INDCs.[1] This reflects a significant disconnect between science and policy, arguably driven by three factors:

- The widespread perception that 88-92% of global warming is caused by the burning of fossil fuels,[2] with only the remaining 8-12% attributed to land-use change emissions;
- The lack of attention paid to the current contribution of land-based sequestration as a 'negative emissions' pathway, as well as its potential to increase that contribution and further assist in bridging the emissions gap; and
- A tendency to very largely attribute land-use emissions to tropical deforestation and thus to overlook the importance of degradation as a source, in tropical forests and other terrestrial biomes. In turn, this has led to the widely-held assumption that land-use carbon emissions as a share of the anthropogenic total have fallen sharply in the last decade.

There is no dispute that fossil fuel combustion is a major driver of anthropogenic climate change and it therefore justifiably forms a large part of the United Nations Framework Convention on Climate Change (UNFCCC) remit. However, the role of land-use in climate mitigation has received less attention as a consequence.

When the Intergovernmental Panel on Climate Change (IPCC) and other terrestrial science data are unpacked, land-use carbon emissions are c.20-30% of the anthropogenic total, rather than the oft-quoted 8-12%. Lack of attention has also been given to the large-scale carbon sequestration services provided by land (1-3GtC of annual removals). When land-use emissions and sequestration data are combined, land-use emerges as up to 30% of the carbon mitigation solution.

Some studies suggest that the land contribution could be as much as 50% of all carbon mitigation to 2050. This would involve reduction of deforestation and degradation emissions to near zero on a global basis, as well as ambitious efforts to increase land-based sequestration via large-scale regreening. These estimates need to be interpreted with care: there may be a large gap between the theoretical and the feasible (see **point 5** below for additional analysis).

Nevertheless, the higher estimates show the latent potential, and indicate that a goal for land-use of 30% of all carbon mitigation may be conservative.

2. The distorting effects of net carbon accounting

Misperception over the relative significance of land-use carbon emissions and sequestration to some extent stems from greenhouse gas accounting rules. The Land-Use, Land-Use Change and Forestry (LULUCF) Agriculture, Forestry, and Other Land-Use AFOLU) frameworks and guidelines, which underpin reporting within the UNFCCC and its Parties, adopt the *net* principle.

This means that emissions are declared as the output of a sum: gross (or actual) anthropogenic carbon emissions *minus* sequestration equals *net emissions.* The approach has led to misperceptions on both counts.[3]

3. Under-reporting of carbon emissions from land-use

Evidence from a range of modelling exercises and field-based studies suggests that calculating *gross carbon emissions* can reveal previously unidentified or overlooked data. On this basis, the total volume of all annual anthropogenic carbon emissions is 12-13GtC, not 9-10GtC as commonly reported.[4] The 2-4GtC per annum gap is attributable to land-use, which in the net accounting context is normally reported as 0.8-1.5GtC. When expressed as percentages of all anthropogenic carbon emissions, the gross estimate for land-use is 20-30%, while the net estimate is 8-12%.

The 3-4GtC gap does not signify fundamental disagreement within climate science over data; volumes for gross and net carbon emissions are included within the IPCC's AR5 (2014-15)[5], and calibrate with the ranges given above.[6]

In a broader context, the proportion of overall anthropogenic GHG emissions attributable to land-use change is higher still, because of methane and nitrous oxide releases deriving from agriculture, although calculations are constrained by the absence of gross estimates.[7]

Toward the analysis of gross land-based emissions

The current land-use accounting system has largely focused on emissions from tropical deforestation. This has led to a lack of scrutiny of emissions arising from two other sources: tropical degradation, and releases from other terrestrial regions and systems.

In tropical forests, degradation accounts for approximately 50% of emissions,[8] where it is also often the precursor of deforestation. Degradation is also likely to be a significant component of CO_2 releases in temperate[9] and boreal[10] forests, grasslands and shrublands,[11] and croplands, biomes that also store significant levels of carbon in soils and vegetation.

In addition, emissions (from deforestation and degradation) sourced from global wetlands,[12] – especially from tropical peat swamp forests in south-east Asia[13] and mangroves[14] – form a part of the 2-4GtC gap highlighted above. The treatment of these very significant anthropogenic sources in greenhouse gas accounting is unclear: some emissions are being included (for example in the reporting of the conversion of peat swamp forest), but that is not always the case for others (e.g. from peat fires where the land has already been deforested).

Policy implications

These factors drive home the importance of full accounting: the evidence to date is that when sources are not fully quantified, the result is policy inaction. Whilst accepting that the technical difficulties are challenging, the way forward must be to work toward the reporting of gross anthropogenic carbon emissions, alongside net data, in national and international greenhouse gas accounting. Beyond disclosure, Parties to the UNFCCC should aim to embed gross emissions data in the range of calculations that underpin climate mitigation goals and actions, from INDCs to the guidance and rule-sets provided to member states, project developers, and others.

Such actions would pave the way for a fresh start on land-use emissions mitigation. Perhaps a beginning point would be to frame the vision around a holistic, global framework,[15] within which the scrutiny of emissions from forest and other land degradation would be a significant component. A valuable further step would be for the UNFCCC to commission a global study of gross carbon emissions from all land-use change.

4. Overlooked, uncounted: terrestrial carbon sequestration and storage

The current sequestration contribution to negative emissions

Sequestration of CO_2 and its conversion to carbon via photosynthesis occurs in all terrestrial systems where above-ground biomass is present. At the global level, aggregate removal volumes are significant: 1-3GtC annually.[16] When expressed as a contribution of all mitigation potential (fossil fuel emissions *plus* land-use emissions *plus* sequestration) terrestrial carbon sequestration accounts for 12-15% of the combined total.[17]

However, current net greenhouse gas accounting processes and protocols essentially treat terrestrial carbon sequestration as a deduction from emissions, not as a distinct 'negative emissions' contribution to the reduction of greenhouse gases.[18] As a result, land-based sequestration is not currently seen as a key mitigation pathway in the policy context.

In turn, this has led to a lack of scrutiny on the 'drivers of sequestration': the physical and socio-economic factors which govern where significant removals take place and how we may be able to increase them above current levels.

Sequestration in primary and secondary forests

Why has terrestrial carbon sequestration fallen to the wayside within climate policy? One response is that fears of double-counting have led to the treatment of some genuine negative emissions gains as zero. An example is the sequestration occurring in formally protected forests and other biomes (PAs), where gains can clearly be attributed to human agency.

The case for including this sequestration category within allowable mitigation is highlighted by an estimate which puts primary tropical forest sequestration (much of which occurs in protected areas) at 0.47GtC per annum.[19] This calibrates with studies which demonstrate the congruence between high carbon stocks and PAs,[20] and other research which explores the causality (more biodiversity leads to more tree diversity and productivity).[21]

These findings do not yet seem to have been incorporated within policymaking, perhaps because a view from the past may still be influencing outlooks. Several decades ago it was thought that senescent (old and mature) trees release as much (or more) CO_2 from decomposition, evaporation, transpiration and oxidation as they absorb via photosynthesis. This perspective is still sometimes heard in forest policy circles, despite a range of field-based studies pointing to significant ongoing sequestration in such trees (with one finding that a single big old tree can add the same amount of carbon to a forest within a year as is contained in an entire mid-sized tree).[22]

Another example relates to the regrowth of secondary forests on abandoned agricultural lands. This is estimated to remove 1.14GtC from the atmosphere, annually: more than double the primary forest volume.[23] While the difficulties inherent in measuring and verifying these gains are considerable, that should spur a redoubling of efforts to resolve them.

This is because the ramifications go beyond 'need to know' in the greenhouse gas accounting context. Allowing secondary forest regrowth within mitigation frameworks could pave the way for economic incentives that encourage farmers and their governments to proactively foster this intervention, where lands are no longer viable in cultivation terms. The result could be an increase in negative emissions gains.

Other sequestration challenges

At the same time, there are aspects of sequestration accounting which may require accounting conservatism. Of these, perhaps the most tendentious is CO_2 fertilisation: the observed increase in biomass growth that can be partially attributed to global warming-induced higher temperatures (but which may also be a function of planetary cycles). The science on this issue is by no means settled.[24] Other challenges include the allocation of sequestration to particular regions and countries, and variations in CO_2 absorption rates that relate to the intensity and distribution of precipitation, changes in nitrogen deposition, and the impact of particular land management practices.[25]

Implications for policy

The various challenges outlined in this preliminary overview help explain why policy formulation within the LULUCF framework has proved so arduous.[26] However, whilst precision over attribution is critical, so too is the need for a proactive rather than a reductive outlook: it is no longer sufficient to exclude sequestration from the mitigation mix. It is perhaps salutary to remind ourselves that, at its formation, the UNFCCC committed to the stabilisation of levels of dangerous greenhouse gases in the atmosphere through the use of the capacity of sinks, as well as abatement of fossil fuel sources.[27]

Storage

In addition to sequestration another important consideration is the ability of terrestrial biomes to store carbon. CO_2 is removed from the atmosphere and then stored in living biomass and soils: a natural carbon capture and storage mechanism.

The storage achieved is enormous: recent studies estimate that 247GtC of carbon reside in the above and below ground biomass of tropical forests alone.[28] This is equivalent to one third of the 692-841GtC estimated by Meinshausen *et al* to be stored in economically recoverable oil, gas and coal reserves.[29] At a global level, an IPCC report estimates that 2,477GtC is stored across all terrestrial biomes, three times higher than the upper end of the Meinshausen estimate for fossil fuel carbon stocks.[30]

The concept of 'unburnable carbon' – reservoirs of known fossil fuel reserves that must remain untouched if we are not to exceed a 2°C warming scenario – has become widespread in recent years, giving rise to a range of divestment initiatives. The data above suggests that it may be fruitful to explore options for extending the approach to encompass 'untouchable' terrestrial carbon stocks.

Assessment of the land carbon sink also needs to loop back to sequestration, because (unlike fossil fuel sinks) it is growing, for the range of reasons outlined above.[31] This synergy (protection maintains and enhances the sink) simply adds urgency to the need for far more ambition in land-use policy.

Negative emissions potential

As the concept of unburnable carbon stores has attracted attention and traction, the effort to achieve 'negative emissions' has increased in parallel. The growth of concern has been driven by a number of modelling studies which estimate that current abatement actions and commitments may not be sufficient to hold global warming to a 2ºC limit.[32] As a result, negative emissions are increasingly seen as the option that can bridge the gap.[33] The urgency of the need for action is further underlined in scenarios that set the limit at 1.5ºC, as is advocated by the Alliance of Small Island States (AOSIS).[34]

Terrestrial carbon sequestration could play a key role in this context, because past damage also presents an opportunity. Exploitation of forests, wetlands and grasslands has severely depleted land carbon stocks, across large areas: for forests alone, 4.2 billion hectares (79% of global forest cover) are in a degraded or fragmented state.[35]

Such degradation could be reversed, through reductions in extractions from natural terrestrial systems (logging, mining, charcoal, woodfuel) and allowing vegetation to recover. How much CO_2 could be removed if restoration strategies were framed at ambitious scales? One major modelling exercise (for tropical forests) estimates that a further 1.55GtC of negative emissions (in addition to current removals) is achievable on an annual basis.[36] If this were to occur alongside reductions in deforestation and degradation emissions, the contribution of tropical forests to overall carbon mitigation could at the upper level be as much as 5GtC a year, or about half of current fossil fuel emissions.

