Missing Pathways to 1.5°C

The role of the land sector in ambitious climate action

Climate ambition that safeguards land rights, biodiversity and food sovereignty

CLARA
Climate Land Ambition and Rights Alliance

Missing Pathways to 1.5°C

The role of the land sector in ambitious climate action

Lead authors: Kate Dooley, Doreen Stabinsky.

Contributing authors: Kelly Stone, Shefali Sharma,
Teresa Anderson, Doug Gurian-Sherman, Peter Riggs.

Editor: Mark Olden

Design: Andy Omel
Graphics: Ethan Cornell
Cover photo: Rhett A. Butler / Mongabay

Acknowledgements:
Hanna Aho, Mary Booth, Dominick DellaSala, Alain Frechette,
Lili Fuhr, Chloe Ginsburg, Jason Hill, Claire Hoolohan,
Stephanie Keene, Cyril Kormos, Sara Lickel, Stephen Leonard,
Brendan Mackey, Christopher Martius, Bernard Mercer,
Hannah Mowat, Anne-Laure Sable, Linda Schneider,
Christoph Thiess, Karin Ulmer, Virginia Young, Linde Zuidema.

Contact CLARA

Media:
Don Lehr (CLARA) / dblehr@cs.com / +1 917 304 4058
Mark Olden (Fern) / mark@fern.org / +44 7973884718
Sophia Har (ActionAid) / Sophia.har@actionaid.org / +1 651 815 1818

Network Coordination:
Peter Riggs (Pivot Point) / peteriggspivotpoint@gmail.com /
+1 360 426 0959

Twitter: @CLARA_Alliance

Table of Contents

Acronyms

AMP: Adaptive multi-paddock grazing

BECCS: Bioenergy with carbon capture and storage

CAFO: Concentrated animal feeding operations

CFS: Committee on Food Security

FAO: Food and Agriculture Organization of the United Nations

GHG: greenhouse gasses

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC: Intergovernmental Panel on Climate Change

REDD+: Reducing emissions from deforestation and forest degradation

RFS: Renewable Fuel Standard

SDGs: Sustainable Development Goals

UNCCD: United Nation Convention to Combat Desertification

UNFCCC: United Nations Framework Convention on Climate Change

List of Figures

List of Boxes

Introduction

Current climate strategies are leading us to brink of disaster. While some level of removal of atmospheric carbon is inevitably required for the 1.5°C goal, due to historical and committed emissions, it is critical to limit this removal to the lowest amount possible, by restricting future greenhouse gas (GHG) emissions. Ecosystem-based solutions can offer immediate, accessible, cost-effective and equitable strategies for meeting the 1.5°C temperature goal. In the context of international efforts to address climate change and increasing evidence of its rapid environmental impacts this report presents a global call to action for governments, development institutions and the broader climate community that challenges the fundamental assumptions that have so far guided national and international climate policies. Here we demonstrate the potential for targeted policies in the land sector to reduce the sustainability risks associated with mitigating climate change, while protecting human rights—particularly the customary rights of indigenous and local communities—and ensuring ecosystem integrity and food security.

Many narratives about climate change begin by asking what mitigation actions are technically or economically feasible, and how we can use the land sector to sequester as much carbon as possible. They focus on addressing climate change now so that we might ensure food security, human rights and biodiversity in the future, with little emphasis on who bears the brunt of the impacts of mitigation. The analysis in this report starts from a different place, giving primacy to food security, protecting human rights and protecting and restoring natural ecosystems in the battle against climate change.

This report addresses the shortcomings of current modelling approaches to deep mitigation pathways. Integrated Assessment Models (IAMs) for 2°C and 1.5°C almost universally rely on intervention in the land sector on a truly massive scale, with most relying on bioenergy with carbon capture and storage (BECCS) to remove carbon-dioxide from the atmosphere and sequester it underground. In this report we substantiate and quantify the evidence that a large proportion, if not all of the required removals, could be achieved by conserving and enhancing natural sinks, while better land management and agricultural practices could avoid significant amounts of ongoing emissions. Further, when the protection and restoration of natural sinks is achieved through the stewardship of Indigenous Peoples and local communities, securing collective land and forest rights represents a far more equitable and cost-effective way to achieve climate mitigation targets than other carbon capture and storage measures *(Frechette et al., 2016)*.

This approach relies on ecosystem restoration to deliver 'the missing pathway' through avoided conversion of natural sinks and enhancing and protecting terrestrial ecosystems. It prioritises securing indigenous and community rights to land and utilises transformative agricultural practices to help eliminate over-production and consumption, including shifting diets and reducing demand for land for agricultural expansion.

Despite the advantages of multiple ecosystem-based carbon removal pathways in maintaining a liveable planet, such approaches have received little attention from policymakers. Policy choices have been largely informed by modelling that is geared toward accommodating our combustion-based economies, for instance building in the false solution of replacing fossil fuels with bioenergy. Policymakers have largely not been offered options that incorporate how behavioural and societal shifts—and strengthening tenure rights—can mitigate climate change.

The frame for considering pathways to 1.5°C must not be narrowly focused on emission reductions. Certainly the need for climate change action is urgent, but understanding the context for action is paramount. The world is one of growing inequality. Climate change arises from that inequality and feeds it, as the world's wealthy continue over-consuming diminishing resources.

The rest of this introductory section situates climate responses in the intersecting crises of climate, rights and biodiversity; addresses the shortcomings of modelling-based approaches to climate mitigation; and outlines our vision for ecosystem-based solutions that are centred on rights and food sovereignty.

Climate, rights and biodiversity—intersecting crises

This report examines three overlapping crises: climate change, biodiversity loss and the growing land and other rights abuses against Indigenous Peoples and local communities who are on the frontline of the climate and biodiversity crises. Driving these global emergencies is the over-consumption of the world's resources by those with the greatest access to them. This report addresses the land and agriculture sectors' role in responding to all three challenges. It shows the importance of ecosystem and rights-based solutions to lower atmospheric concentrations of CO_2 and re-stabilise the biosphere by increasing the biodiversity and resilience of terrestrial carbon stocks. It proposes transformational changes to address agricultural expansion that converts and degrades natural ecosystems, and to mitigate the pressures that drive indigenous and local communities from their lands.

These challenges are linked: eliminating emissions from land-use change is critical to achieving the Paris Agreement's goal of limiting warming to 1.5°C. At the same time, addressing food sovereignty while minimising ecological losses is one of the major challenges the world faces, and key to many of the Sustainable Development Goals (SDGs). These aims do not represent choices or trade-offs, but challenges that must be approached in an integrated and holistic manner that respects human rights and ensures ecosystem integrity.

Around the world, industrial agricultural expansion has led to deforestation, forest degradation and loss of ecosystems *(Rudel et al., 2009)*. Agricultural commodities are now the leading cause of forest loss *(Curtis et al., 2018)*. The loss of these forests and ecosystems has not only had devastating impacts on biodiversity, Indigenous Peoples' rights and hydrological cycles, but led to the conversion of stored terrestrial forest carbon into massive volumes of atmospheric CO_2 that exacerbates climate change *(Foley et al., 2011)*.

Reports from the Food and Agricultural Organization (FAO) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) provide alarming evidence of how close many agricultural and natural ecosystems are to collapse through over-exploitation, fragmentation and pollution, with the risks posed by biodiversity loss on the same scale as those of climate change *(FAO, 2015; IPBES, 2018)*. Half the world's terrestrial vegetation cover has been lost over the past 200 years *(Erb et al., 2017)*, precipitating a global crisis of biodiversity loss *(IPBES, 2018)*. Feedback loops between biodiversity and climate change flow both ways— the more ecosystems are degraded the more carbon is released into the atmosphere, and the harder it will be to mitigate climate change *(CBD, 2014)*.

1.5°C pathways and the trouble with 'negative emissions'

The inclusion of the 1.5°C goal in the Paris Agreement has brought a new scientific focus on deep mitigation pathways. The Intergovernmental Panel on Climate Change (IPCC) relies on modelled mitigation pathways to determine the rate of emissions reductions needed to stay under a given temperature, and the policy options to get us there. All of the more recent 2°C and 1.5°C pathways rely heavily on removing CO_2 from the atmosphere—so called 'negative emissions'. The most recent generation of integrated assessment models uses a set of harmonised policy and economic assumptions called the Shared Socio-economic Pathways (SSPs), that were developed by the climate modelling community *(O'Neill et al., 2017)*. For the 1.5°C compatible pathways, different SSPs show a range spanning from 150 - 1200 Gt CO_2 in cumulative removals over the course of the century *(Rogelj et al., 2018)*. In these models, 'negative emissions' are delivered either via bioenergy with carbon capture and storage (BECCS), a form of geoengineering, or via large-scale plantations *(Williamson and Bodle, 2016)*.

In such scenarios, bioenergy demand of up to 450 EJ/year drives large-scale land-use change and decreases food production, driving food prices upwards *(Searchinger et al., 2015; Humpenöder et al., 2014)*. The land required for energy crops in such 1.5°C pathways almost doubles the global cropping area, which increases by 200-1100 Mha by 2100, with the upper end of this range representing an area larger than the size of the continental United States (US). Impacts on other land-use types are also significant, with a decrease in pasture and other natural lands of up to a billion ha each (land-use

BOX 1:

Beyond carbon budgets

The concept of the carbon budget as a quantity of "allowable" emissions for a given temperature target was developed in the mid-2000s and was proposed by Bolivia as a principle for dividing the remaining allowable emissions between countries in the United Nations Framework Convention on Climate Change (UNFCCC). Carbon budgets gained significant traction as a policy-relevant way of communicating the urgency of reducing greenhouse gas emissions by specifying how much CO_2 can be emitted across the remainder of the century to keep warming below a given temperature goal. However, the invention of the concept of 'negative emissions' has effectively extended the carbon budget, giving the impression that it is always "5 minutes to midnight" *(Geden, 2018)*, as targets appear easier to meet even after two decades of inaction on climate change *(Anderson and Peters, 2016)*.

Estimates of carbon budgets are highly uncertain and range widely, suggesting somewhere between 100 to 900 Gt CO_2 could be released from 2016 onwards while still limiting temperature to 1.5°C *(Kriegler et al., 2018)*. What is clear from intense scientific debates over the size of the remaining carbon budget is that emissions need to go to zero in challenging time-scales for modern society to have any hope of limiting warming to 1.5°C. Peters *(2018, p.380)* advises that we move 'beyond' the concept of a single carbon budget, and that the role that societal choices have on the carbon budget need to be brought out into the open: "carbon budgets are uncertain. There is no magic number that describes the mitigation challenge… the uncertainties, both physical and those due to societal and user choices, may be irreducible."

Moving 'beyond' carbon budgets means understanding what is necessary to respond to the scale of the 1.5°C challenge, and determining what is most socially acceptable, among a variety of climate response choices. As Bertram et al., *(2018, p.1)* point out: "Meeting the 1.5°C goal will require a rapid scale-up of zero-carbon energy supply, fuel switching to electricity, efficiency and demand-reduction in all sectors, and the replenishment of natural carbon sinks. These transformations will have immediate impacts on various of the sustainable development goals. As goals such as affordable and clean energy and zero hunger are more immediate to great parts of an increasing global population, these impacts are central for societal acceptability of climate policies."

change data reported here for 1.5°C scenarios can be found in *Rogelj et al., 2018 SI*).

Analysis of the scale of land-use change driven by bioenergy demand for BECCS in modelled pathways finds that the assumed levels of land conversion exceeds what may be considered sustainable or feasible, with the scale of expected bioenergy use exceeding planetary boundaries *(Dooley et al., 2018; Heck et al., 2018)*. Further, research suggests that BECCS may even lead to an increase in atmospheric emissions *(DeCicco and Schlesinger, 2018; Harper et al., 2018, see also Box 6: Bioenergy)*.

The reliance of modelled scenarios on 'negative emissions' has attracted widespread criticism, both for the potential negative social and environmental impacts *(Bryngelsson and Lindgren, 2013; Dooley and Kartha, 2018; Muri, 2018; Séférian et al., 2018; Smith et al., 2016; Williamson, 2016)*, and for the governance, ethical and legal issues of relying on unproven technologies to deliver politically palatable mitigation pathways *(Anderson, 2015; Anderson and Peters, 2016; Vaughan and Gough, 2016; Fridahl, 2017)*. Prioritising cost minimisation underpins modeling approaches, with the integrated assessment literature emphasising "a single, global (cost-minimising) carbon price as the optimal mechanism to achieve emissions reductions" *(Bertram et al., 2018, p.1)*. However, when cost-minimisation is replaced with other priorities (food security, biodiversity protection and reduced demand for resources) several recent studies show that if we change our lifestyles and substantially reduce consumption we can meet the 1.5°C goal without relying on planetary-scale land-use change for carbon removal *(Bertram et al., 2018; Grubler et al., 2018; Holz et al., 2018a)*.

Building on these critiques, we caution that the terminology of 'negative emissions' can be misleading, as the term can imply that carbon removals (negatives) will cancel out carbon emissions (positives). In fact, Paul Hawken, the editor of Drawdown (2017) suggests that the term 'negative emissions' has no meaning in any language. The removal of carbon-dioxide from the atmosphere does not 'cancel out' the release of emissions, but is needed *in addition to* eliminating emissions, in order to lower atmospheric concentrations of CO_2. Hence a removal is not a 'negative emission', but rather a removal of atmospheric carbon-dioxide, which is inherently more risky than avoiding emissions in the first place.

As the scale of carbon-dioxide removal that could contribute to a 1.5°C mitigation pathway is inherently limited, and bounded by concerns for rights, food and ecosystem integrity, removals cannot offset ongoing emissions from fossil fuels. As Rogelj et al. (2018) put it: "the potential for land management to withdraw carbon from the atmosphere is small relative to the potential for fossil fuel use to add carbon". Our prioritisation of land-based mitigation concurs with other recent papers that state "land management is vital if 2°C, or less, is indeed the goal" *(Houghton and Nassikas, 2018)*; that the full opportunity for terrestrial ecosystems to contribute to climate mitigation is "not fully recognised by prior roadmaps for decarbonisation" *(Griscom et al., 2017)*; and that Indigenous and community land management can help combat climate change by reducing deforestation *(Blackman and Veit, 2018)*.

The missing pathway—ecosystem based approaches

This report shows how ecosystem-based approaches in the land sector and agroecological system changes in food production and consumption could deliver 11 Gt CO_2/year in avoided emissions, and almost 10 Gt CO_2eq/year in carbon sequestered into the biosphere by 2050, while community-based tenure systems continue to protect the equivalent of over 1000 Gt CO_2 as carbon stocks in (and under) community-managed lands and forests.

Hansen et al, *(2017, p.595)* note that "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." Disallowing BECCS and other technological approaches to carbon removal relies on an unprecedented scale of near-term emission reductions, requiring all countries to increase mitigation ambition *(Holz, 2018b)*. We show here that removals at the lowest end of the modelled ranges could be achieved through ecosystem and rights-based pathways and agroecological approaches. These pathways rely on respecting principles of ecosystem integrity to promote the greatest biodiversity and ecosystem resilience possible, and on securing the land rights and other human rights of indigenous and rural communities who have demonstrated the greatest ability for land protection and stewardship.

More than half of the world's land area is under the claims of customary land users, meaning that protecting a significant portion of the planet's natural ecosystems depends on their actions, yet Indigenous Peoples and local communities legally own just 10% of the world's land *(Rights and Resources Initiative, 2015)*.

While these goals sound idealistic, they are significantly more realistic and likely to deliver on both climate mitigation and biosphere integrity than proposals for BECCS and other forms of geoengineering to reduce emissions.

The rest of the report is structured into three sections: on land rights, ecosystems, and agriculture. These sections, and the potential mitigation from following these pathways, are briefly summarised here.

Land rights: Indigenous Peoples' lands account for 37% of all remaining natural lands across the Earth, although they represent just 5% of the global population *(Garnett et al., 2018)*. At least 22% of the total carbon stored in tropical and subtropical forests lies in collectively managed lands, a third of which is found in areas where Indigenous Peoples and local communities lack legal recognition *(Rights and Resources Initiative, 2018)*. It is vital to protect the large stores of carbon in terrestrial ecosystems. In the context of global efforts to protect the world's remaining forests, securing collective tenure rights represents one of the most cost effective, sustainable and equitable strategies to protect and restore vital ecosystem functions, conserve biodiversity, and reduce rates of forest loss and degradation caused by agribusiness and other industrial land uses.

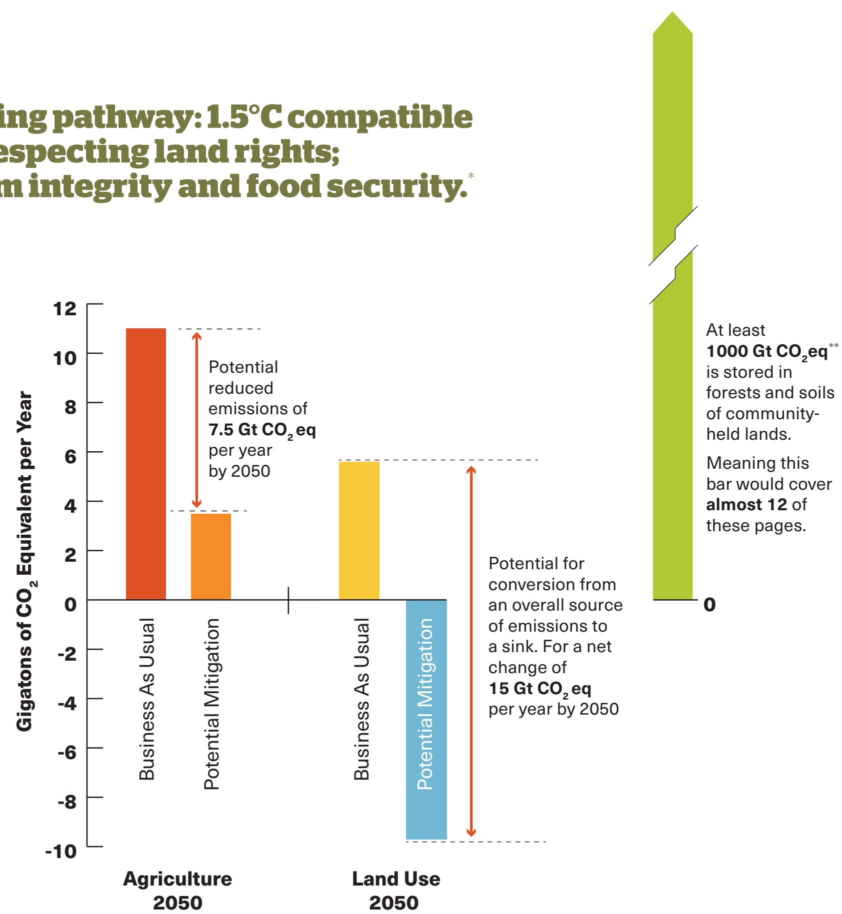
Natural ecosystems: We quantify the potential of restoring one-quarter of the world's natural forests and protecting these along with primary forests, leading to half of global forest cover representing intact ecosystems. This is in line with efforts to double the area of community-titled land, and follows the prioritisation model of protecting and restoring currently degraded primary forests, natural regeneration of recently deforested areas, and responsible use of managed forests to restore biodiversity and ecosystem function. We also discuss the threats facing grasslands and savannahs and the critical importance of preventing the conversion of these ecosystems to protect rich carbon stocks, biodiversity hotspots, and important cultural lands. These interventions would result in 6.1 Gt CO_2eq per year in avoided emissions, and 8.7 Gt CO_2eq per year in carbon sequestered by 2050.

Food and society: Another 7.5 Gt CO_2eq of emissions can be avoided annually by 2050 by transforming agricultural practices and policies to eliminate overproduction and reduce global consumption of meat and dairy (with greater reduction in some regions and increases in others), changing diets in line with health recommendations, and avoiding food waste. Agroecological approaches including agroforestry would sequester 1.04 Gt CO_2eq annually by 2030. This pathway delivers important benefits of reduced nitrogen in the environment, and improved health and well-being.

All of the quantified mitigation potential from the above pathways, which follow rights-based and ecosystem restoration priorities, is summarised in **FIGURE 1** below.

FIGURE 1:

The missing pathway: 1.5°C compatible actions respecting land rights; ecosystem integrity and food security.*



* Calculations and assumptions for all pathways can be found in the supplementary table, available here: www.ClimateLandAmbitionRightsAlliance.org/report

** 1000 Gt CO_2eq is equivalent to the 293 Gt C shown in Figure 2. We use CO_2eq units here for comparability with agriculture and land use pathways.

Part 1. Indigenous and Community Land Rights

Secure tenure rights for Indigenous Peoples and rural communities results in lower rates of deforestation and soil degradation and better protection of the biodiversity and ecosystem functions upon which these communities depend *(Blackman and Veit, 2018; Nolte et al., 2013; Stevens et al., 2014; Robinson et al., 2014)*. For example, Stevens et al. *(2014)* found that between 2000 and 2012 deforestation rates inside community-owned forests in the Amazon region of Colombia and Brazil were three and seven times lower than rates outside, respectively. Blackman and Viet, *(2018)* when controlling for factors such as remoteness of titled forest areas over a similar time-period, found that community management reduced both deforestation and forest carbon emissions in Bolivia, Brazil and Colombia. Securing community land rights creates "more resilient landscapes that directly contribute to climate change adaptation and mitigation".

> **Securing community land and resource rights is key to eliminating poverty, strengthening food security, reducing inequality and conflict, advancing gender equality, and conserving the forests and ecosystems that support life on Earth" *(Rights and Resources Initiative, 2017, p.2)*.**

In 2015 the rights of Indigenous Peoples and local communities were recognised in both the Paris Agreement and the 2030 Agenda for Sustainable Development. Yet despite this progress, only 21 countries, representing less than 13% of the world's tropical and subtropical forest area, included clear commitments to implement community-based tenure or natural resource management strategies as part of their climate change mitigation plans or adaptation actions *(Rights and Resources Initiative, 2016)*. A major implementation gap exists: deforestation is increasing in many countries, threats to human rights and forest defenders are on the rise, and remote Indigenous and community managed areas are under pressure from intensive development *(Garnett et al., 2018; Griffiths, 2018)*.

2017 was identified as the deadliest year yet for environmental activism, with every year since 2015 seeing an increase in documented killings of environmental and human rights defenders *(Global Witness, 2018)*.

> **"Governments and business have failed to act responsibly, ethically and even legally, making them a major driving force behind a litany of crimes against activists last year. They are part of the reason 207 defenders were killed in 2017, making it the worst year on record. And why many, many more were attacked, threatened or criminalised for showing the courage to speak out for their communities, their way of life and our environment" *(Global Witness, 2018)*.**

The rise in violence is linked to agribusiness—those killed are often defending their land from destructive agriculture practices and land grabs for commodity crops such as palm oil, coffee, soya, and timber *(Global Witness, 2018)*.

More needs to be done to protect those on the frontlines of defending the environment and the climate. The UN Special Rapporteur on the Rights of Indigenous Peoples, Victoria Tauli-Corpuz, refers to the escalating criminalisation of, and threats against, Indigenous Peoples as a global crisis *(2018)*. Tauli-Corpuz calls out the collusion between governments and the private sector to "force Indigenous Peoples from their lands by whatever means necessary to make way for infrastructure, agriculture, mining, and extractive projects". Restoring land rights for Indigenous Peoples and local communities, and community-based approaches to land governance and forest management is one of the most urgent and effective steps we can take for climate protection, ecosystem resilience, and the protection of vulnerable front-line defenders.

1.1 Global land tenure baseline

An overview of global trends in collective land ownership in the 21st century shows widespread reform in recognising collectively held lands over the last three or four decades *(Alden Wily, 2018)*. Concerted efforts by Indigenous Peoples have been instrumental in pushing forward reforms in many countries, resulting in the 1989 Indigenous and Tribal Peoples Convention *(ILO No 169)*, and finally in 2007, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). Both of these declarations recognise community rights of ownership and use of lands they traditionally occupy, and call upon governments to recognise and respect these rights. Collective or community land tenure is increasingly recognised as a valuable tenure system, with an upward trend in the legal recognition of community property *(Alden Wily, 2018)*.

However, there is still a long way to go in recognising community-based tenure systems. Globally, community landholders include an estimated 2.5 to 3 billion rural dwellers, and the claims of customary land users cover more than 50% of the world's land area, or at least six billion hectares *(Rights and Resources Initiative, 2015)*. Yet Indigenous Peoples and local communities legally own just 10% of the world's land, and have formal rights to use or manage an additional 8% of lands globally *(Rights and Resources Initiative, 2015)*. Areas not legally owned remain unprotected and vulnerable to land grabs from more powerful entities such as governments and corporations *(Land Rights Now, 2016)*.

Support for, and awareness of, the need to secure community land rights is growing. In 2016, a group of organisations convened by the International Land Coalition, Oxfam and the Rights and Resources Initiative launched a global call to action to secure indigenous and community land rights. Land Rights Now,[1] one of the initiatives responding to that call, is seeking to double the land area recognised as held by Indigenous Peoples and local communities in a "manifesto of solidarity with the ongoing struggles of indigenous peoples and local communities seeking to secure their land rights once and for all" *(Land Rights Now, 2016, p.7)*. International restoration initiatives, such as the Bonn Challenge and the African Forest Restoration 100 Initiative, currently lack international guidelines to ensure the global restoration agenda strengthens and supports community land rights, which must be added to these agendas.

1.2 Carbon and biodiversity in collectively held lands

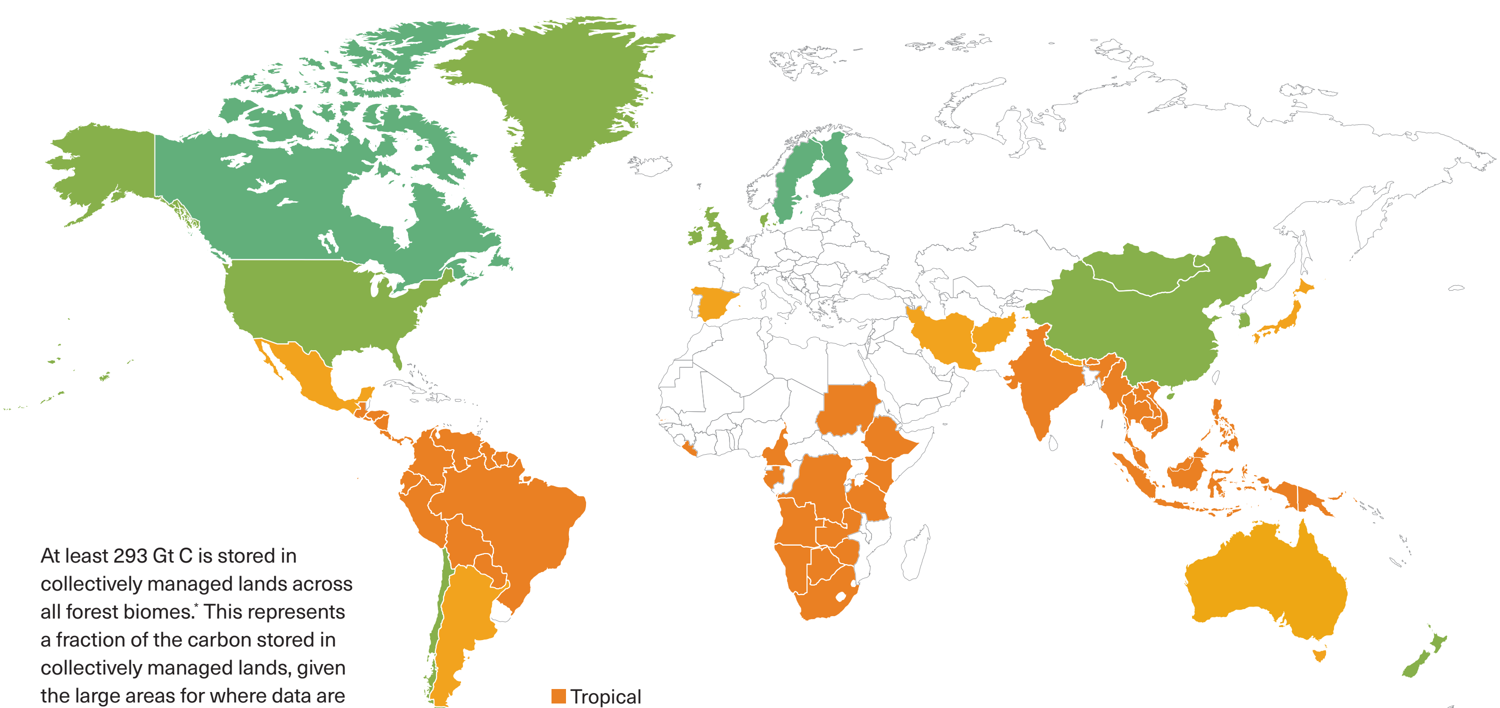
There are clear links between community-based tenure systems and rights, forest conservation, and climate change mitigation *(Stevens et al., 2014)*. Almost a quarter of the carbon stored in the world's tropical and sub-tropical forests is in collectively-managed territories, although one-third of this is in areas where Indigenous Peoples and local communities lack formal recognition of their tenure rights *(Rights and Resources Initiative, 2018)*. A study across 64 countries found that at least 1000 Gt CO_2 is stored in collectively managed lands *(Rights and Resources Initiative, 2018)*. Yet, this amount is likely to be a vast underestimate. As the Rights and Resources Initiative notes, "the full extent of forests and other lands held by indigenous and local communities—and particularly those where communities have yet to achieve formal recognition of their rights—is unknown and spatially explicit data concerning these areas is limited. Thus, vast stores of carbon in carbon-rich countries such as Indonesia and the Democratic Republic of the Congo remain undocumented" *(2018, p.1)*. (**FIGURE 2**)

These lands, the people who inhabit them, and the carbon they store, are under threat. Amazonian indigenous territories alone store 102 Gt CO_2, which is nearly one third of the Amazon region's aboveground carbon (on roughly 30% of the land area) *(Walker et al., 2014)*. In 2014, more than half of the Amazonian region (approximately 420 Mha) was found to be at risk from either current pressures or near-term threats *(Walker et al., 2014)*. This represents a threat to lands holding nearly 46% (146 Gt CO_2) of Amazonian aboveground carbon. In August 2018, the Indigenous Peoples and nationalities of

1 Land Rights Now (www.landrightsnow.org) is an international alliance campaign which calls on governments and others in power to take action to secure indigenous and community land rights everywhere.

