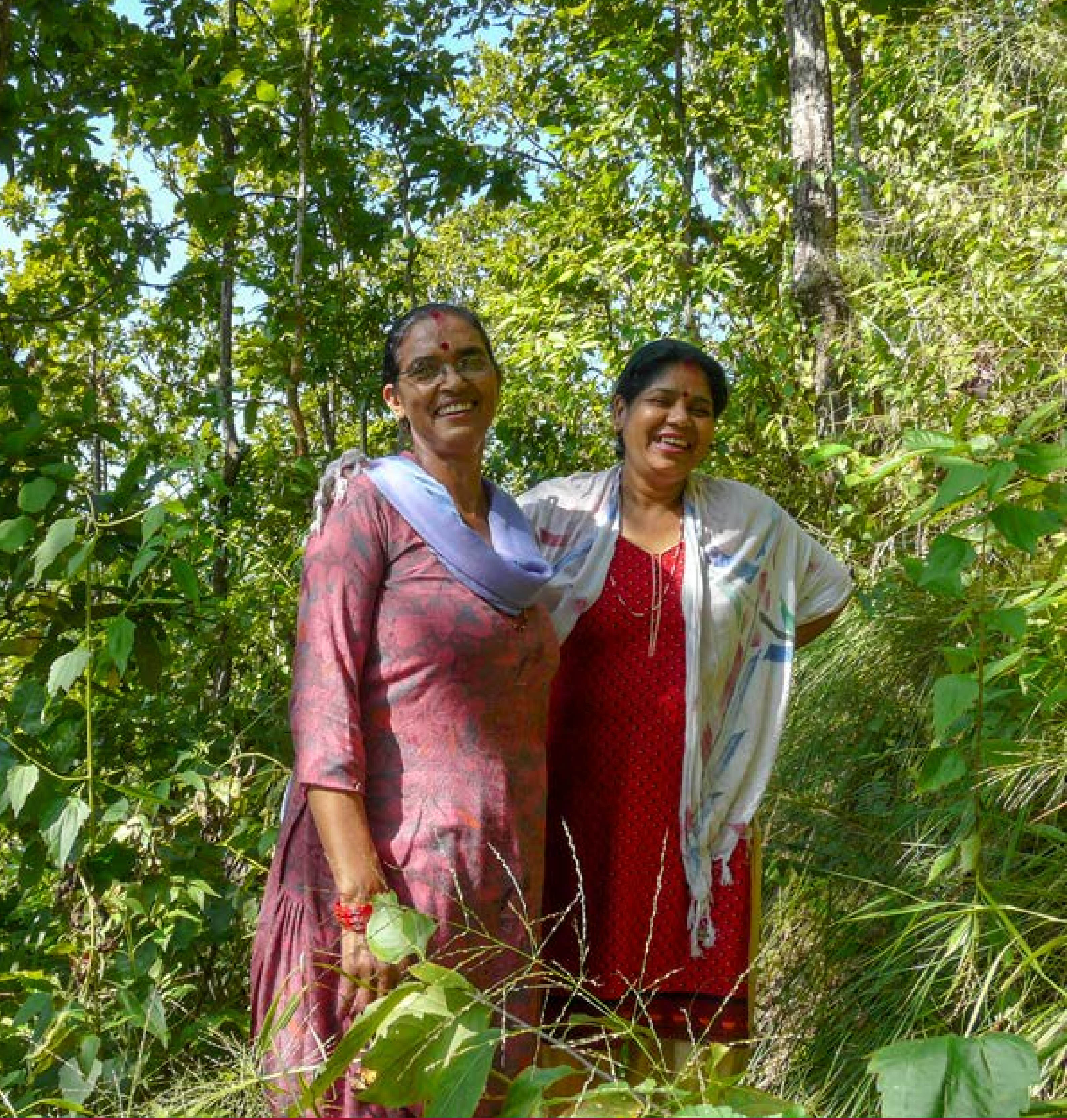

IMPLICATIONS OF NEW RESEARCH FOR THE IPCC 1.5°C SPECIAL REPORT, WITH A FOCUS ON LAND USE

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Cover: The magnitude of Indigenous Peoples' and local communities' contributions to climate change mitigation is even greater than previously realized. Photo: © Hanna Aho, Nepal.

Executive summary

Interested scientists are currently invited to review the Second Order Draft of the Intergovernmental Panel on Climate Change (IPCC) Special Report on the 1.5°C target. The submission deadline for literature to be considered in this version of the Special Report was 1 November 2017. Assembled here are key findings from a number of papers that appeared in the latter half of 2017 and pertain to the land-use sector.

This literature review is intended to assist IPCC authors and external reviewers of the Second Order Draft (SOD) during the comment period, which ends on 25 February. The paper begins with a brief examination of the Sixth Assessment Review (AR6) context for the current IPCC Special Report, and then moves on to a review of newly-published and in-press work predating preparation of the Second Order Draft. Our intention is that compilation will help authors and reviewers incorporate new findings and insights into the SOD and the Summary for Policy Makers.

The paper looks at potentials to unlock more **forest-sector mitigation**, achieved through ecosystem restoration, reforestation, afforestation, and 'improved forest management' defined in relation to appropriate social and ecological safeguards; and then outlines current research frontiers in two other key components of a Paris Agreement-aligned Agriculture, Forestry and Other Land Uses (AFOLU) mitigation strategy with high co-benefits: **agriculture/agroecology/food system change, and community/ indigenous control of land**. Some of this ambition potential is not yet captured in the peer-reviewed literature, but is nonetheless responsive to the 'Chairman's Vision' for the AR6, which is to include the full spectrum of climate risks faced by society.

A continuing research agenda in 2018, relevant also to findings of the IPCC Special Report on Land/ Desertification/Food Security that will appear mid-year, is deeper inquiry into the synergies, trade-offs, and co-benefits associated with these three different areas of land-use mitigation effort. The review does not purport to be comprehensive, and does not discuss radical mitigation pathways outside of land use.

In conclusion this review argues that the Special Report should: continue deeper inquiry into the role that natural climate solutions can play in delivering early, enhanced mitigation outcomes; provide critical analysis of assumptions regarding the feasibility of mobilizing biomass for BioEnergy Carbon Capture and Storage (BECCS); and pay greater attention to both the burden-sharing and inter-generational dimensions of responding to climate risk. Most broadly, the IPCC should find ways to incorporate the greater variety of 'non-overshoot' mid-century scenarios that are now under development, and that will appear in the peer-reviewed literature in 2018, to inform scenario planning related to the long-term (1.5°C) goal. This emerging research strengthens arguments for much greater mitigation ambition in the thirty years to 2050, with the intention of using ecosystem-based climate solutions to fill a substantial portion of the existing 'ambition gap' in Paris pledges.

PART 1
Purpose and context

Purpose

The primary purpose of this paper is to review and comment on literature published or accepted for publication just prior to the cut-off date for consideration of the Second Order Draft (SOD) of the IPCC Special Report (SR) on the 1.5°C goal, to inform a community of climate researchers and practitioners who are current engaged with reviewing the SOD. Specifically, recent (2017) peer-reviewed literature relevant to climate mitigation responses in land-use sectors is considered here, supplemented by context from earlier papers. Later sections also consider potential literature gaps and what addressing those gaps could mean in terms of potential enhanced ambition.

This literature review is not comprehensive. From a subject matter perspective, attention is confined to new literature that pertains to the *land use sector* (agriculture, forestry, and other land use – AFOLU), as well as those negative emission technology pathways with high land-use impacts. From a practical perspective, there is the inherent difficulty of tracking literature ahead of actual publication dates, and thus a more thorough review in 2018 would likely reveal many more pathway, sector, and region-specific analyses than are considered here. But several papers published in the latter half of 2017 deserve attention in relation to this Special Report topic, and so a qualitative synthesis of those research findings should be useful for SR authors and reviewers.

Context

Three nested concerns provide the context for this paper. Most broadly, this review pulls from the 'Chairman's Vision Paper' regarding how products from the Sixth Assessment Review (AR6) should feed into the work of the United Nations Framework Convention on Climate Change (UNFCCC) (Chairman's Vision Paper, March 2017). So the report focuses on current knowledge while a later section also "deliver[s] information that will illuminate pathways to further ambition", and in the Discussion section, notes themes common to this new literature.

The AR6 cycle includes three Special Reports in addition to the full Sixth Assessment Report. The SR on the 1.5°C goal is most clearly aligned with the Facilitative Dialogue[1], which aims to enhance global mitigation ambition, including through pledges submitted for 2020 and those leading up to the 2023 'Global Stocktake'. Noting this challenge, this literature review emphasizes actionable information to inform dialogue at the UNFCCC as it pertains to the land-use sector. Here too this review is guided by statements from the Chairman's Vision Paper:

> AR6 does not focus solely on meeting the information needs for the implementation of the Paris Agreement, but adopts a comprehensive approach to meet the information needs relevant to implementing the broader global development agenda, such as synergies between adaptation and mitigation in the context of sustainable development, associated costs, co-benefits and risks, and climate action solutions in the context of pursuing the Sustainable Development Goals (SDGs).

1 Under UNFCCC Conference of Parties (COP) leadership from the Republic of Fiji, the Facilitative Dialogue was renamed the 'Talanoa Dialogue'. In a decision from COP23: "[The Conference of Parties] welcomes with appreciation the design of the 2018 facilitative dialogue, to be known as the Talanoa dialogue…."

PART 2

Key new literature

Part Two of this review groups relevant new literature into four major headings:

a) updated consideration of non-overshoot pathways;
b) elaboration of mitigation pathways more reliant on ecosystem-based negative emission technologies, often described as 'natural climate solutions', distinct from geoengineered solutions;
c) refinement of assumptions pertaining to the sustainability of bioenergy supply when use of BECCS is deployed at scale; and
d) the international and inter-generational equity implications of scenarios being considered as part of the 1.5°C SR.