When modelling of this type is applied to all land-use, and over greater than annual time-frames, the negative emissions potential is, in theory, substantial. One study (by James Hansen *et al*) estimates land-based removals at 100GtC (from 2031-2080), equivalent to a reduction in GHG concentrations of 47ppm (parts per million),[37] an estimate that correlates with Lovejoy.[38] However, two caveats must be made. These are early estimates, which do not fully factor in the many constraints on available land, thus raising questions over feasibility; and the ranges are very wide. For example, while the upper end of an IPCC estimate (for the year 2030) is broadly in line with Hansen and Lovejoy, the lower end is not.[39]

Balancing feasibility with ambition

These estimates drive home the importance of a balanced assessment of the potential of land-based sequestration. A first step would be to initiate a range of modelling and field-based studies. More estimates (including cross-checking between them) will help build confidence, expose flaws, and (ideally) give a more precise geographical fix on where land-based sequestration could realistically provide negative emissions contributions.

Another valuable advance would be to improve the presentation and communication of data, currently far too abstruse and overly technical: these are constraints which act as barriers to greater understanding and awareness yet should in principle be resolvable.[40]

5. CCS, Bioenergy and BECCS in climate mitigation

Neglect of land-use mitigation has also led to a lack of focus on the efficacy of land-based sequestration versus biomass-based interventions. At an overall level, bioenergy is widely seen as providing two contributions: a carbon-neutral substitute for fossil fuels; [41],[42] and, in the case of Bioenergy with Carbon Capture and Storage (BECCS), a pathway for securing negative emissions.

Carbon neutrality

Assessment of the wise use of biomass to produce bioenergy for mitigation purposes is challenging, because of ongoing uncertainties over the carbon neutrality of some interventions. Some feedstocks (e.g. biogas production from crop residues, food waste, and animal waste) are clearly carbon neutral; and this may also be the case for some direct land-uses where they are implemented at small-scales (for example, jatropha and other wood-based bioenergy plantations, and biochar).

However, at the other end of the spectrum, some forms of bioenergy (particularly liquid biofuels and biomass for power generation) are, in some instances, acting as agents of deforestation and degradation, leading to greater emissions than the implied reductions achieved through fossil fuel substitution.[43],[44]

The most well documented of these is the impact of palm oil plantations on south-east Asian forests. Others may include biomass extractions from US forests, and some corn and sugarcane ethanol production (in the US and Latin America, respectively.

BECCS and negative emissions

In recent years significant interest has been shown about the pairing of bioenergy with Carbon Capture and Storage (CCS)[45] as a way to achieve negative emissions. In this hybrid model, BECCS is seen as a means to capture CO_2 emissions from bioenergy combustion and then store them.

As bioenergy is presumed to be carbon neutral, then the addition of capture and storage is seen as generating negative emissions. Negative emissions from BECCS are projected in a range of 30-204GtC by 2100 (15-95ppm).[46] However, the uncertainties over carbon neutrality outlined above (allied with issues over technical viability) call the projected negative emissions for BECCS[47] into question.

Policy implications

Two priorities emerge from this complex issue. On carbon-neutrality, more needs to be done to achieve greater certainty over efficacy, including the redoubling of efforts to disaggregate viable biofuel mitigation interventions from those which are not. For negative emissions pathways, terrestrial carbon sequestration – an already functioning 'natural technology' – may be both less expensive and more scalable.[48]

6. Land-use mitigation: the roles of agriculture and soils

This policy brief largely concentrates on carbon emissions and terrestrial carbon sequestration resulting from land-use change. However, this is only one component of overall land-use mitigation. Agricultural land-use – crop and livestock production - is both a major source (emitter of greenhouse gases) and a sink (sequestration agent).[49] Soils also play a critical role, within and outside of agriculture.[50]

Assessing the mitigation contribution of agriculture is challenging, for a range of reasons. As in non-agricultural lands, carbon and carbon dioxide are contributors; but significant levels of methane (from ruminant digestion, storage of manure, and rice production) and nitrous oxide (from fertilisers and soils) are also emitted.[51] These gases have very different properties, dynamics and global warming impacts, leading to the need for care in comparative analysis. Whilst the convention of converting all greenhouse gases to 'carbon dioxide equivalent (CO_2e)' is valuable, it can also be misleading.[52]

In parallel, there are attributional difficulties because greenhouse gas releases from certain agricultural activities (e.g. methane from ruminant digestion, and emissions from fertilisers) are classed as indirect or secondary to land-use and may fall under other mitigation headings (and the attribution to one or the other is not always clear).[53]

Soil mitigation assessment is equally complex, because different agricultural and other land-use management regimes can either preserve soil carbon and nitrogen stores, or lead to their conversion to greenhouse gases.[54]

Despite these hurdles, attempts to arrive at more holistic policy and practice are essential, as it is clear that the different sources are often interlinked. For example, livestock farming for beef is a major driver of CO_2 emissions from tropical deforestation,[55] but it is also a significant emitter of methane and nitrous oxide. A decision to expand cattle ranching into forested areas will therefore produce additional emissions of all three gases.

The need for an integrated approach is also clear in the overall greenhouse gas accounting context. At present, data on methane and nitrous oxide emissions are as fragmented and incomplete as those for land-based CO_2.

7. The way forward for land-use carbon mitigation

The science outlined above sends a powerful signal: land-use mitigation could be a much more significant component of the climate solution than is generally understood. The current default view (that carbon emissions are 88-92% attributable to fossil fuel burning, and only 8-12% to land-use) is misleading and detracts from the need for a clear focus and prioritisation of all available pathways that can produce effective results. Several priorities for next steps might be as follows:

Agreeing a land-use mitigation target. At present, a target figure of 30% of all carbon mitigation (the aggregate of efforts to reduce emissions from deforestation, forest and other land degradation, and the safeguarding of existing sequestration) seems to be attracting broad support, and for the present provides a clear goal.[56]

Reforming greenhouse gas accounting. Current greenhouse gas accounting practices have distorted perspectives, as a result of the focus on net reporting. A first step toward reform could be the redesign of INDCs,[57] based on gross accounting, so as to bring more clarity to current summaries and commitments.

Recognising land challenges and opportunities. As explored in Part II, the production of abatement and negative emissions gains from land-use is not primarily constrained by production factors, because forests and other systems are largely self-operating (and proven) natural technologies. By contrast, progress on fossil fuel mitigation is often seen as held back by technical limitations (e.g. improving energy storage and transmission).

However, land-use mitigation does require large areas of land to produce results – and in many cases, the ecosystems producing mitigation are themselves increasingly under threat. The resulting competition for land is at its most acute in developing countries in the tropics, for a range of reasons. These include the sourcing of food, fibres, metals and energy for consumption in developed countries, in-country requirements for the same products, and the construction of settlements and transportation and other infrastructure. The way forward must be based on the balancing of these competing demands, highlighting the need for clarity over objectives, and careful scrutiny of the impacts and outcomes of interventions.

Rebalancing without diminution of effort on fossil fuel mitigation. Land-use mitigation has suffered in the past because of fears that greater efforts in this area could detract from the essential task of sharply reducing fossil fuel emissions and transitioning to clean energy. Now that there is greater understanding of the importance of land-use mitigation that perspective is called into question. Equally, a new prioritisation of land-use should not imply any diminution of effort on fossil fuel mitigation.[58]

Confidence and ambition. It is striking that other at-scale mitigation opportunities (solar, wind, geothermal) are increasingly gaining traction, drawing on support from governments, the private sector, civil society, and the global public. Many of the successes achieved to date (for example, the quarter of electricity now generated in Germany from renewables) would have been inconceivable even a decade ago. These pioneering efforts create hope in a climate safe future, and should spur us to treat the land-use opportunity with the same degree of belief and ambition.

Part II: Terrestrial ecosystem science and land-use policy

1. A golden era of terrestrial ecosystem science

Since 2000, a remarkable burst of new biophysical and ecological science has expanded our understanding of terrestrial ecosystems, shedding light on how they function, and on where, how and why human actions are beneficial or harmful. From the land-use policy perspective, three areas where significant progress has been made are of particular relevance:

- *Carbon, nitrogen, and water*. The dynamics and volumes of terrestrial biomass carbon and nitrogen[59] storage and processes, sequestration, and emissions from degradation as well as complete conversion. There have been many advances in the understanding of the range of water services[60] provided by forests and other land systems, which include global, regional and local climate regulation, water storage and transportation, cloud formation and rainfall generation, and the cooling effect of evapotranspiration;

- *Biodiversity, ecosystem health and renewal, inter-connectedness and synergies.* The growth of knowledge on the ecological and environmental interactions between animals, trees, plants and soils which ensure that terrestrial systems function effectively, and renew and restore themselves;[61] and

- *Terrestrial ecosystems as planetary regulators.* The development of the 'planetary boundaries' framework,[62] using quantified methodologies to define the ecosystem functions that must be maintained in order to avoid breaching planetary limits (e.g. maximum concentrations of atmospheric greenhouse gases).

These advances challenge long-held assumptions. In the past, policymakers viewed natural ecosystems as places of little economic value – and marginal to the mainstream of society. The case for protecting them was largely framed around notions of 'wild habitat,' 'wilderness', the aesthetic and cultural case for the preservation of beautiful and iconic landscape, and the protection of rare and endangered species.

But, in the light of new science, such perspectives are changing. Alongside these arguments there is now a new biosphere-level rationale. From this viewpoint, instead of being marginal, terrestrial ecosystems are (along with the atmosphere and the oceans), the most valuable physical assets we possess. The task ahead is to reform land-use policy so that strategies for ensuring terrestrial ecosystem protection and restoration are the top of the priority list, not down at the bottom.

2. The current state of land-use policy

Progress

The period since 2000 has seen some absorption of the new science by the policy community. The publication of the Millennium Ecosystem Assessment[63] in 2005 did much to raise awareness; and the inception of the Reducing Emissions for Deforestation and Forest Degradation (REDD) initiative for tropical forests in the same year was triggered by growing concern over deforestation.