FIGURE 2

Indigenous and community lands across 64 countries store >293 gigatonnes of carbon.



At least 293 Gt C is stored in collectively managed lands across all forest biomes.[*] This represents a fraction of the carbon stored in collectively managed lands, given the large areas for where data are not available.

Community land rights must be strengthened—over 1/3 of the carbon identified in community lands across the tropics lies in areas without secure tenure rights

[*] Forest biomes are based on FAO 2015 classifications
Source: (Rights and Resources Initiative, 2018).

the Amazon basin declared the 'Andes-Amazonia-Atlántico Biological and Cultural Corridor', the largest contiguous area of tropical forest in the world at 200 Mha, as one territory and called for all action within the corridor to respect the rights and principles of Indigenous Peoples *(COICA et al., 2018)*.

There is growing evidence that recognising Indigenous Peoples' rights to land, benefit sharing and institutions is essential to meeting local and global conservation goals *(Garnett et al., 2018)*. Based on a global map of terrestrial lands managed or owned by Indigenous Peoples throughout the world, Garnett et al., *(2018)* estimated that Indigenous Peoples' lands account for 37% of all remaining natural lands across the Earth, although they represent just 5% of the global population. This represents over a quarter of the world's land surface including many ecologically intact landscapes (for example, boreal and tropical primary forests, savannahs and marshes). These goals extend to climate mitigation when insecure collective land rights render forestlands "particularly susceptible to deforestation and/or degradation pressures from external drivers, increasing the risk of substantial emissions if left unsecured" *(Frechette et al., 2016, p.5)*. This makes titling and securing legal tenure rights for collectively-managed lands an urgent priority. Garnett et al. *(2018, p.370)* conclude that, "even for localities where Indigenous Peoples are still in the process of regaining land rights, the maintenance of the conservation values of a significant share of the planet depend on the institutions and actions of Indigenous Peoples."

1.3 Community managed lands and protected areas

Expanding conservation and protected areas globally is a key approach for achieving the goals of the Convention on Biological Diversity (CBD), the 2030 Agenda for Sustainable Development, and the Paris Agreement on climate change. Research shows that "legally recognised and protected community forestlands tend to store more carbon and experience lower rates of deforestation than forests owned or managed under other regime types, including protected areas" *(Rights and Resources Initiative, 2017, p.4)*. Globally, the overlap between protected areas and the lands of Indigenous Peoples and local communities is estimated at 50–80% *(Stevens et al., 2016)*, with "about 7.8 million km2 (20.7%) of Indigenous Peoples' lands… within protected areas, encompassing at least 40% of the global protected area" *(Garnett et al., 2018, p.370)*.

The relationship between Indigenous Peoples and local communities and conservation areas differs between localities, with some protected areas being under community-based governance and decision-making, while others are governed by state authorities with varying degrees of respect for the presence of Indigenous Peoples and local communities *(Garnett et al., 2018)*. In many cases, protected areas have been imposed without the consent of Indigenous and community land owners, often resulting in conflict, social disadvantage and displacement. In such cases, protected areas have been criticised as a "fortress conservation" model, "creating chronic patterns of abuse and human-rights violations… and a near-constant state of confrontation and ongoing potential for conflict and violence" *(Tauli-Corpuz et al., 2018)*, and could be seen as another example of powerful entities (governments and corporations), taking control of community lands.

An area of dispute is shifting cultivation, or swidden agriculture, where swiddeners are often "marginalized by laws that criminalize their practices, land laws that restrict the use of land to permanent agriculture or forestry, and the expansion of forest departments and conservation organizations, which sometimes evict swiddeners from lands under their control through resettlement" *(van Vliet et al., 2012, p.422)*. Fallow length times in tropical shifting cultivation systems show a decreasing trend in many regions, suggesting a decline in the sustainability of the system *(Arneth et al., 2017; van Vliet et al., 2012)*. The sustainability of swidden depends on fallow-length—however, above-ground carbon may decline by more than 90% when long-fallow swidden systems give way to rotational systems with short fallows or are replaced by continuous annual crops, including oil palm *(van Vliet et al., 2012, p.426)*.

The transition from swidden agriculture to more intensive land uses usually has other negative environmental consequences, including "a permanent decrease in forest cover at the landscape scale combined with substantial losses of wild biodiversity and agrobiodiversity, increases in weed pressure, decreases in soil fertility, accelerated erosion, declines in stream water quality, and potential reductions in sequestered carbon," underscoring the importance of indigenous and community and titling to protect these rights *(van Vliet et al., 2012, p.425-426)*.

BOX 2:

What are indigenous and community lands?

Indigenous and community lands are those used, managed or governed collectively under community-based tenure. Community-based tenure is defined as situations in which the right to own or manage terrestrial natural resources (e.g. forests, pastures, or other lands) is held at the community level *(Rights and Resources Initiative, 2015)*. Community-based tenure systems are the institutional frameworks of Indigenous Peoples and local communities — which may or may not be recognised by statutory laws — that in practice give rise to collective ownership *(Rights and Resources Initiative 2017, p.16-17)*. According to the International Land Coalition, "community lands are owned and managed by a variety of women and men, usually farmers, pastoralists, hunter-gatherers, fisher-folk and others using resources such as forests, water bodies and pastures as a common resource. But they are not static. Every generation adjusts how they use the land to meet new needs and aspirations. Indigenous and community lands are as important to the future as to the past" *(2016, p.12)*.

The Community Conservation Resilience Initiative is a global programme that assesses the resilience of community conservation and the support required to strengthen it. Based on recommendations from communities in 12 countries, the Initiative concluded that "all the communities in one way or another, [are] highly dependent on the biodiversity that they coexist with in their territories, and almost all are actively engaged in managing their natural resources in keeping with their culture and traditions. Numerous communities are also regenerating damaged habitats. However,

> **all the communities are struggling, to different degrees, with a wide range of internal and external threats that impact the resilience of their conservation practices and their capacity to protect their environment" *(Community Conservation Resilience Initiative (CCRI) and Global Forest Coalition (GFC), 2018, p.6)*.**

In many areas, Indigenous Peoples and local communities are achieving conservation outcomes that are at least equivalent to those of government-funded protected areas, with minimal resources *(Tauli-Corpuz et al., 2018)*. The costs of titling indigenous and community forests compare favourably with the costs of establishing new protected areas. Doubling the demarcation, registration, and titling of community forestlands globally is estimated at US$1.9 billion, while the costs of expanding national parks can range from US$200 million to over US$1 billion per country *(Rights and Resources Initiative, 2017)*. The cost of securing forest tenure for 20 years in the Amazon (averaging US$3.66 per hectare) was calculated to be at most 1% of the total net benefit of ecosystem functions (including carbon sequestration), when multiplied by the total land area that could potentially be titled *(Ding et al., 2016)*. Given the significant overlap between natural lands, conservation areas and lands managed by Indigenous Peoples *(Garnett et al., 2018)*, securing land rights makes economic sense, representing a low-cost, high-benefit investment.

Garnett et al., note that there is also the need to consider "any implied expectation of asking Indigenous Peoples to take on the burden of our global conservation challenges without providing them with adequate resources and support," and suggest a range of policy support tools can provide "a collaborative framework that can ensure the full and effective involvement of Indigenous Peoples in conservation, while respecting their rights and institutions" *(2018, pp.270–271)*.

BOX 3:

Recognition of indigenous land rights is a prerequisite for sustainable forest management and development

In Acre, Brazil, land tenure regularisation and recognition of indigenous territories from the 1990s and onward have changed the profoundly unequal distribution of land. It has enabled Indigenous Peoples to exercise better control of their territories and also to recover lost forest lands in an impressive manner. The territories of the Ashaninka of the Amônia river and the Huni Kuin in Colônia 27 are illustrating examples. The communities have been planting local tree species, forbidding the commercialisation of hardwood, regulating the collecting of river turtle eggs , and banning fishing and hunting in specific areas to protect animal numbers. In both cases, securing and restoring forest lands have gone hand in hand with a strong emphasis on traditional culture and indigenous identity, strengthening the communities internally and facilitating joint action. *(cited from: Rainforest Foundation Norway, 2017 Sustainable Rainforest Management)*

Part 2: Ecosystem-based restoration

Building ecosystem resilience by improving biodiversity protection and restoring ecosystem integrity is a fundamental building block for robust climate action in land and forests, and should no longer be thought of as merely a potential co-benefit of climate action. Protecting and restoring biodiverse natural forests and ecosystems by incorporating basic ecological and 'connectivity conservation' principles would improve carbon storage and sequestration outcomes by delivering greater resistance to loss through pests, disease, human-caused fire and climate change. At the same time, all restoration has been preceded by some form of degradation that has likely caused harm to indigenous and local communities. Therefore, the restoration agenda must proceed based on the need to respect and strengthen community tenure rights, not least to ensure that restoration does not become the basis for another wave of land grabs.

> **"Forest losses have impoverished many; their return would benefit still more. The restoration of forests should be seen as a social movement as much as an ecological objective or climate 'fix'. Governments can catalyse this process, but it will be sustained by the support, engagement and often control of forest communities themselves"** ***(Fern and Rainforest Foundation Norway, 2017, p.1)***

This section assesses the mitigation potential from conserving or restoring natural ecosystems—notably forest and grassy biomes[2]—to improve ecosystem resilience, biodiversity protection, and livelihoods derived from natural resources. All carbon in land and forests is not equal—biodiverse, relatively undisturbed, natural ecosystems store more carbon, more safely (lower risk) than modified landscapes (higher risk) *(CBD, 2014; Mackey et al., 2015)*. The CBD defines an 'ecosystem approach' as "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" *(CBD, 2016)*.

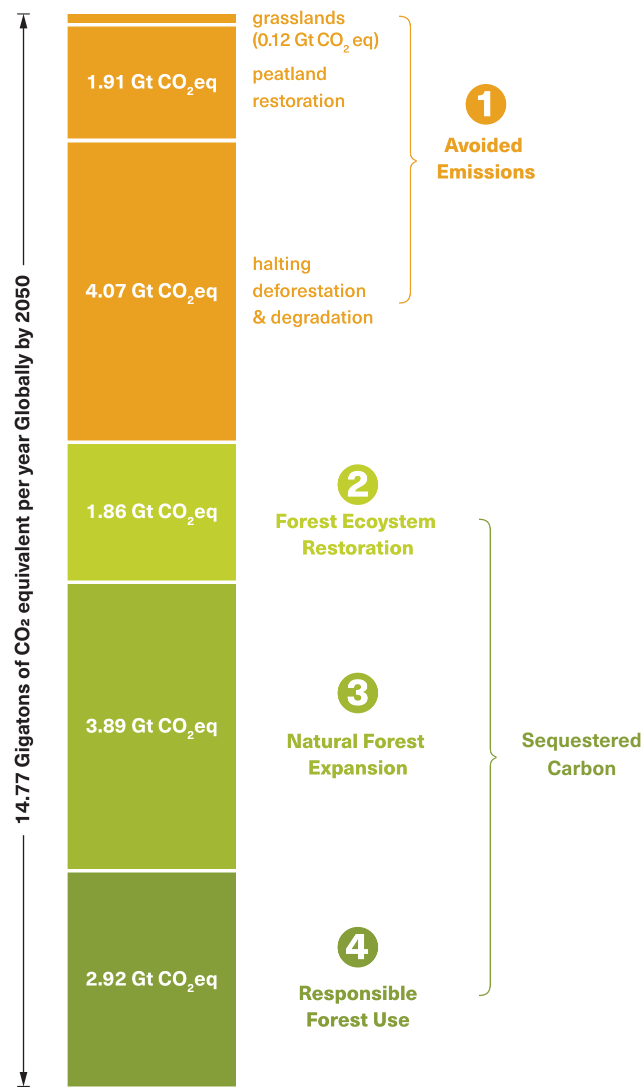
Avoiding forest loss and protecting primary forests must be the first priority in combatting the climate and biodiversity crises, not only to keep emissions out of the atmosphere now, but also to maximise ecosystem integrity and biodiversity protection in the face of climate change *(Mackey, 2014)*. The next priority is to maximise and where possible enhance the restoration of degraded natural forests, followed by forest expansion, to allow the development of natural features common in primary forests. Improving forest management and reforming plantation management and establishment practices have a

2 Inland and coastal wetlands are outside the scope of this report. Mangroves are assumed to be classified as forests in the data sets we have used.

FIGURE 3

Mitigation Potential Across All Ecosystem Based Pathways

Terrestrial ecosystems are key to climate mitigation. 1 Avoiding ecosystem conversion to other land-uses is the first priority to prevent CO_2 emissions entering the atmosphere. 2 Restoration of degraded natural forests increases and further protects existing carbon stocks. 3 Regeneration by allowing forests to regrow in recently forested areas delivers large sequestration potential. 4 Responsible use of forests requires reducing harvest, and using wood products more efficiently.



Calculations and assumptions can be found in the supplementary table, available here: www.ClimateLandAmbitionRightsAlliance.org/report lesser role to play, involving reducing pressure on and increasing the protection of primary and degraded natural forests.

Some 60% of the world's approximately 4 billion ha of forest is subject to industrial logging or designated for multiple uses including wood production (2428 Mha); 7% is classified as plantations (291 Mha); and around 33% (1277 Mha) is considered primary forest according to the FAO *(FAO, 2016)*. Natural forests are comprised partly of primary forest, and partly of what the FAO calls 'other naturally regenerating forest', which is degraded natural forests and naturally regenerated forests. Forests used for production and other commercial purposes differ in their state of 'naturalness' with a variety of stages between very natural forests (never logged, or logged decades ago), to semi-natural forests with a mix of planted and naturally regenerated native and exotic trees. The FAO category of plantations includes both semi-natural forests and monoculture exotic tree plantations— not considered as forests by many ecologists *(DellaSala, in press)*, and which are not considered forests in this report.

In this section we propose that half of the world's current forest area could be restored and protected as intact, biodiverse ecosystems. This would require restoring 25% (600 Mha) of natural but degraded forests. Identifying appropriate areas of land for restoration to a natural ecosystem state (and carbon carrying capacity) could be guided by lands currently under community-based management where tenure systems are insecure, and where forests are subject to extractive activities. Securing tenure-rights to these forests is a mechanism for mitigation that furthers the goal to double the area of legally recognised customary tenure areas. In addition to restoration,

BOX 4:

GHG emissions from agriculture and land-use

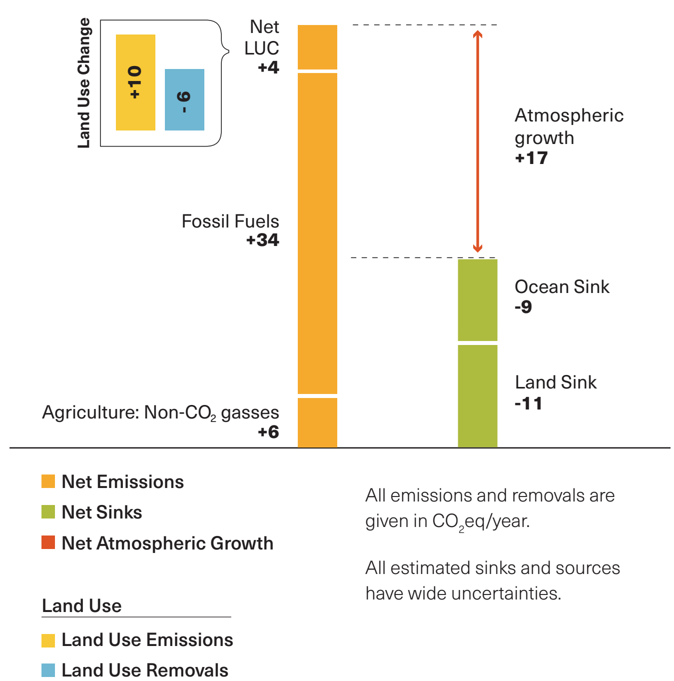
The land sector (agriculture and land-use change) accounts for just under a quarter (approximately 10-12 Gt CO_2eq/year) of all global annual anthropogenic GHG emissions. The main greenhouse gases emitted by the agricultural sector, mainly from livestock and soil and nutrient management, are methane (CH_4) and nitrous oxide (N_2O). Annual emissions of CH_4 and N_2O were estimated to be 5.2-5.8 Gt CO_2eq/year in 2010 (Smith et al., 2014). The majority of N_2O emissions come from soils, following nitrogen applications in the form of synthetic fertiliser or manure. The largest sources of CH_4 are enteric fermentation of ruminants, predominantly cattle, and emissions from anaerobic fermentation in paddy rice *(Smith et al., 2014)*. The other roughly half of emissions from the land sector are carbon-dioxide emissions (CO_2) from land use and land-use change activities (deforestation, forest degradation, forest fires). The largest driver of these emissions is land-use change for agricultural expansion. Net land use and land-use change emissions have remained relatively constant over the past half-century, at approximately 4.3–5.5 Gt CO_2eq/year, or 9-11% of total anthropogenic GHG emissions annually *(Smith et al., 2014)*.

The terrestrial carbon flux is complicated, not least by the difficulty differentiating between anthropogenic emissions and removals (associated with human-induced land-use change, and therefore amenable to influence via changed management practices), and the natural processes on land that remove about 25% of anthropogenic CO_2 emissions each year *(Arneth et al., 2017; Le Quéré et al., 2018)*. This process is known as the residual land sink, which together with the ocean sink removes approximately half of all anthropogenic emissions from the atmosphere *(Le Quéré et al., 2018)*. Gross anthropogenic emissions from land use and land-use change are mostly offset by carbon uptake in regrowing forests and other land-use activities, leaving a net source from land use change of 4.8 Gt CO_2/year (see **FIGURE 4**).

There is enormous potential through changed management practice to flip the land sector from a net source to a net sink to remove carbon-dioxide from the atmosphere, in addition to the residual land sink. Together with rapidly reducing burning fossil fuels, biospheric carbon sequestration can play a critical role in a 1.5°C pathway. There is some concern that the residual land sink uptake may weaken if global temperatures continue to rise. Maintaining existing terrestrial carbon stocks through protecting and enhancing ecosystem integrity is critical to preventing sink reversal. Old-growth tropical forests, for example, accumulate around five tonnes of carbon per square kilometre a year in living biomass, yielding a global carbon sink equivalent to 4.8 Gt CO_2/year *(Kormos, 2018; Luyssaert et al., 2008)*. The mitigation pathways presented in this paper assume a continuing land sink throughout the remainder of this century. Putting ecosystem function and rights-based approaches first maximises the resilience of that sink to natural disturbance and climate impacts.

FIGURE 4:

Global sources and sinks of greenhouse gasses



Sources: Le Quéré 2018; Pan et al 2011; Smith et al. 2014.

allowing natural regeneration of forests in recently deforested areas, and then protecting these forests, would increase the extent of primary forests in line with the planetary boundary threshold necessary for maintaining global forest cover *(Steffen et al., 2015)*. Stopping the expansion of agricultural lands in order to protect existing forests and grassland and responsible use of production forests would also make major contributions to preventing warming.

The potential for annual avoided emissions and emission removals resulting from these activities over the course of the century is summarised below in **FIGURE 3**.

Enhanced sequestration and storage of atmospheric carbon is possible because ecosystems are below their natural carbon densities due to past land use. Thus, the potential scale of sequestration is directly coupled to past emissions—that is, land-use interventions aim to restore previously lost carbon *(Houghton and Nassikas, 2018)*. The historical carbon debt—the amount of carbon previously lost from the terrestrial biosphere through land-use change—has been estimated at between 119–187 Gt C since pre-industrial times *(Arneth et al., 2017; Houghton and Nassikas, 2017; Mackey et al., 2013)*. Arneth et al. *(2017)* suggest that processes previously not included in the land-use change flux mean the carbon debt could be substantially larger, putting the historical carbon debt at the upper end of this range, meaning a greater potential to restore carbon to the biosphere. See **BOX 2** for a discussion of GHG fluxes.

2.1 Avoiding emissions from conversion and degradation of natural ecosystems

Despite forests' critical value to livelihoods, biodiversity protection, and the climate, global forest loss has remained alarmingly high over the past decade. 2017 was the second worst year on record for tropical tree cover loss *(Global Forest Watch, 2018)*. Demand for agricultural commodities, including beef, plantations for soya, coffee and oil palm, and resource extraction through mining have been identified as the leading drivers of deforestation globally *(Curtis et al., 2018; Lambin and Meyfroidt, 2011; Rudel et al., 2009)*. More than half of global forest loss annually, some 5 Mha per year, is directly attributed to land-clearing for agriculture *(Curtis et al., 2018)*. While this section focuses on the benefits of protecting forests, Part 3 of the report looks at how to minimise the agricultural and other commodity drivers that destroy forests.

Protecting natural forests

Given their importance to carbon stocks, biodiversity, and other ecosystem functions, preventing the conversion or degradation of the world's primary forests is of utmost importance *(Kormos, 2018; Mackey et al., 2008, 2015)*. A risk assessment approach that reflects carbon stock stability, restoration capacity and differences in actual and potential carbon density is needed, to identify and prioritise climate action in land and forests that will deliver the most resilient, long lived mitigation results *(Ajani et al., 2013)*. In primary forests and intact landscapes, the natural patterns of distribution and abundance of biodiversity creates the greatest resilience and stability of the natural carbon stock, which strengthens the case for protecting and restoring natural forests, including degraded and secondary forests. An important consideration in forest protection is the identification of "high biomass forests", which have critically important climate benefits that should be maintained and protected because of their disproportionate importance in climate mitigation. Forests ranging from the temperate rainforests of the Pacific Northwest US, to the temperate moist eucalypt forests in south-east Australia, to intact forest reserves in Malaysian Borneo have exceptionally high carbon density *(Asner et al., 2018; Keith et al., 2009; Krankina et al., 2014; Law et al., 2018)*. Protecting these forests is a priority for climate mitigation and brings important ecosystem benefits *(Brandt et al., 2014; Mackey et al., 2017; Mackey, 2014)*.

Recent studies give very different estimates of the magnitude of carbon loss from tropical forest disturbance, ranging from 3 Gt CO_2/year to 4.3 Gt CO_2/year *(Pan et al., 2011; Harris et al., 2012; Baccini et al., 2012; Grace et al., 2014)*. The most recent update on terrestrial carbon fluxes puts emissions from tropical forest loss and degradation at 4 Gt CO_2/year *(Houghton and Nassikas, 2017)* (excluding emissions from peat, discussed below). There are also significant regional differences in tropical deforestation rates, with Tyukavina et al. *(2015)* reporting the highest losses of natural forests in the Amazon basin and the lowest in Central Africa.

Forest degradation, which occurs extensively throughout all forest biomes, is caused by selective logging or temporary clearing, making detection of degradation, as well as quantification of carbon losses, more difficult. More recently, remote sensing technology such as LiDAR (light detection and ranging), has helped us gain better insight into the scale of carbon losses from forest degradation. Emissions from degradation in tropical forests can be as high as 70% of the total deforestation emissions *(Baccini et al., 2017)*, although distinguishing between anthropogenic disturbances (such as forestry, management fires and shifting cultivation), and natural disturbances (storms, droughts and wildfires), is difficult. The proportion of emissions from degradation compared to forest clearing is generally reported as 10-50% *(Baccini et al., 2012; Houghton and Nassikas, 2017; Huang and Asner, 2010; Smith et al., 2014)*. However, it is increasingly understood that emissions from degradation can exceed those of deforestation in some areas *(Baccini et al., 2017)*, and as such must be the focus of management strategies to avoid further carbon losses.

Temperate and boreal forest biomes are reported as an overall sink, with emissions and removals from disturbance and regrowth, and an expansion in forest area in recent decades *(Houghton and Nassikas, 2017; Pan et al., 2011)*. However, analyses show that due to ongoing forest degradation—through increasing management intensity and repeated harvest—in many boreal and temperate forests overall carbon storage and long-term carbon residence times have declined *(Law et al., 2018; Nabuurs et al., 2013)*. This represents significant potential for changed management practices to avoid further degradation and associated emissions, and to restore the carbon carrying capacity (and ecosystem function) of these forests. While this section focusses on avoided emissions from forest loss and disturbance, Sections 2.2, 2.3 and 2.4 discuss restoring natural forests; expanding forests through natural regeneration; and the more sustainable use of natural forests, respectively.

Peatland protection and restoration

Peatlands cover ~3% of the terrestrial surface area, in all climatic regions, store 21% of the global total soil organic C stock, and hold large stores of organic nitrogen *(Leifeld and Menichetti, 2018)*. In an intact state, peatlands contribute to a range of ecosystem functions such as habitat and biodiversity protection, water regulation and carbon sequestration and storage *(Wetlands International, 2015)*. However, draining peatlands and converting them to managed areas, whether for mining peat, or for

BOX 5:

Forest Definitions

Definitions matter. Chazdon et al., *(2016)* argue that efforts to protect and restore forests and prevent further forest loss could fail if "they are not informed by clear and appropriate concepts and definitions of forests. Forest definitions provide the conceptual, institutional, legal, and operational basis for the policies and monitoring systems that drive or enable deforestation, forest degradation, reforestation, and forest restoration." The distinctions between forests— primary and secondary, regenerated, natural, or semi-natural—as well as between what is a forest and what is not a forest— not only differs between countries, but there are no consistent international definitions for forests. Different entities use very different definitions of what constitute a 'forest', and the definition used may be as much political as biological in meaning.

The FAO defines forests as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, and the absence of other land uses *(FAO, 2012)*. This definition of forest excludes tree stands in agricultural production systems (such as fruit trees or oil palms, which are considered a crop), but includes temporarily deforested areas where trees will regenerate. The FAO also distinguishes between natural and planted forests, and between primary (naturally regenerated forest of native species with no visible signs of human disturbance) and secondary forests (naturally regenerated forest where there are clearly visible indications of human activities). However, the FAO definition of reforestation excludes natural regeneration and fails to distinguish between natural and planted forests. An increase in forest area is defined by the FAO as occurring due to either afforestation (planting or seeding of trees on land that was not previously forested) or natural expansion (forests regenerate naturally on land that was previously not classified as forest) (*FAO, 2012)*. The FAO definitions therefore, established from a forestry production perspective, lack the ability to describe the various forms of forest ecosystem restoration.

The IPCC defines reforestation and afforestation both as changes in land cover from non-forest to forest. Reforestation refers to "the establishment of trees on land that has been cleared of forest within the relatively recent past," while afforestation refers to planting trees on lands that have not historically contained forests. The IPCC Guidelines, which were developed explicitly for carbon inventories, are concerned with land-use change (from forest to non-forest or vice-versa), and the definitions have implications for lands which can be included towards Kyoto Protocol targets. Most notably, the IPCC does not differentiate between natural forests and plantations. "Replacing the historical production definition of 'forests' with system-based definitions of natural forests and plantations is needed for coherent policy development in the era of climate change" *(Ajani, 2011, p.61)*.

In the real world, much forest regeneration is carried out through "natural" reestablishment from seed remaining on the site or from retained seed-trees *(Chazdon et al., 2016)*. Such a process is not included in definitions from a forestry or carbon accounting perspective, but enhancing and protecting natural forest regeneration is critical to ecosystem restoration. Chazdon et al., *(2016, p.541)* call for a more "nuanced and diversified approach to defining forests and ''reforests'' that can distinguish natural from planted forests and forests damaged by logging from second-growth forests, and can be used to track the dynamics of regrowing forest patches within agricultural landscapes… If current forest assessments are to be useful for understanding the drivers and rates of land-use change, they must incorporate definitions that include the dynamic properties of forests, their uses for local people, and their changing landscape context. People that rely on the land for their lives and livelihoods tend to have deep knowledge about forest properties. In these cases, local people can significantly contribute to defining, assessing, and monitoring forests and reforests."

In this report we organise forest definitions on the basis of ecological principles, referring to different types of forests and restoration activities as follows:

Intact forest landscape—a large, contiguous area of forest in a primary state, or largely free from human interference. While the term 'intact forest landscapes' is often used to designate areas larger than 50,000 hectares *(Popatov et al., 2017)*, we do not adopt a minimum threshold, but emphasise large contiguous areas of natural forest.

Forest Ecosystem Restoration—allowing a degraded forest to restore to full ecosystem integrity, similar to that of a primary forest. This does not imply any land-use change, as forest remains forest, but ending extractive activities can allow full ecosystem recovery over time, including of biodiversity and carbon stocks.

Primary forest—a forest that has not been logged and does not show sign of human disturbance (excluding traditional uses).

Natural forest expansion—we use this to broadly refer to the expansion of natural forests—whether through natural forest regeneration (passive regeneration), or assisted regeneration such as re-seeding and planting (reforestation). We use this term only to refer to the re-establishment of native mixed-species forest on land that has previously supported forests (i.e., in forest ecoregions), and do not use the term afforestation, which would imply the establishment of plantations.

agriculture such as oil palm crops, alters them from a net sink to a net source of GHG emissions *(Leifeld and Menichetti, 2018)*.

The majority of peatlands are located in boreal regions, which if drained will release CO_2 (and other GHG's) and which are vulnerable to temperature increases *(Dieleman et al., 2015; Dorrepaal et al., 2009)*. However, current hotspots for peatland emissions are located in the tropics due to degradation and burning of peat forests *(Leifeld and Menichetti, 2018; Houghton and Nassikas, 2017)*. The draining and burning of peatlands is a significant contributor to global CO_2 emissions, particularly through clearing peat forests for oil palm plantations in Southeast Asia *(Hooijer et al., 2010)*. This began mostly in the 1980s, with emissions growing from zero in 1980 to 0.73 Gt CO_2/year in 2015 *(Hooijer et al., 2010, 2012)*. Houghton and Nassikas *(2017)* estimate that peatland draining and burning in Southeast Asia accounted for an average of ~0.95 Gt CO_2/year in the last decade. Recent mapping shows that there are far more peatlands globally than previously known, which are vulnerable to further degradation if forest clearing and disturbance continues on current trends *(Dargie et al., 2017; Leifeld and Menichetti, 2018; Murdiyarso et al., 2017)*. Leifeld and Menichetti *(2018)* provide an updated global peatlands map that estimates 50.9 Mha (almost 10% of global peatland extent) is already drained for forestry, cropland or grassland, resulting in emissions of 1.91 Gt CO_2eq/year.