A) Non-overshoot 1.5C pathways

IPCC SR authors in 2017 were able to draw upon existing literature and modeling runs focused on limiting global warming to 2°C, as per the earlier long-term temperature-rise limit adopted by the UNFCCC; but during last year's preparation of the SR First Order Draft the available peer-reviewed literature on adhering to the more-ambitious 1.5°C temperature rise was extremely limited. Here the focus is on three publications that appeared in 2017, each of which used different approaches to limiting warming to well below 2°C.

Rockström *et al* (2017) proposed framing the decarbonization challenge in terms of a global decadal roadmap based on a "carbon law" of halving gross anthropogenic CO_2 emissions every decade, bringing temperatures down to 1.5°C by 2100. Holz *et al* (2017) took seriously the 'ratcheting' opportunity provided for in the upcoming UNFCCC Global Stocktake to increase ambition across all nationally determined contributions (NDCs), and consequently to model pathways that keep to the 1.5°C temperature limit. Kuramochi *et al* (2017) used a sector-by-sector approach to defining necessary ambition, focusing on ten action-oriented benchmarks. They imply the necessity of a 95% reduction in total emissions from the land-use sector globally between 2010 and 2030 as a measure of this sector's appropriate contribution to ambition in limiting warming to 1.5°C.

All three papers acknowledge the necessity of removing carbon from the atmosphere in order to limit global warming this century (see also Minx *et al* 2017). Rockström *et al* (2017) combine a per-decade halving of gross emissions with aggressive carbon removal efforts, including substantial reliance on BECCS. Holz *et al* (2017) assert that even a very strong effort in the land-use sector will still require a dramatic uptick in mitigation ambition, particularly from wealthier countries, in the 2020 decade. Mitigation effort is thus distinguished from 'carbon dioxide removal' (CDR). Kuramochi *et al* (2017) also make clear their assumption regarding near-term land-use emissions: net deforestation by 2025 must be zero. Some authors go even further to suggest that the term 'carbon dioxide removal' should *only* refer to the management of overshoot. Here however I use the term 'carbon dioxide removal' more generally in the land-use context to encompass all strategies that enhance mitigation, and limit the term 'negative emissions' for use in the 'no-overshoot' context of limiting warming to 1.5°C.

The differences between the papers in how they frame and delimit the removal of carbon dioxide from the atmosphere as a contribution to achieving 1.5°C pathways are instructive. Holz *et al* (2017), following the work of Anderson and Peters (2016), argue that the mitigation agenda should proceed on the premise that engineered CDR technologies will not work at scale, thus warranting a 'precautionary approach' to the use of negative emission technologies. In their discussion, the authors note that 1.5°C pathways can be achieved while placing constraints on the use of 'negative emissions' – but doing so, they note pointedly, would require societies to "investigate rates of CO_2 reductions well outside of what is currently deemed plausible" in existing IAMs.

Kuramochi *et al* (2017) do not invoke the precautionary principle, instead stating that "negative CO_2 emissions will unfortunately be necessary at scale from mid-century to limit warming to 2°C, and even more so for 1.5°C", and arguing that BECCS is a "cost-effective mid- to long-term option" for limiting warming. The authors expect that negative emission technologies such as BECCS would need to extract more than 500 GtC02 from the atmosphere up to 2100. Without citing specific volumes of necessary removals, Rockström *et al* (2017) refer to "immediately instigated, scalable carbon removal [efforts] and efforts to ramp down land-use CO_2 emissions" as crucial for achieving 1.5°C pathways. Both countenance greater reliance on BECCS than Holz *et al* . (2017).

Ratcheting ambition

To illuminate some of the tradeoffs between increasing reliance on the land-use sector for removals and early action across sectors, Holz *et al* (2017) start by noting the level of mitigation ambition found in current NDCs, and then investigate two levels of increased performance related to CDR. They then apply these increasingly stringent applications of 'ratchet success' to all sectors, including land. They conclude that if only a minimum ratchet is seen in the coming decade, then demand for carbon dioxide removal is higher than the mean of CDR required in scenarios considered in AR5 (883 $GtCO_2e$ by century's end).

Once again this clarifies a value seen across the literature: mitigation actions in the land-use sector will help, particularly if pursued immediately, but these actions do not in any way excuse or offset the need for drastic emission reductions in other sectors. Kuramochi *et al* (2017) make this explicit in two ways: first, "if a sector does less, in particular the energy, industry and transport sectors, it would leave a high-emissions legacy for many decades". Second, they reject trade-offs between land use action and the pace of fossil fuel CO_2 emission reductions. Instead, land use action provides "essential protection of the natural storage reservoirs of carbon..." – this is one reason the paper frontloads ambition in the land-use sector with a 95% reduction by 2030. In its 2017 Emissions Gap Report, the United Nations Environment Programme (UNEP) states plainly that "carbon dioxide removal is concerned with the management of overshoot, even in the event that all mitigation options are pursued." Finally, Smith *et al* (2015) note that "there is no negative emission technology [NET] (or combination of NETs) currently available that could be implemented to meet the <2°C target without significant impact on either land, energy, water, nutrient, albedo or cost, and so 'plan A' must be to immediately and aggressively reduce [greenhouse gas] GHG emissions."

Contributions from the land use sector and limiting overshoot

Holz *et al* (2017) unpack assumptions relating to CDR, and how biodiversity and food security lenses might be applied to the protection of natural carbon storage reservoirs. Extending use of the precautionary principle to select only those CDR approaches already proven to work at scale and assumed to have adequate social acceptability, they run a 'limCDR scenario' – limited to "afforestation and reforestation" – that yields 206 gigatons of carbon (GtC) of removals over the century. The authors note that "This amount is well in the range of other studies that take a more precautionary approach to CDR. Because of this constraint, deeper emission reductions need to occur in the first half of the century to meet the 1.5°C objective." As is discussed below, both Griscom *et al* (2017) and Dooley and Kartha (2017) find further opportunities for relatively low-cost, near-term opportunities to increase removals through restoration. Overall the trend in the 1.5°C SR SOD toward deepening the examination of land use solutions is welcome, since the potentials from AFOLU sectors provide important empirical grounding against which a postulated reliance on BECCS can be examined.

Overshoot

Dooley and Kartha (2017) present a framework for evaluating the risks pertaining to different negative emissions. First, is it technically feasible? Second, are the impacts – economic (cost), ecological, or social – unacceptably large? Are there potential irreversible harms associated with any 'peaking' scenario above 1.5°C, even if atmospheric CO_2 levels can be lowered? Third, what are the consequences of ineffectiveness – either through the reversal of carbon sequestration (impermanence), or because momentum in the climate system overwhelms earlier-stage CDR efforts? Obtaining a clearer picture of answers to these questions is critically important across the IPCC's current AR6 workplan, as the Chairman's Vision Paper calls for the integration of risk frameworks with "the solutions-focused, problem-solving frameworks [that] should be the overarching framing of the AR6."

The long term

Hansen *et al* (2017) remind us that "Earth's energy imbalance assures... temperature will continue to rise unless and until the global climate forcing begins to decline." McBain *et al* (2017) note that

"Continued overshoot, although possible in the short term, means the global community is increasingly exposed to risks of environmental collapse due to the approach of at least two planetary boundaries relating to land use expansion and climate change." These reminders take on added importance in light of what Geden and Löschel (2017) refer to as "normalization of the overshoot idea". The authors are concerned that the basic parameters of overshoot – duration and magnitude – "would turn into potential sources of political flexibility." They thus urge the development of clear constraints to temperature overshoot in this century; in the absence of such constraints, political leaders "cannot fail or be held accountable." Finally, they join Hansen *et al* (2017) and McBain *et al* (2017) in warning against the 'planetary boundary' threat of allowing for 2°C of temperature rise, since that amount of warming is much more likely to trigger strong slow feedbacks such as accelerated ice sheet collapse: "There is increasing evidence that some slow feedbacks can be triggered within decades, so they must be given major consideration in establishing the dangerous level of human-made climate interference" (Hansen *et al* 2017).

B) Terrestrial carbon dioxide removal potential

Continued uncertainty regarding the volume and permanence of CO_2 removals in forestry, as well as very contested terrain regarding achievable reductions in greenhouse gas emissions from agriculture, has perhaps made Integrated Assessment Model (IAM) modelers and IPCC authors reticent to rely heavily on future projections of terrestrial CDR potential—although it's less clear why under such circumstances, pathways that required a huge volume of negative emissions through BECCS were relied upon. Nonetheless, the previous section makes clear not only the urgency of action in the land-use sector to minimize the duration and magnitude of mid-century and end-of-century temperature overshoot, but also the importance of improving our understanding of the potential volume of ecosystem-based solutions realizable with existing (or near-field) technologies, and/or achievable through policy and market reforms. Hansen *et al* (2017) strike a partly optimistic note by observing that although "the difficulty of stabilizing climate was… markedly increased by a delay in emission reductions from 2013 to 2021… Nevertheless, if rapid emission reductions are initiated soon, it is still possible that at least a large fraction of required CO_2 extraction can be achieved via relatively natural agricultural and forestry practices with other benefits." In this section I explore recent research that brings greater clarity to what that 'large fraction' might be.

Two key papers published late in 2017 on this topic are Griscom *et al* (2017) and Dooley and Kartha (2017). Griscom *et al* describe and quantify twenty discrete mitigation options (which they refer to as pathways) within the AFOLU sector. These twenty pathways are defined as 'Natural Climate Solutions' (NCS). In their analysis, Dooley and Kartha focus solely on forest ecosystem-based pathways, distinguishing between reforestation and forest ecosystem restoration. The heading 'restoration' in Griscom *et al* (2017) is used only in relation to wetlands (coastal and peat); for forests, the three most critical pathways identified are reforestation, avoided forest conversion, and natural forest management.