More recently, the 2010 Aichi targets, formulated by the Convention on Biological Diversity (CBD), have focused attention on the need to set goals for reductions in biodiversity and ecosystem loss. The targets also included the first call for large-scale ecosystem restoration, a step that catalysed the launch of the Bonn Challenge in 2011, which seeks to restore 150 million hectares of degraded forest landscapes by 2020. The scale of ambition significantly increased in 2014, with the commitments announced in the New York Declaration on Forests at the UN Climate Summit. This affirmed support for the Bonn Challenge goal, and also for a new target of restoring an additional 200 million hectares by 2030.[64]

The Summit also saw the release of the *New Climate Economy* (NCE) report, which includes three recommendations on land recovery opportunities: the restoration of 150 million hectares of degraded agricultural land into productive farming, including agroforestry; endorsement of the Bonn Challenge goal; and a call for an additional 200 million hectares of forest landscape restoration by 2030,[65] noting that the target is needed *'to catapult restoration on to the global policy agenda, raise awareness of restoration's benefits, trigger active identification of suitable areas for restoration, create enabling conditions, and mobilise the human and financial resources needed for restoration at scale.'*

Other noteworthy policy developments include: the formation of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) in 2012, the first UN-level body with a specific remit on these issues; recent work by the United Nations Convention to Combat Desertification (UNCCD) to highlight the need for action on restoring degraded lands; and the range of ongoing initiatives to achieve sustainable supply chains (particularly for soybean, palm oil, and beef), and climate-smart agriculture.

Lack of progress

These steps forward are encouraging, and will enable expansion of effort and reach. For example, more companies involved in agricultural and other land-based supply chains can now be engaged in the existing roundtables and related initiatives; and these can also be replicated for other internationally traded commodities. At the same time, efforts can be ongoing on improving the relevant certification schemes. However, there are several areas which are relatively neglected, as highlighted below.

Addressing the role of logging in natural forests as a driver of degradation emissions. Logging (legal and illegal) is estimated as the driver of 52% of forest degradation in developing countries; and is also likely to be a significant contributor to gross carbon emissions in temperate and boreal regions.[66] Although clear-cutting is still used within some forestry operations, the principal model employed is selective logging (usually implied when the 'Sustainable Forest Management' label is used) and its chief variant, Reduced Impact Logging (RIL). These forestry practices target the removal of large trees with high commercial value as timber.

But even when selective or reduced impact logging practices are well conducted, from a mitigation and ecosystems perspective, this is the opposite of the desired outcome. Terrestrial science points unerringly to the fact that big hardwood trees store very significant volumes of carbon (as well as continuing to sequestrate) and are critical to forest ecosystem maintenance.[67]

Increasing tree farming capacity to meet soaring demand. A transition to farmed wood is needed, with a switch to timber sourced from plantations, wherever possible, in order to separate the forest ecosystem role from the supply function. Despite the strides made over the last several decades toward producing timber and other wood-based products via intensive tree farming in plantations, there is a looming 'fibre-deficit' over the coming decades to mid-century, because of soaring demand. If capacity is not increased, the end-game is likely to be yet further natural forest loss and degradation.[68]

Expanding the 'produce and protect' concept to include tree as well as food farming. The 'produce and protect' concept, first articulated in 2013,[69] has already gained significant traction, and can be credited with assisting in processes that have started to involve private sector companies as participants in efforts to bring about more sustainable land use.[70] UN agencies and institutions, and the bilateral agencies of many Annex 1 countries have also proactively been involved.[71]

The essence of the idea is that per hectare smallholder and large-scale crop and livestock yields can be increased, via sustainable intensification, thus lessening the need to convert terrestrial ecosystems to agriculture. In a world where land becomes ever more precious, the idea is rational and persuasive. It should be expanded so as to include tree as well as food farming, through smallholder woodlots as well as larger-scale plantations.

Ensuring proactive protection within 'produce and protect'. A current common weakness with the 'produce and protect' model is that it assumes what might be termed 'inferred protection': if pressure on ecosystems is lessened through the shift to more efficient production, then protection will occur by default. In many cases this is very unlikely, because the undoubted benefit created – the increase in farmer incomes deriving from higher yields – may lead, in the absence of adequate protective measures, to the conversion of more lands to agriculture.

The need is not to roll back the shift to climate-smart agriculture, which is of critical importance. Instead, a parallel investment needs to be made in the tools of proactive protection: the laws and regulations (and funding for enforcement) that are integral to sustainable ecosystem management, as demonstrated in Brazil.[72] The climate policy community could assist on a much-needed next step – the bringing together of food, forestry and conservation and restoration organisations and experts to work on solutions that deliver both components.

The need for a rethink on temperate and boreal land-use. It is commonplace to read claims that Europe and North America have seen an increase in forest cover in recent decades; however, when data for natural forests is disaggregated from plantations, the results show little change.[73] This is symptomatic of a broader issue: the assumption that land-use problems are largely situated in the tropics. There is a need to move beyond these perspectives, because land-use challenges are global (particularly the pervasiveness of forest and other land degradation). Reform of INDCs and greenhouse gas accounting, along the lines outlined above, are important first steps.

3. Land-use policy challenges and opportunities

Terrestrial ecosystem mitigation and other benefits

Perhaps the chief positive of terrestrial systems as providers of mitigation is their in-built and proven functionality. Unlike solar panels, wind turbines, CCS or BECCS, terrestrial ecosystems are self-installing and self-operating, powered by the sun. Trees and other vegetation sequester and store carbon as they grow – and they renew themselves, aided by seed-dispersing birds, mammals, insects, wind, and water, all free of charge. At the same time, forests and other terrestrial systems also offer a range of essential water services: storage, rainfall generation, atmospheric cooling and cloud formation, and precipitation.

The land challenge

But terrestrial ecosystems also come with a built-in disadvantage: they require large areas of land in order to provide their planetary, regional and local mitigation and other services. And, the lands on which they sit are in demand for other human physical needs: food, wood and other fibres, settlements, and infrastructure. Those demands are accompanied by a range of attendant economic, political, social and cultural challenges. Of these, three are especially significant:

Valuation and finance. The absence of public and private sector mechanisms that employ already devised natural capital valuations, and consequent measures to ensure adequate provision of finance for ecosystem protection and restoration;

Rights. The portfolio of sometimes competing claims on lands, including customary and other land rights of indigenous peoples and other communities (including for those that exist but are not yet recognised in law), a wide range of smallholder tenures, and the concessions granted by governments for logging, mining, large-scale commercial agriculture and other development;

Responsibilities and global equity. Current land-use policy is largely focused on the need to reduce emissions from tropical forest ecosystems – a key priority, for which many tropical countries urgently require substantial financial and other support from Annex 1 nations. However, the temperate and boreal regions are also home to a range of ecosystems that are essential for global well-being. Some of these are in need of much greater protection than they are currently afforded, and some are degraded but could be restored.

Improving communications on ecology and ecosystems

The new research since 2000 consistently points in the same direction: the more we know, the more we understand that well-functioning natural terrestrial ecosystems are critical for planetary regulation and human well-being. But this science is barely taught in schools, and remains largely absent from media coverage, and from mainstream policy discussions.

This state of play can be rectified. The evidence from other international educational outreach and collective effort (e.g. successes achieved by the Millennium Development Goals, the campaigns to improve knowledge and understanding on HIV/Aids and other infectious diseases, the rise of rights-based values) is that these investments produce results – with governmental championing and support as vital ingredients.

Improving ecosystem protection

Whether managed by communities, governments, the private sector or civil society, the protected area model – when well run and based on sound ecological principles – is proven to work as a means to maintain and enhance carbon, water and biodiversity assets.

Yet the full potential of this approach is far from being realised, for a range of reasons, including: under-resourcing of human and financial capital in many existing protected areas; the lack of an ambitious global strategy for expansion; and, in some cases, on failures to fully engage with the rights, needs and aspirations of communities.

Balancing rights and responsibilities

These are very significant challenges, indicating that a renewal of investment, energy and effort on protected areas will not be an easy or straightforward undertaking. But one other (hinted at in the paragraph above) outranks all the others in terms of sheer difficulty – and unavoidability.

This is the question of how to achieve a balance between the carbon-water-biodiversity-food-energy-fibre demands on land, whilst at the same time recognising the legally enshrined or customary rights over land that are held by indigenous peoples, farmers, and others, the world over. This is commonly perceived as a purely developing country challenge, but such a view is misleading: these are universal issues, present in Europe and North America as well as the tropics.

There are no absolute answers; both the 'land sparing' (zoning) and 'land-sharing' (mosaic farming) approaches will be appropriate in some instances, but not in others. Perhaps the way forward is to recognise that while large-scale land-use planning is a key strategic tool, effective balancing of demands will ultimately be context-specific.

At the same time, it is important not to lose sight of the overall backdrop. Conversions and degradations of lands have wreaked great damage, leading to loss and depletion of terrestrial ecosystems and their services across the globe. The assumption (widespread even in the recent past) that land is plentiful – and therefore harmful effects can be tolerated – no longer holds true.

Fortunately, awareness of the finitude of land is growing rapidly, and because of that, the issues around how they should be managed, by whom, and for what purposes, has become one of the most pressing issues of our time. A tentative step might be to ally ongoing efforts to secure and respect land rights with a clearer restatement of societal and individual responsibilities for the wise stewardship of global lands.

Such a restatement needs to be framed universally, and be applicable to all landholders – from agribusiness to smallholder farmers, and all points in-between, from Riga to Riau.

Part III: Financing sustainable land-use

The principal focus of current finance proposals that relate to ecosystems is on the tropics, and this is followed here, together with brief commentary on the need for re-examination of financing for ecosystem protection and restoration in the temperate and boreal zones, in the concluding section.

1. Tropical land-use finance challenges

Policy participants (within international institutions, governments, companies and NGOs) are seeking to devise finance solutions for sustainable tropical land-use that are based on natural capital concepts and accounting, the achievement of emissions reductions, and payments for ecosystem services. In line with current perceptions on global warming priorities, attention is primarily focused on slowing and then halting tropical deforestation.

The various finance proposals can be grouped under two headings: interventions that derive finance from market mechanisms and forces; and those that require public sector funding. Some progress has been achieved on the infrastructure required for both (particularly in the REDD+ context). Examples include the voluntary market mechanisms, processes and instruments that have paved the way for private sector involvement, and the multilateral funds that are beginning to channel donor country monies into landscape-scale initiatives.

And, outside of REDD+, other work is ongoing that seeks to secure public and private sector finance, including reform of private sector supply chains that depend on tropical lands, the forest landscape restoration agenda, and climate-smart tropical agriculture and agroforestry.