Drained peat continues to emit for decades to centuries, therefore restoration of peatlands and protecting further areas from degradation has a large mitigation potential, assuming restoration results in a GHG neutral ecosystem *(Leifeld and Menichetti, 2018)*. Because drained peat continues to emit CO_2, the rewetting of peat restores these areas to their original function as carbon sinks. The IPCC assesses changes of carbon in peatlands in terms of GHG emissions rather than changes in carbon stock, as the error in estimating carbon stocks in peatlands is larger than the flux values *(Joosten, 2009)*. For this reason, we consider only the avoided emissions potential of rewetting peatlands as a mitigation contribution, rather than any potential for additional sequestration.

Avoiding conversion of grasslands

Grasslands are ecosystems dominated by herbaceous and shrub vegetation, covering approximately 40% of the ice-free land surface *(White et al., 2000)*. Grasslands include savannahs, shrublands and pastures, although the classifications and extent of these land types is uncertain. Research is making it increasingly clear that, like natural forests, "grasslands should be recognised as a critical—but increasingly threatened—store of global biodiversity" *(Murphy et al., 2016)*. Indeed, grasslands are too often treated as 'marginal', when in fact they may contain high soil carbon pools and high biodiversity *(Courvoisier et al., 2017)*. Many areas categorised as degraded lands - often grasslands and pastureland - are critical for the livelihoods and cultures of rural and indigenous communities *(Gibbs and Salmon, 2015)*.

Natural grasslands are important ecosystems, and hotspots for biodiversity. The Brazilian Cerrado, for example, is an incredibly biodiverse biome, supporting more than 10,000 plant species, over 900 bird and 300 mammal species *(Prager and Milhorance, 2018)*. Natural grasslands sequester huge amounts of carbon because of their deep-rooted plants, but this carbon is lost if areas are converted to cropland, or subject to degrading practices such as overgrazing. Limiting additional release of CO_2 from grasslands is an important climate goal. Release of soil carbon, such as from cultivating land previously covered with perennials such as forest, savannah, or grasslands, has been a significant contributor to CO_2 emissions.

Large-scale land use change is the most serious threat to tropical grassy biome biodiversity globally, with rates of land conversion often exceeding rates of tropical forest loss *(Murphy et al., 2016)*. In the Cerrado, agricultural conversion has caused more than half of the native vegetation to disappear *(Prager and Milhorance, 2018)*. Grasslands have been shrinking over the past decades, while areas for permanent crops have been growing *(FAO, 2018b)*. Almost a quarter of the world's native grazing lands have been converted to cultivated crops *(Conant et al., 2017)*. Large-scale bioenergy use for BECCS, which aims to remove carbon from the atmosphere in modelled mitigation pathways (see Box 6: Bioenergy), represents a new threat to global grasslands. Integrated assessment models deploying BECCS for 1.5°C scenarios find that strict forest protection results in large-scale conversion of pasture to cropland *(Rogelj et al., 2018)*. Analysis of modelled mitigation scenarios for below 2°C shows a potential expansion of crops for bioenergy of up to one billion hectares, with a corresponding loss in 'pastures and other natural lands' *(Dooley et al., 2018)*.

Halting the conversion of grasslands to cropland to prevent losing biodiversity, ecosystem functions and stored carbon is critical. However, the avoided emissions from protecting grasslands and from lower-intensity and improved grazing practices are highly uncertain, with large regional and climatic variations. There is also potential to increase soil carbon sequestration in natural grasslands, through changed grazing practices and species selection. Although we don't quantify the soil carbon sequestration potential (see Box 8 in Section 3.1: Soil carbon), the additional benefits of building soil carbon such as higher water retention, greater fertility and crop productivity, and contribution to climate mitigation and adaptation. Although the quantified climate mitigation potential of grasslands is relatively low, the importance of grassy biomes and their soil carbon stocks for climate mitigation and adaptation, as well as biodiversity and cultural and livelihood practices, cannot be overstated. As the threat to grassland conversion for agriculture is real and growing, this is an ecosystem that requires urgent protection.

Potential for avoided emissions

Estimating the potential for avoided emissions from reducing and halting forest cover loss, forest degradation, and the draining and destruction of peatlands requires assuming a future baseline—a counterfactual— to which emissions under an improved scenario can be compared. Current annual emissions from forest loss and disturbance are reported as 5.6 Gt CO_2/year when including global peat emissions *(Leifeld and Menichetti, 2018; Houghton and Nassikas, 2017)*. According to Gullison et al, (2007), without effective action to slow deforestation, tropical forest clearances will likely release an additional 319 to 477 Gt CO_2 by 2100, equal to the carbon release of more than a decade of global fossil fuel combustion at current rates.

We estimate the mitigation potential from avoided forest loss as equivalent to current global emissions (from both deforestation and degradation), at 4.07 Gt CO_2/year. We also assume that restoring peatlands, and preventing further burning and draining of peat, would avoid another 1.91 Gt CO_2eq/year, mostly from the tropics and European regions (Leifeld and Menichetti, 2018; Wetlands International, 2015). We also include the annual mitigation benefit of 0.12 Gt CO_2/year from the avoided conversion of grasslands (including savannahs and shrublands) to cropland calculated in Griscom et al. *(2017)*. This gives a total of 6.1 Gt CO_2eq/year in avoided emissions, if destructive activities were halted.

Here we—optimistically— assume that current international goals to halve deforestation by 2020 and end it completely by 2030 *(New York Declaration on Forests)* are achieved. One of the most visible current policies relating to forest mitigation is the implementation of REDD+ (reducing emissions from deforestation and forest degradation). We are not evaluating specific policy incentives here, but evidence suggests that REDD+ is failing to promote forest governance and tenure as a focus for action in the forest sector, which must be corrected *(Angelsen et al., 2017; Fletcher et al., 2016; Sunderlin et al., 2018)*. Respect for community land rights must be the starting point for preventing emissions from forest loss and degradation.

"The finding that there is less deforestation in areas where local people have their rights recognized shows that indigenous territories and collective rights to land for local communities can be effective measures against deforestation" ***(Rainforest Foundation Norway, 2014, p.19)*****.**

2.2 Forest ecosystem restoration

Preventing forest loss and protecting primary forests is the first priority in combating climate change and safeguarding biodiversity and other ecosystem benefits. The next priority is to restore degraded forests to encourage those natural features common in intact landscapes. Humans have affected two-thirds of global forests, mainly by harvesting timber, and— more recently—biomass for energy *(Arneth et al., 2017; Grace et al., 2014)*. Research suggests that the extent of forest disturbance has previously been underestimated *(Arneth et al., 2017; Houghton and Nassikas, 2018)*. The global potential of removing carbon from the atmosphere through forest growth is uncertain *(Houghton and Nassikas, 2018)* for a number of reasons: the need to refine analysis of the extent, condition and recovery potential of degraded forest areas; heterogeneity in forest carbon densities across different forest areas and types; and the extent and drivers of current forest uses. However, multiple studies show that after approximately 60-200 years, depending on the forest type, existing but degraded forests can regain most of the carbon stocks and biodiversity levels of primary forests, presenting significant mitigation potential *(Chazdon, 2014; Mackey et al., 2008)*. However, there is a threshold of degradation and forest clearing beyond which forests will not recover—restoration relies on sufficient primary and intact forest within the landscape to provide the 'building blocks', in terms of seed and species remnant, for forest recovery.

Scientists have been calling for "bolder thinking for conservation" for decades, while targets set politically, such as through international treaties, have erred on the side of caution *(Noss et al., 2012, p.1)*. Moving beyond incremental target-setting, in the Pulitzer prize-winning book Half-Earth E.O. Wilson proposes that "only by committing half of the planet's surface to nature can we hope to save the immensity of life forms that compose it" *(Wilson, 2016, p.2)*. Extensive research backs up the proposition that we should protect half of any given ecoregion, based on ecological principles rather than politically determined goals *(Locke, 2014)*. In this section we discuss how

RHETT A. BUTLER / MONGABAY

▲ Increased carbon sequestration is possible because ecosystems are below their carbon carrying capacity as a result of past land use.

forest ecosystem restoration could contribute to the idea of protecting half of the world's natural ecosystems by proposing that one-quarter of existing natural forests that are currently degraded through timber production or other uses should be set aside for restoration to primary forests. This would increase the area of primary forests to 50% of the world's forest cover, a step towards 'Half-Earth'. The potential synergies between conservation goals and goals to increase the area under secure community-based land-tenure systems is also apparent, given that community managed lands cover half the world's surface *(Rights and Resources Initiative, 2015)*, and 37% of remaining natural ecosystems are under the stewardship of Indigenous Peoples *(Garnett et al., 2018)*.

Importance of intact ecosystems to biodiversity, livelihoods and climate

Primary forest and other undisturbed ecosystems play a central role in rebuilding ecological functions. Here, we use the CBD definition that a primary forest is one that has not been logged and has developed following natural disturbances and under natural processes, and is used by indigenous and local communities living traditional lifestyles which conserve and sustainably use biological diversity *(CBD, 2010)*. Therefore, restoring degraded forests to those with primary forest characteristics (intact and undisturbed ecosystems), requires excluding extractive logging and intentional fires, but not traditional and customary uses. The reference to indigenous and local communities in the CBD definition "highlights that it is the intensity of human activity rather than the presence of people per se that matters most to the conservation of a primary forest" *(Kormos, 2018, p.2)*.

In addition to primary forests, the concept of 'Intact Forest Landscapes' has been used to denote large continuous areas of forest ecosystems, with no signs of human disturbance (again, with the exception of low-intensity and traditional lifestyles "such as hunting, scattered small-scale shifting cultivation, and preindustrial selective logging" (Potapov et al., 2017 p, 1)). While some definitions of intact forest landscapes refer to a minimum threshold size, because "their ability to perform ecosystem functions and their resilience to natural disturbance and climate change are functions of their size" *(Potapov et al., 2017, p.1)*, even smaller areas of primary forest and undisturbed ecosystems can play a central role in rebuilding ecological function across the landscape. Focusing restoration action around smaller areas of primary forest to buffer and reconnect them is an effective way to increase the resilience and stability of both the primary forest carbon stock and restored areas through the increased resistance and adaptive capacities of undisturbed forests *(Soule et al., 2004; Nelson et al., 2007)*.

Protecting intact areas from further fragmentation is an urgent priority in order to achieve climate and biodiversity goals *(Barlow et al., 2016)*. Research shows that intact forest area losses are increasing, with the leading causes worldwide being logging and the building of roads and other infrastructure, leading to a cascade of changes which transform landscapes *(Ibisch et al., 2016; Mackey et al., 2015, 2017; Potapov et al., 2017)*. Plantations and more intensive agriculture tend to follow in the wake of selective logging expansion and associated road construction. In short, industrial logging operations "can set off a cascade of interventions that eventually result in the final conversion of natural forests to industrial monoculture plantations" *(Potapov et al., 2017, p.7)*. New oil palm plantations have been found to affect intact forest landscapes in all tropical regions *(Potapov et al., 2017)*. Such fragmentation leads to the 'edge effect', where the forest edge is exposed and becomes more susceptible to drought and fire, and less able to recover from disturbance *(Briant et al., 2010; Grace et al., 2014; Lindenmayer and Sato, 2018)*. Mackey et al., *(2017, p.27)* note that "studies in both tropical and temperate forests provide evidence that unlogged and old growth forests are more resistant to fire events than logged, fragmented and degraded forests". The fragmentation of large continuous forest areas makes forests more vulnerable to further degradation, ecosystem collapse and eventual complete forest cover loss *(Lindenmayer and Sato, 2018)*.

Potential for restoration to intact ecosystems

Degraded forests recover naturally over time if they are not further disturbed by intensive human activities. The CBD has adopted principles and guidance for integrating biodiversity considerations for resilient and long-term ecosystem restoration *(CBD, 2016)*. Recovery times and potential vary depending on many factors, including variations in logging disturbances and constraints due to seed dispersal and other forms of disturbance, but biomass and biodiversity of the original forests can often be recovered (although biodiversity recovery times are much slower) *(Chazdon, 2014; Grace et al., 2014)*. Recovery of selectively logged tropical forests to conditions similar to unlogged forests varies between regions and forest types, but has been estimated to take between 45-150 years in the tropics, dependent on the extent of forest degradation *(Chazdon, 2014)*, and 150 years or more in other forest biomes *(Law et al., 2018; Pingoud et al., 2018; Roxburgh et al., 2006)*.

The mitigation potential of allowing degraded forests to recover is significant, with results from studies across the world's tropics showing that "if these forests are allowed to regenerate without further disturbance, a high fraction of local forest-requiring species will return, and biomass and stored carbon will recover their pre-logging levels" *(Chazdon, 2014, p.163)*. In a case study of secondary temperate forest in Australia, Roxburgh et al. *(2006, p.1149)* observed that "forests recovering from prior logging have the potential to store significant amounts of carbon, with current biomass stocks estimated to be approximately 60% of their predicted carrying capacity, a value similar to those reported for northern temperate forests. Although sequestration activities often focus on the afforestation and reforestation of previously cleared land, our results suggest that… native forest management should also be considered when developing terrestrial carbon management options." In Germany, Böttcher et al. *(2018)* estimated that the current forest area excluded from wood extraction could be tripled, allowing "natural forest communities worth protecting (e.g. ravine and riparian forests)" to be set-aside *(Böttcher et al., 2018, p.6)*. In Malaysian Borneo, Asner et al., *(2018, p.295)* found that previously logged forests show suppressed (although still high) carbon densities, meaning that "[the state of] Sabah could, theoretically, double its total aboveground carbon stock just by allowing the current areas of logged forest to fully regenerate."

The large area of secondary and degraded forests globally, suggests significant potential to remove carbon dioxide from the atmosphere if selective logging and other forest degradation was stopped. This would result in an immediate climate benefit of avoided emissions (which is included in section 2.1 on reducing deforestation and degradation). The second benefit is that recovering forests would rapidly sequester large amounts of CO_2 during the re-growth phase. However, given that in any case, logged forests must regrow before they are logged again, we do not count this sequestration as an additional mitigation benefit. The mitigation we do count as additional is in allowing these forests to continue to recover and mature after the point that they would have been harvested— moving from forests that would have been re-harvested, to a mature and intact forest ecosystem.

Given that we cannot expect all logging in all natural forests to be stopped, we make a simplified assumption that restoring 25% of degraded natural forests—some 600 Mha—would mean half of the world's forests could be conserved as intact forest ecosystems if this newly set-aside forest were protected from further human interference, alongside primary forests at their current spatial extent. This would result in an additional 1.83 Gt CO_2 /year being sequestered by 600 Mha of forest shifting to a mature, intact ecosystem.[3] Such an extensive area 'set-aside' from production would also require reduced consumption of forest products, and would affect the forest economy. These issues are discussed in section 2.4, on the responsible use of forests.

Protecting half the world's natural forest ecosystems is in line with efforts to secure land rights, such as the Land Rights Now coalition's demand to double the area of land under community-based tenure, and the recent declaration from Coordinator of Indigenous Organizations of the Amazon River Basin *(COICA et al., 2018)* to protect the Andes-Amazonia-Atlántico Biological and Cultural Corridor as one contiguous area of forest. Distinguishing different types of forest, different states of 'naturalness' or degradation, and different uses of those forests is critical in determining how changes in land management can contribute to climate mitigation goals, while also meeting social, cultural, biodiversity and other objectives *(Chazdon et al., 2016)*. In many areas, strengthening community-based land tenure will enable restoring degraded forests when these areas have been taken from communities.

3 Forest area taken from FRA2015: 1277 Mha of primary forests, plus 600 Mha of set-aside forests would be equivalent to half the current extent of natural forest area. Post-logging regrowth rates are not included in calculations: forests are assumed to be ready to harvest, rather than just harvested. See supplementary table (www.ClimateLandAmbitionRightsAlliance.org/report) for more information on land area and additionality calculations.

Determining which areas of forest could be restored should be based on achieving the maximum benefits in ecosystem resilience and biodiversity, and in supporting the culture and livelihoods of indigenous land users.

2.3 Natural forest expansion

After protecting existing primary forests from further loss or degradation, and restoring some degraded forests to intact forest ecosystems, the next priority from an ecosystem and rights perspective is to expand the area of natural forests. Doing so through natural regeneration offers a low-cost option for carbon sequestration, with associated benefits for biodiversity conservation and other ecosystem functions. Returning to the idea of protecting half the world's natural ecosystems, it is important to realise that the current extent of forest is greatly reduced compared to the amount of natural forest cover in the past. The planetary boundaries concept, outlining a 'safe' threshold for humanity's impact on the earth, suggests that globally, a threshold of 75% of original forest cover should be maintained *(Steffen et al., 2015)*. With current forest cover at just 62% of original forest extent, would imply that an expansion of natural forests by approximately 400 Mha[4] is needed to remain within the planetary boundary threshold. This section explores how forest expansion can be done in a way that expands natural forest ecosystems, which if protected would contribute to achieving protection for half of global forest cover.

Natural regeneration and reforestation

We distinguish between restoring existing but degraded natural forests (discussed in Section 2.2), and restoration through expanding forests into recently deforested areas (thus creating secondary forests). The former involves restoring degraded primary forests (forest ecosystem restoration), and so from a land cover perspective, does not increase the forest area. The latter— natural forest expansion— does increase the area of forest cover. Forest expansion can be achieved in a number of ways, and encompasses two basic ecological approaches. The first is to encourage natural regeneration by removing elements that suppress forest recovery (e.g., weeds, fire, grazing, etc). The second, in areas where the natural seed bank has been lost, involves re-planting or re-seeding the known regional mix of species present prior to clearing (reforestation). Resilience and longevity for current and new forests will be enhanced if restoration prioritises buffering and reconnecting areas of primary forest *(Soule et al., 2004; CBD, 2014)*. This form of ecologically based restoration will deliver the optimum carbon stock for any given landscape, is the lowest risk and least cost pathway and will provide the most resilient, long lived carbon outcome, with recovery of native species composition (ecological integrity) *(Ajani et al., 2013; Rocha et al., 2018; Sovu et al., 2009)*.

4 Based on current FAO estimate of 3695 Mha of natural forest cover *(FAO, 2018b)*.

The majority of forest expansion currently occurs through natural regeneration *(Chazdon, 2014)*. Over half the world's tropical forests are naturally regenerating forests, not old-growth forests *(Chazdon, 2014)*. It is important to distinguish natural regeneration from reforestation or afforestation with monoculture plantations. Establishing native mixed-species forests in ecologically suitable locations creates dramatically greater carbon and ecosystem-integrity benefits compared to establishing monoculture plantations *(Rocha et al., 2018; Wheeler et al., in press)*. Hall et al., *(2012, p.1135)*, found that "landscapes experiencing increases in natural secondary forest also experienced an increase in carbon stored above and below ground." Plantations, on the other hand, can have negative environmental impacts, such as displacing existing biodiversity, run-off pollution from water and nutrient inputs, and altering local hydrological flows *(DellaSala, in press; Hall et al., 2012; Wheeler et al., in press)*. If plantations replace natural forests, they will result in increased CO_2 emissions *(Grace et al., 2014)*, potentially over long time scales. For multiple low-risk objectives to be met, it is important that reforestation happens within natural forest biomes, with appropriate native species.

Potential for natural forest expansion

Recent studies on South America *(Chazdon et al., 2016)* Borneo (Asner et al., 2018), and the neo-tropics (Rozendaal 2018), suggest high carbon-sequestration potential from allowing secondary forests to regrow. Secondary forests deliver a suite of ecosystem functions that are closely linked to their biomass resilience, with recovery rates increasing in higher rainfall areas, and decreasing with the degree of forest loss in the surrounding landscape (implying lower seed availability) *(Poorter et al., 2016)*. Although secondary forests have substantially lower carbon stocks and biodiversity than the old-growth forests, their carbon sequestering potential is high *(Chazdon et al., 2016; Nabuurs et al., 2017; Poorter et al., 2016)*. Boreal regions are generally excluded from forest regrowth or expansion estimates because albedo effects may offset climate benefits *(Houghton and Nassikas, 2018; Grace et al., 2014; Arneth et al., 2017)*. However, the loss of boreal forests would contribute more to warming than potential albedo effects from forest expansion. The boreal forest biome plays a critical role in land-atmosphere temperature regulation and is vital to planetary stability *(Steffen et al., 2018)*.

Recognising the significant carbon mitigation potential naturally regenerating forests deliver can motivate efforts to reach political targets for forest restoration, as set forth in the Convention on Biological Diversity Aichi Targets, the Bonn Challenge, and the New York Declaration on Forests. We assume that forest expansion happens on a scale inline with these latter two targets, that is, 350 million hectares of closed-canopy forest restoration by 2030. The World Resources Institute has developed a 'forest and landscape restoration opportunities' atlas, which identifies more than two billion hectares of deforested and degraded landscapes suitable for restoration *(WRI, 2011)*. Of this, 1500 Mha is identified suitable for 'mosaic' restoration—mixed use landscapes combining trees and other land-uses— while 500 Mha is identified as suitable for 'closed-canopy' forest restoration, which would preclude other intensive land-uses *(WRI, 2011)*. Our scenario focusses on the potential for 350 Mha under the Bonn Challenge to be met through closed-canopy forest restoration, not the wider landscape restoration goals. However, the risk that such a large area of forest expansion could increase competition for land and displace agricultural activities can be minimised through respecting and strengthening tenure systems, changes in agriculture production, and effective governance systems for restoration activities *(Latawiec et al., 2015)*.

Our assumptions for mitigation potential are in line with current pledges under the Bonn Challenge—80% of which are in tropical regions— but not in line with the type of pledged restoration activity *(Wheeler et al, in press)*. While the Bonn Challenge pledges are currently divided between natural regeneration and plantations, Wheeler et al. *(in press)* show that leaving forests alone to naturally regenerate offers carbon sequestration benefits 97% higher than establishing commercial plantations. Such findings suggest that significant climate and other environmental benefits will only be realised if the area pledged for closed-canopy restoration is dedicated to natural forest regeneration rather than used to establish plantations. Wheeler et al. *(in press)* note that "whilst the general perception of forest restoration is often the recovery of ecosystems to a more natural state, the reality of forest restoration is quite different. If current commitments are carried out as suggested, then potentially close to 160 Mha of land could be converted to plantations, which will provide very different carbon outcomes in comparison to natural regeneration of degraded forest back to an intact forest state. If given long-term protection, naturally regenerating forest could offer substantial carbon sequestration."

Our scenario therefore highlights the greater carbon sequestration, biodiversity, and forest resilience that are achieved if governments prioritise natural regeneration over plantations. The natural regeneration of 350 Mha (80% in the tropics and 20% in temperate zones), would provide 3.9 Gt CO_2/year in sequestration. If protected from further harvest or degradation, this regenerated forest would increase the area of global forest cover to almost 75% of original forest cover—the planetary boundary threshold for land-system change *(Steffen et al., 2015)*.

2.4 Responsible use of forests

We have now explored three types of ecosystem restoration which can help keep temperature increases to 1.5°C, while respecting land rights and biodiversity: halting deforestation and forest degradation; restoring degraded forests to primary forests; and expanding secondary forest areas through natural regeneration. The fourth pathway we examine is the responsible use of natural forests that are being used for timber production or other purposes. This involves changing management practices—a new balance between forest conservation and wood harvest is needed *(Thies, 2018)*. Harvesting wood typically reduces carbon density in managed forests *(Arneth et al., 2017)*, yet many studies into forest management do not tackle the fundamental requirement for harvests to be reduced in order for forest carbon stocks to increase. Key management practices that are consistently reported to yield greater forest carbon stocks include reduced thinnings and residue removal, increased rotation lengths, better utilisation of harvested wood products (HWP) *(Smyth et al., 2014; Canadell and Schulze, 2014; Nabuurs et al., 2017)*, and shifting from wood production to forest protection *(Böttcher et al., 2018; Keith et al., 2009; Law et al., 2018)*.

Several recent studies have emphasised the climate mitigation potential from increasing the life of HWPs *(Nabuurs et al., 2017; Houghton and Nassikas, 2018)*. Yet analysis shows that 'long-lived' HWPs tend to actually be short-lived *(Keith et al., 2015)*. Research on the value of HWPs, and in particular the volume of harvest that remains in wood products on decadal time scales, is both scant and problematic. Perpetuating the idea that HWPs are good for the climate maintains sustainable harvest as a dominant forest mitigation strategy over conservation, although conservation has far greater climate and ecosystem benefits *(Keith et al., 2015)*. A more balanced appraisal of how wood-product markets impact the establishment of forests, and wood 'residency times' in long-lived wood products, is urgently needed. Below we consider 'sustainable use' and conservation strategies to highlight the trade-offs and challenges associated with increasing carbon sequestration in production forests, which minimise the role of HWPs.

An example of how changed management practices in temperate forests can increase sequestration, is provided by Böttcher et al., 2018, who modeled a "Forest Vision" across all Germany's forests implementing "ecological forest management" *(Böttcher et al., 2018)*. The authors found three key practices that could increase forest carbon stock in Germany by 0.06

BOX 6:

Bioenergy

Large-scale bioenergy use as a climate mitigation strategy—whether through biofuels as a substitute for fossil-fuels, solid biomass burned for heating and electricity, and most recently, the expectation that BECCS will remove carbon from the atmosphere— is ubiquitous throughout modelled scenarios for 2°C and 1.5 °C. While there are numerous technological, economic and biophysical constraints to increasing bioenergy use, which are highlighted elsewhere *(Fern, 2018)*, here we address the issue of the carbon neutrality of burning biomass, and the question of a sustainable supply of biomass for energy in the context of an ecosystem and rights-based approach.

Modelled 2 °C pathways assume a level of bioenergy production by 2050 that would require doubling the current harvest of all global biomass for all uses (food, feed and fibre) *(Dooley et al., 2018; Searchinger et al., 2015)*. Field and Mach *(2017, p.707)* highlight the issues at stake, suggesting that converting land on the scale required for bioenergy in many modelled climate change mitigation scenarios would "pit climate change responses against food security and biodiversity protection". Such a massive intervention would have immense social, economic and ecological impacts, including diverting land from food production and driving up food prices *(Boysen et al., 2017)*.

Bioenergy is seen as a mitigation strategy because of its assumed carbon neutrality. This is based on the theory that when bioenergy is combusted, CO_2 is released, but this is recaptured when the biomass stock grows back, or, that if 'residues' are burned they would decompose and emit CO_2 if not burned for energy. Yet the combustion of biomass for power generation or heating "will generally release more carbon dioxide to the atmosphere per unit of delivered electricity or heat than fossil fuels, owing to biomass having lower energy density and conversion efficiency CO_2 emissions per unit of energy produced" *(Courvoisier et al., 2018, p.21)*. There is a clear scientific consensus that using forest products for bioenergy (woodpellets or wood chips), through harvesting live forest biomass is not carbon neutral *(DeCicco and Schlesinger, 2018; Searchinger et al., 2017; Smyth et al., 2014; Sterman et al., 2018)*. Increased atmospheric concentrations from burning bioenergy may worsen irreversible impacts of climate change before forests eventually grow back to compensate *(Booth, 2018; Courvoisier et al., 2017; Schlesinger, 2018)*. Schlesinger states that "cutting trees for fuel is antithetical to the important role that forests play as a sink for CO_2 that might otherwise accumulate in the atmosphere" *(Schlesinger, 2018, p.1328)*. Ultimately, increased forest harvest for bioenergy decreases the forest carbon sink, which is the opposite of good climate mitigation policy. Even net emissions from forestry residues burned as fuel are significant over the mid-term (20-40 years), a time-scale relevant to current climate mitigation efforts *(Booth, 2018)*.

The use of annual or short rotation crops for bioenergy is also considered to be carbon-neutral due to the annual nature of regrowth, which avoids the long pay-back periods of forest harvest. Many countries have mandates that require biofuels to be blended into fuel for cars and trucks, either at a specific volume or percentage level. For example, the US Renewable Fuel Standard (RFS) calls for blending 15 billion gallons of conventional ethanol, typically corn ethanol, into the US fuel system. However, stakeholders including green groups, farmers' and indigenous peoples' organisations, and development agencies have joined researchers in refuting the climate claims made about biofuels. Full life cycle assessments have shown that biofuels can have higher emissions than the fossil fuels they are meant to replace *(Searchinger et al., 2015, 2017)*. Most land is part of the terrestrial carbon sink or is used for food production, meaning that harvesting for bioenergy will either deplete the existing carbon stock, or displace food production leading to indirect land use emissions *(Searchinger et al., 2015, 2017)*. Given high demands on land for food production and other uses, climate policy should not support bioenergy from energy crops and other dedicated uses of land, such as wood harvest for bioenergy. The supply of wastes and residues as a bioenergy source is always inherently limited and the collection and use of wastes and agricultural residues present logistical and cost barriers, although the use of secondary residues (cascade utilisation) may decrease logistical costs and trade-offs associated with waste use *(Smith et al. 2014)*.

In conclusion, this brief overview of current debates around bioenergy use suggests that sourcing bioenergy from forest harvest is not carbon neutral; any bioenergy from the 'dedicated use of land' is unlikely to be carbon neutral and comes with a significant land opportunity cost; and the use of residues and wastes for bioenergy is limited.

Gt CO_2 /year (over 10.6 Mha): 1) excluding areas from wood extraction; 2) forest restructuring through preferencing native (broadleaf) trees over conifers; and 3) reduced management intensity and increased tree diameters. Of these, the most effective management change to increase carbon sequestration and storage in production forests, was to expand the area excluded from wood harvest. For the areas remaining in productive use, reducing harvest intensity allowed forests to regenerate, increasing biodiversity and ecosystem functions compared to forests under intensive management *(Böttcher et al., 2018)*. The 'substitution effect' of HWP and biofuels replacing other GHG emissions-intensive products such as buildings or transport fuels was excluded, due to a lack of data for a well-founded description of the effects *(Böttcher et al., 2018)*. (See also, **BOX 6**).