The two papers address themselves to different precedents and cross-cutting global goals. The twenty Griscom *et al* (2017) pathways are disaggregated from the eight broad land-use categories[2] reported by IPCC Working Group 3 in the previous (AR5) assessment. Griscom *et al* find "a greater share of cost-constrained potential through reforestation, forestry, wetland protection, and trees in croplands than the IPCC AR5, despite our stronger constraints on land availability, biodiversity conservation, and biophysical suitability for forests… NCS [can] provide 37% of the necessary [CO_2 equivalent] CO_2e mitigation between now and 2030 and 20% between now and 2050 [for a 2°C pathway]….Half of this cost-effective NCS mitigation is due to additional carbon sequestration of 5.6 Pg$C0_2$e/yr by nine of the pathways, while the remainder is from pathways that avoid further emissions of CO_2, CH_4, and N_2O." They conclude that "our estimate [of AFOLU mitigation potential] is higher, despite our food, fiber, and biodiversity safeguards, because we include a larger number of natural pathways…. 30% higher than prior constrained and unconstrained maximum estimates." The authors' use of cost thresholds for effective mitigation actions in the land-use sector is helpful: "effective NCS carbon sequestration opportunities compare favorably with cost estimates for emerging technologies, most notably bioenergy with carbon capture and storage (BECCS)."

Dooley and Kartha (2017) address the synergies and trade-offs between land-based negative

2 Urban, Cropland, Cropland Fallows, Grazing Lands, Extensive Grazing, Forestry, Unused forests, other Unused (Natural, or Regenerating).

emission technologies and three of the SDGs, which "represent a consensus set of global objectives related to development." They evaluate four land-based NETs – avoided emissions in the land sector, forest ecosystem restoration, reforestation, and BECCS – first in relation to its proposed or assumed mitigation potential, and then in relation to the three SDGs selected. ('Forest ecosystem restoration' assumes the ability to build upon natural processes to restore forests; Dooley and Kartha constrain their definition of 'reforestation' specifically to areas where "the land's capacity for natural regeneration has been lost or severely impaired.") The authors then provide "an indicative estimate of what might be considered a 'sustainable' mitigation potential for each NET, considering SDG constraints." From these four pathways, they suggest that 370-480 Gt CO_2 (101 – 131 GtC) in carbon removal *could* be achieved "without jeopardizing other critical land uses and sustainable development objectives." They note a frequently-underestimated source of land-use-sector emission reductions: landscape-level restoration –"both restoration of closed-canopy forests and mosaic restoration of more intensively used landscapes." Dooley and Kartha see a further 100GtC in *restoration* potential, in ways that Griscom *et al* (2017) did not explicitly capture in their focus on *reforestation*.

Dooley and Kartha's analysis has been given a further boost by the recent work of Erb *et al* (2017) which suggest that "land management effects" – defined as biomass stock changes within a particular land-use type, which is to say primarily sub-canopy and structural forest degradation, but not complete deforestation resulting in land conversion – contribute 42-47% of the difference between current and potential biomass stocks – a figure they argue has been underestimated in the literature.

Transforming global land use from a net source of emissions to a net sink is itself an enormous undertaking. Overall, Kuramochi *et al* (2017) note that for a two degree pathway, "an emissions abatement effort of around 1 $GtCO_2e$/yr by 2030 is required in the agriculture sector against baseline projections of 7.5-9 GtC02e/yr." The express goal of turning '20% of the problem into 20% of the solution' – that is, to reverse emissions from deforestation and agriculture to achieve net sink status – is possible. Dooley and Kartha (2017) suggest however that achieving a meaningful volume of CDR from afforestation, reforestation, and forest ecosystem restoration is "extremely challenging ...[and] would impose a demand for land that could jeopardize other critical land uses....present[ing] serious risks if not implemented with strong governance, legal and human rights oversights."

Griscom *et al* (2017) conclude that "reforestation is the largest natural pathway and deserves more attention to identify low-cost mitigation opportunities." One controversial aspect of this study is its assumption that all grazing land in forest ecoregions would be reforested—thus, 42% of the reforestation opportunity they identify is in lands now used for grazing within forest ecoregions. Griscom *et al* do include a sensitivity analysis assuming 25%, 50%, and 75% of these grazing lands were not reforested, with corresponding reductions. On the other hand, they note that "this <2 degree ambition mitigation level...would displace only 4% of global grazing lands."

A note on units and comparability

Papers covered in this review use Petagrams of carbon, Petagrams of carbon dioxide equivalent, Gigatons of carbon, and Gigatons of carbon dioxide equivalent. Fortunately, Petagrams and Gigatons of carbon are equivalent. The issue that frequently confounds comparability is in conversion from C to CO_2 (or vice-versa), because carbon dioxide has a molecular weight that is 3.67 that of C (due to the presence of two oxygen atoms). Thus, one ton of carbon equals 3.67 tons of carbon dioxide.

When in quotes, the original units of the published source are used; but elsewhere units are converted to Gigatons of CO_2e to improve comparability. More standardization of units used to describe mitigation potentials would be helpful to lay readers in understanding the levels of ambition associated with different research findings.

In sum, Griscom *et al* (2017) identify the maximum additional mitigation potential from all natural pathways, with safeguards, as 23.8 Gt CO_2 /yr *at a 2030 reference year*; while Dooley and Kartha (2017) identify a *cumulative* 21st century target of 370-480 Gt CO_2 in carbon removal. Griscom *et al's* (2017) optimistic, "all-of-the-above" scenario thus suggests that the 21st century reduction target proposed by Dooley and Kartha (2017) could be reached by 2050. Dooley and Kartha assume a sixty year period after which carbon gains cannot be counted on, due to saturation, thus dividing by sixty (and not using a 'peak' reference year), the authors see the potential for annual $GtCO_2$ removals of 6-8 Gt CO_2. Houghton *et al* (2015) note that although estimates of land areas available for reforestation vary, reforestation of 500 Million hectares could sequester more than 1 Gt CO_2 /year for decades. They summarize potential gains in relation to three strategies for increase: halting deforestation/forest degradation; allowing secondary forests "recovering from harvest" to re-grow; and afforestation.

Meanwhile, Hansen *et al* (2017) also start from a re-examination of whether a concerted global effort on carbon storage in forests and soil might have potential in this century to provide a carbon sink of roughly 100 PgC (367 Gt CO_2) – and conclude that this is an "appropriately ambitious estimate for potential carbon extraction via a concerted global-scale effort to improve agricultural and forestry practices with carbon drawdown as a prime objective." Equally important, they point out that BECCS appears to be a much more expensive approach to carbon extraction – perhaps prohibitively so, if other forms of ambition are not simultaneously pursued. Smith *et al* (2016) are more cautious in suggesting that reforestation and afforestation together have a carbon storage potential of only about 1.1 Gt C/year (~4GtCO_2 / year). They use 50 years as the average time to reach C storage saturation (thus a cap of 55 PgC (202 Gt CO_2)) this century; other studies use non-linear rates of sequestration that reach saturation after sixty years. Perhaps most important is to understand that this potential source of carbon 'drawdown' is a time-limited opportunity, and can be pursued aggressively, one time only, as part of a broader multi-decade suite of strategies to limit warming to 1.5°C.

C) Potentials from agriculture

Agriculture-based pathways were not included in the discussion of 'CDR' strategies above. There may indeed be significant mitigation gains through CDR that could be realized from agroecological approaches using the different agriculture techniques described below. Overall, however, we believe that the debate on agriculture-sector reductions has overemphasizes CDR approaches at the expense of the two more significant areas where reductions can be sought, namely, through a focus on non-CO_2 emission reductions, which in particular can help in addressing the forcing potential of shorter-lived GHGs out to 2030 and 2050; and also, demand-side changes in production systems, diet, and the localization of food systems, all of which are important sources of mitigation ambition, and none of which are captured well in existing IAMs.

With respect to agriculture, then, here are laid four 'contested' strategies and four 'barely considered' strategies. By 'contested' is meant only that the strategy is intensively discussed in the peer-reviewed literature, and that different research teams have reached different conclusions. For 'barely considered' strategies, a general absence of quantitative assessments of the mitigation potential of these four strategies are noted. The 'barely considered' strategies, as part of a broader *food systems* response, may in fact hold much greater total mitigation potential than the set of the *techniques* that have mostly defined the debate. For this section to remain consistent with the focus on 2017 literature informing debate on the 1.5°C goal, considered here are the 'contested' contributions to the debate regarding techniques for enhancing mitigation. 'Non-CO_2' pollutants and a broader food systems perspective are taken up in the next section (the 'barely considered').

Climate smart agriculture

Discussions about agriculture at the UNFCCC have tended to focus on 'climate smart agriculture' (CSA) – a term with a highly contested pedigree (Neufeldt et al. 2013). In an important review publication released this year, Saj et al (2017) compared and contrasted CSA with research on agroecology. "Research on agroecology reveals an extensive knowledge about food security and adaptation, often at scales which can be considered complementary to those of CSA." Saj *et al* (2017) assert further that better use of agroecology research results may improve a focus on mitigation, but also crucially, will help clarify trade-offs and synergies between mitigation, adaptation and food security. Addressing the paucity of agroecology research in the peer-reviewed literature, the authors note that agroecology "actually responds to the needs of CSA in terms of site-specificity and potential for adoption by farmers because it is strongly based on local practices," and as such the authors argue that ecological and social approaches to CSA "represent a *sine qua non* condition if CSA is to promote inclusive development and contribute to collective efforts to manage agriculture and food systems under climate change."

Soil Carbon: an excessive expectation?

The debate over 'climate smart agriculture' – is it a set of mitigation and adaptation practices, is it a new systems approach? – has crystallized around the issue of enhanced sequestration of carbon in agricultural soils. In a recent paper laying out the case for the programmatic goal of increasing soil carbon levels by 0.4% annually ("4 per mille"), Minasny et al (2017) state that "under best management practices, 4 per mille or even higher sequestration rates can be accomplished." The authors acknowledge that the potential to increase soil organic carbon (SOC) is 'mostly on managed agricultural lands,' and that the highest response rates come in the first five years of any soil management intervention.