Finance constraints

Progress toward the amplification of available finance has, however, been slow. For REDD+ alone, the influential New Climate Economy report suggests that donor countries should aim to provide US$5 billion per year; a trifling sum relative to annual renewables subsidies of US$270 billion in 2014,[74] and less than 1% of the US$548 billion of subsidies for fossil fuels in 2013.[75] Yet if this were to be achieved, it would represent a doubling of current financing.[76]

One widely-held view on the paucity of funding is that it is a function of lack of political will on the part of donor countries. In this perspective, the imperatives of austerity economics (and consequent lack of budgetary room for manoeuvre), the prioritisation of the switch to renewables, and the residual strength of climate scepticism all play parts in bolstering reluctance.

In turn, this narrative is invoked to partially explain the lack of investor interest and commitment: private equity and capital market investment flows are seen as being in a holding pattern, waiting for public sector leadership. In parallel, investors cite sparse investment-grade opportunities and high levels of country risk as additional challenges.

These factors are undoubtedly contributory; but it may be the case that the focus on overcoming them is leading to neglect of several other issues: ongoing difficulties relating to the valuation of ecosystem assets and opportunity costs; the need for a greater focus on financing direct protection; incorporation of sustainable fibre production into 'produce and protect' models; and the inclusion of measures to address degradation within finance proposals.

Valuation of ecosystem assets and opportunity costs

The extent to which ecosystem assets are being fully valued (and internalised within land-use economics) and the related issue of opportunity costs (the revenues that would be required from ecosystem protection for it to out-compete other land-use options in conventional economic terms) have been at the heart of financing discussions on tropical forests since the publication of the Stern and Eliasch Reviews (2006 and 2008, respectively). In broad terms, these remain unresolved issues; the argument for the unaffordability of tropical ecosystem protection can always be powerfully made by reference to the price requirement for a ton of CO_2 to outbid timber (c.US$25-$40), or palm oil (c.US$100).[77]

Three overall points need to be made. The first is that the new awareness of the significance of land-use mitigation as up to 30% of the climate solution serves to underline the importance of developing financing approaches that deliver results in this area of abatement. The alternative – the argument that unaffordability trumps rising global temperatures – is unthinkable.

Related to this is the observation that land-use mitigation is not alone in facing a finance gap. A recent United Nations Environment Programme (UNEP) report on finance required to realise the UN Sustainable Development Goals estimates that both developing and developed countries face annual investment gaps of US$2.5 trillion and $10 trillion, respectively.[78]

The third point is to note the implications of the gaps in current finance proposals for ecosystems, as outlined below. Until the costs of protection (including measures to address degradation) are costed into strategies and plans, then donors and investors alike will continue to be provided with incomplete land-use mitigation solutions that do not fully address the challenges.

The missing 'protect' component

At present, many 'produce and protect' proposals largely concentrate on the financing of the production of physical goods: principally food (from crops, livestock, and agroforestry).[79] There is no question over the necessity of this strategy: it is mission-critical to transition from inefficient and destructive agriculture through a shift to sustainable intensification of production. This must be done in ways that also increase incomes and prosperity, in order to meet rising demand for food, in a world where many of the biggest current and projected population increases are in tropical countries.

However, as explored above, there are vulnerabilities in many of the 'produce and protect' propositions made to date. The 'sustainable intensification' rationale as developed thus far is necessary – but not yet sufficient. The assumption that by achieving higher farmer incomes from higher yields (in itself a very significant gain) then ecosystem protection will necessarily follow is flawed, if the regulatory and financial underpinning of protection is not present.

The missing tree farming component within the 'produce' model

Although some aspects of the wood and fibre challenge are included within the 'produce' concept, the primary focus is on food. As noted earlier, there are significant current and looming wood-deficits in many tropical countries, which contribute to forest degradation. The answer is to include plantation and woodlot forestry within the produce framework. The rationale is the same as in the food context: efficient production outside of natural forests will help relieve pressure on them.

The missing degradation and sequestration components

As noted earlier, degradation accounts for 50% of tropical forest emissions; calls for the financing of measures to reduce these contributions to global warming would therefore seem to be a critical component within the range of strategies proposed. However, these appear to be largely absent, in the ecosystem restoration sense. The degradation proposals that are on the table primarily focus on the rehabilitation of lands for agricultural and other production.[80] This gap in finance calls appears to be mirrored on the sequestration aspect. Our researches to date have not identified any large-scale projects aiming to optimise land-based negative emissions.

Sourcing financing from the public and private sectors

Hostility to the use of private sector finance in land-use mitigation goes back to the negotiations that led to the Kyoto Protocol and the decision to exclude tropical forestry offsets from the treaty (a decision that also led to their exclusion from the EU Emissions Trading Scheme). The factors that drove exclusion (fear of flooding the market with cheap credits, and fears that offsets would lessen the pressure on Annex 1 countries to reduce their fossil fuel emissions) remain extant, if more muted.

To some extent, the lessons have been learned: forest offsets have morphed (in the multilateral and bilateral context) into 'payments for performance', in recognition of the need to make payment for mitigation achieved. But, elsewhere (for example in the California carbon market, and the voluntary market) the offsets concept and associated mechanisms and processes continue to be employed, with proponents arguing that markets for tradeable forest CO_2 are essential in order to tap adequate levels of private sector finance.

Putting this debate to one side, it can be argued that the real ensuing damage has been a polarisation of attitudes, with different actors pinning their colours either to the public or private sector approaches. Such positioning is often at odds with current financing arrangements, which often combine both.

Looking ahead, pragmatism suggests that there is no single silver bullet; given the scale of finance required, land-use mitigation will require support from across the range of sources: multilateral institutions; the bilateral agencies of Annex 1 countries; in-country governments; contributions from private sector companies (notably those with tropicsdependent supply chains); charitable grants and donations from foundations and individual givers; and revenues from the sale of CO_2 and other ecosystem services credits.

2. The road ahead: financing terrestrial ecosystems as green infrastructure

It is instructive to look at the standard language used in finance, business and economics to denote the range of activities relating to the natural world. 'Natural resources' as a sector heading embraces agriculture, forestry, fishing and fisheries, mining, coal, oil and gas, renewables; 'infrastructure' includes road and rail systems, airports, hydroelectric dams, communications and power lines, and gas and oil pipelines – the essential basic physical systems of an economy or region.

The categorisations illuminate the disconnectedness between current economics and planetary management. There is no place in this scheme of things for terrestrial ecosystems: they are essential physical systems, but are not treated as infrastructure. Within the natural resources sector, all of the companies listed on the world's stock exchanges (with the exception of renewables) are extracting physical products from ecosystems, not maintaining and restoring them.

However, attitudes are changing. Renewables are demonstrating that actions to address global warming can be economically viable – and their assets (solar grids, wind farms geothermal installations) are increasingly seen as forms of infrastructure. The assets of terrestrial ecosystems (carbon and nitrogen sequestration and storage, water services) are also seen as potentially monetisable, generating revenues from tariffs, taxes and tradeable credits.

The availability of finance for infrastructure is not in question: last year's G20 announcement of support for expansion of roads, dams, power and gas lines, and other physical assets to 2030 estimated projected investment levels (primarily from the private sector) at US$60-70 trillion.[81] True valuation and pricing of terrestrial ecosystem services might pave the way for their integration within such initiatives.

Financing sustainable land-use in temperate and boreal zones

An optimistic take on temperate and boreal challenges is that much of the work carried out on tropical land-use finance is in principle applicable in these regions. Requirements for proactive ecosystem protection could be evaluated in order to draw up finance proposals; and the suite of Funds, other instruments, and payments for emissions reductions (and ecosystem services) could also be employed.

However, while there is likely to be merit in looking for synergies and the leveraging of technical capital, the reality is that the requirements for ecosystem-based finance have not been systematically assessed in the light of the new science, in either temperate or boreal zones. A first step might be for the European Union to show leadership, by commissioning a state of ecosystems study across all member states.

Part IV: Some first steps on international land-use policy reform

Advancing actions to achieve a 30% mitigation goal for land-use necessarily involves the need to assess how best to move the agenda forward within the current institutional infrastructure, particularly at the UN level. This brief does not seek to fully explore the options, but instead focuses on outlining some initial steps that could be taken.

Land-use champions and reform of INDCs

One way forward on the need to build momentum might be to form an initial grouping of Annex I and non-Annex 1 countries and other organisations willing to act as land-use champions and advocates. If this could be formed, some valuable first steps could include:

- Assessment of land-use mitigation within INDCs, and recommendations for how this component of overall abatement could be improved;
- Commissioning of research that would increase understanding of the challenges, such as global studies on gross carbon and other greenhouse gas emissions released via land-use activities, and on sequestration;
- The development of a set of safeguards for land-use mitigation, including for (but not limited to): full greenhouse gas accounting; the avoidance of competition or trade-offs with fossil fuel endeavours; clarification of land-related rights and responsibilities; and the articulation of the value and importance of natural ecosystems, their criticality in climate mitigation, and the global duty to protect and restore them; and
- Initial scoping of global land-use mitigation finance requirements and opportunities, drawing on advances already made in the REDD+, natural capital and related fields.

Part V: The regreening endeavour

Regreening as framed here is a relatively new idea, although its constituent parts have long histories as land-uses. This overview recapitulates some of the earlier analysis and findings, and adds some policy options for consideration.

Vision and goals

The central vision of regreening is that the earth's above and below ground biomass (trees and other vegetation) can be massively increased, both by volume, and by carbon content. The opportunity exists because the ecosystems that held the most biomass – forests, wetlands, mangroves, grasslands – have all been greatly reduced in extent, and degraded, with losses and damage driven by logging, deforestation and other conversions to croplands and pastures, and the drainage of wetlands and mangroves. At the same time, tree cover has also reduced on many agricultural lands, from Europe and North America to the Sahel.

Regreening is driven by climate, ecosystem, fibre and food, and socio-economic goals. The aim is to maximise the climate goal through significant reductions in greenhouse gas concentrations, via the removal of CO_2 and N_2O from the atmosphere, and their storage as carbon and nitrogen within terrestrial systems. The ecosystem goal is a function of protection and restoration – the maintenance and recovery of water services, soils, biodiversity, and ecosystem resilience. The fibre and food goal is sought by achieving increases in outputs from tree and food farming so as to meet rising demand.

On socio-economics, the goal is to create a regreening industry, much like the fledgling renewables sector: generating revenues and profits, creating jobs, and bringing demonstrable increases in the prosperity and quality of life of citizens and communities on the lands where regreening takes place. In parallel, it must also be fully aligned with sustainable development goals, particularly the imperatives to comply with the highest social and environmental standards.

Science and land-use analysis

As noted earlier, the state of knowledge on global land-use emissions and sequestration is incomplete. Steps could be taken to rectify this, through new assessments, and the commissioning of research to fill existing gaps. This will require collaborative effort by scientists and other experts. To foster the necessary efforts, consideration could be given to the formation of a new UN level group for land-use science and analysis, perhaps similar in its scope and terms of reference to the High level Advisory Group on Climate Change Financing (AGF), which reported in 2010.[82]

Other priorities include the need to improve the quantity and accessibility of secondary analysis, particularly comparative studies on the climate and ecosystem results obtained from the range of interventions employed. Such studies could also include new approaches to land-use classifications that reflect ecosystem values and attributes. An example is the need to disaggregate plantations from natural forests within definitions of forest cover.