Modelling of the temperate forests of the Pacific Northwest of the US, a region with some of the highest carbon density forests in the world, found that lengthening rotation rates from 42 to 80 years and reducing harvest in some areas by 50% could increase carbon stocks by an average of 0.05 Gt CO_2 /year over the century *(Law et al., 2018)*. Another model assessing 85 Mha of mostly temperate forests in the European Union (EU), found potential to double mitigation benefits (and sequester 0.3 Gt CO_2 /year) by 2050 with a variety of management practices *(Nabuurs et al., 2017)*. Again, excluding areas from harvest, and expanding forest area offered the biggest mitigation opportunities *(Nabuurs et al., 2017)*, (when energy substitution was excluded from the results for the reasons given above).

Studies on boreal forests indicate that long-rotation forestry generally increases forest carbon stocks when compared to almost any baseline with less-intensive thinnings, shorter rotations, substitution effects, or HWPs, due to the foregone carbon sequestration under more intensive management *(Pingoud et al., 2018)*. By reducing the number of thinnings and extending the rotation age, the carbon stocks in the forests of southern Finland could be doubled if residues are also left in the forest to build future productivity *(Pingoud et al., 2018)*. Therefore, across tropical and boreal biomes, the most effective changes in management practices for forests that remain in use, is reducing the intensity of forest harvest. Houghton and Nassikas *(2018)* found that under current conditions, industrial wood harvest led to an 18% reduction in carbon storage in temperate and boreal forest biomes, compared to a simulation without industrial wood harvest. An approach is needed where wood harvest is reduced to levels that allow forest carbon stocks to recover, alongside biodiversity and forest ecosystem functions.

Reducing wood harvest through extending rotation times and excluding areas from harvest will ultimately decrease the volume of wood produced. In the studies described above, reduction in wood production (not always quantified) was around 25% over the century *(Böttcher et al., 2018; Law et al., 2018; Nabuurs et al., 2017)*.[5] Any harvest reduction requires decreased demand for timber products, and/or increased efficiency in the use of wood products, to ensure that reduced wood harvest does not drive greater demand for steel and concrete for building. Production and efficiency of wood products is discussed in the section below on plantations. Böttcher et al. *(2018, p.10)* suggest that implementing a "Forest Vision" for sustainable management and increased biodiversity and carbon stocks in production forests, "requires that the use of harvested wood will have to be different from today." Due to decreasing substitution effects, "a significant increase in the efficiency of wood use through more material and less energetic use, especially of wood from broadleaf trees, is required not only from the point of view of climate protection, but also to achieve a more sustainable use of resources" *(Böttcher et al., 2018, p.10)*.

The responsible use of tropical forests differs from the more intensively managed areas of boreal and temperate forests. A meta-analysis of reduced-impact logging in tropical forests found no evidence that differences in logging intensity—the volume of wood removed per hectare—affects above-ground carbon stocks or tree species richness *(Martin et al., 2015)*. Other authors assert that selectively logged forests retain substantial biodiversity, carbon, and timber stocks (compared to completely cleared areas) *(Chazdon et al., 2016; Putz et al., 2012)*, leading some to argue that a 'middle way' between deforestation and total protection, such as reducing logging intensity by half, deserves more attention *(Mazzei et al., 2010; Putz et al., 2012)*. Ultimately, most commercial harvest of tropical forests is aimed at selectively removing large-diameter trees, the valuable hardwood timber that stores as much as 50% of the above-ground carbon in forest ecosystems, taking centuries to mature *(Lutz et al., 2018)*. Research shows that industrial logging regimes in the tropics are "several hundred years out of sync with the life cycles of high-value timber trees", making commercial timber operations in the tropics both uncommercial and ultimately unsustainable *(Zimmerman and Kormos, 2012, p.485)*. Instead, industrial harvest in all three major tropical forest regions—even when practiced under sustainable forest management principles— reduces the above-ground carbon stocks when large trees are removed, and ensures the commercial and biological depletion of high-value timber species within three harvest rotations *(Martin et al., 2015; Zimmerman and Kormos, 2012; Lutz et al., 2018)*.

The other big driver of emissions in the tropics is swidden agriculture, a traditional farming practice that involves rotational periods of fallow cropping and forest regrowth *(Ziegler et al., 2012)*. When practiced traditionally, with long fallow periods, swidden can be sustainable *(Ziegler et al., 2012)*. Population increases and/or land constraints in some areas have shortened rotation times, decreasing soil fertility and pushing swidden agriculture into intact forest areas that were previously left untouched *(Coomes et al., 2017; Mackey et al., 2018; van Vliet et al., 2012)*. The sustainabiliyy of swidden agriculture can be improved *(Mackey et al., 2018; Sovu et al., 2009; Ziegler et al., 2012)*, while non-traditional practices, such as illegal slash and burn and forest clearing, must be halted.

5 Note this would not correspond to a global decrease in wood production by 25%, given that a significant share of wood harvest comes from plantations, rather than natural forests—see discussion below on plantations.

Mitigation potential through responsible use of forests

Almost half (1187 Mha) of global secondary forests are designated as production forests, according to the FAO *(FAO, 2016)*. For temperate and boreal regions we assume that the responsible use of natural forests translates to significantly reduced wood harvest and lengthened rotation times *(Law et al., 2018; Pingoud et al., 2018)*, resulting in less income for landowners and lower wood production levels. HWP are excluded from our assessment, as the mitigation value of HWP is disputed *(Keith et al., 2015; Law et al., 2018)*. In tropical forests, as discussed above, reduced harvest and sustainable management practices have not been shown to increase carbon stocks or biodiversity *(Martin et al., 2015; Zimmerman and Kormos, 2012)*. Therefore we characterise responsible forest use in the tropics as the withdrawal of industrial logging and other extractive activities. Shifting cultivation (or swidden agriculture)—identified as a significant contributor to degradation emissions in tropical forests *(Houghton and Nassikas, 2018)*— is assumed to be reduced by half, with any ongoing disturbance from shifting cultivation offset by regrowth in abandoned fallows, lengthened fallow times or improved swidden practices.

We assume these measures are applied across forests currently designated as 'production' forests—about half of the total natural forest area outside primary forests according to the FAO *(FAO, 2016)*. Improving forest management through reduced harvest and extended rotation times across temperate and boreal forests, and halting industrial timber extraction and improving the sustainability of swidden in tropical forests, results in additional sequestration of 2.1 Gt CO_2/year, based on biome-average sequestration rates for the above-specified activities.

Plantations

Exotic tree plantations have been shown to damage communities and biodiversity, and are more susceptible to pests, disease and fire than biologically diverse (and therefore more resilient) natural forests. Civil society networks such as the Global Forest Coalition have rejected monoculture plantations as mitigation:

> **"Following the adoption of the Paris Agreement, an increasing number of climate mitigation project proposals for large-scale monoculture tree plantations are emerging mainly in developing countries. Due to their harmful environmental and social impacts, large-scale monoculture tree plantations should not be defined as forests and have no place in climate change policies. They are commercial enterprises, and should not be subsidised with climate finance" *(Global Forest Coalition, 2017)*.**

Most areas specifically planted and managed for wood production will have a much lower average carbon stock than primary forests, and lower sequestration rates than secondary natural forests *(DellaSala, in press; Wheeler et al., in press)*. Establishing plantations leads to increased emissions if they replace natural ecosystems *(Grace et al., 2014)*. Existing plantations can be made "semi-natural" by planting diverse native seeds and enhancing structural diversity, thereby improving resilience *(DellaSala, in press)*. Even with such actions, plantations are not forests. The first principle of restoration is thus to stop the loss of ecosystem integrity before it happens, by preventing the conversion of natural ecosystems to plantations *(DellaSala, in press)*.

Plantations (including planted and semi-natural forests) currently account for 7% of global forest area *(FAO, 2016)*. Sedjo and Botkin *(1997)* estimated that in order to meet global demand for wood products, some 5% of the world's forests would need to be maintained in plantations *(cited in DellaSala, in press)*. In 2005, forest plantations were estimated to supply about 70% of global roundwood harvest *(Ajani et al., 2013)*. Roundwood harvest is estimated to have been relatively stable for the last 15 years, with approximately 1.8 billion m3 harvested for roundwood every year *(Nabuurs et al., 2007)*. While plantations are likely to be providing somewhat less than 70% of the roundwood production they provide today, they continue providing the majority of commodity wood production (wood products that compete on price alone).

Ajani et al., *(2013, p.62)* proposed the concept of a "new forest policy frame centred on allocating natural forests and plantations to the jobs they do best. Natural forests are best used for biodiversity conservation, carbon storage and uptake, while plantations are best used for wood production." Achieving such a vision will however, rely heavily on reducing overall wood product use, through increased efficiency, recycling, and less consumption, if an expansion of plantation area is to be avoided. The FAO reports a trend of increasing efficiencies in wood use, such as a shift from sawn products to composite timber products, expanded recycling, and higher recovery rates *(Muller et al., 2018)*. Reducing wasteful consumption and finding alternatives to wood products is required, while the conversion of native forests to plantations must end *(DellaSala, in press)*. The value of native and intact forest ecosystems is far beyond the value of the timber harvested from them, and the associated ecological destruction is short-sighted, and will be long regretted.

Part 3: Agriculture

Agriculture plays a critical role in any analysis of drivers and impacts of climate change. The sector makes substantial contributions to climate change, through emissions of CO_2, CH_4, and N_2O (see **BOX 4**: GHG emissions). Industrial agricultural expansion has led to deforestation, forest degradation and the loss of ecosystems around the world *(Rudel et al., 2009)*. Agricultural commodities are the leading cause of forest loss *(Curtis et al., 2018)*. Stopping the expansion of agricultural lands in order to protect existing natural ecosystems would make major contributions to preventing warming.

At the same time, agriculture will bear much harm from the climate impacts which the sector itself faces: extreme events of flooding, hail, and heat; slow onset events of desertification, salinisation of water supplies, increasing temperatures, and changing rainfall patterns. Food producers will need to change their practices over the coming decades to adapt to climate impacts as far as possible. In some areas, food production may no longer be possible and food producers will need to find other livelihoods or relocate to continue food production.

The Paris Agreement's 1.5°C goal therefore has two significant implications for agriculture. First, the sector should be a source of significant emission reductions and agroecosystem-based removals, making a large contribution in pathways to 1.5°C. The second dimension is equally important. Food production is essential to lives and livelihoods—to the lives of everyone on the planet and to the livelihoods of billions, including many of the world's most vulnerable. Efforts to limit temperature rise to 1.5°C helps to ensure food security, maintain rural livelihoods, and ultimately to fulfill the sustainable development goals (SDGs) related to ending poverty and hunger. Concern for mitigation measures must therefore be balanced with measures to protect food supplies and food producers. Mitigation proposals that rely on taking extensive areas of land out of food production would threaten food security and must be avoided.

Many of the necessary transformations in the agriculture sector that will enable a significant contribution to reaching the 1.5°C target, while building resilience, will look substantially different from business as usual. Puerto Rico serves as a recent, striking example.[6] The island has been hit by devastating hurricanes in recent years, including Maria in 2017, which wiped out 80% of crop value across the island, particularly affecting cash crops such as coffee, sugar cane and bananas. New farming strategies to adapt to climate change and the strong winds of regular hurricanes rely on planting underground crops—tubers, such as cassava, yams, and malanga—which would continue to provide income and food in times of disaster. Farmers call their new, climate-resilient practices agricultura subterranea—underground agriculture.

Radical system/systemic changes, such as deciding to switch from coffee to yams, from cash crops to underground staples, are not easily captured in analyses that start with a mitigation frame or in integrated assessment models. And yet these are exactly the sorts of transformations in agriculture that will be essential to cut emissions and adapt to climate impacts *(FAO, 2018a)*.

In the following sections we summarise research that quantifies emissions reduction potential across various elements of global and local food systems: agroforestry systems and crop production (Section 3.1), livestock production (Section 3.2), and downstream processing and consumption (Section 3.3). The analysis starts from first principles: agroecological principles of production and the human rights principle of the right to food.

Agroecological practices reflect the workings of natural ecosystems, and aspects of those ecosystems fundamental to their functioning. Agroecological farming systems rely on the recycling of nutrients, rather than the exogenous addition of critical nutrients such as nitrogen. Systems are built on diversity, which contributes to resilience and enhances productivity. How diversity is incorporated in any particular agroecosystem will vary depending on the features of the system—cultural, ecological, biophysical, economic. Trees are incorporated into pastures; farmers create multi-storey home gardens; or they give up their above ground systems for below ground cropping that provides security for families and communities in the wake of climate disasters.

In Section 3.2, we describe an ecological food systems approach that leads to significant emission reductions in livestock production and consumption. It too is a transformative approach, confronting the illogicality of an industrial system that feeds food crops to animals while humans go hungry. The ecological leftovers approach instead feeds food crops to humans, while providing leftovers—such as food scraps and crop residues—to animals. We combine this with the advantages of using agroeoclogical farming practices on the remaining acres. Grasslands—where we can also plant trees in silvopastoral systems—are still used to graze animals, rather than converted to crop production, protecting the massive stores of carbon found in the soils of these perennial systems, not to mention biodiversity and other ecosystem functions.

Ecological leftovers is a full life-cycle approach that significantly reduces emissions associated with livestock production, by using leftovers for animal feed instead of dedicated crops. It also significantly reduces the amount of meat produced globally and therefore also requires a transformation in consumption practices, particularly in the wealthy countries of the global

6 Miguel Altieri, a prominent agroecologist and professor emeritus from the University of California at Berkeley, tells a story from a recent visit (email communication).

North and the wealthy strata within developing countries. The final section of this chapter on agriculture (Section 3.3) takes a critical look at consumption and the emissions reductions possible at the far end of the farm to fork continuum.

Reducing meat consumption, overconsumption and food loss and waste, could substantially reduce the land required to ensure food and nutrition security for the planet's population. Shifts to healthy diets, through reducing the consumption of animal products and consuming only those that could be ecologically produced, and reducing overconsumption and food waste, could halve the area of agricultural land required by 2050 *(Röös et al., 2017)*. While such global estimates are impressive, a much more detailed regional view is required, as each region will have to use their own resources and contextualise and apply agroecological and agroforestry solutions to their climate, landscapes, and populations. We also do not assume that reduced land demand for agriculture could be used towards climate mitigation, and the ecosystem restoration numbers discussed above in Part 2 do not rely on converting agricultural land to natural ecosystems.

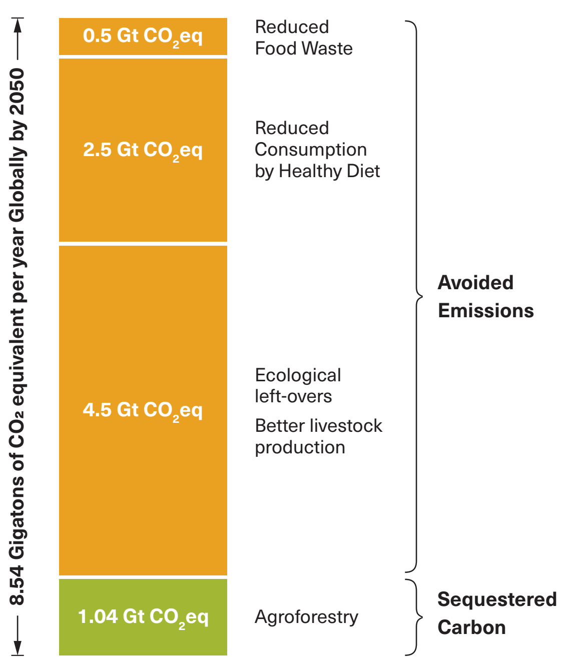
If agriculture is to contribute its fair share of emissions reductions and carbon removals to a 1.5°C pathway, business as usual is not an option. Incremental adjustments and tinkering around the edges of the industrial agricultural system responsible for close to a quarter of current global emissions will fall far, far short of what is needed. How we produce our food, where, and for whom will need to change profoundly *(FAO, 2018a)*.

This final chapter on agriculture focuses then on three necessary elements of food system transformation: 1) adoption of agroecological production methods; 2) transforming how we produce and consume livestock; and 3) addressing food and agriculture-related related waste and over-consumption. These three elements are addressed separately but are interwoven in the quest for equitable pathways to 1.5°C, which ensure food security and sovereignty. The interrelationships and connections are significant and consequential *(Foley et al., 2011)*. We proceed linearly, with the intent of drawing a multi-dimensional picture of what is required.

FIGURE 5

Mitigation Potential Across All Agricultural Pathways

The potential for avoided emissions by better production, less consumption and reduced waste of food and agricultural products is significant. At the same time, agroecological practices such as agroforestry can increase carbon stocks.



Calculations and assumptions can be found in the supplementary table, available here: www.ClimateLandAmbitionRightsAlliance.org/report

3.1 Agroecological approaches

Agroecological principles and practices form the basis of the four approaches and pathways to reduce GHGs from agriculture that we describe in this chapter: integrating trees into cropping and livestock systems (agroforestry); enhancing soil fertility through more emphasis on nutrient cycling within systems, rather than on external inputs of synthetic nitrogen; ecologically-based feeding and management of livestock, coupled with an overall decrease in livestock numbers in line with what healthy ecosystems can support (section 3.2); and smarter integration, shorter value chains, and more ecologically-based eating and recycling of waste in the broader food system, from farm to fork (section 3.3). These pathways are summarised in **FIGURE 5**.

Principles and practices of agroecology

According to the International Assessment of Agricultural Knowledge, Science and Technology for Development (MacIntyre et al., 2009), agroecology is:

> "the science of applying ecological concepts and principles to the design and management of sustainable agroecosystems. It includes the study of the ecological processes in farming systems and processes such as: nutrient cycling, carbon cycling/sequestration, water cycling, food chains within and between trophic groups (microbes to top predators), lifecycles, herbivore/predator/prey/host interactions, pollination, etc. Agroecological functions are generally maximized when there is high species diversity/perennial forest-like habitats."[7]

Altieri *(as cited in Farrelly et al., 2016)* sets out six foundational

7 The above definition focuses on the scientific discipline of agroecology. Authors *(e.g., Tomich et al., 2011)* also often note two other dimensions or ways in which the term agroecology is used: agroecology as practice, or set of practices, and agroecology as a movement. Because this chapter of the report is focused on greenhouse gas emissions of agricultural systems, here we emphasise literature that discusses the science and the practices of agroecology. Of course we understand the practice of agriculture has important social and economic dimensions,

principles that underlie the science and practice of agroecology:

1. Enhance the recycling of biomass with a view to optimising organic matter decomposition and nutrient cycling over time.
2. Strengthen the "immune system" of agricultural systems through enhancing functional biodiversity, using natural enemies, antagonists, etc.
3. Provide the most favourable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biological activity.
4. Minimise losses of energy, water, nutrients and genetic resources by enhancing conservation and regenerating soil and water resources, and agrobiodiversity.
5. Diversify species and genetic resources in the agroecosystem over time and space at the field and landscape level.
6. Enhance beneficial biological interactions and synergies among the components of agrobiodiversity, thereby promoting key ecological processes and functions.

Agroecological practices make these principles concrete, and show how to design systems using agroecological principles that reduce emissions from agriculture while adapting to a changing climate. Two broad categories of practices are particularly important in designing climate-resilient systems: those that enhance biodiversity, and those focused on improving the health and fertility of soils. Practices that enhance biodiversity and agrobiodiversity (principles 2, 4, 5 and 6) include: intercropping; polycultures (e.g., including perennial grain); crop rotations; mixed rice-fish systems; mixed crop-livestock systems; agroforestry systems (e.g., silvopastoral, agrosilvopastoral, agrosilviculture, and home gardens); and hedgerows, windbreaks, shelterbelts, and living fences. Soil-enhancing practices (principles 1, 3, 4, 5, and 6) include: composting; mulching; green manures; nitrogen-fixing trees; animal manures, recoupling animals with crop nutrient cycles; cover cropping; low soil disturbance tillage; and practices that enhance below ground diversity, such as valuable mycorrhizal fungi and other soil microorganisms important to many ecosystem functions such as soil fertility management.

But agroecology is more than a set of practices, it is an alternative to industrial farming that is also a way of life for peasant farmers.

> **"There is now extensive evidence that peasant-based agroecological systems are superior to high external input industrial agriculture and are highly productive, highly sustainable, empower women, create jobs, engage youth, provide greater autonomy, climate resilience, and multiple social, cultural and environmental benefits for women and men in rural and urban communities. Farms adopting agroecological approaches suffer less and recover more quickly from climatic stress and disasters" *(ActionAid, 2018)*.**

which we expect is evident implicitly in the practices we describe, if not explicitly.

Key characteristics of agroecological systems *(after IPES-FOOD, 2016)* include: temporal diversification (e.g. crop rotation) and spatial diversification (e.g., intercropping; mixed farming); diversification employed at various levels, including plot, farm and landscape; use of a wide range of species and less uniform, locally-adapted varieties/breeds, based on cultural preferences, taste, productivity and other criteria; emphasis on natural synergies and integration of production types (e.g. mixed crop-livestock-tree farming systems and landscapes); more labour-intensive systems; maximisation of multiple outputs; low external inputs and recycling of waste within full nutrient cycling and circular economy approaches; production of a wide range of less homogeneous products often destined for short value chains; and multiple sources of production, income and livelihood.

BOX 7:

The adaptation treadmill of climate change

We are no longer in a linear world, where steadily increasing agricultural productivity can be relied upon, where current gaps in yields between "developed" and "developing" world agricultural systems would be filled by adopting modern practices and synthetic fertiliser. Climate change will greatly impact agricultural production and productivity in all corners of the planet, but some more than others. Rain-fed agriculture will become much more vulnerable to unpredictable rain patterns, making this an increasingly precarious livelihood in many places. Livestock keepers, particularly pastoralists, in arid and semi-arid regions will see disruption of water and pasture.

The treadmill is necessary context for any consideration of 'productivity', 'land sparing', 'sustainable intensification', or 'yield gaps'. The term 'productivity' consistently emerges in analyses of how to reduce agricultural emissions. If small-scale producers can increase their productivity, the argument goes, then emissions per unit might fall, and this class of farmers could make positive contributions to the emissions reductions effort. Increased productivity is also cited as a means to reduce new land conversion—'land-sparing'. These ideas are bundled together in the term 'sustainable intensification'. Often discussions on productivity are in the context of closing 'yield gaps'—gaps between actual yields attained by farmers in a particular region with the biological or technical potential, as manifest in the highest on-farm yields attained using optimum management practices and inputs.

But in the context of climate change, and consequent impacts on agricultural yields, yield gaps become a moving target. Small-scale food producers face a range of serious adaptation challenges that obviously take priority over mitigation. The challenges require a holistic approach: to consider at the same time how we produce food, provide livelihoods, maintain biodiversity and ecosystem functions, adapt to increasing temperatures and increasing variability of rainfall, and minimise emissions.

Agroecology and climate change: Agroecological practices are particularly valuable in buffering agricultural systems from the impacts of climate change. Specialised industrial agriculture systems, based on genetic uniformity, monocultures, the use of expensive external inputs, and long value chains, are particularly vulnerable to climate impacts *(Altieri et al., 2015; IPES-FOOD, 2016)*. Numerous studies from a wide variety of crop and livestock systems around the world demonstrate that enhancing agrobiodiversity can reduce vulnerability and increase system resilience Indeed diversification of agroecosystems may be required to maintain and stabilise yields in an increasingly unpredictable climate *(Isbell et al., 2017)*. Practices that enhance soil organic matter and manage soil cover greatly improve the ability to preserve vital moisture and nutrients in soils *(Altieri et al., 2015)*. Verchot et al., *(2007)* present evidence that agroforestry has an important role in adaptation, particularly for smallholder farmers. Mortimer et al., *(2015)* and Akinnifesi et al., *(2010)* show how fertiliser trees enhance soil fertility and increase yields.

Agroecological practices also contribute to mitigation, for example through carbon removal in agroforestry systems and reducing nitrous oxide emissions by recycling nutrients. We review the potential of each of these two contributions in turn.

Potential for sequestration in agroforestry systems

Agroforestry systems are a diverse set of agricultural production practices that in one way or another integrate woody perennials on farms *(Mbow et al., 2014)*. The International Assessment for Agricultural Knowledge, Science and Technology for Development *(MacIntyre et al., 2009, p. 560)* defines agroforestry as "a dynamic, ecologically based, natural resources management system that through the integration of trees in farms and in the landscape diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels".

Agroforestry systems include multi-storey homegardens on Mount Kilimanjaro and those found across Asia *(Kumar and*

BOX 8:

Soil carbon sequestration

Soil carbon sequestration on agricultural land has received much attention in climate science and policy circles *(Frank et al., 2017; Paustian et al., 2016; Smith, 2016; Zomer et al., 2017)*.

There are many agronomic and climate adaptation reasons to take measures to increase the carbon content of soils. Increasing soil carbon can enhance resilience and adaptive capacity. Soil organic carbon (SOC) is associated with increased soil fertility and increased yields, thereby also increasing income for farmers. Soils richer in SOC have better infiltration capacity, can hold more moisture, and store it for longer periods of dryness *(Gaudin et al., 2015; Kaye and Quemada, 2017)*. With better soil structure and greater organic matter content, soils hold more nutrients which improves those nutrients bioavailability. All these properties increase the resilience of the farming system *(Smith et al., 2014)*.

Moreover, efforts should be taken to protect the carbon already stored in the reservoir of the world's soils—holding more carbon (2400 GtC in depths up to 2m) than the atmosphere and all plant biomass combined *(Ciais et al., 2013)*. Options to increase soil carbon may include trade-offs such as biodiversity loss and health impacts that need to be addressed. Conservation agriculture is an option often mentioned in the literature, but it can result in a significant increase in the use of herbicides and pesticides with side effects on biodiversity *(Baveye et al., 2018; Giller et al., 2009)*.

The sequestration of soil carbon is also considered important because of its mitigation potential. However, quantifying mitigation benefits from the sequestration of soil carbon is challenging and contentious, in particular for reasons of non-permanence and the finite nature of soil carbon sink capacity *(Minasny et al., 2017; White et al., 2018)*. Carbon sequestered in topsoils is not there permanently—as evidenced by the loss of soil carbon over the last few centuries through agricultural and other soil degrading practices. Processes that lead to reversals may increase under climate change: fires, insect damage, storms, droughts, and heat waves *(Ciais et al., 2013; Crowther et al., 2016; Smith et al., 2014)*. Furthermore, due to insufficient knowledge on the mechanisms impacted by agricultural practices, it is hard to predict their effects on soil carbon stocks. Agricultural practices that increase soil organic matter are often considered to have a positive impact on carbon storage. However, their impacts on mechanisms that contribute to the storage or destocking of soil carbon are not yet clearly understood. Meta-analyses and long-term field studies showed that the relative intensity of mechanisms contributing to storage and those contributing to destocking may change over time *(Dignac et al., 2017)*.

The soil carbon sink capacity is finite: there are limits to the total amount of carbon soils can sequester, as well as limits to the amount of carbon sequestered in any given time frame. Depleted soils might initially soak up carbon at a faster rate, but that rate diminishes over time until saturation *(Powlson et al., 2014)*. There is some disagreement over whether the terrestrial biosphere will remain a sink through to the end of the century, or whether processes affecting sink functions or permanence of stocks—such as increased respiration and oxidation due to temperature rise and the loss of soil carbon stored in Arctic permafrost—will flip the land sector to becoming a net source of carbon dioxide *(Ciais et al., 2013)*.

For these reasons of reversibility and sink saturation, most pathways and scenarios exclude soil carbon sequestration, implicitly challenging the IPCC finding in AR4 that 89% of the mitigation potential in agriculture was in soils *(Smith et al., 2007)*.

There is, therefore, a need for other forms of valuing soil carbon, besides mitigation potential, in particular the adaptation and resilience benefits highlighted above. Sequestration options can "benefit the environment and make ecosystems more resilient to extreme climate events… Greenhouse Gas sequestration will never equal reducing emissions, since there is no way of guaranteeing the permanence and non-reversibility of sequestration. The aim is, therefore, to retain [soil] carbon sustainability; knowing that such sequestration is non-permanent" *(CCFD-Terre Solidaire, 2018)*.

Nair, 2004); multi-strata crop systems, such as shade-grown coffee, tea, or cacao *(Tscharntke et al., 2011)*; silvopastoral systems where cattle graze under tree cover while land regenerates *(Calle et al., 2012)*; parkland systems of the Sahel (Luedeling and Neufeldt, 2012); rotational woodlots *(Mbow et al., 2014)*; improved fallows *(Rosenstock et al., 2014)*; and shelterbelts, alley cropping, and hedgerows.

There is no widely accepted classification for agroforestry practices or systems *(Torquebiau, 2000)*. While many authors work with a broad and diverse definition for agroforestry, including any agricultural lands with greater than 10% of tree cover *(Zomer et al., 2014)*,[8] others work under narrower definitions which only cover five types of practices: alley cropping, forest farming, silvopastoralism, riparian forest buffers, and windbreaks *(Wilson et al., 2016)*. We treat agroforestry as a whole-system approach—often reflecting centuries of adaptive measures, and the application of traditional knowledge, within specific biocultural frames—whose practices vary across time, ecological space, and culture.

Agroforestry is common to many regions. Thirty percent of the world's rural population—more than 1.2 billion people—depend on agroforestry systems and live on the over one billion hectares of land that this represents *(Zomer et al., 2014, 2016)*. "Trees on agricultural land have direct impacts on the livelihoods of hundreds of millions of small farmers around the globe… subsistence farming… particularly in the tropics frequently incorporates trees" *(Zomer et al., 2016, p.3,5)*. Agroforestry is more commonly practiced in humid climates; both tree cover and biomass carbon on agricultural lands tend to be higher in more humid climates *(Zomer et al., 2016)*. In Southeast Asia, Central America, and South America, over 50% of agricultural areas include agroforestry *(Zomer et al., 2014, p. 28)*. There is a wide disparity between regions, and "in many regions there is still potential for increasing biomass carbon on agricultural land" *(Zomer et al., 2016, p.3)*.