The '4 per mille' concept has its critics however. White *et al* (2017) challenged the scientific basis of this goal if sequestration growth rates compound to 2050, which they argue is unrealistic. Baveye *et al* (2018) argue that more attention to the conditions under which soils may act as a net source of emissions is needed: "the capacity of soils to sequester carbon is time-constrained, but also, and perhaps far more importantly, that this capacity starts decreasing as soon as sequestration is initiated... Therefore, the claim that soils can sequester between 2-3 Gt C year $^{-1}$, which effectively offset 20–35% of global anthropogenic greenhouse gas emissions, is likely to be true at best only for a few years." White *et al* (2017) accept the estimates of C sequestration rates used by Minasny *et al* (2017) for afforestation (~0.6 t C/ha / yr), as well as the estimate for conversion to pasture (~0.5 t C/ha/yr); but they calculate much lower figures for three practices (residue incorporation, no or reduced till, and crop rotation) than those given by the '4 per mille' team.

No-till agriculture

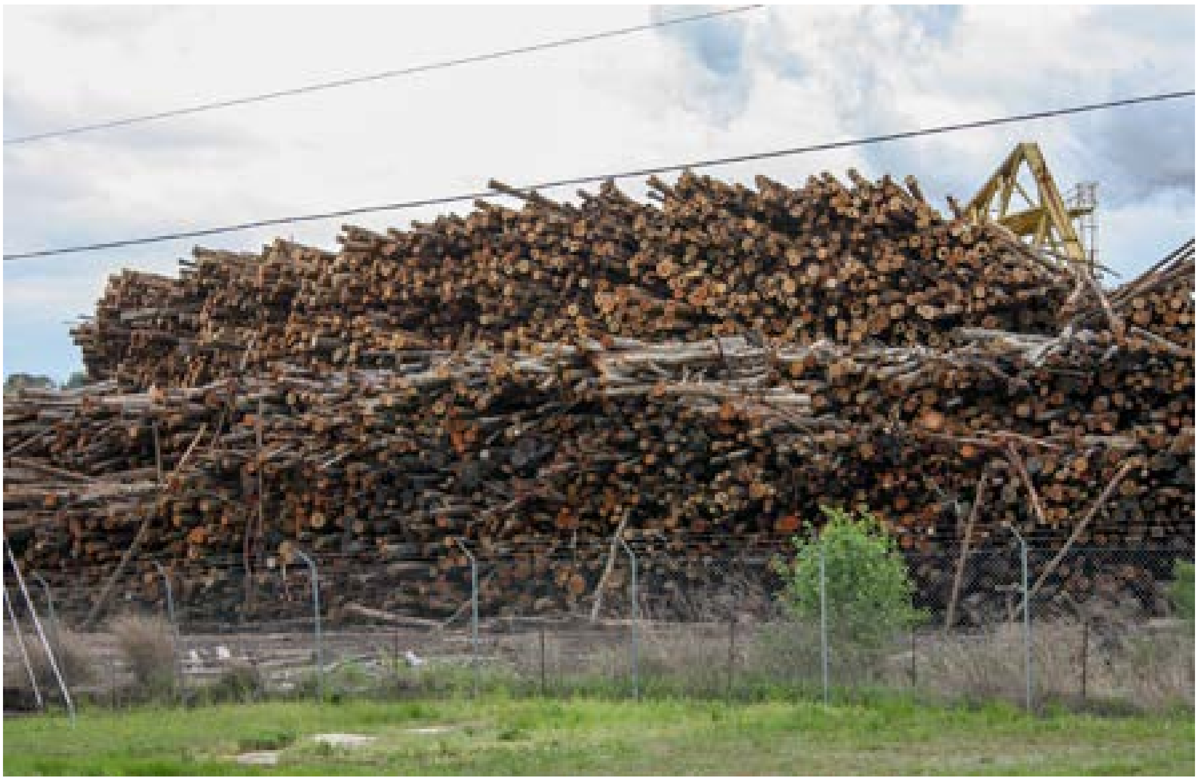
Minasny *et al* (2017) acknowledge that the "[b]enefit of soil C stock increase has now been scaled back as it has been widely observed that SOC stocks do not necessarily increase under reduced tillage methods when greater soil depths are investigated.... The calculated increases in carbon stocks under reduced tillage were largely based on top soil or plough layer. When SOC at deeper depths is accounted for (>40 cm), studies have shown that there is no significant difference between reduced and conventional tillage." Griscom *et al* (2017) do not include 'no-till' as one of the twenty constructed pathways – stating that "we did not include additional potential benefits from no-till farming given recent reviews concluding that reduced or zero-tillage does not store carbon when considering deeper soil horizons and the potential for higher N2O emissions following the implementation of no-till" – but did include 'conservation agriculture' as one of their twenty pathways investigated. The paper's supplementary material makes clear that this pathway is most dependent on expanded use of *cover crops* to increase soil carbon levels and improve resilience – a relatively simple management change, and one already extensively used in agroecological farming approaches. Dignac *et al* (2017) focused on the early results from reduced tillage interventions, but also the risk of reversibility: "the long-term effects of tillage were studied for 41 years in a large-scale cropping area in France....Reducing tillage resulted in rapid C accumulation in the first four years, and then the C stocks only slightly changed over the next 24 years... additional stored C was later lost."

Biochar

Biochar as a soil amendment useful for adaptation *and* mitigation is another contested area of research and practice. Biochar is resistant to microbial decay, and may improve the water-holding capacity of soils, and buffer changes in soil pH or nutrient availability. Frank *et al* (2017) found that "biochar additions can influence plant productivity and hence C inputs to soil in the form of plant residues." Liu *et al* (2016) find that additions of biochar can lead to dramatic increases in productivity in acidic, nutrient-poor tropical zone soils. Expanded use of biochar is one of the critical pathways modeled by Griscom *et al* (2017), even as they note that the "addition of biochar to soil offers the largest maximum mitigation potential among agricultural pathways, but unlike most other NCS options, it has not been well demonstrated beyond research settings." The critical literature on biochar suggests that as a set of soil amendment techniques, its mitigation potential has been oversold. Minx *et al's* (2017) 'topic modeling' revealed the "notable lack of policy and implementation discourse...around biochar – that should be urgently addressed," and the need for more real-world deployment and study of this approach to soil amendments, in light of food security and resilience goals, should be carried out. Focusing on another soil amendment approach, Hansen *et al* (2017) didn't rule out the utility of 'enhanced weathering', suggesting that "the cost of enhanced weathering might be reduced by deployment with reforestation and afforestation...; this could significantly enhance the combined carbon sequestration potential of these methods." In sum, mitigation gains from both biochar and enhanced weathering should be treated as speculative for the moment, and require further investigation.

D) Non-CO_2 emissions – reductions from industrial agricultural sectors

The section above outlines four 'contested strategies' for improving CO_2 sequestration performance. However, the *mitigation potential* through *reduced emissions* of the greenhouse gases associated with livestock production and fertilizer management – as



Wood that will be used for bioenergy. The land-use intensity of bioenergy carbon capture and storage is still poorly modeled, and such technology is still little understood. Photo: © Linde Zuidema.

opposed to the CDR potential from sequestering carbon in soils and ecosystems – should be a higher priority due to high potentials for mitigation *and* the greater risk from failing to abate these potent but short-lived GHG forcers. This is the first of our 'barely considered' options (the others are considered in a subsequent section). However, Holz *et al* (2017) do take up this theme, arguing for the "strong necessity of adding approaches to non-CO_2 mitigation in the Facilitative Dialogue" during the window for new, 'ratcheted' NDC commitments. Paustian *et al* (2017) note that "Improved management of N inputs, both to sustain crop productivity and soil organic matter increases and to minimize N2O emission and other losses of pollution-causing reactive nitrogen to the environment, will be an important part of strategies for negative emissions *[sic]* from soils." There is a huge volume of livestock-sector emission reductions to explore in some of this modeling, but presenting that analysis is beyond the scope of this paper.

E) Sustainable bioenergy supply potential for BECCS

A challenging legacy of the IPCC AR5 process was that assessment's reliance on BECCS to achieve <2°C pathways. AR5 authors had the unenviable challenge of squaring observed emission trends with the earlier UNFCCC goal of limiting warming to 2°C. In identifying what changes were needed to reach 2°C pathways, Working Group 3 used BECCS as the key risk-minimizing technological approach to removing emissions. The ease of including BECCS 'at scale' in the models, and the greater challenge of including in the models other, more diffuse and socially-embedded approaches such as ecosystem restoration, helps to explain why this particular technology became dominant in the modeling community. Now, however, we must grapple more deeply with some of the assumptions made in the AR5 about whether, and from where, a sustainable supply of bio-based feedstocks could realistically be obtained to fuel the growth of this proposed energy-supplying, carbon-removing technology.

Grappling with the supply question, of course, first suggests conviction that BECCS *can* work at scale, and as noted there is no proof-of-concept even for CCS at scale. This leads us to the second stage of risk assessment in Dooley and Kartha (2017): even if the scale-up of BECCS is feasible from a technical point of view, can it be deployed at scale without triggering unacceptable social and environmental costs?

Rights-based considerations come immediately to the fore. Burns and Nicholson (2017) caution that "some members of the geoengineering community... portray CDR options as 'benign' or relatively risk free, often in comparison to potential SRM [solar radiation management] technologies. We believe that it is critical that BECCS be scrutinized in a manner that protects the interests of the very same people that may be disproportionately impacted by the climate change." Although a few years old now, nonetheless it's worth citing the numbers generated by Popp *et al* (2011) with respect to the jump in food prices, if bioenergy is deployed at scale with strict forest protections remaining in place: it projects food price increases in Africa of 82%, in Latin America of 73%, and in the Asia-Pacific of 52%.