Enabling conditions
The enabling conditions for wise land-use must be founded on recognition and support for the customary and other land rights of indigenous peoples and communities, and the need to obtain their free, prior and informed consent to regreening initiatives. The conditions also include requirements to build donor and investor confidence in the durability and functionality of contractual arrangements, land-use planning and enforcement, and the need for effective frameworks at international, regional and local levels.

Progress has been made on some of these areas over the last decade, but much more needs to be done. Priorities include: institution building, governance, social and environmental safeguards, participation, and land tenure reform.

Protected areas
A fruitful first step would be the commissioning of a global mapping exercise to identify currently unprotected ecosystems with the highest carbon, water and biodiversity values. This could build upon the extensive data already collected and collated under the auspices of the International Union for the Conservation of Nature (IUCN) Global Protected Areas Programme, the work of the World Conservation Monitoring Centre (WCMC) and the World Heritage Convention and the map of global ecological land units produced by the Association of American Geographers.[83]

Forestry
A welcome development in recent years has been the increasing participation of companies from the agricultural commodities sector in climate and land-use policy discussions. By contrast, representatives from the forestry industry are rarely present. Unless the industry is engaged with regreening strategies, progress will be constrained. Governments and civil society could do much to redress this, by fostering and encouraging forestry participation and engagement.

Certification, standards, and safeguards
Many valuable contributions have been made to help ensure that the range of land-use activities and products meet and comply with social, environmental and consumer standards and safeguards. These include 'Free Prior and Informed Consent' (FPIC), the 'High Conservation Value Forests' (HCVF) land designation, Forest Stewardship Council (FSC) and the range of other certification schemes, and the ongoing efforts to provide appropriate guidance on high carbon stocks (HCS) within land-use decisions.

However, some approaches were originally devised before the modern era of terrestrial climate and ecosystem science. As a result, the definitions, rules and assessment processes do not necessarily reflect current thinking. This is particularly true in the certification context, where many within that community are aware of the need for changes, but need encouragement and support to move forward.

A first step might be for an initiative to set a consultation and report process in train that would provide all stakeholders – including NGOs and other bodies that work on ecosystem protection and restoration, as well as certifiers, and the private sector – with an opportunity to provide input.

Ambition
Plans are ongoing in Africa for a Great Green Wall of the Sahara and Sahel, and China's own Great Green Wall is eventually envisaged as extending from Xinjiang province in the far west to Heilongjiang province in the east. While scrutiny needs to be applied to the efficacy and suitability of these large schemes, the intent and ambition are highly laudable contributions to regreening, and its visibility.

Countries in temperate and boreal regions could consider similar projects of their own. One option would be to evaluate the feasibility of a new European Union forest, ideally based around existing fragments of primary forests, and where there is potential for reconnecting them, through natural regeneration. Such a project would send an important signal of solidarity and joint endeavour to those tropical countries that are being urged to do more to protect their own forests.

Ecosystem infrastructure projects
Large-scale infrastructure projects are integral to the natural resources sector, from Sakhalin oil and gas to the Chad-Cameroon pipeline. These are often rightly criticised by environmental groups because of their negative social and ecosystem impacts.

However, the public-private sector partnerships that are integral to the model are often very successful in financial and economic terms. If the model could be adapted to an example project, this could help pave the way for ecosystem infrastructure to enter the economic mainstream.

Re-evaluating tree protection options
There is a need to re-evaluate approaches to tree protection in the light of new science on the criticality of large trees; the rapid spread of selective logging across the globe; and recent data on the very large annual net loss of trees.[84] Looking ahead, the solution to this major component of forest degradation is likely to involve a transition from natural to farmed wood; this could be assisted by a combination of civil society advocacy and educational outreach, and forestry innovation.

From the policy perspective, tightening existing regulations might be a sensible beginning point. One option might be to explore the potential for expanding the list of tree species deemed illegal for the purposes of trade through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the endangered and vulnerable categories maintained by the IUCN Red List.

Restoration commitments
The restoration commitments made in support of the Bonn Challenge, and the subsequent additional pledges made as a part of the New York Declaration on Forests were, in the eyes of many, the high point of 2014, from a land-use perspective. The aggregate total area of 350 million hectares, if successfully restored, will be a remarkable achievement, and a major contribution to the regreening endeavour.

As governments and companies move to implementation, the importance of transparency and public domain accessibility on the various plans is becoming clear. At present, too little is known on goals and purposes, particularly over the adoption of sustainable production as one pathway, and ecosystem restoration on a non-extractive basis as another.

About Restore UK

Restore UK was established in 2001 as a grant-making charity to invest in the protection and restoration of Britain's natural habitat. This vision has since been expanded to embrace environmental and biodiversity issues across the world, and at global scales.

The charity has identified regreening as a major priority and is embarking on a range of initiatives to stimulate interest, involvement and action on the issue. These include the commissioning of a report, *Regreening the Planet: Towards a Framework for Effective Action,* to be published in 2016, for which consultations and research began in August. This policy discussion brief draws on the early stages of that work to present some preliminary findings and guidance, in the climate policy context.

Author information and feedback

Bernard Mercer prepared this policy brief, with assistance from Isobel Mercer. Bernard's previous research on land-use includes preparation of the International Sustainability Unit's *Tropical Forests: A Review* (2015) and *Protecting and restoring forest carbon in tropical Africa: A guide for donors and funders* (FPAN, 2011).

We would be very glad to receive feedback on this consultation draft. Please send any comments to bmercer@mercerenvironment.net.

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Endnotes

[1] See UNFCCC (2015).

[2] **Summary of total anthropogenic carbon emissions**
Le Quere, et al., (2015), states that *'for the last decade available (2004–2013), EFF [fossil fuel emissions] was 8.9 ±0.4 GtC yr−1, ELUC [land-use emissions] 0.9 ±0.5 GtC yr−1.* This adds up to a total of 9.8 GtC annually, of which fossil fuels contribute 91% and Land Use Change contributes 9%.

Smith, et al., (2014) [AR5]: '*FOLU accounted for about a third of anthropogenic CO_2 emissions from 1750 to 2011 and 12% of emissions in 2000 to 2009.'* (p.825). This is further supported in Clarke et al 2014, which states '*currently about 10-20% of global CO_2 emissions originate from land-use and LUC'* (p.29).

Clarke, et al., (2014) [AR5] promotes the perception that fossil fuel emissions far outweigh those from land-use: '*Though uncertain, the estimated contribution of land-use related carbon over the coming century is small relative to emissions from fossil fuels and industry, with some models projecting a net sink late in the century'* (p.18).

[3] **Summary of net and gross emissions accounting**
The most common approach to emissions accounting is to calculate the *net emissions*, which is defined as *emissions by sources minus removals by sinks* (Tubiello, et al., 2014). This approach is pursued in accordance with the 2006 IPCC Guidelines for National GHG Inventories. Net emissions are calculated by measuring the change in terrestrial carbon pools. This approach is therefore only measuring change in the *balance* of carbon in an ecosystem. For further explanation see: Tubiello, et al. (2014); Ciais et al., (2013:489) [AR5].

Net emissions from land-use change are generally estimated to be in the region of 0.8 – 1.5 GtC $year^{-1}$ ISU, 2015 (0.8-0.9); DeB Richter and Houghton, 2011 (1.5); Harris, 2012a (0.8); Van der Werf, 2009 (1.2); Stocker, 2014 [AR5] provides a range of 0.1 – 1.7 GtC yr^{-1} for land-use emissions.

In recent years an alternative approach has arisen, which seeks to estimate the *gross emissions* from land-use change and the *gross emissions* removed, or sequestered, through land each year. DeB Richter and Houghton (2011) found that '*gross sources of CO2 total 4.3 PgC $year^{-1}$ from ecosystems influenced by deforestation, burning, harvesting of wood and cultivation for the years 2000-2005. Gross sinks of CO_2 affected by global land-use change are estimated to total approximately -2.8 PgC $year^{-1}$'* (p.43).

Pan et al. (2011), only calculate emissions from deforestation, rather than including other land-use change, but found a '*gross tropical deforestation emissions of 2.9 ± 0.5 PgC yr^{-1} partially compensated by a C sink in tropical forest regrowth of 1.6 ± 0.5 PgC yr^{-1}. Together the fluxes comprise a net global forest sink of 1.1 ± 0.8 PgC yr^{-1}'.*

Harris et al. (2012b), also focus solely on tropical deforestation, but again highlight the importance of the *gross emissions* approach. The paper finds that '*emissions from gross deforestation in tropical regions contributed 3.0 Gt CO_2 yr^{-1} to the atmosphere.'* Harris estimates that gross emissions from peat soils and forest degradation could contribute another 2.3 Gt CO_2 yr^{-1}.

DeB Richter and Houghton (2011) highlight some of the implications of these two different accounting systems: '*the net release of CO_2 from global land-use change has remained at approximately 1.5 PgC $year^{-1}$ since the early 1960s…in general agreement with widely cited estimates. The model also demonstrates how this generally steady net global release of CO_2 entirely masks the large and increasing global CO_2 sources in the tropics that are counterbalanced by decreases in gross CO_2 sources in the temperate zone and the lagged but increasing gross CO_2 sinks in both the temperate zone and tropics'* (p.43).

[4] **Recalculating the carbon budget**

One of the key implications of the *net* versus *gross emissions* accounting debate outlined above is the impact on overall anthropogenic carbon emissions. Estimated using the *gross emissions* accounting system, and adding the total annual fossil fuel emissions with gross annual land-use emissions, the global anthropogenic emission of carbon are usually around 12-13 GtC rather than 9-10Gt as is commonly reported (DeB Richter and Houghton 2011). The contribution of fossil fuel emissions towards the total carbon budget therefore falls from 88-92% to around 75%.

Houghton (2013a) explains the implication of this: '*more carbon is emitted to and removed from the atmosphere each year as a direct result of human activity than is revealed by the estimates of the net flux'*. Fossil fuels therefore still represent the majority share of carbon emissions; however these figures strongly support the need for a global strategy to reduce emissions from land-use.

[5] **Summary of IPCC on land-use**
In line with other studies on land-use emissions the key approach within AR5 has been to calculate *net* rather than *gross* emissions. The report does acknowledge this choice of methodology, stating that: '*we do not assess individual gross fluxes that sum up to make the net land use change CO_2 emissions, because there are too few independent studies'* (Ciais et al. 2013 p. 491).