Because of the diversity of practices involved and the range of climatic conditions in which agroforestry systems flourish, forest cover on agricultural lands is not systematically accounted for *(Zomer et al., 2016)*. Absent from global carbon budgets, regional calculations, or national carbon accounting systems, agroforestry is indeed a 'missing pathway', and one that is difficult to quantify in either its amount of acreage or its carbon sequestration potential. "With no reliable estimates on the extent of area and the gross variability expected in terms of tree species and soil attributes, it is an 'almost insurmountable' task to estimate C stocks in agroforestry," let alone carbon flows and sequestration *(Ramachandran Nair et al., 2010, p.245)*. It is not surprising that "the global role of tree-based carbon sequestration on agricultural land is thus far poorly understood and possibly has been significantly underestimated" *(Zomer et al., 2016, p. 1)*.

Despite these challenges, here we review literature in order to postulate a potential for above ground biomass sequestration from agroforestry. We do not include below ground sequestration because of significant uncertainties, in particular those related to measurement and permanence (see **BOX 7**: Soil carbon), although increased trees in agricultural landscapes have been shown to improve soil carbon *(Chatterjee et al., 2018)*. The International Centre for Research in Agroforestry (ICRAF) and its collaborators across the humid tropics "concluded that the greatest potential for C sequestration in the humid tropics is above ground, not in the soil: through the establishment of tree-based systems on degraded pastures, croplands, and grasslands" *(Montagnini and Nair, 2004, p.286)*.

Zomer et al., (2016) provide a baseline estimate of carbon accumulation through incorporating more trees into agricultural landscapes. They estimate from remote sensing data that between 2000-2010 tree cover on agricultural land increased by 3.7%, resulting in approximately 0.73 Gt CO_2/year, mostly as tree biomass *(Zomer et al., 2016)*. Again, this carbon is not yet captured in national accounts. The literature on agroforestry's potential to increase aboveground carbon includes estimates ranging from 0.37 to 3.5 Mg C/hectare/year *(Griscom et al., 2017; Dixon et al., 1994; Montagnini and Nair, 2004; Cardinael et al., 2017)*. The significant regional variation is highlighted by Montagnini and Nair *(2004)*, who report average carbon storage across semiarid, subhumid, humid, and temperate regions as 9, 21, 50, and 63 Mg C/hectare respectively.

As noted above, Zomer et al. *(2016)* conclude that approximately 40% of global agricultural land includes tree cover. Several sources indicate approximately 600 Mha of land area would be suitable for agroforestry *(Dixon et al., 1994; Ramachandran Nair et al., 2009; Watson et al., 2000)*. We make a conservative assumption that agroforestry systems are maintained and increased on half of this potential land area, some 300 Mha.[9] While we do not rule out a broad range of agricultural practices, as discussed above, we limit our quantified pathway to trees in croplands, to avoid potential double-counting with forest expansion. Silvopastoralism in particular has much potential for growth, and governments are keen to expand pasture areas under agroforestry.[10]

Given the range of practices and estimates of carbon uptake potential through agroforestry, we take a biome average sequestration for above ground carbon increase from a range of agroforestry practices *(Cardinael et al., 2017; Dixon et al., 1994; Ramachandran Nair et al., 2009; Watson et al., 2000)*, and subtract from this the baseline increase observed by Zomer et al., *(2016)*. Assuming agroforestry practices were sustained on only 20% of agricultural land over 50 years, these would result in an additional 1.04 Gt CO_2/year. This is in line with other recent global estimates for agroforestry potential, of 1.04 Gt CO_2/year *(Griscom et al., 2017)* and 2.43 Gt CO_2/year *(Hawken, 2017)*. Maintaining such a wide geographical extent of agroforestry should be a priority for protecting carbon stocks

8 Note that land with greater than 10% tree-cover is defined by the FAO as forest, but in a context of mixed-use (crops grown between trees), such land would be classified agriculture, which prevents double-counting with forest in this pathway.

9 Here we are referring to permanent cropping area, which the FAO puts at 1648 Mha in 2015 *(FAO, 2018b)*. This area does not include pasture land, and so significantly underestimates the increase in area under agroforestry that is possible.

10 Informal communications with government representatives in Brazil and the Dominican Republic.

and continued sequestration, including policies necessary to maintain integrated systems of livestock and trees, diverse crop-tree systems, and community-based agroforestry systems.

Nitrogen in agricultural systems

Nitrous oxide is a significant greenhouse gas. The largest source of nitrous oxide emissions is agriculture (See **BOX 4**: GHG emissions, and **FIGURE 6**). Emissions primarily come from applying nitrogen fertilisers to crops as synthetic nitrogen or manure, the incomplete uptake of that nitrogen, and the conversion of some of the excess reactive nitrogen to nitrous oxide. Agroecological approaches emphasise recycling nutrients within agricultural systems (principles 1, 3 and 4), rather than adding exogenous synthetic nitrogen. Recycling nutrients and ensuring that nitrogen sources are applied when plants need them most can substantially reduce overall nitrous oxide emissions. Moreover, as nitrous oxide emissions are reduced, these approaches also build overall resilience in agricultural systems by enhancing soil health and fertility, increasing soil water-holding potential, and increasing the diversity of soil microflora and fauna. These soil qualities will be critical in dealing with the varied impacts of drought and flooding due to climate change.

The problem of too much nitrogen: Nitrogen is an essential nutrient for plants and a core element in the amino acids that make up proteins. Lack of sufficient nitrogen in cropping systems contributes to poor yields and lower quality food. However, we currently face the challenge of a massive overabundance of nitrogen in our environment, with pollution threatening ground and surface water supplies, contaminating the air we breathe, and contributing to atmospheric warming through emissions of nitrous oxide, a greenhouse gas with an atmospheric residence time of between 114 and 131 years, and which has 298 times the warming potential of carbon dioxide *(Davidson and Kanter, 2014; Zhang et al., 2015)*.

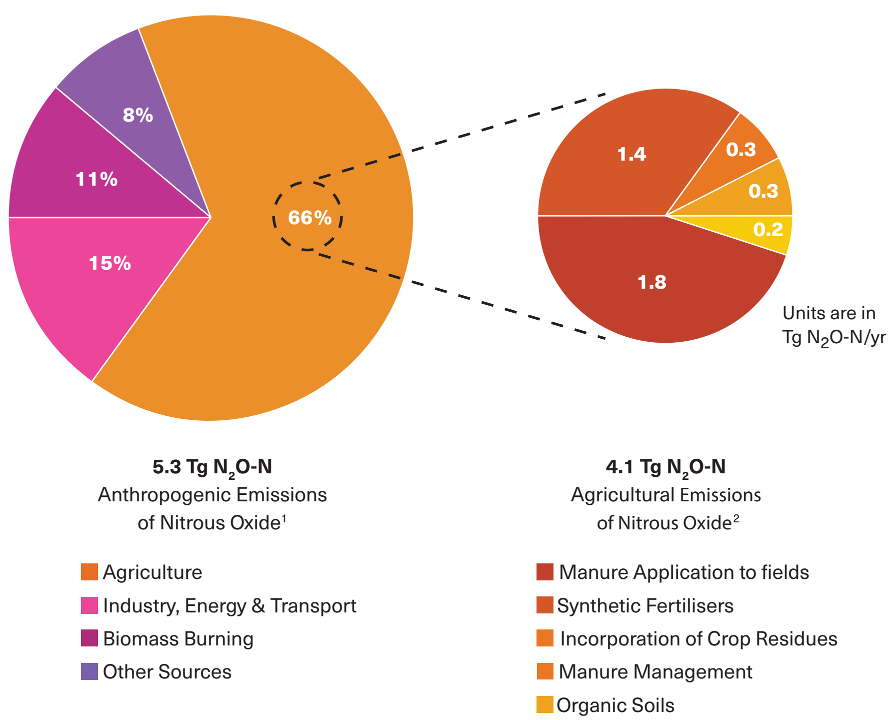
Excess nitrogen is entirely a 20th century problem, beginning when Haber and Bosch discovered a way to convert nitrogen from its non-reactive form (N2), which is abundant in the atmosphere, into a reactive form that can be taken up by plants *(Davidson and Kanter, 2014; Erisman et al., 2008)*. Industrial processes now create more than 125 Tg of synthetic nitrogen fertilisers yearly *(Lal, 2018)*. What is not taken up by plants after fertilisation pollutes waterways and human water supplies. It is also available for conversion to nitrous oxide. On average around 50% of nitrogen applied to soils is not taken up by crops *(Bodirsky et al., 2012; Davidson, 2012; Davidson and Kanter, 2014; Erisman et al., 2008)*. Non-linear relationships between application rates and uptake mean that higher rates of synthetic nitrogen use result in more surplus nitrogen in the environment *(Davidson and Kanter, 2014; Mueller et al., 2014; Shcherbak et al., 2014)*. Net anthropogenic emissions

FIGURE 6:

Anthropogenic sources of nitrogen in the environment

Agriculture is the most important source sector of nitrous oxide emissions. The bulk of agricultural emissions come from application of manure or synthetic fertilisers to soils.

Emissions from the production of synthetic nitrogen fertilisers and emissions from human sewage and food waste are not included in agricultural emissions, but are accounted for in other sectors (industry and waste).



Sources: *(Davidson and Kanter, 2014) (Sutton and UNEP, 2013)*.*

* Note: These figures do not include emissions from the production of synthetic nitrogen fertilisers, nor emissions from human sewage and food waste, which are accounted for in other sectors (industry and waste) *(Oenema et al., 2014)*. To produce the 125 Tg of synthetic nitrogen used annually, the Haber-Bosch process consumes about 2% of global energy *(Mueller et al., 2014) (Lal, 2018)*. In the process, *(Snyder et al., 2009)* estimate that 4 kg of CO2 are generated for each kg of nitrogen fertiliser produced.

of nitrous oxide are currently approximately 5.3 Tg N_2O-N/ year.[11] Business as usual scenarios predict almost a doubling of anthropogenic nitrous oxide emissions by 2050, to 9.7 Tg N_2O-N *(Davidson and Kanter, 2014)*.

Nitrogen is not stored in ecosystems; external inputs of nitrogen eventually become losses *(Bodirsky et al., 2014)*. Indeed "all N that is not recycled within the agricultural sector is a potential environmental threat" *(Bodirsky et al., 2012, p.4181)*. Losses happen directly or indirectly—through emissions directly from farm fields when not all the fertiliser applied is taken up by plants; indirectly, as fertiliser washes downstream into water bodies; or even more indirectly, as nitrogen in plants is taken up and then excreted in the form of animal manure and human sewage.

Manure is a secondary source of nitrogen in the environment, recycled and redeposited *(Garnett et al., 2017)*. We first feed animals nitrogen-containing crops: grain-fed animals eat approximately 40% of grain and 80% of the soy produced globally *(Davidson, 2012; Reay et al., 2012)*. Synthetic fertiliser to grow crops for livestock production can potentially generate twice as much nitrous oxide as fertiliser used on crops for direct human consumption: "N_2O is first produced when fertiliser is applied to crops for growing the animal feed grain, and then it is produced a second time when the manure-N, which has been reconcentrated by livestock consuming the feed, is recycled onto the soil or otherwise treated or disposed of" *(Davidson, 2009, p. 662)*. As such, Bodirsky et. al., *(2012, p.4181)* note that "more efficient livestock feeding will not necessarily relieve the pressure from the Nr [reactive nitrogen] cycle".

Strategies to reduce nitrogen emissions in agriculture: Reducing nitrogen in the environment, and associated nitrous oxide emissions, requires reducing the quantities of nitrogen applied and/or increasing the efficiency with which plants take up nitrogen. The conventional strategies that are proposed to reduce emissions rely on increasing nitrogen use efficiency through the four Rs: right source, at the right rate, at the right time, in the right place *(Davidson, 2012; Mueller et al., 2014; Zhang et al., 2015)*. IPCC estimates of emission reduction potentials, based on these conventional strategies, reflect just how insufficient they are: in AR4, IPCC authors concluded only 2% of the mitigation potential in agriculture could come from reductions in nitrous oxide emissions *(Smith et al., 2007)*. A number of authors push beyond IPCC assumptions and point out that nitrogen use could be cut in half in intensive farming systems with little impact on productivity *(Chen et al., 2011; Mueller et al., 2014; Muller et al., 2017; Zhang et al., 2015)*.

Agroecologically-based strategies outside the nitrogen use efficiency box can lead to much more significant reductions—through not just reducing, but replacing altogether the use of synthetic fertilisers, and therefore avoiding completely emissions and energy use associated with their production and distribution. Because of the significant emissions associated with fertiliser production, there is likely to be substantial additional mitigation potential from converting to agroecological production systems that greatly minimise or do not rely at all on the use of synthetic nitrogen fertilisers. For example, Muller et al. *(2016)* estimate that abandoning the use of synthetic fertilisers altogether in the EU would result in an 18% reduction in total agricultural emissions (total EU agriculture emissions in 2016 were 0.925 Gt CO_2-eq), *(Olivier et al., 2017)*.

Agroecological approaches to soil fertility rely considerably or completely on recycling nitrogen already present in agricultural systems—compost, crop residues, and animal manure—and on other biologically-derived sources of nitrogen—appropriate crop rotations and mixed cropping systems, including legumes and nitrogen-fixing trees *(Lal, 2018; Mueller et al., 2014)*. Some authors go further and assume some amount of human sewage could also be returned to farmlands *(Bodirsky et al., 2012)*.

Unfortunately most of the relevant scientific literature only provides an assessment of potential emission reductions from increasing nitrogen use efficiency. In proposing a pathway for nitrous oxide emission reductions, we use this existing literature to provide a lower estimate of the potential contribution of an agroecological transformation.

Erisman et al., *(2008)* estimate that nitrogen use could be reduced by 40-60 Tg per year by improving nitrogen use efficiency. Bodirsky et al. *(2014)* propose that more efficient fertilisation (4 Rs) and increased use of biologically-derived nitrogen inputs like manure and crop residues could reduce field losses by 58 Tg Nr (0.69 Gt CO_2e).[12] Based on these publications we propose that potential reductions of 0.69 Gt CO_2eq/year is a reasonable assumption for emission reduction based on more efficient use of fertilisers coupled with "better use of other N flows such as manure and legumes to reduce the total amount of synthetic fertiliser needed" *(Griscom et al., 2017, p. 64)*. As we note above, this is a low estimate as it does not include emission reductions from less fertiliser production.[13]

Reducing the production and use of synthetic fertilisers is one of three interconnecting pathways to cutting nitrous oxide emissions from agriculture. Additional livestock feeding, behaviour, and lifestyle changes could further reduce production and use of fertilisers, and therefore nitrous oxide emissions from the agriculture sector, while also improving food security and sovereignty. In the next two sections, we explicitly outline the emissions reductions that can be achieved through changes in livestock production practices, healthy diets, including less meat consumption, and limiting food waste.

11 Informal communications with government representatives in Brazil and the Dominican Republic.

12 Nitrogen in the environment is measured in grams, and the orders of magnitude we are dealing with at the global scale mean that we are working in teragrams (Tg = 1012 grams)

13 Calculated using a fertiliser emission factor of 2.54%, which does not incorporate emissions savings from reduced fertiliser production.

3.2 Livestock and climate change

Transforming livestock production is critical to maintaining our food systems within planetary boundaries. Ensuring a just transition away from an energy and resource intensive industrial livestock system, to one that is grounded in agroecology principles, and one which respects planetary boundaries, human rights, and rural livelihoods, will not only result in less meat and dairy production as necessitated by climate imperatives, but also in better quality and more nutritious meat and dairy (discussed further in section 3.3). As highlighted earlier, agriculture is the biggest global driver of land-use change. Livestock use about 70% of global agricultural land, through feed and forage production *(Van Zanten et al., 2018)*, with about 20% of global land surface devoted to grazing livestock, according to one estimate *(Henderson et al., 2015)*. A transition towards livestock practices that build agricultural resilience and strengthen rural communities is a critical component of a global climate solution.

Livestock production can be broadly categorised along a spectrum of extensive or confined industrial systems. At one end of the spectrum are pastoralist systems, well-managed pasture, and range. The other end of the spectrum includes poorly managed grazing associated with mass industrial production and concentrated animal feeding operations (CAFOs). Mixed crop-livestock systems produce both feed crops and livestock on the same farm. These systems vary substantially in production practices and include the harvesting and feeding of grain, grazing or harvest of crop residues (such as stubble) and the use of crop leftovers unsuitable for human production, in various proportions.

In this section, we look in more depth at a few of the major production systems and GHG emissions associated with those systems, and propose where transformational shifts in livestock production can deliver the greatest benefits— both ecologically, as well as for the well-being of animals and people— and contribute to climate solutions. We avoid a singular focus on reducing livestock-related GHG emissions, which would be inappropriate given the relative importance of livestock in many communities and pastoralist societies, and the reliance on livestock as an economic safety net and for their critical contributions to food security and food sovereignty.

Current livestock production trends

Three hundred and ten million tons of meat are currently produced per year globally *(Tirado et al., 2018, p. 16)*. The FAO estimate that 455 million tons would be needed to meet business as usual growth by 2050 *(FAO, 2018b)*. With current projections for population growth, increased demand and the commensurate increase in livestock production, one widely cited model predicts that GHG emissions from agriculture would increase by 77% over baseline 2009 levels of 11.6 to 20.2 Gt CO_2 eq/year in 2050, and that land use would increase by 42% from 1560

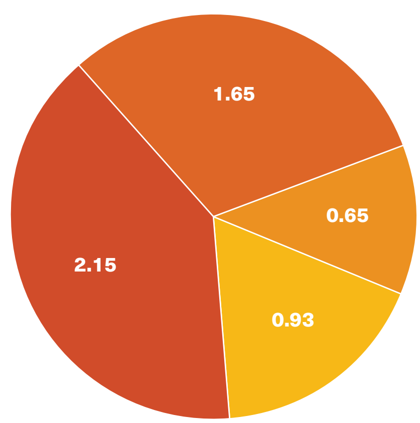
BOX 9:

GHG emissions from livestock

Livestock contribute about 14.5% of anthropogenic greenhouse gas emissions when land use change such as deforestation, feed production, and post-production energy use is included *(Gerber and Food and Agriculture Organization of the United Nations, 2013)*. This amounts to approximately 7.1 Gt CO_2-equivalents (CO_2-eq) per year, or about 60% of agricultural GHGs *(Van Zanten et al., 2018)* **(FIGURE 7)**. Ruminants, especially cattle, due to their digestive production of methane through enteric fermentation (as well as manure), are the largest livestock sources of agricultural GHGs. The primary GHGs associated with livestock production are CH_4— especially from ruminant enteric fermentation and secondarily from manure— and N_2O primarily produced in soil by microbial metabolism of manure and nitrogen fertiliser used in animal feed production. Livestock also contribute to CO_2 emissions—through fossil fuel energy use for nitrogen fertiliser production, transportation and processing of feed, farm equipment operations, and other farm-related energy uses that also produce CO_2. (Energy-related emissions from agriculture are outside the scope of this report.) Livestock also contribute to CO_2 emissions from land-use, as a key driver of deforestation, and through the production of feed and forage crops which contribute to CO_2 emissions from soils (discussed in Section 2.5 on grasslands).

FIGURE 7:

Average GHGs from livestock from 1995-2005



All units are in average Gt Co_2eq per year.

- Enteric fermentation from cattle. METHANE (CH_4)
- Feed sources originating from soil application of synthetic fertiliser and organic sources NITROUS OXIDE (N_2O)
- Manure METHANE & NITROUS OXIDE (CH_4 & N_2O)
- Feed related (excluding land-use change) CARBON DIOXIDE (CO_2)

Source: *(Herrero et al., 2016)*

to 2220 Mha under current yield trends, including increased intensification *(Bajželj et al., 2014)*. A substantial contribution to this growth in emissions would be due to increased livestock production and consumption. Such increases are completely incompatible with a 1.5°C climate goal.

Geographically, most meat and dairy emissions come from a small number of countries or regions with large land masses (see **FIGURE 8**). The US and Canada; the EU; Brazil and Argentina; and Australia and New Zealand all have both surplus production and high per capita consumption of meat and dairy. Together, they account for 43% of total global emissions from meat and dairy production, even though they are home to 15% of the world's population *(GRAIN and IATP, 2018)*. Nearly two-thirds of global emissions come from these six countries and the EU, as well as China, whose more urban and affluent populations also have high per capita livestock consumption. Just five countries (the US, Brazil, Argentina, Australia and China) and the EU account for nearly 68 percent of global beef production; while three countries (Brazil, Australia and the US) account for 46.5 percent of global exports—adding India's buffalo meat exports brings the total to 65 percent of global exports *(GRAIN and IATP, 2018)*.

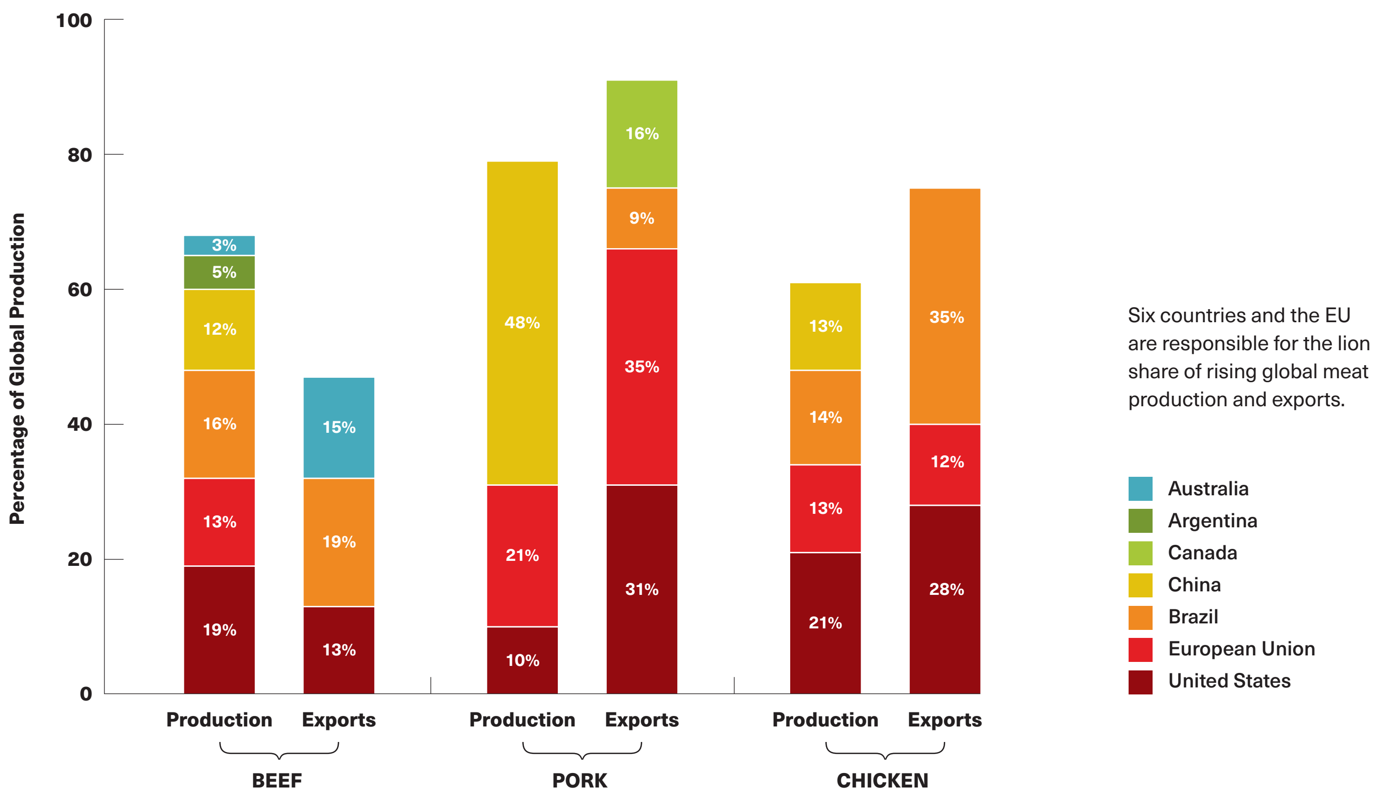
The geographical concentration for pork production is even greater. Two countries (China, US) and the EU produce 80% of the world total, while four (the EU, the US, Canada and Brazil) are responsible for over 90% of world exports. Only four countries—the US, China, Japan and Mexico—account for nearly 60% of world pork imports. Similarly, four countries and regions (US, Brazil, EU and China) account for 61 percent of global chicken production, while just two (Brazil and the US) account for 63% of world exports. Adding the EU, these three account for 81% of world exports. Finally, the EU, the US and New Zealand account for 46% of all global dairy production *(GRAIN and IATP, 2018)*.

The problems with confinement-based systems

Globally, industrial livestock production systems associated with global value chains—that is, where activities must be coordinated across geographies—dominate the livestock sector. These industrial systems can vary, using confinement-based systems where animals are kept, usually at high density, in structures that house large numbers of poultry or pigs in confined environments, or in

FIGURE 8:

Concentration in global meat production and exports



Source: Compiled by IATP from USDA's Production, Supply and Distribution Database (Top Countries by Commodity) for 2017, accessed at: https://apps.fas.usda.gov/psdonline/app/index.html#/app/topCountriesByCommodity; see also https://www.iatp.org/emissions-impossible, pg. 6-7.

feedlots for beef cattle. Confinement-based systems rely on bringing feed, especially grains, to the animals and removing waste, whereas in extensive systems animals largely forage for food, at much lower densities. Confinement systems are the dominant methods for poultry and pig production worldwide, producing 76-79% of these products; and high-density feedlot systems are dominant in North America, and on the rise in Latin America, Europe, and East Asia (especially China) *(Herrero et al., 2013)*.

Confinement-based systems rely on energy-dense feed. Many of the technological gains in the livestock sector since the 1960s come from increasing feed conversion efficiency (the ability of livestock to better utilise the nutritional value of feed and thus gain more weight per unit of feed). And yet, feeding human-edible cereals to animals is highly inefficient in converting calories into meat and milk *(GRAIN and IATP, 2018; Nellemann et al., 2009)*. Just 17-30 out of every 100 calories fed to animals as cereals enter the human food chain as meat. The FAO warns that further use of cereals as animal feed could threaten food security, by reducing the grain available for human consumption. Human diets based primarily on crops are nutritionally beneficial, produce far less GHGs, and require considerably less land than feeding grains to livestock *(Berners-Lee et al., 2018)*.

Technological approaches for increasing productivity (which also reduces GHG emissions per unit of product) have also focused on more efficient use of inputs such as fertilisers, pesticides and other additives. Dramatic increases in production have come from exploiting economies of scale, crop and livestock genetic changes, plus the sharp rise of using inputs such as synthetic fertilisers. These trends have led to massive overall increases in total GHG emissions from the sector, biodiversity loss, land, air and water pollution and significant negative public health impacts *(Diaz and Rosenberg, 2008; Pew Commission on Industrial Farm Animal Production, 2008)*. Climate emissions from CAFO-based production are already unacceptably high, and will increase substantially by mid-century and beyond, even with significant technical gains in so-called production efficiency and reduced emissions intensity.

BOX 10:

Environmental harms from industrial agriculture

Environmental harms from industrial agriculture have continued to worsen where confinement-based systems dominate. For example, nitrate leaching from fertilised maize and manure, largely from US CAFOs or other confinement systems (also referred to as landless systems), has led to the largest hypoxic zone on record (colloquially the dead zone) in the Gulf of Mexico, at 8,776 sq. miles in 2017 *(NOAA, 2017)*.

Other environmental harms arise from land-use change associated with livestock production, which has been responsible for 65% of global land use change in just 50 years (1960-2011) *(Tirado et al., 2018)*. This has coincided with the rapid expansion of livestock processing corporations, their consolidation and concentration in a handful of regions. Despite efforts to slow and halt forest conversion, deforestation rates in Brazil from converting land for feed crops and pastures has increased by over a quarter since 2014, which has coincided with Brazil becoming the world's largest exporter of soy, beef and poultry, and the second largest exporter of maize *(Bajželj et al., 2014; Röös et al., 2017)*.

In addition to contributing to climate change, converting land in the region for mass livestock production and feed have led to biodiversity loss and disrupted critical rainfall patterns that affect northern Argentina, Paraguay and southern Brazil, bringing drought to the region, including in the Cerrado of central Brazil *(Sharma and Schlesinger, 2017)*. The Cerrado - the source of several rivers that supply water to three important aquifers and six major water basins in the country - has seen concentrated feed grain expansion take place over the last 16 years *(Sharma and Schlesinger, 2017)*.

In addition to these well-documented environmental problems, the expansion of livestock and feed production in Brazil has led to human rights violations, including slave labour linked to beef and poultry value chains *(Sharma and Schlesinger, 2017)*.

Confinement-based systems are often situated in poor rural communities, which are then disproportionately harmed by their presence *(Kravchenko et al., 2018)*. More frequent climate events, such as Hurricane Florence, dramatically compound the environmental and health impacts of such facilities when they are densely situated in hurricane-prone areas, which recently resulted in massive over-flooding of manure lagoons at confined pig-raising facilities in North Carolina *(Brown, 2018)*.

Limitations of an emissions intensity approach for a 1.5˚C pathway

Emissions intensity refers to emissions generated per kilogram of meat or milk. Emissions intensity targets focus on GHG reductions per kilo, but are greatly outweighed by total emissions that result from the overall increase in the number of animals produced. While intensity may be kept in check or even reduced, total emissions will continue to rise in tandem with the increasing scale of production *(GRAIN and IATP, 2018)*. Arguments for reducing emissions intensity in the absence of targets to reduce the livestock sector's total emissions are dangerous, because limiting emissions per unit of food is simply inadequate to get onto 1.5°C pathways. Even with the greater efficiency that lowers emissions intensity, livestock GHGs would rise compared to recent (e.g. 2010) values, as long as overall production continues to increase.