A final, 'embedded' rights consideration: overall, it appears that the value of *co-benefits* from different mitigation approaches was not central to the 1.5°C First Order Draft. Since the 1.5°C SR is focused on a mitigation target – keeping warming as close to 1.5°C as possible – concern for co-benefits is perhaps less central to this report in comparison to the mandate for the other SP now being prepared by the IPCC, on land, desertification, and food security. Nevertheless, authors and reviewers *should* focus *qualitatively* on the fact that increases in soil C levels and the use of appropriate soil amendments, plus the ecosystem-based adaptation methods that inform the practice of agroecology, are more likely to lead to substantial and necessary social and ecological co-benefits, while such co-benefits are much less prevalent in scenarios that call for extensive deployment of BECCS technologies.

A further concern is the biodiversity impacts caused by any new, large-scale mobilization of the planet's primary productivity by humans for energy generation purposes. Williamson (2016) makes the startling claim that wide-scale use of BECCS would be worse for biodiversity of terrestrial species than would a 2+°C temperature rise. Kartha and Dooley (2016) register concerns about the extent to which wide-spread BECCS deployment would require copious quantities of fertilizer ("human perturbation of the N cycle already causes significant environmental pollution and would need to be reduced by 75% to keep within planetary boundaries"); while Smith *et al* (2015) argue that "Irrigated bioenergy crops were estimated to double agricultural water withdrawals in the absence of explicit water protection policies, which could pose a severe threat to freshwater ecosystems, as human water withdrawals are dominated by agriculture and already lead to ecosystem degradation and biodiversity loss." In another simulation, Smith *et al* (2015) excluded irrigation from bioenergy production while keeping total yield constant, and found that land requirements for bioenergy crops increase by ~40%, mainly from pastures and tropical forests." Conclusion: "There will be a trade-off between water and land requirements if bioenergy is implemented at large scales."

Boysen *et al* (2017) also took up the question of what lands could be dedicated to bioenergy production: "Even if considerable (RCP4.5) emissions reductions are assumed, terrestrial Carbon Dioxide Removal (tCDR) with 50% storage efficiency requires >1.1 Gha of the most productive agricultural areas or the elimination of >50% of natural forests...The implications still remain severe if only a quarter of natural or agricultural land is taken for biomass plantations. Agricultural calorie production on cropland would be reduced by 43-73% when converting the most suitable 10-25% of cropland for the purpose of tCDR. In view of a world inhabited by a least nine billion people in 2050, it is unlikely that such deficits could be overcome by sheer management intensification or improvement."

A number of papers surveyed had further concerns regarding how BECCS is presented – particularly when presenting measures of *gross* or *net* sequestration from BECCS, and the generous incorporation of annual per-ha yield gains to 'free up' land for BECCS. Holz *et al* (2017) noted the importance of explicitly considering storage loss in any mitigation scenario that relies heavily on negative emissions, "since reporting only net values obscures the true scale of CDR deployment." Searchinger (2017) comments that "to avoid converting more cropland by 2050, yield gains would have to exceed current and historical rates of growth *even without expansion of biofuels*" (italics added). "Bioenergy demand "makes it less likely that the world could meet expanding food demand without large cropland expansion" – with negative consequences for biodiversity and a likely increase in social tensions.

Kurz *et al* (2016) reviewed three national studies (from Annex I countries) in suggesting alternative path-ways for sequestering forest carbon while meeting climate mitigation goals through improved forest management. With respect to potential forest sector contributions, "Relative to the baseline management of harvested wood products (HWPs), a small shift from pulp and paper products towards increased production of long-lived wood products yielded cumulative mitigation benefits by 2050 of 435

$MtCO_2e$." On the contrary, "shifting HWP use toward bioenergy increased overall emissions." Management improvements in natural forests and tree plantations are counted as two separate pathways by Griscom *et al* (2017). The two pathways suggest globally-significant mitigation opportunities, but uncertainty values associated with these two pathways remain high.

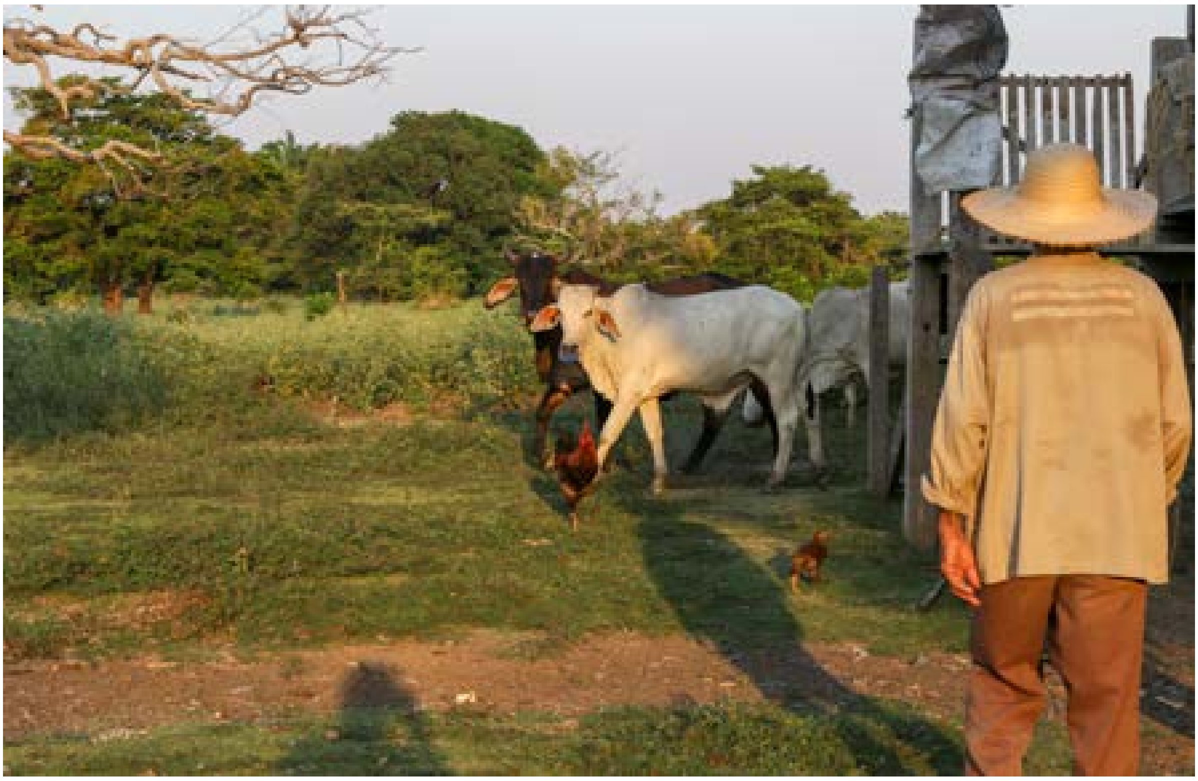
Common to almost all papers reviewed regarding the challenge of implementing BECCS at scale is deep concern regarding both total land requirements and the speed at which this technology must be scaled up to contribute meaningfully to reversing temperature overshoot by 2050. Using modeling results available to them in 2015, Smith *et al* (2015) showed that "median BECCS deployment of around 3.3 GtC/yr is observed for [IPCC] scenarios consistent with the <2°C target," and that the area devoted to BECCS in that case would represent 7-25% of total agricultural land, and 25-46% of the globe's arable plus permanent crop acreage.

Searchinger *et al* (2017) suggest "theoretical conditions" where BECCS at scale could be a useful addition to the global mitigation tool kit. Those theoretical conditions include "surplus agricultural land, high energy crop yields, and the prior or simultaneous elimination of all fossil fuel emissions... the time for energy policy to seriously consider BECCS will be if and when these basic conditions come true."

F) Minimizing overshoot at 2050: the equity dimensions

Above I reviewed a number of papers that come to bounded conclusions about the timing and intensity of global mitigation efforts involving land use. For the most part, those papers do not attempt to answer "who" will pursue or "where" particular solutions can be implemented. Is there literature that IPCC Authors and Reviewers can use to better understanding the temporal and spatial dimensions of different mitigation efforts, and thus the equity dimensions associated with a particular climate response? A couple of recent papers point the way.

Hansen *et al* (2017) should be read for its urgent attention to *intergenerational equity* – the "young people's burden of dealing with negative CO_2 emissions". Without near-term increases in ambition, future generations could be stuck with



Agroecology is likely to lead to substantial and necessary social and ecological co-benefits. Photo: © Nicole Polsterer.

a situation where the "scale and cost of industrial CO_2 extraction, occurring in conjunction with a deteriorating climate and costly dislocation, may become unmanageable."

Holz *et al* (2017) and Robiou du Pont *et al* (2017) should be read for their attention to *burden sharing*. In setting 'ratchet' levels (increased ambition as part of the UNFCCC 'Global Stocktake'), Holz *et al* (2017) refer to the existing categorization of states at the UNFCCC (Annex I and non-Annex I, developed and developing). As such, for purposes of constructing 1.5°C pathways, they suggest that developing countries fulfill their NDCs as communicated (generally, year 2030), that developed countries achieve their NDCs in 2025 (five years earlier than the current commitment for most countries), while the United States needs to achieve 150% of its 2025 NDC effort.

Robiou du Pont *et al* (2017) identified "global cost-optimal mitigation scenarios", then allocated emissions dynamically to countries according to five equity approaches. Analyzing the existing NDCs, the authors concluded that if China and G8 (wealthy) countries could "adopt the average of the five [equity] approaches, [then] the gap between conditional INDCs and 2°C-consistent pathways could be closed." Kartha *et al* (2017) criticized the approach taken by Robiou du Pont *et al* (2017), pointing out the "overwhelming prominence given to 'grandfathering'…[which] privileges today's high-emitting countries in the allocation of future emission entitlements…[that] would entitle EU and the US to emit approximately four and nine times more GHG *per capita* respectively than India." Holz *et al* (2017) further suggest that "equitably limiting warming to 1.5 °C rather than 2 °C requires that individual countries achieve mitigation milestones, such as peaking or reaching net-zero emissions, around a decade earlier" than is foreseen in existing NDCs.