However the report does briefly summarise that '*gross emissions from tropical deforestation and degradation were 3.0 ± 0.5 PgC yr^{-1} for the 1990s and 2.8 ± 0.5 PgC yr^{-1} for the 2000s using forest inventory data, FAO (2010) and the bookkeeping method (Pan et al., 2011)'* (p.491). This point is quite significant, considering that elsewhere in AR5 Stocker, et al, states '*[land use change emissions estimates] includes gross deforestation emissions of around 3 PgC yr^{-1} compensated by around 2 PgC yr-1 of forest regrowth in some regions, mainly abandoned agricultural land'* (p.50). This emphasises that most of the land-use change estimates (excluding agricultural emissions) in AR5 are heavily dominated by tropical deforestation.

[6] **Discussion on consensus and uncertainty**
Gross emissions estimates do not present a clear divergence from previously established *net* emissions estimates, having produced a similar *net* emissions range but represents a different methodology calculating different variables (see DeB Richter and Houghton, 2011).

However, even within the *gross emissions* land-use accounting system key uncertainties remain, including: the size of the residual terrestrial sink; double-counting; emissions from biomes other than tropical forests; sequestration and storage capacities these other biomes; emissions from degradation and impact of degradation on ability of forests to sequester and store carbon; and terminological and methodological differences in emissions accounting systems.

These uncertainties have resulted in a wide range of values for emissions estimates, accompanied by high levels of uncertainty (uncertainty of land-use estimates can be as great as 50% - see Pongratz, et al, 2014, and Tubiello et al, 2015). A second consequence of these issues is a difficulty in comparing the estimates provided by the different studies, as it is clear that few measure the same variables.

Uncertainties concerning the residual terrestrial sink (that is sequestration of carbon by land *not* affected by land-use change) are great. This sink has not been directly measured, but is instead *inferred* through calculating the balance of other sources and sinks (fossil fuel emissions, LU emissions, ocean sinks, land-use sinks and atmospheric sinks). Le Quere (2015) estimated the residual terrestrial sink to be -2.9 ± 0.8 Gt yr-1 for the 2014 carbon budget. Other estimates range from -2.5 Gt yr (DeB Richter and Houghton, 2011; Clarke et al, 2014) to -9.53 (Smith et al, 2014), indicating significant uncertainty and disagreement about this sink..

[7] **Overall Greenhouse Gas Accounting for Land Use Change**
In: IPCC [AR5] (2014) p.8, AFOLU is estimated to contribute 24% of direct GHG emissions and 0.87% of indirect GHG emissions. Fossil fuels and cement production make up the remaining share. This

figure is cited again in Smith, et al. (2014) p.816: *'The AFOLU sector is responsible for just under a quarter of anthropogenic emissions (10-12 Gt CO_2eq/yr) (robust evidence; high agreement)…the share of AFOLU emissions to total anthropogenic emissions has decreased to 24% (in 2010), largely due to increases in emissions in the energy sector (robust evidence, high agreement).'* Tubiello et al. (2015) estimate the proportion of AFOLU emissions to be 21.2% of total anthropogenic emissions. It is important to note that these figures represent *net* emissions; *gross* estimates of total GHG emissions are unavailable.

[8] **Emissions from degradation**
For emissions from degradation of tropical forests see: Harris, N., et al. (2012b)(0.6GtC for degradation, 1.4GtC for deforestation and degradation); Houghton, R.A.(2013a) (1.32GtC for degradation, 2.28GtC for deforestation and degradation); Pan, Y., et al. (2011) (2.9GtC – this does not fully distinguish between deforestation and degradation). Baccini, A., et al. (2012) reports a total of 2.22GtC for all emissions. Grace, J., et al. (2014) reports 1.1GtC from degradation. This includes 0.54GtC for emissions from tropical peatland forests, an element of degradation that has been excluded from a number of studies. These estimates are substantial; and it is likely that degradation is also significant in other regions and terrestrial systems. However, to date, no overall global study of degradation emissions has been attempted.

[9] **Temperate forests** are considered to be a net carbon sink. Pan et al. (2011) estimate the carbon stored in temperate forests to be around 199 PgC, 13% of total global carbon stocks. The study also found that *'temperate forests (767 Mha) contributed 0.7 ± 0.1 and 0.8 ± 0.1 PgCyr^{-1} (27% and 34%) to the global C sink in established forests for two decades.'* Lal and Lorenz (2012) found that *'total ecosystem C pool in biomes and soils of temperate forest is equivalent to, and sometimes even more, than that of tropical rainforest ecosystems.'* However, as with boreal forests, there is evidence that increased deforestation, degradation as well as increased natural disturbance events as a result of climate change could lead to temperate forests transitioning from a net C sink to a net C source (Millar and Stephenson, 2015).

[10] **Boreal forests** have received increasing attention in recent years due to the discovery that they store high amounts of carbon and are considered to be a net sink for emissions. Pan et al. (2011) found that 32% of the global carbon stock is stored in boreal forests, 20% in biomass and 60% in soil. Trumper et al (2009) found that 382.2 GtC are stored in boreal forests, the second largest volume on land, after tropical and subtropical forests (547 GtC). Carlson et al (2009) Estimates carbon storage in boreal forests at 703 GtC.

Gauthier et al (2015) also claimed that carbon stocks in boreal forests are '*on a level comparable to, if not greater than, that of tropical forests…The boreal forest is estimated to sequester approximately 20% of the total C sink generated by the world's forests*'. The paper also indicates that '*globally, the boreal forest may have started transitioning from a C sink to a C source and certain regions [e.g. Western Canada and Siberia] may already be emitting more C than they capture*'. For further information see also: Bond-Lamberty, et al. (2013); Moen, et al. (2014); Bradshaw et al. (2015).

[11] **Grasslands** (rangelands, shrublands, pastureland and cropland sown with pasture and fodder crops): current rates of carbon loss from grassland systems not well quantified. Conan (2012) found that grasslands contain around 20% of the world's soil carbon stocks. The study further found that around 20% of global native grasslands have been converted for agricultural practices, between 5-10% have been degraded by overgrazing and that this may have caused the loss of 993 GtC to the atmosphere. Imer (2013) found that '*while most of the atmospheric CO_2 is sequestered by forests, grasslands are a small net sink for atmospheric CO_2.*'

[12] **Wetlands:** the most recent Ramsar Briefing Note (2015) established that 64-71% of global wetlands have declined in the 20th Century (Davidson (2014). Wetlands are complex because they emit methane (CH_4) but sequester CO_2 and therefore much uncertainty remains about the overall GHG sink/source status of wetlands. Currently wetlands are estimated to be responsible for 30% of global methane emissions (Petrescu, 2015).

[13] See: Davidson (2014); Gaveau (2014); Hooijer (2010); Moore (2013); Murdiyarso (2010); and Page (2011). See also Nelsen (2015), who found that '*peat swamp forests account for around 5% of global carbon dioxide emissions. It has been estimated that replacing palm oil and acacia plantations in south-east Asia with wet cultivation could cut 500 Mt of Co2, the equivalent of 1-2% of annual global emissions'.*

[14] See: Donato (2011); Hutchison (2013); McLeod (2011); and Pendleton (2012).

[15] Popp, A. et al (2014) argue that a narrow focus on tropical forests and the overlooking of other carbon-rich ecosystems within policy can lead to a shift in land-pressures and subsequent carbon leakage from forests to non-forest biomes. The authors argue that: '*a global forest policy could reduce carbon emissions by 77 Gt CO_2, but would still allow for decreases in carbon-stocks of non-forest lands by 96 GtCO_2 until 2100 due to non-forest leakage effects'.*

[16] See Pan et al (2011); Grace (2014); and Houghton (2013b).

[17] See: ISU (2015), Table 6.

[18] In Clarke et al. (2014) [AR5] both avoided deforestation and afforestation are acknowledged as sequestration options, however the potential of afforestation to achieve results on a large-scale is questioned (p.433). The chapter states: *'scenarios suggest a substantial cost-effective and possibly essential role for land in transformational pathways…with baseline land-use emissions and sequestration an important uncertainty' (p.445)*. Increased afforestation and improved soil management are seen as some options to achieving this. However, as is clear from recent INDCs, this has not so far been translated into policy.

[19] See Grace (2014).

[20] See: Strassburg et al (2009); Kapos et al (2008); and Scharlemann (2010).

[21] See: Paquette and Messier (2011); and Ruiz-Benito et al (2014).

[22] See: Luyssaert et al (2008) ; Sillett et al (2010) ; and Stephenson et al (2014). The latter notes: '*large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees… at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree.'*

[23] See Grace (2014).

[24] See, for example: Sun, Y., et al., (2014); McGrath, M. (2014); Canadell, P. (2014); Shevliakova, E., et al. (2013); Lewis, S.L., et al. (2009); Van der Sleen, P., et al. (2015); Hovenden, M.J., et al. (2014).

[25] See, for example, Erb et al (2013).

[26] For a valuable overview of many of the issues which have dogged international discussions on sequestration and other LULUCF issues, see Streck and Scholz (1992).

[27] See UNFCCC (1992).

[28] **Estimated Carbon Stored in Tropical Forests**
Saatchi et al. (2011) mapped the biomass carbon stocks over 2.5 billion ha of tropical forest over three continents: *The total biomass carbon stocks of forests in the study region is estimated to be 247 Gt C, with 193 Gt C stored aboveground and 54 Gt C stored belowground in roots. Forests in Latin America, sub-Saharan Africa, and Southeast Asia accounted for 49%, 25% and 26% of the total stock, respectively.*

[29] **Estimated Carbon Stored in known Fossil Fuel Reserves**
Meinshausen et al (2009) '*derived a mid-estimate of 2,800 Gt CO_2 emissions [for all proven fossil fuel reserves – the fraction that is economically recoverable with current technologies and prices], with an 80% uncertainty range of 2,541 – 3,089 Gt CO_2'*. If we convert this figure into C (2800/3.67=762) we see that the estimated carbon stored in tropical forests alone equate to approximately a third of carbon stored in fossil fuel reserves. Meinshausen et al state that *emitting the carbon from all proven fossil fuel reserves would therefore vastly exceed the allowable CO_2 emission budget for staying below* 2°C. This again supports the immediate and improved protected of all known terrestrial carbon stores.

[30] **Estimated Carbon stored in all terrestrial biomes**
An IPCC Special Report on LULUCF (2000) estimates the total carbon stored across *all* terrestrial biomes, including tropical, temperate and boreal forests, tropical savannas, temperate grasslands, deserts and semi-deserts, tundra, wetlands and croplands to be ten times higher at 2477 Gt C. 466 GtC was estimated to be stored in soils and the remaining 2011 GtC in above and below ground biomass.

[31] See Le Quere et al (2015), Table 8.