> **"Over the past century, farmers and corporations have reduced the emissions intensity of livestock production and processing, but these gains have been overwhelmed by increases in absolute emissions as a result of the doubling, and then the quadrupling, of production and consumption. We are emitting less per kilogram, but overall, we are emitting more GHGs because we are producing and consuming many, many more total kilograms. In 2010, the global average GHG emissions per kilogram of chicken**

were one-third to one-half what they were in 1961. But the total GHG emissions from chicken production in 2010 were nearly five times higher than in 1961" *(GRAIN and IATP, 2018, p.14)*.

Analysis of available research and historical data shows that these approaches alone, as well as greatly expanding the adoption of intensive industrial operations that utilise these technologies, will not come close to meeting 2°C *(Bajželj et al., 2014; Röös et al., 2017)*, let alone the lower temperature threshold called for in the Paris Agreement. Yet smallholders are well placed and can be supported to respond to climate challenges in the 21st century (water, air, biodiversity, food security, etc.) when applying agroecological and agroforestry approaches.

Agroecological approaches with well-managed pasture and grazing systems

Livestock are integral to many agroecological food systems. Agroecological approaches to raising livestock include a high diversity of feed or forage cropping systems on long rotations; closed nutrient cycles; grazing that encourages healthy pastures and range; and grazing that includes pastures of mixed perennial species.

One ecological grazing system that shows particular promise is adaptive multi-paddock grazing (AMP). This system rotates cattle between partitioned paddocks, preventing overgrazing and allowing recovery and healthy forage growth between grazing cycles. It is intended to mimic the movement of grazers in natural systems, and has been reported to increase pasture productivity, carbon sequestration, and forage quality compared to high stocking rates in continuous pasture *(Stanley et al., 2018)*.

A recent life cycle analysis (LCA) based on five years of field data from an AMP beef pasture grazing system in the United States, found that when carbon sequestration was included, overall GHG emissions fell from 9.62 kg carbon dioxide equivalents/kg carcass weight to -6.65 kg carbon dioxide equivalents/kg carcass weight, while for the CAFO feedlot the value was 6.12 (Stanley et al 2018). Sensitivity analysis further showed that related improvements in forage quality in AMP systems would result in a 15% reduction in methane production in grazing beef cattle, compared to current IPCC default values *(Stanley et al., 2018)*.

Despite ample empirical evidence that food, feed and forage crop production using agroecological methods leads to substantially better social and environmental outcomes *(Davis et al., 2012; Gaudin et al., 2015; Lechenet et al., 2014, 2017)*, and are much more climate-resilient than industrial monocultures, a powerful research bias against agroecological approaches continues. This is due to the perception that such systems produce lower yields than conventional farming methods. However, Gaudin et al *(2015)* showed that increasing the length of typical corn-soybean rotations in a long-term temperate zone experiment by including other crops, improved corn and soybeans yields in the rotations by 7% and 22% respectively during hot and dry years. Bennet et al *(2012)* demonstrated that extended crop rotations—a common component of agroecological farming systems—lead to higher crop yields than the monocultures or short rotations common with industrial feed producers.

Increased use of perennials in feed grain cropping systems and integrated crop-livestock systems have also been shown to reduce nitrogen leaching, and increase soil fertility and carbon sequestration *(Asbjornsen et al., 2014; Bell et al., 2014; Russelle et al., 2007)*. Integrated systems also show greater climate adaptability and resilience through improved drought tolerance *(Asbjornsen et al., 2014; Bell et al., 2014; Russelle et al., 2007)*. Integrated crop-livestock systems also have potential to increase productivity substantially compared to grazing alone. In problem soils in Australia these integrated systems have shown the potential to increase production 25%-75% *(Bell et al., 2014)*.

However, there have been few or no comprehensive life cycle assessments aimed at quantifying overall GHG emissions from integrated systems. Based on measured parameters, there is a reasonable possibility that such systems will have climate benefits compared to non-integrated systems, but that has yet to be determined. The available research shows promise, and more research should be devoted to understanding the strengths and limitations of these systems, which can vary considerably.

Livestock system transformation with an ecological leftovers approach

A transformative approach to limiting GHG emissions and the land area devoted to livestock production, dubbed 'ecological leftovers for livestock', has been explored in several recent research efforts. With an ecological leftovers approach, livestock feed largely comes from parts of the food stream not consumed directly by people, such as food scraps, crop stubble, or food waste and grazing on land that is mostly unsuitable for arable crop production—hence the term ecological leftovers. The ecological leftovers approach is based on greatly limiting the use of food crops to feed livestock, in contrast to merely decreasing emissions intensity through technological innovation and more efficient production methods, which would continue to increase emissions by the mid-century due to the rising consumption of livestock products.

Grasslands that cannot be used efficiently for annual crop production can still be used to produce livestock, mainly ruminants. By eliminating or greatly reducing the use of grains to feed livestock, and thereby reserving land that can produce crops for direct human consumption, livestock feed production no longer competes with these crops for land. Because direct human consumption is considerably more climate and land efficient than livestock product consumption, land use and GHG emissions are substantially lower than for intensive industrial crop and livestock systems.

Improved pasture and range management of forage within ecological leftover systems can make significant contributions to potential GHG emissions reductions through the higher quality of forage produced. Stanley et al. *(2018)* showed that cattle in AMP management systems had greater forage efficiency than under typical continuous grazing approaches, which translated into a 15% reduction in methane emissions. Other research cited by these authors *(Pelletier et al., 2010)* show reduced GHG emissions from grazing cattle compared to feedlots when carbon sequestration was included. In a three-year experiment, Finn et al. *(2013)* found that mixtures of four pasture species containing complementary functional groups (e.g. nitrogen fixing legumes and grasses, and crops that established quickly vs. more persistent species) had 32% higher mean yields than monocultures of these species, and higher yields than even the highest yielding monocultures. Higher grassland yield means potentially lower land requirements and often greater soil carbon sequestration. Maintaining a diversity of forage-crop mixtures over time can be a challenge, but Finn et al. *(2013)* were able to maintain functional levels of diversity. Prieto et al. *(2015)* found that increasing genetic diversity of forage species increased drought tolerance. These findings challenge the support given to feedlot systems based on their supposed climate efficiency, when soil carbon sequestration, improved productivity, or improved forage feed efficiency is included in the assessments comparing feedlots with improved pasture systems.

The ecological leftovers approach could reduce GHG emission levels by 19%-50% by 2050 compared to current trends, while still producing enough nutritious food for an increasing global population *(Van Zanten et al., 2018)*. Combined with changes in livestock production based on well-managed grazing systems, the livestock sector's potential contribution to a 1.5˚C pathway is significant.

3.3 Food systems

Every part of the food system will need to be transformed to equitably reach the 1.5°C goal. So far we have focused on improvements in production systems. Yet attaining a food system that is fit for purpose in an era of climate change requires not only transformations in food production, but also changes to the ways in which food is planned, distributed, eaten and disposed of. From farm to fork, and through eliminating food waste, there are multiple points for potential intervention *(Hoolohan et al., 2016)*.

Reducing meat consumption based on healthy diets

Considering the climate challenge we face, agroecological production methods alone are insufficient. We must also address consumption. The ecological leftovers approach, in that respect, combines lower land use with far less production and consumption. In addition to transformational changes in production, as discussed in the previous section, systems that incorporate healthful reductions in consumption of livestock products (where there is currently overconsumption) are needed. A focus on healthy levels of meat and dairy consumption are also necessary to reach our climate goals. Reducing animal product consumption (particularly in high income countries) and avoiding projected increases in consumption that exceed nutritional requirements, provides a considerable emissions savings opportunity *(Bajželj et al., 2014; Niles et al., 2018; Poore and Nemecek, 2018; Röös et al., 2017; Springmann et al., 2016)*. 'Less, but better' (or better and less) meat and dairy consumption is a crucial strategy for reducing livestock-related emissions. The meat and animal products that can be produced by an ecological leftovers approach still provides more than enough calories and nutrition to keep a growing population healthy in 2050 *(Röös et al., 2017)*.

Current baseline scenarios project that agriculture emissions will grow to 11 Gt CO_2eq per year in 2050, largely because of increasing animal product consumption *(Röös et al., 2017; Tirado et al., 2018)*. But what if global meat and dairy production was transformed to meet climate, environmental, and health goals (producing better), while per capita consumption stabilised, then declined to healthy levels (consuming less)? Modelling of regional scenarios based on an ecological leftovers production approach and recommended healthy diets, lead to projected GHGs of only 4 Gt CO_2 eq. in 2050 *(Röös et al., 2017)*. Based largely on this research, Tirado et al. *(2018)* found that this decrease could be achieved by reducing the production and consumption of animal products by 50% by 2050, saving 7 Gt CO_2eq per year, a reduction of 64% over baseline emissions in 2050.

A 50% reduction would mean reducing meat production to 155 million tons per year by 2050. At an individual level, that means meat consumption would be limited to 300 g per capita per week, which is roughly two five-ounce servings of meat per week. Dairy consumption would be a bit higher, at 630 g per capita per week (for example, two glasses of milk and two four-ounce servings of cheese) *(Tirado et al., 2018)*. This is a significant reduction from consumption patterns in developed countries, but is in keeping with nutritional guidelines and health needs (sugar, animal product consumption and calories are reduced to healthy levels based on recommendations from the World Health Organization, Harvard Medical School and the American Heart Association) *(Röös et al., 2017)*. Under these dietary guidelines, everyone would have sufficient calories and nutrients to lead healthy lives; what is eaten would simply be more plant-based food with "less, and better" meat and dairy. A recent study on the "safe operating space" for European livestock production and consumption comes to the same conclusion: halving the EU28's consumption of meat and dairy would be much more in line with what national dietary authorities recommend, and with our planetary boundaries *(Buckwell and Nadeu, 2018)*.

It is important to emphasise that this does not mean that each region or country would need to halve its consumption. The 50% reduction is a global goal, and because of current disparities in consumption, high-consuming countries will need to cut animal product consumption by much more than 50% to reach the per capita consumption levels called for


BREAD FOR THE WORLD

above. Countries with high levels of food insecurity would be expected and should be supported to address their nutritional needs, including by increasing consumption.

The unhealthy parts of our current food system highlight the additional benefit of decreasing meat and dairy consumption. Our food system today leaves 821 million people hungry *(FAO et al., 2018)* and two billion people suffering from the health impacts of overconsumption *(Tirado et al., 2018)*. The level of livestock consumption in high income countries is well in excess of what is nutritionally necessary and healthy *(Springmann et al., 2016)*. Overconsumption of red and processed meats, for instance, has been found to increase obesity and excessive weight; both are major risk factors for cardiovascular diseases, diabetes, and even some cancers *(World Health Organization, 2018)*. Even a limited reduction in consumption while increasing fruit and vegetables in a daily diet can cut mortality by 6-10% globally, by conservative estimates *(Springmann et al., 2016)*. Notably, these diets do not focus on trying to reduce red meat consumption only.

While it is critical to acknowledge the role of ruminants in creating emissions, pigs and chickens are the most heavily integrated into industrial global supply chains, and currently represent 70% of total global meat production *(Tirado et al., 2018)*. Data from FAOSTAT shows that between 1990 and 2013, global beef consumption decreased by 10%, but pork and poultry consumption increased by a striking 23% and 96%, respectively *(Tirado et al., 2018)*. Continued growth in poultry and pork consumption, even if beef is reduced, still has a significant emissions footprint. This is especially true when the amount of feed crops grown specifically for livestock and the emissions costs of that production is considered. Our proposed emphasis on better production, means that beef raised largely on grazing on natural grasslands (i.e. not converted forests) not suitable for food production, and pigs and chicken raised largely on food waste and small amounts of locally grown feed, are encouraged.

Reducing over-consumption

As detailed above, the single biggest impact on reducing GHGs in the food system could be brought about through shifting to “less and better” meat and dairy products. The importance of consumption, however, is not only limited to meat and animal products. Unnecessarily high-calorie diets also contribute significantly to GHG emissions.

Many people in developed countries (and some in developing countries) eat more than they need, and sometimes much more than is healthy. This could be understood as a form of food waste (or more accurately, a waste of food). In some cases, consumption so far exceeds the requirements for a healthy person that it causes harm. Food waste from overconsumption may actually be greater than consumer waste of food that is left uneaten *(Alexander et al., 2017)*. Addressing overconsumption should be considered a climate priority as well as a health one.

The emissions created to produce the food consumed beyond what is necessary for food security and health are properly seen as wasted resources. Reducing over-consumption thus presents an opportunity for emissions reductions. Ending overconsumption of food could reduce global GHG emissions by 11% *(Niles et al., 2018)*. Most models of food systems in the literature which successfully limit GHG emissions are based on healthy diets, where overall calorie consumption per capita is limited to comfortably above what is necessary, but less than what might be predicted without a change in behaviour *(Bajželj et al., 2014; Röös et al., 2017; Springmann et al., 2016)*.

There are clear links between overconsumption and diets heavily reliant on animal products. A study of diets in the US, for example, found that meat was responsible for the overwhelming share of the emissions from high-emitting diets, but that these diets were also associated with the highest number of calories *(Heller et al., 2018)*. Similar results were found in France *(Seconda et al., 2018)*. The US study also found that 45% of food-based emissions in the US were produced by 20% of people on the highest emission diets *(Heller et al., 2018)*. This means that only 44.5 million people out of a population of over 300 million are responsible for nearly half of the US's food-based emissions. The pattern echoes that of energy consumption, in which a small section of the wealthier parts of society consume much more than the rest and contribute more than their fair share of emissions.

Reducing overconsumption then would benefit the climate in multiple ways, including reducing the energy and resources required for production; avoiding emissions created through the production of food that does not provide a benefit; and by feeding future populations with the freed-up land, avoiding deforestation.

Based on the ecological leftovers approach outlined above, and projecting the uptake of healthy diets, agriculture emissions would be reduced to around 6.5 Gt CO_2eq per year. Limiting overall consumption to calorie levels in line with dietary guidelines would bring emissions down to 4 Gt CO_2eq per year, saving a further 2.5 Gt CO_2eq per year *(Röös et al., 2017)*.

Addressing food loss and waste

Nearly one billion people go hungry every day. Yet about 30% of all food produced is wasted. Some estimates put that figure at close to 50%. Growing food that is wasted creates emissions and no nutritional benefit. Reducing food waste would mean that more people could be fed with less production, reducing GHG emissions from agriculture, and potentially freeing up land for ecosystems. Reducing food waste, however, is a complex issue, and requires coordination throughout food supply chains to achieve.

Food loss comes at every stage of the system and requires a range of different interventions. When food is lost during the production, processing and transport stages, it is known as food loss. When it reaches the retailer or consumer and is fit for consumption but never eaten, it is called food waste.

Generalising broadly, food loss is more prevalent in developing countries, where infrastructure, preservation or storage challenges prevent food from getting to market. A lack of reliable means to transport food to market in a timely fashion, and limited cold-chain storage, can lead to food spoilage. Food waste is more common in richer countries, where supermarkets and consumers throw away large amounts of food that is still perfectly edible, for cosmetic reasons or due to confusion over 'best by' labels *(Foley et al., 2011)* or through food that is purchased, but simply not eaten.

While the argument for reducing food loss is straightforward, the reality of achieving reductions is more complicated. Addressing food loss has long been a priority for development efforts in agriculture. Increasing cold chain storage, improving storage techniques and infrastructure, packaging to improve 'shelf-life', and investing in more efficient transport systems can all help to reduce pre-consumer food losses. These interventions of course often have their own emissions cost, but generally the benefits of avoiding food loss outweigh the emissions associated with system improvements *(Niles et al., 2018)*.

Different interventions would be needed in developed countries, where food waste largely comes at the consumer and retail level, such as cosmetic requirements for fresh produce, and 'best-buy' dates causing waste and bad storage practices *(Foley et al., 2011)*. There are multiple possible approaches to cut waste at the consumer level, which some of these interventions are focused on providing or altering services—such as waste disposal services or changing packaging—while others try to influence consumer behaviour *(Foden et al., 2017)*, or retail behaviour and practices *(Hoolohan et al., 2016)*.

Reducing food waste by half would have significant climate benefits *(Bajželj et al., 2014)*. Röös et al. *(2017)* estimated that reducing food waste by 50% would lead to 0.5 Gt CO_2e emission reductions annually. The exact amount of benefit from this food waste reduction depends on emissions in the food systems overall—obviously, reducing waste of highly emissive foods has a larger carbon savings than reducing the same amount of waste from lower emissions foodstuffs.

Reducing energy use from transport and heating in food systems

In recent decades, the year-round supply of fresh fruit and vegetables has been facilitated by their production in artificial conditions, particularly in the global North, and the rise in air-freight. Fresh tomatoes, salads and bell peppers for example have become part of many people's daily diets in developed countries, even in climates where they may only be expected to grow in warmer seasons. Air-freighting produce and or heating greenhouses for out-of-season production may bridge gaps in national food self-sufficiency (for example in regions with low rainfall, short growing seasons and/or low crop production), but it has also created an artificially boosted demand for fruits and vegetables *(Hospido et al., 2009)*, the production of which is GHG-intensive *(Coley et al., 2009)*.

There is significant scope to reduce global emissions by reducing the unnecessary air-freight of food, with opportunities to decarbonise land- and sea-freight much closer to being realised than for airfreight *(Bows-Larkin, 2015)*. However, as with any other intervention, known rebound effects in other sectors must be avoided. Reducing food transported by air-freight may result in an increase in climate-controlled food production, if consumer preferences remain the same. Shifting from airfreight to climate-controlled production is unlikely to provide any climate benefit as artificially heated (or cooled) greenhouses can have GHG emissions comparable to those of imported food *(Milà i Canals et al., 2008)*

Complementary strategies to reduce air-freight and fossil-fuel heated greenhouses could include refocussing catering and store offerings to prioritise produce that is neither airfreighted nor grown in artificial conditions. This would require suppliers to find a balance between import distances and seasonality; effective marketing strategies to support shifts in consumer expectations towards more local, seasonal or preserved produce (as appropriate); and refreshing people's tacit knowledge of how to prepare and cook dishes with regional ingredients (Hoolohan et al., 2013). Policies to strengthen local food systems, shorten supply chains, and increase crop diversity—improving tolerance to climatic variation—are all important mechanisms for reducing the GHG impact of modern food production. Further, supporting efforts to decarbonise the transport sector and source renewable energy supplies to heat greenhouses would offer complementary benefits in other sectors.

Food processing and refrigeration

The strategies discussed earlier in this section are where the vast majority of the emissions and mitigation potential in the food system exist. This section considers food processing, refrigeration and packaging as areas of possible intervention that could have emission reduction potential for the global food system. As with many of the strategies identified in this section, opportunities to reduce emissions in the food system are generally more applicable in the contexts of industrialised countries. However, in GHG mitigation terms, these interventions offer smaller potential reductions overall than the strategies identified above, which focus on producing better, and less food.

Refrigeration is one possible area for mitigation potential in the food system, as it is responsible for 15% of global electricity demand *(Niles et al., 2018)*. Key interventions will require efforts to 'rightsize' refrigeration, ensuring that the right amount of refrigeration is used for the required need, to avoid energy waste in running empty fridges and freezers. A second element would be to shift electricity sources for refrigeration to renewable energy. Third, guidance to increase the efficiency of cooling systems and reduce emissions has now been agreed by the world's governments in the Kigali Amendment to the Montreal Protocol *(Niles et al., 2018)*.

The term 'processed foods' is very broad, and can include simple processes such as pasteurising, fermenting, cooking, preserving, drying or pickling foods. However, the term is also often used to describe products created by industry to make convenience or snack foods. In developed countries, where their consumption high, foods such as ready-to-eat meals have a higher emissions footprint than fresh food *(Niles et al., 2018)*. These processes are quite energy intensive, so shifting the source of the energy to renewables and increasing efficiencies could have a worthwhile carbon benefit *(Niles et al., 2018)*.

Once again, in peasant and small-scale farming systems, there is probably more scope to increase food processing while reducing GHGs, especially if these efforts are undertaken by poorer rural communities to stem food loss, add value to products, and thus increase agricultural incomes. Locally-appropriate food processing systems can both strengthen farmers' livelihoods and improve regional food security. In this context, food processing could potentially play a positive role for climate change and sustainable development, particularly for vulnerable communities.

Conclusions

Toward a holistic vision of climate action

The Climate, Land, Ambition and Rights Alliance (CLARA) came together due to a shared concern that issues related to land and forests were being sidelined or subordinated in discussions of how to respond to the climate crisis. The mitigation potential from natural and working lands was poorly quantified in these discussions and the importance of intact ecosystems for resilience was treated as an afterthought. These issues were overlooked in favour of a vision of carbon-commodified landscapes such as in REDD+, or as energy crop area for biomass in models fixated on Bioenergy with Carbon Capture and Storage (BECCS) as the key carbon-removal response.

As this report makes clear, the quantification task is challenging, but possible. We concur with Hansen et al. *(2017)* that improved agriculture and forestry practices, plus shifts in consumptions patterns, could fill much of the current mitigation 'ambition gap' required to reach below 2°C pathways, and that such approaches are far more likely to align with achieving the UN Sustainable Development Goals.

Aside then from the hopeful message that 'we can do this', two other outcomes from this report are highlighted in the conclusion. While based largely on peer-reviewed science across multiple disciplines, the report nonetheless departs from other scientific projections of mitigation potential by allowing for— and as far as possible quantifying— gains that can be achieved through political and societal change, in response to the enormity of the climate challenge.

As such, this report poses a different vision of our future, one that most social justice and faith-based, development organisations pursued long before engaging in the climate conversation—namely, support for human rights, indigenous land rights, and the right to food; for healthy and people-centred food systems which will contribute to achieving food sovereignty; for working to support biodiversity and ecosystem health—rather than attempting to rework landscapes according to their extractive potentials. This holistic, nature-centred approach is no less a complete vision of our future than that implied, but never explicitly stated, in models suggesting the need for planetary geoengineering and devoting large areas of land to bioenergy cropping to achieve so-called 'negative emissions'—a term we reject as dangerous, and dangerously disconnected from land and place.

Our 'alternative' vision therefore posits a profoundly different relationship to nature in a changing climate; and equally important, a profoundly different understanding of the dangers of deepening global inequality, a topic on which most current climate models are silent, since 'distributional impacts' in those models are not treated with first-order importance.

The second outcome to highlight here is a different perspective on the question of 'urgency'. The introduction makes clear that we see three interlocking, equally urgent crises pertaining to rights, biodiversity, and climate. The need for deep changes in human systems to ensure that additional warming does not overwhelm the conditions that make civilisation possible is not disputed. Less clearly articulated is the potential for patterns of past use and resulting long-term harm to biodiversity and ecosystems to destroy and damage existing carbon stocks before the full impacts of climate change are felt, making it in turn ever more difficult to meet the challenge of climate change. We will fail to solve either the climate or biodiversity crises, while the dominant discourse in responding to the former remains technocratic, and is based on a technical solution developed at arms' length from current social practices.

Our assertion is that the climate and biodiversity crises are intrinsically related to systems of inequality and injustice, and solutions that do not address these root causes merely deepen the prospect of 'disaster capitalism' *(Klein 2012)*. At the same time, the report acknowledges the critical importance of the reorientation in production and consumption systems, going into considerable detail about the need to protect and restore resilient natural ecosystems and adopt current technical solution sets based on agroecological principles, improvements in human well-being through changes in diet and lifestyle, and greater scientific humility in the presence of place-based understanding.

Change is urgent. A further factor influencing our attention to mitigation pathways currently overlooked, is that for the most part integrated solutions can be achieved at lower cost, delivering improved outcomes for climate, biodiversity and ecosystems and human health. The full trajectory of mitigation benefits for many of these solutions—particularly those related to carbon storage and biodiversity restoration in ecosystems—do not realise their full potential for at least a decade. The science also tells us that 2020–2040 are the critical decades for bending the emissions curve down, and for preventing the extremely dangerous feedback loops that will compound damage if solutions are not deployed soon.

Policy recommendations

For the reasons outlined, we emphasise the following policy recommendations:

In **finance**, greater long-term public investment must anchor the scale, criteria and the need for public goods to encourage robust private investment. In many cases, for example in land titling and secure resource rights, this is the provision of necessary public goods; while in other cases, public investment provides the stability that allows for a variety of medium and long-term private investment opportunities in a productive capacity. The necessary ramp-up of public goods provision and investment support align temporally with the decade or decades-long increase in additional, and additive, sequestration potential that will ameliorate the worst consequences of rapid temperature rise.

Second, we recommend greater **coherence and coordination** between various international treaties, objectives and political goals. Coordination between the UN 2030 Sustainable Development Agenda, the three Rio Conventions (the UNFCCC, the CBD and the UNCCD), and other political spaces (CFS) and declarations such as the New York Declaration on Forests and the Bonn Challenge would deliver a greater focus on human rights, ecosystem integrity, sustainable development and poverty eradication. A cross-cutting work programme is needed to ensure indicators and targets between these different goals are complementary and mutually supportive.

Finally, although it has been stated many times throughout the report, we emphasise that the most important action that can be taken in any sector to reduce the risks climate change poses to people and ecosystems, is to **prevent the further release of GHG emissions.** Ending the burning and combustion of fossil fuels is far easier and cheaper than removing those emissions from the atmosphere. While agricultural emissions from non-CO_2 gasses cannot be reduced to zero, the analysis in this report shows the potential for significant emissions reductions in these sectors, while prioritising food security and healthy diets for all.

Glossary

Adaptive Multi-Paddock Grazing: The practice of grazing livestock, especially cattle, in restricted areas for a limited time period, based on preventing overgrazing of forage. When optimal grazing has occurred in one paddock, the cattle are moved to another and the original paddock vegetation is allowed to recover before it is grazed again. This practice protects the quality of the pasture, which can result in greater productivity of the vegetation and greater soil carbon sequestration and quality, than poorly managed continuous grazing (see below).

Agroecology: Farming systems that are based on the principles of ecology and that depend on biological, genetic, and cultural diversity, and largely closed nutrient cycles. Diversification employed at various levels, including plot, farm and landscape; use of a wide range of species and less uniform, locally-adapted varieties/breeds, based on multiple uses (including traditional ones) to achieve high and resilient productivity, reduce losses to pests, and maintain healthy soils and rural communities. They are typically more labour-intensive systems, with low external inputs and recycling of waste within full nutrient cycling and circular economy approaches.

Carbon Sequestration: Removal of carbon-dioxide from the atmosphere by immobilising it in biomass, soils, etc.

Confinement-based livestock systems: Methods for raising livestock in which often thousands of animals are kept in structures at high density, and for which food, mostly in the form of easily digestible grains, are supplied and waste is removed. These include CAFOs (Concentrated Animal Feeding Operations) and feedlots. They are generally more associated with the export sector, especially for poultry and pigs, than most other livestock production methods.

Continuous Grazing: A traditional grazing system whereby livestock are allowed to freely graze an entire pasture in an unrestricted manner. This can result in preferential grazing, and overgrazing, of certain areas of grasslands, and congregation of livestock leading to over-deposition of faeces and urine.

Crop Rotations: The alteration of crop species in a given place over time. Rotations reduce the need for inputs such as pesticides and synthetic fertilisers, and tend to promote higher diversity of beneficial organisms such as pollinators and pest natural enemies. Longer rotations, e.g. 3 or more crops, and rotations that include perennials, often enhance these benefits compared to shorter rotations. They typically have higher yields and are more sustainable and resilient than monocultures, but are more complex to manage and require more labour.

Ecosystem: A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (CBD Article 2).

Ecosystem-based approach: A strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way, is based on the application of appropriate scientific methodologies focused on levels of biological organisation which encompass the essential processes, functions and interactions among organisms and their environment. It recognises that humans, with their cultural diversity, are an integral component of ecosystems (CBD Dec.5/V6).

Ecological Leftovers Systems: Food systems in which livestock are mainly fed from resources that cannot be consumed directly by people, including grazing on land that cannot productively produce food crops, use of food waste, crop stubble or residues, and food byproducts. The premise of these systems is that direct consumption of food products by humans is much more efficient in terms of climate emissions, land use, and use of other resources such as water, than consumption of livestock products.

Emissions Intensity: The amount of GHGs produced per unit of food product. Lower emissions intensity means less emissions per unit of product.

Enteric Fermentation: The digestive process that occurs in ruminants (e.g. cattle, sheep and goats). It involves the first steps of digestion by specialised microorganisms. This process releases substantial amounts of the climate change gas methane. This process does not occur in monogastric (single stomach) livestock like pigs and poultry.

Feed Conversion Efficiency: The proportion of feed that is converted to animal product. Often also positively associated with the digestion rate of the feed. Higher feed efficiency usually means relatively less feed is needed and less GHGs produced per unit of product.

Feed Grains: Crops such as maize, barley or wheat that are used to feed livestock, especially in confinement. These are often annual crops, in contrast to forage crops which are typically perennials.

Food Sovereignty: The right of local people and countries to determine their own food and agriculture policies and practices without outside interference, and including equitable access to needed resources such as land, credit, water and seed. Often juxtaposed to neoliberal trade policies that prioritise unencumbered trade and comparative advantage, which allows economically powerful countries and corporations to impose food and agriculture systems on others.

Forage Crops: Crops such as grasses, alfalfa (lucern), clover, and others that are grazed on pastures or natural rangeland (collectively, grasslands), or harvested for feeding of livestock. When harvested they may be dried or fermented into silage for improved digestibility. They consist of the vegetative parts of plants rather than grains and are thus distinguished from feed crops. They are often perennial crops while feed grains are often annuals. Perennial crops typically provide better protection against soil erosion and better carbon sequestration than annual crops.

Forest loss / Deforestation: The conversion of forest to non-forest land through human influence.

Forest degradation: any action which results in a change to the natural patterns of species distribution and abundance and results in a reduction in carbon stock below the stock in primary forests.

Life Cycle Analysis: Modelling that attempts to include many or all of the important variables of a system and their relationship to each other, which is used to estimate impacts such as climate emissions when parameterised. They can be static or projected over time.