Robiou du Pont *et al* (2017) also appear to have omitted the UNFCCC's "Responsibility Principle" – that those who have contributed most emissions are obliged to do the most to reduce emissions – and neglect other equity considerations recognized by the UNFCCC. Kartha *et al* (2017) agree with Robiou du Pont *et al* that "equity is still central for the ratcheting process and when discussing the adequate magnitude of climate finance and support." Ideally, products of the AR6 that feed into the UNFCCC's 'Global Stocktake' will provide further guidance regarding the adequacy and equity dimensions of the ratcheting process.

Recent papers have also deepened understanding of what types of restoration and reforestation interventions are most appropriate for particular ecosystems. Houghton *et al* (2015) point to the overriding importance of tropical forests for mitigation efforts, due both to the amount of carbon that can be sequestered per hectare, but also because albedo effects are not as determinative in the tropics: the "biophysical effects of tropical forests (albedo + evapotranspiration) do not offset biogeochemical (carbon sequestration), as they may in boreal forests." Smith *et al* (2015) elaborate by noting that the "exact location…of the BECCS or afforestation/reforestation [effort], and the vegetation it replaces, is critical in assessing the impact on albedo. Albedo can significantly reduce or even reverse net radiative forcing from afforestation/reforestation at northern latitudes… [potentially limiting] the value of afforestation and restoration for climate mitigation in northerly regions." A deeper analysis of the restoration potentials in these different systems – and what this implies for burden-sharing and adequacy of response – would be a useful output from AR6 products. As Hansen *et al* (2017) conclude, "at least part of the developed country support [for mitigation/adaptation] should be channeled through agricultural and forestry programs, with continual evaluation and adjustment to reward and encourage progress."

PART 3

Pathways of 'greater ambition' deserving wider recognition?

The previous section reviewed papers that proposed 'non-overshoot pathways', asserted opportunities for greater mitigation ambition in AFOLU sectors, and registered increasing concern over the ongoing reliance on an unproven 'negative emission' technology, such as BECCS, as a response to closing the current 'ambition gap'. From this literature review, I conclude, first, that non-overshoot 1.5°C pathways to 2050 are still possible – but require unprecedented increases in ambition that should be taken up in the coming decade as part of the 'Global Stocktake. Yet there is likely still more ambition to capture – in 'natural climate solutions', forest ecosystem restoration, agroecology and food systems change, and in community/indigenous land tenure-focused solutions.

The approaches mentioned here, which only now are starting to be properly modeled in IAMs and other predictive scenarios, can go a long way – but not all the way[3] – to meet the challenge of minimizing temperature overshoot through carbon dioxide removals and non-CO_2 emission reductions. The other SR being prepared in 2018 by the IPCC – focusing on land, food security, plus desertification and other land-sector issues – will help clarify the co-benefits and trade-offs associated with mitigation in relation to food security, ecosystem integrity, and the food rights of smallholders.

But if an 'ambition gap' remains, how should it be addressed? Should BECCS continue to dominate the approach, as in the AR5? Analyses presented above make it clear that the land-use consequences of meeting even a 2°C pathway through primary reliance on BECCS are simply enormous, and the assumptions built into achieving the necessary scale-up of BECCS between 2030 and 2050 are daunting. The important distinction between *net* and *gross* emission control approaches should again be mentioned: looking only at net negative emissions tends to downplay the immensity of the scale-up challenge.

Invoking the language of moral responsibility here, our collective global task is to *minimize temperature overshoot at 2050*.[4] Doing so both ameliorates the risk associated with over-reliance on an unproven negative emission technology, and foregrounds the importance of achieving pathways well below 2°C by 2050 – without the expectation that negative emissions can 'save' us in the second half of the century.

The other option for addressing the 'ambition gap' is to ask whether there are particular land-use pathways that would allow us to increase mitigation and limit emissions in the next two decades – approaches that have not yet been captured in IPCC assessments. To take one example, both Griscom *et al* (2017) and Dooley and Kartha (2017) found more mitigation opportunity, appropriately safeguarded, through reforestation and improvements in forest health than did the AR5.

Other pathways – both within AFOLU, but also on the behavioral, 'demand side' – could yet translate into greater ambition than has been considered to date. The paucity of peer-reviewed literature from which to assert this position may be due to: the wide range of conclusions regarding the efficacy of particular

3 For this conclusion see Houghton *et al* (2015): "total loss of carbon from land as a result of human activity over the past centuries has been 200-300 Pg C (734 – 1,100 Gt CO_2), [so] even if all this loss were to be recovered through reforestation, it would still be insufficient to offset unabated use of fossil fuels."

4 The goal could also be expressed as an annual rate of *decline* in atmospheric concentrations of CO_2.

sequestration methods; underrepresentation of agroecological approaches in the peer-review literature – most writing on low-carbon, low-input agriculture systems is presented as case studies, and generalizing from those specific cases is challenging; the difficulty of modeling behavioral change in IAMs; fatalism about non-CO_2 greenhouse gas emission reductions in agriculture because of the major management challenges associated with such efforts; or some combination of these factors. Another possible factor has been the past problem of 'over-promising' – carbon uptake in agricultural soils through 'no-till', uses of biochar, and/or expected gains from nutrient management in feedlots and other concentrated animal feeding operations have all been presented as 'game-changers', but the numbers are not yet there to back up that assertion.

All of these mitigation pathways are important and legitimate. Particularly with respect to the agriculture component of AFOLU interventions, not only is the extent of the changes required to meaningfully reduce agriculture emissions becoming clearer to land managers, but also, as part of burden-sharing, all must reckon with major diet and food-system change, that can reduce pressure on crop and grazing lands, ideally reducing land pressures. But are those 'demand-side' changes fully considered in the 1.5°C Report? I move now to a quick overview of these 'barely considered' options.

A) Agriculture system changes for greater ambition

Briefly here I suggest that a) the bias toward the use of global commodity market assumptions within the IAMs, and b) the further limitations of the IAMs' ability to capture behavior-based changes in food sourcing – may have led researchers to 'leave some ambition on the table.'

Demand-side measures

Modelers are appropriately reluctant to incorporate assumptions that suggest rate-of-change trajectories that are far outside observed experience. 'Hindcasting' has shown that the accuracy of IAMs outputs is challenged in cases where institutional or individual 'learning curves' – basically, system-wide adjustments to new information, or rapid increase in social willingness to act on new information – create major breaks with underlying historical patterns. For example, IAMs have relied on International Energy

'Avoided deforestation' looms large as the most cost-effective immediate opportunity for reducing land-use emissions. Photo: © Hannah Mowat, Slovenia

Agency (IEA) predictions that were until recently quite pessimistic (and year after year, wrong) about the speed of uptake of renewable energy technologies (Evans, 2016). As with energy pathways, so too with food pathways: the acceleration of renewable energy uptake responded to both price and behavioral signals, and it is certainly possible that demand-side signals related to diet, in particular the consumption of meat and dairy products, could shift in light of greater awareness about the individual health and global climate consequences of this diet. (However, current patterns trend in the opposite direction, toward higher *per capita* meat and milk consumption.) How might regulatory attempts to catalyze behavioral change, for example by shifting relative prices for foodstuffs, be incorporated into AR6 scenarios? How much of a difference could it make if *per capita* meat and dairy consumption declined? Perhaps this question will be addressed in the SR on land, desertification, and food security – but clearly dietary shifts could be a key component of 'enhanced ambition' toward a 1.5°C temperature limit.

Hansen *et al* (2017) note the IPCC Working Group 3 finding from 2014 – with 'robust evidence and high agreement' – that "demand-side measures in the agriculture and land-use sectors, especially dietary shifts, reduced food waste, and changes in wood use have substantial mitigation potential, but they remain under-researched and poorly quantified." Kuramochi *et al* (2017) similarly suggest that to meet a 1.5°C target, "A shift to lower-carbon food sources will likely be required for those parts of the world that are currently overconsuming." Finally, Griscom *et al* (2017) acknowledge that "A large portion (42%) of our maximum reforestation mitigation potential depends on reduced need for pasture accomplished via increased efficiency of beef production and/or dietary shifts to reduce beef consumption." All three papers thus briefly consider, but do not expand upon, this area of potential ambition.

In sum, deeper consideration is needed of four types of demand-side-focused, land-use ambitions with co-benefits: a) dietary change away from beef, pork, other animal-production systems; b) re-localization of food production systems, with major changes in nutrient flows, and a reduction in food miles traveled; c) shifting agriculture away from peatlands, and increased peatlands restoration; and d) provision of technical assistance to smallholders for increased food production not dependent on nitrogen fertilizers. The long-term gains associated with demand-side measures, however, are mediated by two external circumstances – soil temperatures, and global grain prices.

Soil temperatures and C retention

Crowther *et al* (2016) assembled data from 49 field experiments located in North America, Europe, and Asia and found that, despite uncertainty, 'the direction of the global soil carbon response is consistent across all scenarios... [providing] strong empirical support for the idea that rising temperatures will stimulate the net loss of soil carbon to the atmosphere, driving a positive land carbon-climate feedback that could accelerate climate change." Hansen *et al* (2017), extrapolating from Crowther, found that "every 1°C global mean soil surface warming can cause a 30 PgC soil carbon loss", suggesting that continued high fossil fuel emissions "might drive 2°C soil warming and a 55 PgC soil carbon loss by 2050." Recent work by Baveye *et al* (2018) suggests that a business-as-usual climate scenario would drive the loss of 55 ± 50 petagrams of carbon (202 $GtCO_2$ ± 180) from the upper soil horizons by 2050. This value is around 12-17% of the expected anthropogenic emissions over this period....given these estimates, it is possible that future efforts to raise soil carbon stocks by '4 per 1000' per year will achieve little more than compensate for the loss of soil carbon caused by rising temperatures." Dooley and Kartha's (2017) risk management framework further reminds us that the success of some AFOLU responses is inextricably linked to the current temperature regime, and that delaying mitigation action "could wreak havoc with efforts to achieve the net soil and biospheric carbon storage that is likely necessary for climate stabilization" (Hansen *et al* 2017).