[32] **2ºC Warming Scenario and Current Emissions Reductions**
Several studies have communicated concerns that current emission reduction pathways are likely to result in an overshoot of the 2°C warming scenario. For instance New et al (2011) argue that '*the continued rise in greenhouse gas emissions in the past decade and the delays in a comprehensive global emissions reduction agreement have made achieving this target extremely difficult, arguably impossible, raising the likelihood of global temperature rises of 3°C or 4°C within this century'*. Similarly, Rogelj et al (2010) argue that *current national emissions targets can't limit global warming to 2°C – they might even lock the world into exceeding 3°C warming.*

[33] **Negative Emissions**
Bridging the 'emissions gap' from current emission reduction pledges to the reduction required to remain within a 2°C warming scenario has therefore become a major concern within the climate science community. The solution this problem is increasingly seen as achieving what has been dubbed 'negative emissions'. Gasser et al (2015) define negative emissions as '*capturing more CO_2…this definition does not distinguish whether carbon dioxide is captured on site or removed from the free atmosphere.* The study concludes the *negative emissions are needed even in the case of very high mitigation rates, but also that negative emissions alone cannot ensure meeting the 2°C target'*.

[34] See: AOSIS (2014); and AOSIS (2015).

[35] See ISU (2015), Tables 1 and 2. These data are the basis of the *World of Opportunity* map developed by WRI and others for the Bonn Challenge. For background on the development of the map, see Laestadius et al (2012).

[36] See Houghton (2013b).

[37] See Hansen et al (2013): '*Of course fossil fuel emissions will not suddenly terminate. Nevertheless, it is not impossible to return CO_2 to 350 ppm this century. Reforestation and increase of soil carbon can help draw down atmospheric CO_2.'*

[38] See Lovejoy (2014), which includes a recommendation for the rehabilitation of mangrove forests within its prescription. The estimate of a 50ppm reduction is equivalent to 107GtC.

[39] See Smith et al (2014) [AR5], p869: '*forestry mitigation options − including reduced deforestation, forest management, afforestation, and agro-forestry − are estimated to contribute 0.2 – 13.8 $GtCO_2$ / yr of economically viable abatement in 2030 at carbon prices up to 100 USD / tCO_2eq.'* If these data are expressed

over the 2031-2080 time scale employed by Hansen, the lower figure produces a negligible impact on GHG concentrations (a reduction of 1.2ppm) but the top end of the estimate is higher (83ppm).

[40] **Calculating negative emissions potential for land-based sequestration**
The basic mathematics is relatively simple. For example, Grace (2014) and Houghton (2013a) both employ 2 tons of carbon per hectare per year as the default value for sequestration; this is in wide use in a range of other studies, and appears to be largely derived from plot-based research within primary tropical forests. The implication is that higher rates (up to, perhaps, 8-12 tons per hectare per year) are obtainable in recovering and other secondary forests. It is hard at the present time to be more precise than this: no overall and comprehensive synthesis of sequestration results seems to be currently available, although a number of studies are in train.

To calculate equivalencies between tons of carbon, tons of CO_2 and parts per million, the sum (using 2 tons per hectare per year as the basis) is: 2 tons of carbon * [area in hectares] * 3.67 [conversion to CO_2], divided by 7.81 [conversion to parts per million].

[41] **The Mitigation Potential of Bioenergy**
Bio-energy features prominently in nearly all emission reduction strategies, including those in IPCC's AR5, where it is seen as the principal pathway for land-based mitigation in the 21st century. Smith et al (2014) [AR5] indicates that bioenergy deployment levels of between 100 and 300 EJ have been suggested, though it is acknowledged that this would carry considerable risks. Clarke, et al (2014) stated: '*Cumulatively, over the century, bioenergy was the dominant strategy, followed by forestry, and then agriculture. Bioenergy cumulatively generated approximately 5 to 52 $GtCO_2eq$ and 113 to 749 $GtCO_2eq$ mitigation by 2050 and 2100, respectively. In total, land-related strategies contributed 20 to 60 % of total cumulative abatement to 2030, 15 to 70 % to 2050, and 15 to 40 % to 2100.*'

[42] **Bioenergy Conversion Pathways**
Biomass used in energy production takes many forms, including agricultural and forestry residues, crops, organic municipal waste and animal waste (manure). Conversion technologies include the combustion of solid biomass, the production of liquid biofuels and the generation of biogas.

Bio-energy is therefore seen as providing a renewable alternative to fossil fuels that can be used across all three energy sectors – electricity, heat and transport. The basic climate mitigation concept behind bio-energy is that plants and trees absorb the same amount of CO_2 via photosynthesis as is emitted when they are used in combustion. Therefore, so long as living biomass stocks continue to be replenished at the rate of biomass combustion, then net emissions will be carbon neutral.

Bioenergy feedstocks can broadly be divided into two categories: organic wastes and living biomass.
Wastes used to produce bioenergy include organic household and commercial wastes, agricultural wastes such as crop residues, forestry residues and animal waste such as manures and slurries. The most common bioenergy pathway for waste is through anaerobic digestion to produce biogas. Though there can be various barriers to deployment, this type of bioenergy is generally seen to be a sustainable and logical waste-treatment option.

The other feedstock category comprises any living biomass such as crops and trees that are harvested for the purpose of bioenergy conversion. Liquid biofuels are produced from crops such as maize and sugarcane (ethanol) and rapeseed, soybean and palm oil (biodiesel). Biomass wood pellets harvested from forests, often in North America and Canada are used in combustion. Biogas can also be produced from cereal crops (maize, rye), grassland, and sugar beet. For more information see: Chum et al, 2011; Mendes Souza, G. et al, 2015; Smith et al (2014); Clarke et al (2014).

[43] **Bioenergy Risks**

The key issues associated with improperly managed bioenergy are: damaging direct and indirect land-use change that can increase the release of carbon from soils and vegetation, as well as altering surface albedo, loss of biodiversity and negative impacts for local populations regarding land tenure and food security. See Chum et al (2011); Mendes Souza, G. et al, 2015, for more information.

Smith et al (2014) [AR5] explain that land use and land demand for bioenergy depends on: *(1) the share of bioenergy derived from wastes and residues; (2) the extent to which bioenergy production can be integrated with food and fibre production, and conservation to minimize land-use competition; (3) the extent to which bioenergy can be grown on areas with little current production; and (4) the quantity of dedicated energy crops and their yields.* (p.835).

[44] **Bioenergy, Carbon Neutrality and the Carbon Debt**
A growing body of research suggests that the carbon neutrality of bioenergy cannot simply be assumed, see: Searchinger, et al (2009); Fargione et al (2008); Haberl (2012); and Haberl (2013). The carbon debt debate revisits the assumption that when biomass is harvested for energy, the carbon emitted is 're-paid' (re-absorbed) within a relatively short time frame. The debate indicates that regeneration of biomass, in particular trees, may not occur as quickly as assumed and therefore a significantly larger time frame of carbon 'pay-back' is implied. Estimates of the carbon debt timeframe vary from 16-38 years (McKechnie et al, 2011; Mitchell et al, 2012) to as high as 150-230 years (Holtsmark 2010).

[45] **CCS (Carbon Capture and Storage)**
CCS is a type of technology that captures large volumes of CO_2 from combustion of fossil fuels, through extraction from the exhausts of power stations and industrial sources, which are then pumped into saline aquifers, depleted oil wells and un-mineable gas seams. It has emerged as one of the most prominent options for large-scale emissions reductions, and is seen as playing a major role in future energy scenarios.

Considerable uncertainties remain about the potential for deployment of CCS at scale and there has been a slow transition from the demonstration phase to the commercial phase. A recent IEA special report (2015) '*the present pace of progress, however, falls short of that needed in order to achieve the pace and scale of CCS deployment necessary to achieve a 2° pathway*' (p.22). The report further states that currently only 27 Mt CO_2 is captured through CCS a year and only 5.6 Mt CO_2 of this is stored (p.116). The key barriers to large-scale CCS are: technical issues with transport and storage of the carbon, high upfront unit costs and establishing a carbon price high enough to incentivise uptake.

Uncertainties surrounding deployment of CCS have translated to major uncertainties about energy modeling scenarios. Clarke, et al (2014) [AR5] concluded that '*many models could not achieve atmospheric concentration levels of about 450ppm CO_2eq by 2100 if additional mitigation is considerably delayed or under limited availability of key technologies, such as bioenergy, CCS and their combination BECCS*'. The IPCC (2014) further calculated that in a scenario with no CCS availability total discounted mitigation costs (2015-2100) would increase by 138% (Table SPM.2), therefore '*the lack of availability of CCS is most frequently associated with the most significant cost increase*'. For further information see Johnsson et al (2012); IPCC (2005).

[46] Smith et al (2014) [AR5] states, that were BECCS to become commercially available then *the economic potential for mitigation is between 2-10 $GtCO_2$ yr.*

[47] There are currently no commercial scale BECCS plants in operation.

[48] There are strong indicators that the cost of sequestration per tonne of CO_2 would be significantly lower for natural terrestrial sequestration than CCS or BECCS. Humpenöder, et al (2014) compare afforestation and BECCS as climate change mitigation strategies under a global scenario in which GHG emissions are taxed to incentivise land-based mitigation, concluding: '*afforestation is a cost-*

efficient strategy for carbon removal at relatively low carbon prices, while bioenergy CCS becomes competitive only at higher prices.'

49 **Sources and sinks in agriculture**
Estimation of sources and sinks in agriculture is challenging, because of difficulties in estimating gross and net emissions, both for particular activities and as a proportion of total GHGs.

Sources of direct agricultural emissions include: enteric fermentation by ruminants (cattle, sheep etc.) (CH_4); manure deposited on grazing lands (N_2O); synthetic fertilisers (N_2O); rice production (anaerobic decomposition on flooded fields) (CH_4); stored manure (CH_4 and N_2O); crop residues (N_2O), manure deposited on croplands (N_2O); and cultivation of organic soils N_2O).

Tubiello et al. (2015) estimate that agricultural emissions, defined as *crop and livestock production,* approximate 5.4 Gt CO_2eq yr^{-1} - in comparison to other land-use emissions which total around 4.8 Gt CO_2 yr^{-1}. Accordingly, agricultural emissions contribute around 10% of total GHG emissions annually (although there is uncertainty over the gross or net status of some of the data). The paper emphasises that while land-use emissions have remained stable: '*agriculture emissions have continued to grow… and remained larger than the land use sector in 2012'.* These findings were in line with Smith et al (2014) [AR5].

50 **Soil and Carbon**
Soil plays a vital role in the global carbon cycle: *'soils generally hold more carbon than vegetation across biomes and account for 81 percent of terrestrial carbon stock at the global level'* (World Bank, 2012, p.5). Lal, R., et al. (2012) estimate the global soil C pool at approximately 3,294 Pg, in comparison to the biomass C pool which is estimated to be approximately 620 Pg. Lal further explains that soil carbon stocks vary widely across terrestrial biomes, being particularly high in boreal forests and peatland soils .