Monoculture: Technically, production of a single crop in the same space for multiple years, often over large areas of land. This temporal and spatial genetic uniformity increases susceptibility to pests, and often does not take advantage of other beneficial and complementary properties that vary between crops. It may be favoured for its management simplicity, lower labour requirements, and ease of scaling.

Natural regeneration: passive and assisted. Used here to refer to forest expansion, where land use changes from non-forest to forest.

Integrated, or Mixed, Crop-Livestock Systems: Systems for raising both crops and livestock on the same farm. More farms raise livestock by this means than any other, especially in the global south, although confinement systems are replacing them in many regions and produce more products.

Primary forest: a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age. Primary forest does not exclude the use by indigenous and local communities living traditional lifestyles relevant for the conservation and sustainable use of biological diversity.

Protection/conservation: refers to the protection of an ecosystem from further degradation or destruction. Does not refer to Protected Areas or specific conservation practices unless explicitly stated. Hence, protection can be achieved through a variety of means, including community managed lands, PA, and other conservation practices. In this report, we argue that extending the secure titled areas of community managed lands represents the most just and low cost protection for natural lands.

Reforestation: Hence we refer to as reforestation—establishing native mixed species of forest on lands that naturally support forests (i.e., in forest ecoregions), representing a change in land use from non-forest to forest, in line with the IPCC definition.

Secondary forest: Forest regenerating following disturbance. Chazdon (2014) suggests that to reduce ambiguity and confusion, the term secondary forests should only be applied to those forests regenerating following complete or nearly complete clearance of the original forest.

Shifting cultivation: Houghton and Nassikas (2018) define shifting cultivation broadly to include any rotational land use. In this they include traditional practices of swidden agriculture (allowing fallows to regrow), but they also include any form of temporary slash and burn that clears land every few years, such as short-term crops or pasture, agroforestry, illegal logging, fuelwood harvest, and other uses. Shifting cultivation and traditional subsistence or swidden agriculture need to be considered separately.

Bibliography

ActionAid (2018) *Agroecology: scaling-up, scaling-out*. Johannesburg, South Africa. Available from: http://www.actionaid.org/sites/files/actionaid/agroecology_def_web.pdf

Ajani, J. (2011) The global wood market, wood resource productivity and price trends: an examination with special attention to China. *Environmental Conservation*. 38 (01), 53–63. Available from: http://www.journals.cambridge.org/abstract_S0376892910000895

Ajani, J. I. et al. (2013) Comprehensive carbon stock and flow accounting: A national framework to support climate change mitigation policy. *Ecological Economics*. 8961–72. Available from: http://linkinghub.elsevier.com/retrieve/pii/S092180091300030X

Akinnifesi, F. K. et al. (2010) Fertiliser trees for sustainable food security in the maize-based production systems of East and Southern Africa. A review. *Agronomy for Sustainable Development*. 30 (3), 615–629. Available from: http://link.springer.com/10.1051/agro/2009058

Alden Wily, L. (2018) Collective Land Ownership in the 21st Century: Overview of Global Trends. *Land*. 7 (2), 68. Available from: http://www.mdpi.com/2073-445X/7/2/68

Alexander, P. et al. (2017) Losses, inefficiencies and waste in the global food system. *Agricultural Systems*. 153190–200. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308521X16302384

Altieri, M. A. et al. (2015) Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development*. 35 (3), 869–890. Available from: http://link.springer.com/10.1007/s13593-015-0285-2

Anderson, K. (2015) Talks in the city of light generate more heat. *Nature*. 528 (7583), 437–437. Available from: http://www.nature.com/doifinder/10.1038/528437a

Anderson, K. & Peters, G. (2016) The trouble with negative emissions. *Science*. 354 (6309), 182–183. Available from: http://science.sciencemag.org/content/354/6309/182

Angelsen, A. et al. (2017) Learning from REDD+: a response to Fletcher et al.: Learning from REDD+. *Conservation Biology*. 31 (3), 718–720. Available from: http://doi.wiley.com/10.1111/cobi.12933

Arneth, A. et al. (2017) Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed. *Nature Geoscience*. 10 (2), 79–84. Available from: http://www.nature.com/articles/ngeo2882

Asbjornsen, H. et al. (2014) Targeting perennial vegetation in agricultural landscapes for enhancing ecosystem services. *Renewable Agriculture and Food Systems*. 29 (02), 101–125. Available from: http://www.journals.cambridge.org/abstract_S1742170512000385

Asner, G. P. et al. (2018) Mapped aboveground carbon stocks to advance forest conservation and recovery in Malaysian Borneo. *Biological Conservation*. 217289–310. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0006320717310790

Baccini, A. et al. (2012) Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*. 2 (3), 182–185. Available from: http://www.nature.com/articles/nclimate1354

Baccini, A. et al. (2017) Tropical forests are a net carbon source based on aboveground measurements of gain and loss. *Science*. 358 (6360), 230–234. Available from: http://www.sciencemag.org/lookup/doi/10.1126/science.aam5962

Bajželj, B. et al. (2014) Importance of food-demand management for climate mitigation. *Nature Climate Change*. 4 (10), 924–929. Available from: http://www.nature.com/articles/nclimate2353

Barlow, J. et al. (2016) Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nature*. 535 (7610), 144–147. Available from: http://www.nature.com/articles/nature18326

Baveye, P. et al. (2018) The "4 per 1000" initiative: A credibility issue for the soil science community? *Geoderma*. 309118–123. Available from: https://www.sciencedirect.com/science/article/pii/S0016706117306171?via%3Dihub.

Bell, L. W. et al. (2014) Evolution in crop–livestock integration systems that improve farm productivity and environmental performance in Australia. *European Journal of Agronomy*. 5710–20. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1161030113000543

Bennett, A. J. et al. (2012) Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations. *Biological Reviews*. 87 (1), 52–71. Available from: http://doi.wiley.com/10.1111/j.1469-185X.2011.00184.x

Berners-Lee, M. et al. (2018) Current global food production is sufficient to meet human nutritional needs in 2050 provided there is radical societal adaptation. *Elementa Science of Anthropocene*. 6 (52).

Bertram, C. et al. (2018) Targeted policies can compensate most of the increased sustainability risks in 1.5 °C mitigation scenarios. *Environmental Research Letters*. [Online] 13 (6), 064038. Available from: http://stacks.iop.org/17489326/13/i=6/a=064038?key=crossref.ff7b320414e7bb-8c685ea4743f5d4c28 (Accessed 5 July 2018).

Blackman, A. & Veit, P. (2018) Titled Amazon Indigenous Communities Cut Forest Carbon Emissions. *Ecological Economics*. 15356–67. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0921800917309746

Bodirsky, B. L. et al. (2012) N2O emissions from the global agricultural nitrogen cycle – current state and future scenarios. *Biogeosciences*. 9 (10), 4169–4197. Available from: http://www.biogeosciences.net/9/4169/2012/

Bodirsky, B. L. et al. (2014) Reactive nitrogen requirements to feed the world in 2050 and potential to mitigate nitrogen pollution. *Nature Communications*. 5 (1). Available from: http://www.nature.com/articles/ncomms4858

Booth, M. S. (2018) Not carbon neutral: Assessing the net emissions impact of residues burned for bioenergy. *Environmental Research Letters*. 13 (3), 035001. Available from: http://stacks.iop.org/17489326/13/i=3/a=035001?key=crossref.f74731db1160bbd7aa9dd0fc7b30ae85

Böttcher, H. et al. (2018) Forest Vision Germany. Öko-Institut e.V., Berlin. Available from: https://www.greenpeace.de/files/publications/20180228-greenpeace-oekoinstitut-forest-vision-methods-results.pdf

Bows-Larkin, A. (2015) All adrift: aviation, shipping, and climate change policy. *Climate Policy*. 15 (6), 681–702. Available from: https://doi.org/10.1080/14693062.2014.965125.

Boysen, L. R. et al. (2017) The limits to global-warming mitigation by terrestrial carbon removal, *Earth's Future*. 5 (5), 463–474. Available from: http://doi.wiley.com/10.1002/2016EF000469

Brandt, P. et al. (2014) Multifunctionality and biodiversity: Ecosystem services in temperate rainforests of the Pacific Northwest, USA. *Biological Conservation*. 169362–371. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0006320713004242

Briant, G. et al. (2010) Habitat fragmentation and the desiccation of forest canopies: A case study from eastern Amazonia. *Biological Conservation*. 143 (11), 2763–2769. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0006320710003307

Brown, H. C. (2018) *After Florence, nearly 2 million birds lost and 26 flooded lagoons reported* Available from: https://newfoodeconomy.org/hurricane-florence-north-carolina-farms-bird-deaths-flooded-lagoons/

Bryngelsson, D. K. & Lindgren, K. (2013) Why large-scale bioenergy production on marginal land is unfeasible: A conceptual partial equilibrium analysis. *Energy Policy*. 55454–466. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0301421512010889

Buckwell, A. & Nadeu, E. (2018) *What is the safe operating space for EU livestock?* Available from: http://www.risefoundation.eu/images/files/2018/2018_RISE_LIVESTOCK_FULL.pdf

Calle, Z. et al. (2012) Integrating forestry, sustainable cattle-ranching and landscape restoration. *Unasylva*. 6311.

Canadell, J. G. & Schulze, E. D. (2014) Global potential of biospheric carbon management for climate mitigation. *Nature Communications*. 5 (1). Available from: http://www.nature.com/articles/ncomms6282

Cardinael, R. et al. (2017) Increased soil organic carbon stocks under agroforestry: A survey of six different sites in France. *Agriculture, Ecosystems & Environment*. 236243–255. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0167880916305928

CBD (2014) *Connecting biodiversity and climate change mitigation and adaptation: report of the second Ad Hoc Technical Expert Group on Biodiversity and Climate Change.* Available from: http://www.deslibris.ca/ID/242849

CBD (2016) *Decision XIII/5. Ecosystem restoration: short-term action plan*. p.10.

CBD (2010) *Forest Biodiversity Definitions*. Available from: https://www.cbd.int/forest/definitions.shtml

CCFD-Terre Solidaire (2018) *Our land is worth more than carbon*. Available from: https://ccfd-terresolidaire.org/IMG/pdf/rapport_carbone_exe_anglais_180913.pdf

Chatterjee, N. et al. (2018) Changes in soil carbon stocks across the Forest-Agroforest-Agriculture/Pasture continuum in various agroecological regions: A meta-analysis. *Agriculture, Ecosystems & Environment*. 26655–67. Available from: http://www.sciencedirect.com/science/article/pii/S0167880918302913

Chazdon, R. L., Broadbent, E. N., et al. (2016) Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. *Science Advances*. 2 (5), e1501639–e1501639. Available from: http://advances.sciencemag.org/cgi/doi/10.1126/sciadv.1501639

Chazdon, R. L. (2014) *Second Growth: The Promise of Tropical Forest Regeneration in an Age of Deforestation*. Chicago and London: The University of Chicago Press.

Chazdon, R. L., Brancalion, P. H. S., et al. (2016) When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio*. 45 (5), 538–550. Available from: http://link.springer.com/10.1007/s13280-016-0772-y

Chen, X.-P. et al. (2011) Integrated soil-crop system management for food security. *Proceedings of the National Academy of Sciences*. 108 (16), 6399–6404. Available from: http://www.pnas.org/cgi/doi/10.1073/pnas.1101419108

Ciais, P. et al. (2013) 'Chapter 6: Carbon and Other Biogeochemical Cycles', in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. Available from: http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter06_FINAL.pdf

COICA et al. (2018) *Declaration of Indigenous Peoples within the framework of the international coordination meeting for the sacred and territorial biocultural AAA corridor (Andes-Amazonia-Atlántico)*. 17 August. Available from: https://avaazimages.avaaz.org/AMAZONIA%20%20DECLARATORIA%20PUEBLOS%20INDIGENAS%20BOGOTA%2017-08-2018.pdf.

Coley, D. et al. (2009) Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. *Food Policy*. 34 (2), 150–155. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0306919208000997

Community Conservation Resilience Initiative (CCRI) and Global Forest Coalition (GFC) (2018) *Report of the Community Conservation Resilience Initiative*. Available from: https://globalforestcoalition.org/wp-content/uploads/2018/06/global-report-EN.pdf

Conant, R. T. et al. (2017) Grassland management impacts on soil carbon stocks: a new synthesis. *Ecological Applications*. 27 (2), 662–668. Available from: http://doi.wiley.com/10.1002/eap.1473

Coomes, O. T. et al. (2017) What fate for swidden agriculture under land constraint in tropical forests? Lessons from a long-term study in an Amazonian peasant community. *Journal of Rural Studies*. 5439–51. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0743016716305022

Courvoisier, T. et al. (eds.) (2017) *Multi-functionality and sustainability in the European Union's forests*. EASAC policy report 32. Halle (Saale): EASAC Secretariat, Deutsche Akademie der Naturforscher Leopoldina. Available from: https://www.easac.eu/fileadmin/PDF_s/reports_statements/Forests/EASAC_Forests_web_complete.pdf

Courvoisier, T. J. et al. (eds.) (2018) *Negative emission technologies: what role in meeting Paris Agreement targets?* EASAC policy report 35. Halle (Saale): EASAC Secretariat, Deutsche Akademie der Naturforscher Leopoldina. Available from: https://easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_Report_on_Negative_Emission_Technologies.pdf

Crowther, T. W. et al. (2016) Quantifying global soil carbon losses in response to warming. *Nature*. 540 (7631), 104–108. Available from: http://www.nature.com/articles/nature20150

Curtis, P. G. et al. (2018) Classifying drivers of global forest loss. *Science*. 3611108–1111. Available from: https://www.ncbi.nlm.nih.gov/pubmed/30213911

Dargie, G. C. et al. (2017) Age, extent and carbon storage of the central Congo Basin peatland complex. *Nature*. 542 (7639), 86–90. Available from: http://www.nature.com/articles/nature21048

Davidson, E. A. (2012) Representative concentration pathways and mitigation scenarios for nitrous oxide. *Environmental Research Letters*. 7 (2), 024005. Available from: http://stacks.iop.org/17489326/7/i=2/a=024005?key=crossref.d46cc0e9affa249e1693d7fd7a52248e

Davidson, E. A. (2009) The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860. *Nature Geoscience*. 2 (9), 659–662. Available from: http://www.nature.com/articles/ngeo608

Davidson, E. A. & Kanter, D. (2014) Inventories and scenarios of nitrous oxide emissions. *Environmental Research Letters*. 9 (10), 105012. Available from: http://stacks.iop.org/1748-9326/9/i=10/a=105012?key=crossref.01a0f3325fa29b16abd7cf9b4bb98871

Davis, A. S. et al. (2012) Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health John P. Hart (ed.). *PLoS ONE*. 7 (10), e47149. Available from: http://dx.plos.org/10.1371/journal.pone.0047149

DeCicco, J. M. & Schlesinger, W. H. (2018) Opinion: Reconsidering bioenergy given the urgency of climate protection. *Proceedings of the National Academy of Sciences*. 115 (39), 9642–9645. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1814120115

DellaSala, D. L. (in press) '"Real" vs. "Fake" Forests: Why Tree Plantations are Not Forests', in *Encyclopedia of the World's Biomes*. UK: Elsevier.

Diaz, R. J. & Rosenberg, R. (2008) Spreading Dead Zones and Consequences for Marine Ecosystems. *Science*. 321 (5891), 926–929. Available from: http://www.sciencemag.org/cgi/doi/10.1126/science.1156401

Dieleman, C. M. et al. (2015) Climate change drives a shift in peatland ecosystem plant community: Implications for ecosystem function and stability. *Global Change Biology*. 21 (1), 388–395. Available from: http://doi.wiley.com/10.1111/gcb.12643

Dignac, M.-F. et al. (2017) Increasing soil carbon storage: mechanisms, effects of agricultural practices and proxies. A review. *Agronomy for Sustainable Development*. 37 (2). Available from: http://link.springer.com/10.1007/s13593-017-0421-2

Ding, H. et al. (2016) *Climate Benefits, Tenure Costs: The Economic Case For Securing Indigenous Land Rights in the Amazon*. World Resources Institute, Washington, DC. Available from: https://www.wri.org/publication/climate-benefits-tenure-costs

Dixon, K. et al. (1994) Integrated land-use systems: Assessment of promising agroforest and alternative land-use practices to enhance carbon conservation and sequestration. *Climatic Change* 27, 71-92.

Dooley, K. et al. (2018) Co-producing climate policy and negative emissions: trade-offs for sustainable land-use. *Global Sustainability*. 1. Available from: https://www.cambridge.org/core/product/identifier/S2059479818000066/type/journal_article

Dooley, K. & Kartha, S. (2018) Land-based negative emissions: risks for climate mitigation and impacts on sustainable development. *International Environmental Agreements: Politics, Law and Economics*. 18 (1), 79–98. Available from: http://link.springer.com/10.1007/s10784-017-9382-9

Dorrepaal, E. et al. (2009) Carbon respiration from subsurface peat accelerated by climate warming in the subarctic. *Nature*. 460 (7255), 616–619. Available from: http://www.nature.com/articles/nature08216

Erb, K.-H. et al. (2017) Unexpectedly large impact of forest management and grazing on global vegetation biomass. *Nature*. 553 (7686), 73–76. Available from: http://www.nature.com/doifinder/10.1038/nature25138

Erisman, J. W. et al. (2008) How a century of ammonia synthesis changed the world. *Nature Geoscience*. 1 636–639. Available from: https://www.nature.com/articles/ngeo325

FAO (2015) *Status of the world's soil resources: main report.* Food and Agriculture Organization of the United Nations, Rome. Available from: http://www.fao.org/3/a-i5199e.pdf

FAO (2016) *Global Forest Resources Assessment 2015: How are the world's forests changing?* Food and Agriculture Organization of the United Nations, Rome. Available from: http://www.fao.org/3/a-i4793e.pdf

FAO (2018a) *Chair's Summary. 2nd International Symposium on Agroecology Scaling up agroecology to achieve the Sustainable Development Goals (SDGs). 3 - 5 April 2018, Rome*. Available from: http://www.fao.org/3/CA0346EN/ca0346en.pdf

FAO (2018b) *FAOSTAT database* Available from: http://www.fao.org/faostat/en/#home

FAO et al. (2018) *The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition*. Food and Agriculture Organization of the United Nations, Rome. Available from: http://www.fao.org/3/I9553EN/i9553en.pdf

Farrelly, Mi. et al. (eds.) (2016) *Agroecology: the bold future of farming in Africa*. Dar es Salaam, Tanzania: Alliance for Food Sovereignty in Africa. Available from: https://afsafrica.org/wp-content/uploads/2017/02/Agroecology-the-bold-future-of-farming-in-Africa-ebook1.pdf

Fern (2018) *Six problems with BECCS*. Moreton-in-Marsh, UK. Available from; https://fern.org/BECCSbriefing

Fern and Rainforest Foundation Norway (2017) *Return of the Trees: How restoring natural forests can stem climate change and revive rural communities*. Moreton-in-Marsh, UK and Oslo, Norway. Available from: https://fern.org/ReturnoftheTrees

Field, C. B. & Mach, K. J. (2017) Rightsizing carbon dioxide removal. *Science*. 356 (6339), 706–707. Available from: http://www.sciencemag.org/lookup/doi/10.1126/science.aam9726

Finn, J. A. et al. (2013) Ecosystem function enhanced by combining four functional types of plant species in intensively managed grassland mixtures: a 3-year continental-scale field experiment. Brian Wilsey (ed.). *Journal of Applied Ecology*. 50 (2), 365–375. Available from: http://doi.wiley.com/10.1111/1365-2664.12041

Fletcher, R. et al. (2016) Questioning REDD+ and the future of market-based conservation: Fletcher et al. *Conservation Biology*. 30 (3), 673–675. Available from: http://doi.wiley.com/10.1111/cobi.12680

Foden, M. et al. (2017) *Food waste and kitchen practices: implications for policy and* intervention. University of Sheffield, UK. Available from: nexusathome.wordpress.com/reports: doi:10.13140/RG.2.2.23212.56960

Foley, J. A. et al. (2011) Solutions for a cultivated planet. *Nature*. 478 (7369), 337–342. Available from: http://www.nature.com/articles/nature10452

Frank, S. et al. (2017) *The potential of soil organic carbon sequestration for climate change mitigation and food security*. Available from: https://ccafs.cgiar.org/publications/potential-soil-organic-carbon-sequestration-climate-change-mitigation-and-food-security#.W7s7LS9L2qA

Frechette, A. et al. (2016) *Toward a Global Baseline of Carbon Storage in Collective Lands: An updated analysis of indigenous peoples' and local communities' contributions to climate change mitigation*. Rights and Resources Initiative. Available from: https://rightsandresources.org/wp-content/uploads/2016/10/Toward-a-Global-Baseline-of-Carbon-Storage-in-Collective-Lands-November-2016-RRI-WHRC-WRI-report.pdf

Fridahl, M. (2017) Socio-political prioritization of bioenergy with carbon capture and storage. *Energy Policy*. 10489–99. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0301421517300605

Garnett, S. T. et al. (2018) A spatial overview of the global importance of Indigenous lands for conservation. *Nature Sustainability*. 1 (7), 369–374. Available from: http://www.nature.com/articles/s41893-018-0100-6

Garnett, T. et al. (2017) *Grazed and Confused: Ruminating on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question – and what it all means for greenhouse gas emissions*. Food Climate Research Network, University of Oxford. Available from: https://www.fcrn.org.uk/sites/default/files/project-files/fcrn_gnc_report.pdf

Gaudin, A. C. M. et al. (2015) Increasing Crop Diversity Mitigates Weather Variations and Improves Yield Stability Jose Luis Gonzalez-Andujar (ed.). *PLOS ONE*. 10 (2), e0113261. Available from: http://dx.plos.org/10.1371/journal.pone.0113261

Geden, O. (2018) Politically informed advice for climate action. *Nature Geoscience*. 11 (6), 380–383. Available from: https://www.nature.com/articles/s41561-018-0143-3

Gerber, P. J. & Food and Agriculture Organization of the United Nations (eds.) (2013) *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities*. Rome: Food and Agriculture Organization of the United Nations, Rome. Available from: http://www.fao.org/3/a-i3437e.pdf

Gibbs, H. K. & Salmon, J. M. (2015) Mapping the world's degraded lands. *Applied Geography*. 5712–21. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0143622814002793

Giller, K. et al. (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*. 114 (1), 23–34. Available from: http://publications.cirad.fr/une_notice.php?dk=551043

Global Forest Coalition (2017) *Monoculture treee plantations: Fuelling the climate fire*. Available from: https://globalforestcoalition.org/7432-2/

Global Forest Watch (2018) *2017 was the worst year on record for tropical tree cover loss*. Available from: https://blog.globalforestwatch.org/data/2017-was-the-second-worst-year-on-record-for-tropical-tree-cover-loss.

Global Witness (2018) *At What Cost? Irresponsible business and the murder of land and environmental defenders in 2017*. Available from: https://www.globalwitness.org/en/campaigns/environmental-activists/at-what-cost/

Grace, J. et al. (2014) Perturbations in the carbon budget of the tropics. *Global Change Biology*. 20 (10), 3238–3255. Available from: http://doi.wiley.com/10.1111/gcb.12600

GRAIN and IATP (2018) *Emissions impossible: How big meat and dairy are heating up the planet*. Available from: https://www.iatp.org/blog/emissions-impossible

Greenpeace (2013) *Ecological Livestock: Options for reducing livestock production and consumption to fit within ecological limits, with a focus on Europe*. Available from: https://www.greenpeace.org/international/publication/7332/ecological-livestock/

Griffiths, T. (2018) *Closing the Gap: Rights-based solutions for tackling deforestation*. Forests Peoples Programme, Moreton-in-Marsh, UK. Available from: https://rightsanddeforestation.org/policy-paper/closing-the-gap-online.pdf

Griscom, B. W. et al. (2017b) Natural climate solutions. *Proceedings of the National Academy of Sciences*. 114 (44), 11645–11650. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1710465114

Grubler, A. et al. (2018) A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. *Nature Energy*. 3 (6), 515–527. Available from: http://www.nature.com/articles/s41560-018-0172-6

Gullison, R. E. et al. (2007) ENVIRONMENT: Tropical Forests and Climate Policy. *Science*. 316 (5827), 985–986. Available from: http://www.sciencemag.org/cgi/doi/10.1126/science.1136163

Hall, J. M. et al. (2012) Trade-offs between tree cover, carbon storage and floristic biodiversity in reforesting landscapes. *Landscape Ecology*. 27 (8), 1135–1147. Available from: http://link.springer.com/10.1007/s10980-012-9755-y

Hansen, J. et al. (2017) Young people's burden: requirement of negative CO₂ emissions. *Earth System Dynamics*. 8 (3), 577–616. Available from: https://www.earth-syst-dynam.net/8/577/2017/

Harper, A. B. et al. (2018) Land-use emissions play a critical role in land-based mitigation for Paris climate targets. *Nature Communications*. 9 (1). Available from: http://www.nature.com/articles/s41467-018-05340-z

Harris, N. L. et al. (2012) Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. *Science*. 336 (6088), 1573–1576. Available from: http://www.sciencemag.org/cgi/doi/10.1126/science.1217962

Hawken, P. (2017) *Drawdown: the most comprehensive plan ever proposed to reverse global warming*. USA: Penguin.

Heck, V. et al. (2018) Biomass-based negative emissions difficult to reconcile with planetary boundaries. *Nature Climate Change*. 8 (2), 151–155. Available from: http://www.nature.com/articles/s41558-017-0064-y

Heller, M. C. et al. (2018) Greenhouse gas emissions and energy use associated with production of individual self-selected US diets. *Environmental Research Letters*. 13 (4). Available from: http://iopscience.iop.org/article/10.1088/1748-9326/aab0ac.

Henderson, B. B. et al. (2015) Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems & Environment*. 20791–100. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0167880915001139

Herrero, M. et al. (2013) Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences*. 110 (52), 20888–20893. Available from: http://www.pnas.org/cgi/doi/10.1073/pnas.1308149110

Herrero, M. et al. (2016) Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change*. 6, 452-461. Available from: https://www.nature.com/articles/nclimate2925

Holz, C. et al. (2018a) Ratcheting ambition to limit warming to 1.5 °C–trade-offs between emission reductions and carbon dioxide removal. *Environmental Research Letters*. 13 (6), 064028. Available from: http://stacks.iop.org/1748-9326/13/i=6/a=064028

Holz, C. (2018b) Modelling 1.5°C-Compliant Mitigation Scenarios Without Carbon Dioxide Removal, in: Heinrich Boll Stiftung (eds) *Radical Realism for Climate Justice*, Publication Series Ecology, Volume 44.8. Available from: https://www.boell.de/sites/default/files/radical_realism_for_climate_justice_volume_44_8.pdf?dimension1=ds_radicalrealism

Hooijer, A. et al. (2010) Current and future CO2 emissions from drained peatlands in Southeast Asia. *Biogeosciences*. 7 (5), 1505–1514. Available from: http://www.biogeosciences.net/7/1505/2010/

Hooijer, A. et al. (2012) Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences*. 9 (3), 1053–1071. Available from: https://www.biogeosciences.net/9/1053/2012/

Hoolohan, C. et al. (2013) Mitigating the greenhouse gas emissions embodied in food through realistic consumer choices. *Energy Policy*. 631065–1074. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0301421513009701

Hoolohan, C. et al. (2016) Trends and drivers of end-use energy demand and the implications for managing energy in food supply chains: Synthesising insights from the social sciences. *Sustainable Production and Consumption*. 81–17. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2352550916300070

Hospido, A. et al. (2009) The role of seasonality in lettuce consumption: a case study of environmental and social aspects. *The International Journal of Life Cycle Assessment*. 14 (5), 381–391. Available from: http://link.springer.com/10.1007/s11367-009-0091-7

Houghton, R. A. & Nassikas, A. A. (2017) Global and regional fluxes of carbon from land use and land cover change 1850-2015: Carbon Emissions From Land Use. *Global Biogeochemical Cycles*. 31 (3), 456–472. Available from: http://doi.wiley.com/10.1002/2016GB005546

Houghton, R. A. & Nassikas, A. A. (2018) Negative emissions from stopping deforestation and forest degradation, globally. *Global Change Biology*. 24 (1), 350–359. Available from: http://doi.wiley.com/10.1111/gcb.13876

Huang, M. & Asner, G. P. (2010) Long-term carbon loss and recovery following selective logging in Amazon forests: Carbon Dynamics Following Amazon Logging. *Global Biogeochemical Cycles*. 24 (3), n/a-n/a. Available from: http://doi.wiley.com/10.1029/2009GB003727

Humpenöder, F. et al. (2014) Investigating afforestation and bioenergy CCS as climate change mitigation strategies. *Environmental Research Letters*. 9 (6), 064029. Available from: http://stacks.iop.org/17489326/9/i=6/a=064029?key=crossref.5fa44a1462d2acebebaa002315d8e4a6

Ibisch, P. L. et al. (2016) A global map of roadless areas and their conservation status. *Science*. 354 (6318), 1423–1427. Available from: http://www.sciencemag.org/lookup/doi/10.1126/science.aaf7166

IPBES (2018) *Regional/subregional assessment reports on biodiversity and ecosystem services*. Available from: https://www.ipbes.net/deliverables/2b-regional-assessments.

IPES-FOOD (2016) *From uniformityto diversity: a paradigm shift from industrial agriculture to diversified agroecological systems*. [online]. Available from: http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

Isbell, F. et al. (2017) Benefits of increasing plant diversity in sustainable agroecosystems Richard Bardgett (ed.). *Journal of Ecology*. 105 (4), 871–879. Available from: https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/1365-2745.12789

Joosten, H. (2009) *The Global Peatland CO2 Pictur: Peatland status and drainage related emissions in all countries of the world*. Wetlands International. Available from: https://unfccc.int/sites/default/files/draftpeatlandco2report.pdf

Kaye, J. P. & Quemada, M. (2017) Using cover crops to mitigate and adapt to climate change. A review. *Agronomy for Sustainable Development*. 37 (1). Available from: http://link.springer.com/10.1007/s13593-016-0410-x

Keith, H. et al. (2009) Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. *Proceedings of the National Academy of Sciences*. 106 (28), 11635–11640. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.0901970106

Keith, H. et al. (2015) Under What Circumstances Do Wood Products from Native Forests Benefit Climate Change Mitigation? Paul Adam (ed.). *PLOS ONE*. 10 (10), e0139640. Available from: http://dx.plos.org/10.1371/journal.pone.0139640

Klein, N (2007) The Shock Doctrine: The Rise of Disaster Capitalism. Knopf, Canada.