Paustian *et al* (2017) provide a useful framework for thinking about the maturity of different potential responses. They divide management interventions into, on the one hand, "well known-proven techniques that are conservation-oriented management practices" or that are "best management practices" (BMPs) for building soil carbon; and on the other hand, "frontier technologies, [such as] application of biochar to cropland soils, deployment of perennial grain crops, and adoption of annual crops that have been bred to produce deeper and larger root system for enhanced carbon transfer to soil." Their conclusion is optimistic, as Paustian *et al* (2017) estimate 4-5 Gt CO_2 / year as the global potential for soil carbon sequestration "via a broad suite of well-understood BMPs on grasslands and croplands globally". Longer term, "if 'frontier technologies' are successfully deployed," the global estimate could grow to 8 Gt CO_2 / year. This is consistent with the most optimistic, 'all-in' scenarios for performance from the agriculture sector, which approach 300 Gt/CO_2 mitigation potential to 2100.

Trade-offs between ambition mitigation targets and food prices

Current models suggest that "low levels of AFOLU GHG abatement can be cost-efficiently achieved with a global carbon price at relatively little cost in terms of caloric loss per capita" (Frank *et al* 2017). However, with increased ambition, "a uniform carbon price across sectors does lead to trade-offs with food security" (Frank *et al* 2017). These authors suggest that "land-rich" countries could effectively reduce their emissions from land use change with limited food security trade-offs – but for China or India, this would not be so easy. Others suggest that with improvements in agroforestry and localization of food systems, the potential conflicts between food security and aggressive reforestation efforts can be minimized (see for example Hanspach *et al* 2017 and the social-ecological systems perspective presented therein).

B) Indigenous and community control of land

A new information and best-practice sharing platform was launched at COP23 (November 2017): the 'Local Communities and Indigenous Peoples Platform' (UNFCCC 2017). The launch came less than a year after the release of a study providing an initial estimate of the volume of the tropical forest and carbon estate held, formally or informally, within lands claimed and managed by local communities and indigenous peoples. That figure is 24% of the total above ground carbon stored in tropical forests globally (RRI 2016). Importantly – and in line with both Griscom *et al's* (2017) and Dooley and Kartha's (2017) findings regarding the importance of 'avoided conversion' as a mitigation strategy – RRI (2016) also found that at least 10% of the total carbon found above ground in the world's tropical forests today "is located in collective forestlands lacking formal [land title] recognition, placing over 22 GtC [81 $GtCO_2$] at risk from external deforestation."

Arguing that "the magnitude of Indigenous Peoples' and local communities' contributions to climate change mitigation…[is] even greater than previously realized", RRI (2016) further asserts that the "results of this study reinforce the urgent need to make collective tenure security a critical part of national emission reduction strategies." This research program is ongoing, and peer-reviewed literature on the topic should appear in time to inform other IPCC SR in the AR6 cycle. Others have identified what they believe to be a gap in the literature regarding the mitigation benefits of intact forests, since the IPCC in general focuses only on 'managed land.'

Results from Paustian *et al* (2017) give further impetus to the importance of 'avoided conversion': "native ecosystems usually support much higher soil C stocks than their agricultural counterparts… Total losses once the soil approaches a new equilibrium are typically ~30%-50% of topsoil C stocks." Building on that 'no-conversion' theme, Kormos and his co-authors (2017) argue for the unique importance of preserving primary forests, given their high levels of biodiversity, contribution to climate resilience, and ongoing stewardship by local communities and indigenous peoples. They point out that 35% of the 'pre-agricultural' forest cover is already lost; only 32% of remaining forest cover globally is primary forest. For socio-cultural reasons, these are important perspectives to bear in mind when considering the task of greatly increasing ambition through restoration and reforestation.

Three other dimensions of local community and indigenous control of land should also be taken into account when considering the social acceptance of aggressive climate-mitigation measures in the land-use sector:

- ✓ Agroecological and agroforestry efforts to reduce tensions between carbon sequestration and local food security, as noted in the discussion above.
- ✓ Local use of 'no-till' (cover crop), soil amendments, and other mitigation technologies to enhance smallholder productivity, reduce soil C emissions and increase C sequestration.
- ✓ Traditional knowledge of joint mitigation-adaptation techniques to improve climate resilience.

PART 4
Discussion

Part Two described how Griscom *et al* (2017) and Dooley and Kartha (2017) indicated the potential to unlock more **forest-sector mitigation**, to be achieved through ecosystem restoration, reforestation, afforestation, and 'improved forest management' defined in relation to appropriate social and ecological safeguards. Part Three outlined current research frontiers in the two other key components of a Paris Agreement-aligned AFOLU mitigation strategy with high co-benefits: **agriculture, and community/ indigenous control of land**. Because each of these three approaches are at different stages of articulation (as concepts), experimentation (for inclusion in scientific literature and to inform practice), and implementation (through NDCs or other commitments), summing the potential mitigation gains from the three areas – or at least outlining the research frontiers associated with better measuring that potential – would be a useful addition to the IPCC SOD, and crucial for broadening the set of options for increased ambition going into the 'Global Stocktake'.

This section notes some of the common themes found in this survey of recent peer-reviewed research on the AFOLU sector and BECCS, and potential responses.

A) SOD should indicate that ambition from the land-use sector can be scaled up immediately

Recent literature sharpens our understanding of the critical need for action now and through 2030. Most compelling is the degree to which effective near-term action in the land use sector could prevent later reliance on negative emission strategies with potentially much more negative consequences for food security and biodiversity. Starting now to ensure minimal overshoot of the 1.5°C goal is also 'precautionary' in the sense that some of the key interventions noted below become less effective at higher temperatures. "Delay in adequate near-term climate action swiftly locks 2°C pathways deeply into negative emissions. To limit warming to 2 degrees C, current NDCs lead to pathways that are fundamentally dependent on the large-scale availability of negative emissions technologies" (UNEP 2017). Stated differently, Houghton *et al* (2015) note that gross emissions from forest management are two to three times higher than net emissions, indicating the possibility that improvements in carbon uptake and reductions in emissions could account for almost half of needed emission reductions. Hansen *et al* (2017) provide a final, overarching, biophysical rationale for early action: "the inertia of the climate system allows possibility of actions to limit the climate response by reducing human caused climate forcing in coming years and decades.... the response time itself depends on how strongly the system is being forced... the response might be much delayed with a weaker forcing.... All amplifying feedbacks, including atmospheric water vapor, sea ice cover, soil carbon release and ice sheet melt could be reduced by rapid emissions phasedown."

Ending deforestation to make global forests a net 'sink'

'Avoided deforestation' looms large as the most cost-effective immediate opportunity for reducing land-use emissions. Ending deforestation plus associated restoration (see below) can transform the tropical forest estate from net source to net sink. Austin *et al* (2017) noted an important trend between 2000-2012 (during which time tropical deforestation increased by 53%): an increase in average deforestation clearing size, suggesting that "small-scale clearings for household needs or local markets are being overshadowed by forest loss associated with export-oriented agriculture." Probably the most important multisector commitment toward reducing deforestation is the 'New York Declaration on Forests', a non-binding political declaration by states, companies, and other actors, working toward the goal of halving deforestation by 2020 and ending it by 2030. This could mean 350 Million ha of 'avoided deforestation'.

Further, countries and companies pledged under the Declaration to "help meet the private-sector goal of eliminating deforestation from the production of agricultural commodities such as palm oil, soy, paper and beef products by no later than 2020, recognizing that many companies have even more ambitious targets." Austin *et al* (2017) noted that 80% of tropical deforestation was found in four countries – Brazil, Indonesia, the Democratic Republic of Congo, and Malaysia – and that the trend toward the larger-sized clearings was particularly pronounced in Latin America and Southeast Asia. The "ability to distinguish small- vs. large-scale activities is particularly important for characterizing deforestation in landscapes where there is more than one [deforestation] driver," but clearly more work can be done to reduce emissions from the 'deforestation commodities' noted above.

Range of opportunities from reforestation and 'natural climate solutions'

The forest restoration, improved forest management, and reforestation opportunities identified by Griscom *et al* (2017) and Dooley and Kartha (2017) are significant. Griscom *et al* (2017) argue that their findings provide "a solid basis for immediately prioritizing natural climate solutions as a cost-effective way to provide 11 $PgCO_2$ CO_2 e/year of climate mitigation within the next decade – a terrestrial ecosystem opportunity not fully recognized by prior roadmaps for decarbonization." One mechanism for a major part of this opportunity is the 'Bonn Challenge', a political declaration of intent by nation-states to restore 150M ha of land by 2020, and 350M ha of degraded and deforestation lands restored by 2030.

Much more can be done to incorporate both New York Declaration and the Bonn Challenge into NDCs, and technical support to help countries meet the goals of the Bonn Challenge and the New York Declaration on Forests should be encoded as part of the NDC commitments on finance for wealthy countries. Griscom *et al* (2017): "A small portion of the 11.3 $PgCO_2$ e/yr NCS opportunity we report here has been included in existing NDCs. Across all sectors, the NDCs fall short by 11-14 $PgCO_2$ e/year of mitigation needed to keep 2030 emissions in line with cost-optimal 2°C scenarios. Hence, NCS could contribute a large portion – about 9 $PgCO_2$ e/yr – of the increased ambition needed by NDCs to achieve the Paris Climate Agreement." Arneth *et al* (2017) suggest that CO_2 emissions from land-use change have historically been substantially underestimated, and argue that a larger net flux as a result of land-use change thus implies greater terrestrial uptake of CO_2. "Consequently, reforestation projects and efforts to avoid further deforestation could represent important mitigation pathways, with co-benefits for biodiversity."