The erosion of soil through deforestation, degradation of terrestrial biomes and agricultural practices can therefore have a significant negative impact, resulting in the release of substantial portions of these soil carbon stocks to the atmosphere. Lal, R., et al. (2012) estimate that there are 3.5 billion hectares of degraded soils and desertified ecosystems worldwide and that: *'the technical potential C sequestration through restoration of degraded lands is estimated at 0.5-1.4 PgC yr, of which that through the restoration of the world's saline soils is 0.3-0.7 PgC yr* (p.33).

Smith et al (2008) estimate that around 50 PgC have historically been emitted from the erosion of soil in agricultural systems. Lal, R. et al. (2012) estimates soil sequestration potential in croplands to be 0.4-1.2 Pg C yr and the sequestration potential of improved grazing land management to be 0.3 – 0.5 PgC yr.

51 Smith et al (2008) state that: *Agriculture accounts for 52 and 84% of global anthropogenic methane and nitrous oxide emissions. Agricultural soils may also act as a sink or a source for CO_2, but the net flux is small.*

52**Representation of all GHGs as CO_2 equivalent**
The relationship between emissions from land-use and emissions from agriculture can be confusing and misleading. This is due in part to the system of converting all non CO_2 Greenhouse Gases into CO_2eq. This is problematic because emissions from agriculture tend to comprise primarily of CH_4 and N_2O, whereas emissions from land-use comprise mostly of CO_2. For instance Boucher and Ferretti (2015) claim that *'the two main components of the sector's* [AFOLU's] *annual global warming emissions have been trending in opposite directions, with those from **forests**…declining to about 4.8 billion tons of CO_2eq yr-1. By contrast, emissions from **agriculture** have been growing, and they now account for about 5.4 Gt CO_2eq yr-1'*. However, if we were to compare emissions from these two sectors only in terms of carbon dioxide, then land-use emissions would far outweigh agriculture.

Neubauer and Megonigal (2015) further explains that in the conversion of all GHGs to CO_2eq the temporally variable elements of the different gases are lost, and the system does not account for continued or sustained release of emissions into the atmosphere over time – instead gases are seen to be emitted in one single 'pulse'.

[53] **Terminological Issues**
The accounting systems for land-use and agricultural emissions present various definitional issues and ambiguities that can confuse or obscure emissions and sequestration data. It is not always clear exactly what aspects of agriculture are counted under AFOLU and which are counted under other categories. For instance, analysis in Tubiello et al (2015) showed that all the three data sets used in Smith et al (2014) [AR5] accounted for different variables: the FAOSTAT database covers all agriculture, forestry and other land use activities and their associated CO_2, CH_4 and N_2O emissions, the EDGAR dataset which further included emissions from energy use in agriculture, which should be reported in the energy sector, and finally the Houghton approach which estimates CO_2 from land use and land use change but does not include agriculture. These three datasets demonstrate the complexity of the accounting approaches in this field.

[54] Dickie, A., et al. (2014) explains: '*Levels of carbon in the soil and above-ground biomass eventually reach saturation at which point additional sequestration is not possible. In the future that carbon can also be released back into the atmosphere depending on the crop management practice and climatic conditions*' (p.28).

[55] On beef as a driver of deforestation, see Stokes et al (2014) and Climate and Land-Use Alliance (2014); on estimates of methane emissions from livestock, see Steinfeld (2006).

[56] **Estimates of land-use mitigation potential**
Houghton (2013b) estimates overall forest mitigation at 3-5GtC per annum, through the aggregate of three pathways: '*1.Halting deforestation and forest degradation, 2. Protection of re-growing forests, and 3. Re-establishment of forests on lands formerly forested but not intensively use now*) *could reduce emissions by 3 -5 PgC yr, enough to stabilise the concentration of emissions of CO_2 in the atmosphere*.' See also Houghton (2015) which repeats the 5GtC per annum estimate, together with analysis of how such concerted actions could play a significant part in meeting global abatement requirements to 2050.

Most other estimates that include sequestration are in the 24-30% range. See: Global Commission on the Economy and Climate (2014), See Chapter 3: Land-Use, p17, Box 5; Wolosin (2014); Goodman et al (2015); Busch et al (2014). Houghton et al (2015).

[57] See UNFCCC (2015), p31, point 137: *'Some of the INDCs contain information specific to LULUCF accounting. Many of them, however, do not include comprehensive information on the assumptions and methods to be used in the accounting of emissions and removals from LULUCF. This presents a major challenge in the assessment of the aggregate effect as it represents a major area of uncertainty.'*

[58] See Houghton (2015) for a full analysis of the possible roles of tropical forest mitigation and fossil fuel abatement through the 21st century.

[59] See : Jain, A.K., et al. (2013). For a commentary on the paper, see Pongratz, J. (2013); and Batterman, S.A., et al. (2013).

[60] See: Spracklen, D.V., et al. (2012); Aragao, L.E.O.C. (2012); Hilker, T., et al. (2014); Butler, R. (2014); Butler, R. (2014b); Nobre, A. (2014); Lawrence, D. and K.Vandecar. (2014).

[61] See ISU (2015), p31-35 for an overview on these topics, and citations for a range of relevant papers.

[62] See: Rockstrom, J., et al. (2009); Steffen, W., et al. (2015a); and Steffen, W., et al. (2015b).

[63] See Millennium Ecosystem Assessment (2005), the product of four years of work by 1300 authors in 95 countries.

[64] See: United Nations (2014).

[65] The Global Commission on the Economy and Climate. 2014. See pp.115-116 and p.117.

[66] Hosonuma, N., et al. (2012). Comprehensive data for temperate and boreal forests does not appear to be available.

[67] See: Slik, J.W.F., et al.(2013). See also Nascimento, H.E.M. and W.F.Laurance (2002), which found 82 per cent of aboveground biomass residing in trees of greater than 10cm diameter. See also Brown, I.F., et al. (1995), which found that that 50 per cent of live aboveground biomass was found in just 3 per cent of the trees; and Malhi, Y., et al (2014).

[68] **Projecting Future Wood Demand**
According to the FAO (2015) the current area of global planted forest is 290 million ha, which shows a net increase of 15 million ha between 2010-2015. In the same period net natural forest has decreased by 33 million ha and total carbon stocks of above and below ground biomass have decreased. This indicates that the current rate of plantation increase may not be sufficiently relieving pressure on natural forests. The report also found that the global demand for wood products has increased from 2.75 billion m^3/yr in 1990 to 3 billion m^3/yr in 2011.

Several recent studies have projected a future imbalance between the supply and demand for wood products, in particular industrial roundwood timber. For instance: Elias and Boucher (2014) estimate that a total of 125 million hectares of additional plantations would be needed to meet global wood demand in 2060. A report by Indufor (2012) predicts total global plantation area to only reach 91 million ha in 2050. Payn et al (2015) also question whether our current trajectory could attain plantations on this scale: *'the annualised rate of increase in area of planted forests slowed in the 2010-2015 period to 1.2% below the 2.4% rate suggested is needed to supply all of the world's timber and fibre needs.'*

Indufor (2012) forecast that by 2050 plantation based wood will satisfy between 24-35% of global industrial wood requirements. The reports medium scenario sees a decrease in supply met by plantations from 33% in 2010 to 24% in 20150. This indicates that the majority share will still be sourced from natural forests. The report concludes that it is highly unlikely that plantations will be able to supply growing demand for industrial wood products.

Other studies have highlighted that increasing the area of plantations for wood supply has had a positive effect on global forests. For instance Buongiorno and Zhu (2014) estimated that planted forests have reduced roundwood harvesting from natural forests by 26%, indicating that around 816 million m^3 of natural forests have been saved from deforestation and degradation as a result.

Studies have also shown that sourcing wood from plantations is preferable to selective logging and reduced impact logging (RIL) techniques. Shearman et al (2012) calculated that 20% of global tropical forests are currently allocated to selective logging operations and estimated the time taken for logged forests to resemble primary forest in biomass, timber volume and species diversity to be 45-100, much longer than the 30-35 year cycle of logging. Shearman found RIL to reduce but not fully tackle the forest degradation problem and predicted that in the absence of fundamental change: *'logged tropical forests will continue to be overharvested…leading to an inevitable global decline in native timber supplies'.*

See also: Naburs et al (2014); Jürgensen et al (2014).

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[69] See: Assunção, J., et al. (2013).

[70] See the Tropical Forest Alliance 2020 (http://www.tfa2020.com/) and the Consumer Goods Forum (http://www.theconsumergoodsforum.com/).

[71] See the BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL) (http://www.biocarbonfund-isfl.org/). This initiative is supported by the UK, the US and Norway. For more information on their $280 million pledges to the ISFL see DECC (2013).

[72] See Nepstad et al (2014).

[73] Rautiainen, A., et al. (2010) states that between 2000 and 2005 the European Union accounted for 12% of global afforestation – a figure three times larger than its share of global forest area – due to the expansion of forests (in particular preserved forests) and national parks in the second half of the 20th Century.

However, disaggregated data that separates plantations from natural forests shows minimal changes. In the US for instance the total planted forest area increased by 29.27%, however natural forest area only increased by 0.09% - this is commonly reported as a gross change of 2.53%. Similarly in the European Union total planted forest area increased by 16.09% and net natural forest increase was 3.35%, however this is reported as a gross forest increase of 7.86% (Data adapted from Tables 3 and 9, *Global Forest Resources Assessment 2010*, FAO).

[74] See: UNEP (2015a).

[75] See https://www.iisd.org/GSI/fossil-fuel-subsidies.

[76] See New Climate Economy, 2014, chapter 3, p117.

[77] For an overview of these topics (and references to key papers and reports) see ISU (2015), pp38-42).

[78] See UNEP (2015). The figure of US$10 trillion annually for developed countries is from 2020.

[79] The produce concept does to some extent include bioenergy (charcoal and woodfuel plantations for domestic consumption) and some deployment of suite of forestry approaches (selective logging of high-value timbers, some reforestation and afforestation, within and outside of natural forests).

[80] See, for example, the presentations made at the 2014 Global Landscapes Forum, London, 10th June. These are all downloadable at http://www.landscapes.org/london/. The presentation on the new UNCCD Land Degradation Neutrality (LDN) Fund (http://www.slideshare.net/CIFOR/ldn-fund-presentation-london-glf3) is particularly noteworthy.

[81] See OECD (2015); Alexander, N. (2014).

[82] See http://www.un.org/wcm/webdav/site/climatechange/shared/Documents/AGF_reports/AGF%20Report.pdf

[83] See Sayre et al (2014).

[84] See Crowther et al (2015). This study found that approximately 15 billion trees are cut down each year. The total is offset by the growth of 5 billion new trees per annum, leaving a net tree loss of 10 billion trees per year.