Kormos, C. (2018) 'OBSOLETE: Primary Forest: definition, status and future prospects for global conservation', in *Reference Module in Earth Systems and Environmental Sciences*. Available from: http://linkinghub.elsevier.com/retrieve/pii/B9780124095489097116

Krankina, O. N. et al. (2014) High-Biomass Forests of the Pacific Northwest: Who Manages Them and How Much is Protected? *Environmental Management*. 54 (1), 112–121. Available from: http://link.springer.com/10.1007/s00267-014-0283-1

Kravchenko, J. et al. (2018) *Mortality and Health Outcomes in North Carolina Communities Located in Close Proximity to Hog Concentrated Animal Feeding Operations*. 79 (5), 21. Available from: https://www.ncbi.nlm.nih.gov/pubmed/30228132

Kriegler, E. et al. (2018) Pathways limiting warming to 1.5°C: a tale of turning around in no time? *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 376 (2119), 20160457. Available from: http://rsta.royalsocietypublishing.org/lookup/doi/10.1098/rsta.2016.0457

Kumar, B. M. & Nair, P. K. R. (2004) 'The enigma of tropical homegardens', in P. K. R. Nair et al. (eds.) *New Vistas in Agroforestry*. Dordrecht: Springer Netherlands. pp. 135–152. Available from: http://link.springer.com/10.1007/978-94-017-2424-1_10

Lal, R. (2018) Saving global land resources by enhancing eco-efficiency of agroecosystems. *Journal of Soil and Water Conservation*. 73 (4), 100A-106A. Available from: http://www.jswconline.org/lookup/doi/10.2489/jswc.73.4.100A

Lambin, E. F. & Meyfroidt, P. (2011) Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences*. 108 (9), 3465–3472. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1100480108

Land Rights Now (2016) *Common Ground. Securing land rights and safeguarding the earth*. Available from: https://www.oxfamamerica.org/static/media/files/GCA_REPORT_EN_FINAL.pdf

Latawiec, A. E. et al. (2015) Creating space for large-scale restoration in tropical agricultural landscapes. *Frontiers in Ecology and the Environment*. 13 (4), 211–218. Available from: http://doi.wiley.com/10.1890/140052

Law, B. E. et al. (2018) Land use strategies to mitigate climate change in carbon dense temperate forests. *Proceedings of the National Academy of Sciences*. 115 (14), 3663–3668. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1720064115

Le Quéré, C. et al. (2018) Global Carbon Budget 2017. *Earth System Science Data*. 10 (1), 405–448. Available from: https://www.earth-syst-sci-data.net/10/405/2018/

Lechenet, M. et al. (2014) Reconciling Pesticide Reduction with Economic and Environmental Sustainability in Arable Farming Raul Narciso Carvalho Guedes (ed.). *PLoS ONE*. 9 (6), e97922. Available from: http://dx.plos.org/10.1371/journal.pone.0097922

Lechenet, M. et al. (2017) Reducing pesticide use while preserving crop productivity and profitability on arable farms. *Nature Plants*. 3 (3), 17008. Available from: http://www.nature.com/articles/nplants20178

Leifeld, J. & Menichetti, L. (2018) The underappreciated potential of peatlands in global climate change mitigation strategies. *Nature Communications*. 9 (1). Available from: http://www.nature.com/articles/s41467-018-03406-6

Lindenmayer, D. B. & Sato, C. (2018) Hidden collapse is driven by fire and logging in a socioecological forest ecosystem. *Proceedings of the National Academy of Sciences*. 115 (20), 5181–5186. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1721738115

Locke, H. (2014) *Nature Needs Half: A neccesary and hopeful new agenda for protected areas.* Parks 2013, Vol 19.2. Available from: https://cmsdata.iucn.org/downloads/parks_19_2_locke_1.pdf

Luedeling, E. & Neufeldt, H. (2012) Carbon sequestration potential of parkland agroforestry in the Sahel. *Climatic Change*. 115 (3–4), 443–461. Available from: http://link.springer.com/10.1007/s10584-012-0438-0

Lutz, J. A. et al. (2018) Global importance of large-diameter trees. *Global Ecology and Biogeography*. 27 (7), 849–864. Available from: http://doi.wiley.com/10.1111/geb.12747

Luyssaert, S. et al. (2008) Old-growth forests as global carbon sinks. *Nature*. 455 (7210), 213–215. Available from: http://www.nature.com/doifinder/10.1038/nature07276

MacIntyre, B. D. et al. (2009) *International Assessment of Agricultural Knowledge, Science and Technology for Development, Volume 1: The Global Report: Agriculture at a Crossroads*. Available from: http://www.fao.org/fileadmin/templates/est/Investment/Agriculture_at_a_Crossroads_Global_Report_IAASTD.pdf

Mackey, B. et al. (2017) Assessing the risk to the conservation status of temperate rainforest from exposure to mining, commercial logging, and climate change: A Tasmanian case study. *Biological Conservation*. 21519–29. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0006320717305773

Mackey, B. (2014) Counting trees, carbon and climate change. *Significance*. 11 (1), 19–23. Available from: http://doi.wiley.com/10.1111/j.1740-9713.2014.00720.x

Mackey, B. et al. (2018) *Options and Implementation for Ecosystem-based Adaptation, Tanna Island, Vanuatu*. Griffith Climate Change Response Program, Report No. ESRAM-3.

Mackey, B. et al. (2015) Policy Options for the World's Primary Forests in Multilateral Environmental Agreements: Policy options for world's primary forests. *Conservation Letters*. 8 (2), 139–147. Available from: http://doi.wiley.com/10.1111/conl.12120

Mackey, B. et al. (2013) Untangling the confusion around land carbon science and climate change mitigation policy. *Nature Climate Change*. 3 (6), 552–557. Available from: http://www.nature.com/articles/nclimate1804

Mackey, B. G. et al. (2008) Green Carbon: The role of natural forests in carbon storage. The Fenner School of Environment & Society, The Australian National University. Available from: https://press.anu.edu.au/node/231/download

Martin, P. A. et al. (2015) Impacts of tropical selective logging on carbon storage and tree species richness: A meta-analysis. *Forest Ecology and Management*. 356224–233. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0378112715003837

Mazzei, L. et al. (2010) Above-ground biomass dynamics after reduced-impact logging in the Eastern Amazon. *Forest Ecology and Management*. 259 (3), 367–373. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0378112709007737

Mbow, C. et al. (2014) Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability*. [Online] 661–67. [online]. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1877343513001449

Milà i Canals, L. et al. (2008) *Life cycle assessment (LCA) of domestic vs. imported vegetables. Case studies on broccoli, salad crops and green beans*. Available from: https://www.surrey.ac.uk/ces/files/pdf/0108_CES_WP_RELU_Integ_LCA_local_vs_global_vegs.pdf.

Minasny, B. et al. (2017) Soil carbon 4 per mille. *Geoderma*. 29259–86. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0016706117300095

Montagnini, F. & Nair, P. K. R. (2004) Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems*. 61281–295. Available from: http://www.sidalc.net/repdoc/A3678I/A3678I.PDF

Mortimer, P. E. et al. (2015) Alder trees enhance crop productivity and soil microbial biomass in tea plantations. *Applied Soil Ecology*. 9625–32. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0929139315300160

Mueller, N. D. et al. (2014) A tradeoff frontier for global nitrogen use and cereal production. *Environmental Research Letters*. 9 (5), 054002. Available from: http://stacks.iop.org/1748-9326/9/i=5/a=054002?key=crossref.f45f5e496fa14f61e015e3e6e5b2c40b

Muller, A. et al. (2016) *Organic farming, climate change mitigation and beyond: Reducing the environmental impacts of EU agriculture*. IFOAM EU Group. Available from: https://www.ifoam-eu.org/sites/default/files/ifoameu_advocacy_climate_change_report_2016.pdf

Muller, A. et al. (2017) Strategies for feeding the world more sustainably with organic agriculture. *Nature Communications*. 8 (1). Available from: http://www.nature.com/articles/s41467-017-01410-w

Muller, E. U. et al. (2018) *The state of the world's forests: forest pathways to sustainable development*. Food and Agriculture Organization of the united Nations, Rome. Available from: http://www.fao.org/3/I9535EN/i9535en.pdf

Murdiyarso, D. et al. (2017) *New map reveals more peat in the tropics*. Available from: https://www.cifor.org/library/6452/new-map-reveals-more-peat-in-the-tropics/

Muri, H. (2018) The role of large—scale BECCS in the pursuit of the 1.5°C target: an Earth system model perspective. *Environmental Research Letters*. 13 (4), 044010. Available from: http://stacks.iop.org/1748-9326/13/i=4/a=044010?key=crossref.eafd00be1352155ba5ab58071c558d75

Murphy, B. P. et al. (2016) The underestimated biodiversity of tropical grassy biomes. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 371 (1703), 20150319. Available from: http://rstb.royalsocietypublishing.org/lookup/doi/10.1098/rstb.2015.0319

Nabuurs, G.-J. et al. (2017) By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry. *Forests*. 8 (12), 484. Available from: http://www.mdpi.com/1999-4907/8/12/484

Nabuurs, G.-J. et al. (2013) First signs of carbon sink saturation in European forest biomass. *Nature Climate Change*. 3 (9), 792–796. Available from: http://www.nature.com/articles/nclimate1853

Nabuurs, G.-J. et al. (2007) '*Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*', in Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Nellemann, C. et al. (eds.) (2009) *The environmental food crisis: the environment's role in averting future food crises: a UNEP rapid response assessment*. Arendal, Norway: UNEP. Available from: http://www.pbl.nl/en/publications/2009/The_Environmental_Food_Crisis_the_environments_role_in_averting_future_food_crises

Nelson, E. A. et al. (2007) Combating Climate Change Through Boreal Forest Conservation: Resistance, Adaptation, and Mitigation. *Environmental Reviews*, 22(3): 256-285

Available from: http://www.nrcresearchpress.com/doi/abs/10.1139/er-2013-0064#.W7tC0C9L2qA

Niles, M. T. et al. (2018) Climate change mitigation beyond agriculture: a review of food system opportunities and implications. *Renewable Agriculture and Food Systems*. 33 (03), 297–308. Availablefrom:https://www.cambridge.org/core/product/identifier/S1742170518000029/type/journal_article

NOAA. (2017) *Gulf of Mexico 'dead zone' is the largest ever measured*. National Oceanic and Atmospheric Administration. Available from: https://www.noaa.gov/media-release/gulf-of-mexico-dead-zone-is-largest-ever-measured

Nolte, C. et al. (2013) Governance regime and location influence avoided deforestation success of protected areas in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*. 110 (13), 4956–4961. Available from: http://www.pnas.org/cgi/doi/10.1073/pnas.1214786110

Noss, R. F. et al. (2012) Bolder Thinking for Conservation: Editorial. *Conservation Biology*. 26 (1), 1–4. Available from: http://doi.wiley.com/10.1111/j.1523-1739.2011.01738.x

Oenema, O. et al. (2014) Reducing nitrous oxide emissions from the global food system. *Current Opinion in Environmental Sustainability*. 9–1055–64. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1877343514000463

Olivier, J. G. J. et al. (2017) *Trends in global CO2 and total greenhouse gas emissions - 2017 Report*. PBL Netherlands Environmental Assessment Agency. Available from: http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2017-trends-in-global-co2-and-total-greenhouse-gas-emissons-2017-report_2674.pdf

O'Neill, B. C. et al. (2017) The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*. 42169–180. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0959378015000060

Pan, Y. et al. (2011) A Large and Persistent Carbon Sink in the World's Forests. *Science*. 333 (6045), 988–993. Available from: http://www.sciencemag.org/cgi/doi/10.1126/science.1201609

Paustian, K. et al. (2016) Climate-smart soils: a new management paradigm for global agriculture. *Nature*. 532,49–57. Available from: http://www.nature.com/articles/nature17174

Pelletier, N. et al. (2010) Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. *Agricultural Systems*. 103 (6), 380–389. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0308521X10000399

Peters, G. P. (2018) Beyond carbon budgets. *Nature Geoscience*. 11, 378-380. Available from: https://www.nature.com/articles/s41561-018-0142-4

Pew Commission on Industrial Farm Animal Production (2008) *Putting Meat on the Table: Industrial farm production in America*. Available from: https://www.pewtrusts.org/~/media/assets/2008/pcifap_exec-summary.pdf

Pingoud, K. et al. (2018) Trade-offs between forest carbon stocks and harvests in a steady state – A multi-criteria analysis. *Journal of Environmental Management*. 21096–103. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301479717312641

Poore, J. & Nemecek, T. (2018) Reducing food's environmental impacts through producers and consumers. *Science*. 360 (6392), 987–992. Available from: http://science.sciencemag.org.ezp.lib.unimelb.edu.au/content/360/6392/987

Poorter, L. et al. (2016) Biomass resilience of Neotropical secondary forests. *Nature*. 530 (7589), 211–214. [online]. Available from: http://www.nature.com/articles/nature16512

Potapov, P. et al. (2017) The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. *Science Advances*. 3 (1), e1600821. Available from: http://advances.sciencemag.org/lookup/doi/10.1126/sciadv.1600821

Powlson, D. S. et al. (2014) Limited potential of no-till agriculture for climate change mitigation. *Nature Climate Change*. 4 (8), 678–683. Available from: http://www.nature.com/articles/nclimate2292

Prager, A. & Milhorance, F. (2018) Cerrado: appreciation grows for Brazil's savannah, even as it vanishes. *Mongabay*. Available from: https://news.mongabay.com/2018/03/cerrado-appreciation-grows-for-brazils-savannah-even-as-it-vanishes/

Prieto, I. et al. (2015) Complementary effects of species and genetic diversity on productivity and stability of sown grasslands. *Nature Plants*. 1 (4), 15033. Available from: http://www.nature.com/articles/nplants201533

Putz, F. E. et al. (2012) Sustaining conservation values in selectively logged tropical forests: the attained and the attainable: Sustaining tropical forests with forestry. *Conservation Letters*. 5 (4), 296–303. Available from: http://doi.wiley.com/10.1111/j.1755-263X.2012.00242.x

Rainforest Foundation Norway (2014) *State Of The Rainforest 2014*. Oslo, Norway. Available from: http://stateoftherainforest.regnskogfondet.no/uploads/docs/StateOfTheRainforest_lo.pdf

Rainforest Foundation Norway (2017) *Sustainable rainforest management: Local initiatives meet supporting policies in Acre, Brazil*. Oslo, Norway. Available from: https://d5i6is0eze552.cloudfront.net/documents/Publikasjoner/Andre-rapporter/Rapport-Acre-lavopplost-oppslag-ID-43389.pdf?mtime=20170928112428

Ramachandran Nair, P. K. et al. (2009) Agroforestry as a strategy for carbon sequestration. *Journal of Plant Nutrition and Soil Science*. 172 (1), 10–23. Available from: http://doi.wiley.com/10.1002/jpln.200800030

Ramachandran Nair, P. K. et al. (2010) 'Carbon Sequestration in Agroforestry Systems', in *Advances in Agronomy*. Elsevier. pp. 237–307. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0065211310080053

Reay, D. S. et al. (2012) Global agriculture and nitrous oxide emissions. *Nature Climate Change*. 2 (6), 410–416. Available from: http://www.nature.com/doifinder/10.1038/nclimate1458

Rights and Resources Initiative (2018) *A Global Baseline of Carbon Storage in Collective Lands: Indigenous and local community contributions to climate action*. Washington, DC. Available from:https://rightsandresources.org/en/publication/globalcarbonbaseline2018/#.W7sqXy9L0dU

Rights and Resources Initiative (2016) *Indigenous Peoples & Local Community Tenure in the INDCs: Status and Recommendations*. Washington, DC. Available from: http://rightsandresources.org/wp-content/uploads/2016/04/Indigenous-Peoples-and-Local-Community-Tenure-in-the-INDCs-Status-and-Recommendations_RRI_April-2016.pdf

Rights and Resources Initiative (2017) *Securing Community Land Rights: Priorities and opportunities to advance climate and sustainable development goals*. Washington, DC. Available from: http://rightsandresources.org/wp-content/uploads/2017/09/Stockholm-Prorities-and-Opportunities-Brief.pdf

Rights and Resources Initiative (2015) *Who Owns the World's Land? A global baseline of formally recognized indigenous and community land rights*. Available from: http://rightsandresources.org/wp-content/uploads/GlobalBaseline_complete_web.pdf

Robinson, B. E. et al. (2014) Does secure land tenure save forests? A meta-analysis of the relationship between land tenure and tropical deforestation. *Global Environmental Change*. 29281–293. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0959378013000976

Rocha, R. et al. (2018) Secondary forest regeneration benefits old-growth specialist bats in a fragmented tropical landscape. *Scientific Reports*. 8 (1). Available from: http://www.nature.com/articles/s41598-018-21999-2

Rogelj, J. et al. (2018) Scenarios towards limiting global mean temperature increase below 1.5°C. *Nature Climate Change*. 8 (4), 325–332. Available from: http://www.nature.com/articles/s41558-018-0091-3.

Röös, E. et al. (2017) Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change*. 471–12. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0959378016306872

Rosenstock, T. et al. (2014) Agroforestry with N2-fixing trees: sustainable development's friend or foe? *Current Opinion in Environmental Sustainability*. 615–21. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1877343513001218

Roxburgh, S. H. et al. (2006) Assessing the carbon sequestration potential of managed forests: a case study from temperate Australia: Carbon sequestration potential. *Journal of Applied Ecology*. 43 (6), 1149–1159. Available from: http://doi.wiley.com/10.1111/j.1365-2664.2006.01221.x (Accessed 23 July 2018).

Rudel, T. K. et al. (2009) Changing Drivers of Deforestation and New Opportunities for Conservation. *Conservation Biology*. 23 (6), 1396–1405. Available from: http://doi.wiley.com/10.1111/j.1523-1739.2009.01332.x

Russelle, M. P. et al. (2007) Reconsidering Integrated Crop–Livestock Systems in North America. *Agronomy Journal*. 99 (2), 325. Available from: https://www.agronomy.org/publications/aj/abstracts/99/2/325

Schlesinger, W. H. (2018) Are wood pellets a green fuel? *Science*. 359 (6382), 1328–1329. Available from: http://www.sciencemag.org/lookup/doi/10.1126/science.aat2305

Searchinger, T. et al. (2015) Do biofuel policies seek to cut emissions by cutting food? *Science*. 347 (6229), 1420–1422. Available from: http://www.sciencemag.org/cgi/doi/10.1126/science.1261221

Searchinger, T. D. et al. (2017) Does the world have low-carbon bioenergy potential from the dedicated use of land? *Energy Policy*. 110434–446. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301421517305104

Seconda, L. et al. (2018) Comparing nutritional, economic, and environmental performances of diets according to their levels of greenhouse gas emissions. *Climatic Change*. 148 (1–2), 155–172. Available from: http://link.springer.com/10.1007/s10584-018-2195-1

Séférian, R. et al. (2018) Constraints on biomass energy deployment in mitigation pathways: the case of water scarcity. *Environmental Research Letters*. 13 (5), 054011. Available from: http://stacks.iop.org/1748-9326/13/i=5/a=054011?key=crossref.671ab2d6531e32025ff7b3bc5099d243

Sharma, S. & Schlesinger, S. (2017) *The Rise of Big Meat: Brazil's Extractive Industry*. Institute for Agriculture and Trade Policy. Available from: https://www.iatp.org/the-rise-of-big-meat

Shcherbak, I. et al. (2014) Global metaanalysis of the nonlinear response of soil nitrous oxide (N2O) emissions to fertilizer nitrogen. *Proceedings of the National Academy of Sciences*. 111 (25), 9199–9204. Available from: http://www.pnas.org/cgi/doi/10.1073/pnas.1322434111

Smith, P. et al. (2016) Biophysical and economic limits to negative CO2 emissions. *Nature Climate Change*. 6 (1), 42–50. Available from: http://www.nature.com/articles/nclimate2870

Smith, P. et al. (2007) 'Chapter 8: Agriculture', in *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Smith, P. et al. (2014) 'Chapter 11: Agriculture, Forestry and Other Land Use (AFOLU)', in *Climate Change 2014 Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. [Online]. Cambridge: Cambridge University Press.

Smith, P. (2016) Soil carbon sequestration and biochar as negative emission technologies. *Global Change Biology*. 22 (3), 1315–1324. Available from: http://doi.wiley.com/10.1111/gcb.13178

Smyth, C. E. et al. (2014) Quantifying the biophysical climate change mitigation potential of Canada's forest sector. *Biogeosciences*. 11 (13), 3515–3529. Available from: https://www.biogeosciences.net/11/3515/2014/

Snyder, C. S. et al. (2009) Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems & Environment*. 133 (3–4), 247–266. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0167880909001297

Soule, M. F. et al. (2004) The Role of Connectivity in Australian Conservation. *Pacific Conservation Biology*. 10266–279. Available from: https://denr.nt.gov.au/__data/assets/pdf_file/0007/255067/2006SouleM.E.MackeyB.G.RecherH.F.WilliamsJ.E.WoinarskiJ.C.Z.DriscollD.DennisonW.C.andJonesM.pdf

Sovu et al. (2009) Recovery of secondary forests on swidden cultivation fallows in Laos. *Forest Ecology and Management*. 258 (12), 2666–2675. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0378112709006677

Springmann, M. et al. (2016) Analysis and valuation of the health and climate change cobenefits of dietary change. *Proceedings of the National Academy of Sciences of the United States of America*. 113 (15), 4146–4151. Available from: http://www.pnas.org/content/113/15/4146

Stanley, P. L. et al. (2018) Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. *Agricultural Systems*. 162249–258. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0308521X17310338

Steffen, W. et al. (2015) Planetary boundaries: Guiding human development on a changing planet. *Science*. 347 (6223), 1259855–1259855. Available from: http://www.sciencemag.org/cgi/doi/10.1126/science.1259855

Steffen, W. et al. (2018) Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences*. 115 (33), 8252–8259. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1810141115

Sterman, J. D. et al. (2018) Does replacing coal with wood lower CO2 emissions? Dynamic lifecycle analysis of wood bioenergy. *Environmental Research Letters*. 13 (1), 015007. Available from: http://stacks.iop.org/1748-9326/13/i=1/a=015007?key=crossref.036dae50363ab20bcbd6444b-546fb641

Stevens, C. et al. (2014) *Securing Rights, Combating Climate Change: How Strengthening Community Forest Rights Mitigates Climate Change*. Rights and Resources Initiative. Available from: https://www.wri.org/sites/default/files/securingrights-full-report-english.pdf

Stevens, S. et al. (2016) *Recognising and Respecting ICCAs overlapped by protected areas: a report to the ICCA Consortium.* Available from: www.iccaconsortium.org/wp-content/uploads/2016/11/publication-Recognising-and-Respecting-ICCAs-Overlapped-by-PAs-Stevens-et-al-2016-en.pdf.

Sunderlin, W. D. et al. (2018) Creating an appropriate tenure foundation for REDD+: The record to date and prospects for the future. *World Development*. 106376–392. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0305750X18300202

Sutton, M. A. & UNEP (eds.) (2013) *Our nutrient world: the challenge to produce more food and energy with less pollution.* Edinburgh: Centre for Ecology & Hydrology. Available from: http://nora.nerc.ac.uk/id/eprint/500700/1/N500700BK.pdf

Tauli-Corpuz, V. et al. (2018) *Cornered by Protected Areas*. Available from: https://www.corneredbypas.com

Tauli-Corpuz, V. (2018) *They should have known better: A Letter from the UN Special Rapporteur on the Rights of Indigenous Peoples*. Available from: https://www.theyshouldhaveknownbetter.com.

Thiess, C. (2018) Re-greening the Earth: Protecting the climate through ecosystem restoration, in: Heinrich Boll Stiftung (eds) *Radical Realism for Climate Justice*, Publication Series Ecology, Volume 44.7. Available from: https://www.boell.de/sites/default/files/radical_realism_for_climate_justice_volume_44_7.pdf?dimension1=ds_radicalrealism

Tirado, R. et al. (2018) *Less is More: Reducing Meat and Dairy for a Healthier Life and Planet Scientific Background*. Greenpeace. Available from: https://storage.googleapis.com/p4-production-content/international/wp-content/uploads/2018/03/698c4c4a-summary_greenpeace-livestock-vision-towards-2050.pdf

Tomich, T. P. et al. (2011) Agroecology: A Review from a Global-Change Perspective. *Annual Review of Environment and Resources*. 36 (1), 193–222. Available from: http://www.annualreviews.org/doi/10.1146/annurev-environ-012110-121302

Torquebiau, E. F. (2000) A renewed perspective on agroforestry concepts and classification. *Comptes Rendus de l'Académie des Sciences - Series III - Sciences de la Vie*. 323 (11), 1009–1017. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0764446900012397

Tscharntke, T. et al. (2011) Multifunctional shade-tree management in tropical agroforestry landscapes – a review. *Journal of Applied Ecology*. 48 (3), 619–629. Available from: https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2664.2010.01939.x

Tyukavina, A. et al. (2015) Aboveground carbon loss in natural and managed tropical forests from 2000 to 2012. *Environmental Research Letters*. 10 (7), 074002. Available from: http://stacks.iop.org/17489326/10/i=7/a=074002?key=crossref.c8ed12129918e21f8d7cd0c0c3bf80d0

Van Zanten, H. H. E. et al. (2018) Defining a land boundary for sustainable livestock consumption. *Global Change Biology*. 1-10. Available from: http://doi.wiley.com/10.1111/gcb.14321

Vaughan, N. E. & Gough, C. (2016) Expert assessment concludes negative emissions scenarios may not deliver. *Environmental Research Letters*. 11 (9), 095003. Available from: http://stacks.iop.org/17489326/11/i=9/a=095003?key=crossref.857f5dec1289a7ab6a51049ce522720c

Verchot, L. V. et al. (2007) Climate change: linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change*. 12 (5), 901–918. Available from: http://link.springer.com/10.1007/s11027-007-9105-6

van Vliet, N. et al. (2012) Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. *Global Environmental Change*. 22 (2), 418–429. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0959378011001622

Walker, W. et al. (2014) Forest carbon in Amazonia: the unrecognized contribution of indigenous territories and protected natural areas. *Carbon Management*. 5 (5–6), 479–485. Available from: http://www.tandfonline.com/doi/full/10.1080/17583004.2014.990680

Watson, B. et al. (2000) *Summary for policymakers: land use, land-use change, and forestry : a special report of the Intergovernmental Panel on Climate Change.* IPCC.

Wetlands International (2015) *Save Peat for Less Heat*. Available from: www.wetlands.org. Available from: www.wetlands.org.

Wheeler, C. et al. (in press) The mitigation potential of large-scale tropical forest restoration: assessing the promise of the Bonn Challenge.

White, R. et al. (2000) *Grassland Ecosystems: Pilot Analysis of Global Ecosystems*. World Resources Institute, Washington DC. Available from: http://www.wri.org/wr2000.

White, R. E. et al. (2018) A critique of the paper 'Soil carbon 4 per mille' by Minasny et al. (2017). *Geoderma*. 309115–117. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0016706117307462

Williamson, P. (2016) Scrutinize CO2 removal methods. *Nature*. 530153–155. Available from: https://www.nature.com/news/emissions-reduction-scrutinize-co2-removal-methods-1.19318

Williamson, P. & Bodle, R. (2016) *Update on Climate Geoengineering in Relation to the Convention on Biological Diversity: Potential Impacts and Regulatory Framework*. CBD Technical Series. Available from: https://www.cbd.int/doc/publications/cbd-ts-84-en.pdf

Wilson, E.O. (2016) *Half Earth: Our Planet's Fight for Life*. New York: Liverwright Publishing Corporation.

Wilson, M. et al. (2016) Agroforestry—The Next Step in Sustainable and Resilient Agriculture. *Sustainability*. 8 (6), 574. Available from: http://www.mdpi.com/2071-1050/8/6/574

World Health Organization (2018) *Obesity and overweight*. WHO factsheets. Available from: http://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

WRI (2011) *A World of opportunity*. World Resources Institute, Washington, DC. Available from: http://pdf.wri.org/world_of_opportunity_brochure_2011-09.pdf

Zhang, X. et al. (2015) Managing nitrogen for sustainable development. *Nature*. 528, 51-59. Available from: http://www.nature.com/doifinder/10.1038/nature15743

Ziegler, A. D. et al. (2012) Carbon outcomes of major land-cover transitions in SE Asia: great uncertainties and REDD+ policy implications. *Global Change Biology*. 18 (10), 3087–3099. Available from: http://doi.wiley.com/10.1111/j.1365-2486.2012.02747.x

Zimmerman, B. & Kormos, C. (2012) Prospects for Sustainable Logging in Tropical Forests. *BioScience*. 62 (5), 479–487. Available from: https://academic.oup.com/bioscience/article-lookup/doi/10.1525/bio.2012.62.5.9

Zomer, R. . et al. (2014) *Trees on farms: an update and reanalysis of agroforestry's global extent and socio-ecological characteristics*. Working Paper 179. World Agroforestry Center (ICRAF) Southeast Asia Regional Program. Bogor, Indonesia. Available from: http://www.worldagroforestry.org/downloads/publications/PDFs/WP14064.PDF

Zomer, R. J. et al. (2017) Global Sequestration Potential of Increased Organic Carbon in Cropland Soils. *Scientific Reports*. 7 (1). Available from: http://www.nature.com/articles/s41598-017-15794-8

Zomer, R. J. et al. (2016) Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. *Scientific Reports*. 6 (1). Available from: http://www.nature.com/articles/srep29987