Modifying rich-country diets to reduce existing land pressures and emissions from meat consumption

The scientific case for the necessity of a dietary shift, particularly away from red meat to reduce climate and environmental impacts, has been made clear over the last ten years. Springmann *et al* (2016) showed the substantial global climate change mitigation gains that could be made through "emissions pricing of food commodities," and suggested that the health benefits of that diet shift could be as significant globally as abatement in air pollution from a phase-out of coal-fired power plants. The authors recognized however that taxation of agricultural commodities could negatively impact food security, and called for more research on both climate and health linkages, and the distributional impacts of the use of pricing mechanisms to reduce emissions from the livestock sector in particular. Searchinger (2017) notes that some integrated assessment models assume much higher prices for (or a global tax on) beef to 'free up' high-quality pasture – and without this change, the models for emission reductions do not work. There is much more analysis to be done in this area, in collaboration with cities that are attempting to reduce the emissions footprint from the food supply through increased local sourcing.

Increased ambition – emission reductions from industrial agricultural sectors

Earlier the importance of prioritizing non-CO_2 emissions as part of the near-term mitigation effort was noted. Holz *et al* (2017) also argue for attention to emission reductions from non-CO_2 gases, and the "strong necessity of adding approaches to non-CO_2 mitigation in the Facilitative Dialogue" during the window for new, 'ratcheted' NDC commitments.

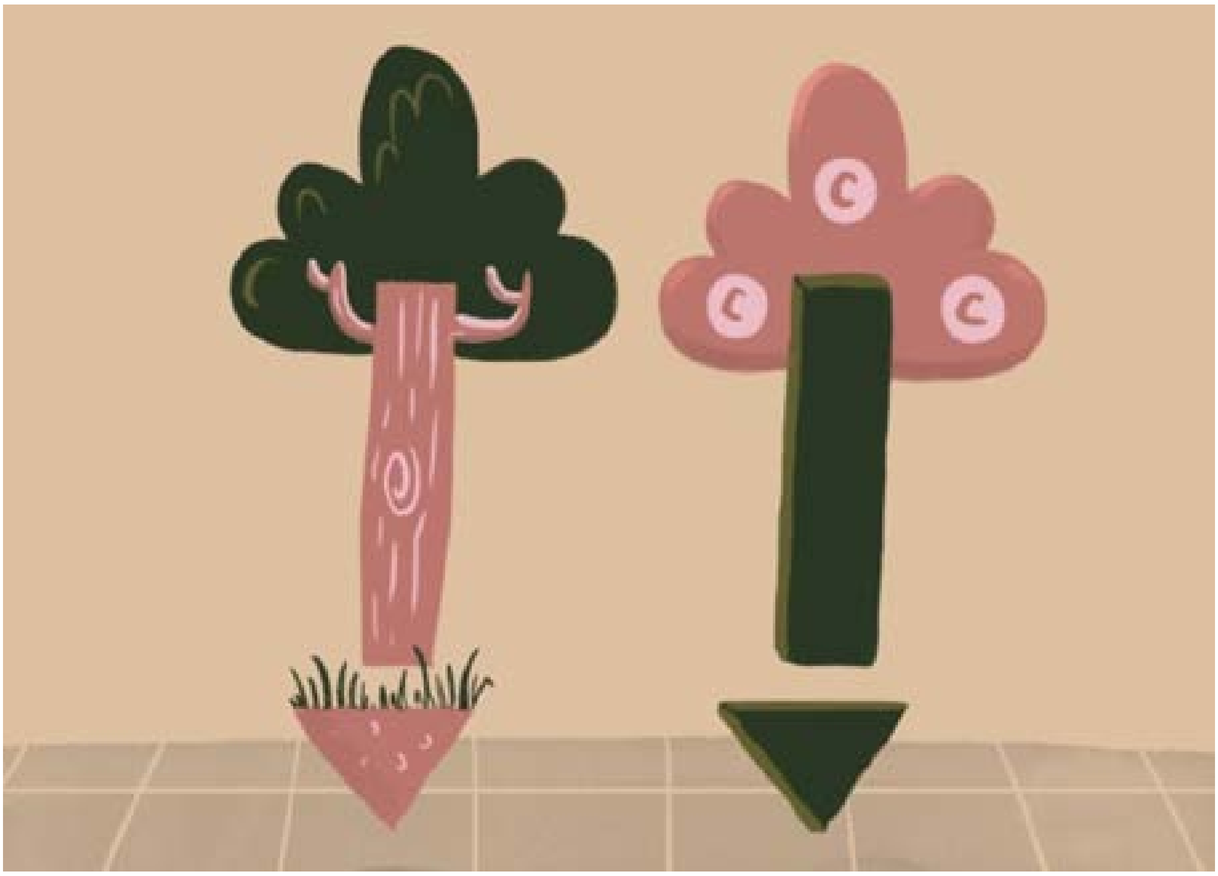
Research on crop soil carbon sequestration, forest soil carbon dynamics, and the restoration of coastal systems are all important. Improving sequestration while reducing methane and N2O emissions is challenging, and the realizable emission values from both kinds of efforts remain contested. Griscom *et al* (2017) excluded potential gains from 'no-till' agriculture and from improved manure management in concentrated animal feeding operations. Overall, Kuramochi *et al* (2017) implied that for a two degree pathway by 2050, an annual improvement in agriculture sector emissions of one $GtCO_2$ e would be needed by 2030.

Another major but poorly-measured source of agriculture-sector emissions reduction could be achieved through the re-localization of food systems through resurrection of traditional diets, by shifting to more agroecological practices, and (to a lesser extent) through reduction in 'food miles traveled'. Meanwhile, more research is needed on the integration of appropriately scaled livestock production into complex farming systems, and into silvo-pastoral systems—and the emissions and land-use consequences of moving away from industrial meat production.

B) The SR's approach to describing and deploying 'negative emissions' could be diversified in the final draft

In recent years, the key constraints on land and water in large-scale dependence on BECCS has been made much clearer in the peer reviewed literature (see for example Anderson and Peters 2016). The SOD should open up space for further discussion of the positive co-benefits from NCS, and move away from an exclusive reliance on BECCS. The Chairman's Vision Paper paid particular attention to how the SR will integrate with the SDGs; this may be elaborated further in the First Order Draft of the next IPCC Special Report on land, food security, and desertification.

Finally, the land-use intensity of BECCS is still poorly modeled, and BECCS as a technology is still poorly understood. Peters and Geden (2017) note that "currently no countries have mentioned BECCS in their Nationally Determined Contributions, and only a dozen even mention the key ingredient of carbon capture and storage."



We need to achieve pathways well below 2°C by 2050 – without the expectation that negative emissions can 'save' us in the second half of the century.

Conclusion

This review attempts to take note of and briefly summarize recent peer-reviewed literatures dealing with mitigation and co-benefits from the land-use sector. I amplified themes found in the AR6 Chairman's Vision Paper to suggest more attention to aligning the AR6 'solution set' with the SDGs, and to quantifying co-benefits from different 'negative emission' approaches. I also noted that a great deal more work is now going into developing 'no-overshoot pathways'. Future modeling runs should better incorporate the broader range of mitigation approaches achieved through 'natural climate solutions', forest-ecosystem restoration, agroecology, and rights-based approaches to avoided deforestation. This emerging research should also inform the Facilitative Dialogue. The call made for Kuramochi *et al* (2017) to refine equity considerations at the sectoral level, so as to better conjoin risk analysis with the 'solutions set' of AR6, should be heeded.

Finally, it is important to acknowledge that the high reliance on Integrated Assessment Models creates its own challenges for IPCC authors. How to diversify the sources of scientific input without compromising the integrity of the peer-review process is obviously a topic that goes far beyond this literature, but is nonetheless a critical factor in the presentation of findings here. Searchinger *et al* (2017) suggest that "the real issue with these IAMs is that they are not truly trying to predict the future but rather to estimate what might be achievable under idealized and contingent circumstances." Anderson and Peters (2016) voiced a related concern in answering the question of why BECCS is used so prolifically in emission scenarios: "Integrated assessment models often assume perfect knowledge of future technologies and give less weight to future costs. In effect, they assume that the discounted cost of BECCS in future decades is less than the cost of deep mitigation today. In postponing the need for rapid and immediate mitigation, BECCS licenses the ongoing combustion of fossil fuels while ostensibly fulfilling the Paris commitments… if the many reservations increasingly voiced about negative-emission technologies… turn out to be valid, the weakening of near-term mitigation and the failure of future negative-emission technologies will be a prelude to rapid temperature rises." Minx *et al* (2017) do not reject the use of IAM projections, but at the same time, call for "greater engagement of social sciences and humanities in debates on the issue of negative emission technologies."

As so many of the options discussed here are time-urgent, and as that window of available options narrows, a key question for the IPCC scientific endeavor is whether, and how, to take on board more of the behavioral and policy-barrier dimensions of the climate mitigation challenge – that is, not just attention to options, but also more attention to closing windows of opportunities. Attention to the time-limited nature of these opportunities strikes us as a matter of urgent policy relevance, since "policy makers are taking the policy relevant assumptions agreed upon by the scientific community for granted, but refuse to acknowledge or highlight them politically" (Geden and Löschel 2017).

The task of the IPCC is indeed to suggest the 'policy relevant assumptions'. Reviewers should look forward to a Second Order Draft that incorporates non-overshoot (1.5°C) pathways, that takes 'natural climate solutions' more seriously, and that better recognizes the enormous risks associated with 2°C pathways and with relying primarily on BECCS for emission removals in the second half of the century to bring temperatures down. That direction is amply sketched out in the papers reviewed here. The work of the IPCC should be celebrated, and the lead authors of this Special Report congratulated. It now falls to all of us to more thoroughly acquaint policy-makers with the behavioral and political ramifications of the mitigation choices we now face.

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