CLIMATE FOCUS

How Improved Land Use Can Contribute to the 1.5°C Goal of the Paris Agreement

Working Paper

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Executive Summary

The goals of the Paris Agreement cannot be met without significant contributions from the land sector, including supply-side measures in forestry and agriculture, and demand-side measures related to healthier diets and reduced food waste.

Through significant emissions reductions and carbon removals, the land sector can contribute about 25 percent of the progress needed to meet the 1.5°C goal formulated under the Paris Agreement.

Land-sector emissions have to peak by 2020 and become net-zero by 2040–50 and net-negative thereafter.

We developed a roadmap of action that relies on:

- effective forest protection (reduced deforestation)
- enhanced restoration
- sustainable forest management
- halting peatland burning
- peatland restoration
- a shift to healthier diets
- reduced food waste and losses
- enhanced soil carbon sequestration
- increased efficiency of synthetic fertilizer production and use
- reduced emissions from rice paddies
- reduced emissions from livestock (enteric fermentation)

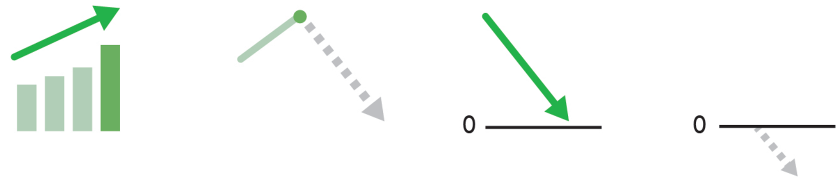
The roadmap is based on the technical mitigation potential of various land-use activities corrected for political feasibility, which we assessed applying indicators that estimated political will, and ability to implement policy measures.

Negative emission technologies, in particular forestation and land-based enhancement of carbon sinks, are essential strategies to meet global climate goals. However, we caution against a large-scale and singular reliance on engineered carbon sinks (bio-energy with carbon capture and storage — BECCS), which come with significant land-use tradeoffs and ecological risks.

We find that it is still feasible to meet the 1.5°C temperature goal of the Paris Agreement. However, action needs to be both more decisive and aggressive and backed by a long-term vision for sustainable landscapes.

Overview of Action

To reach the 1.5°C Paris Agreement goal, we developed a roadmap of action for the land sector:



today
rising emissions

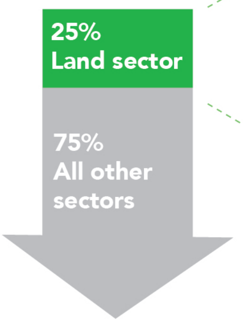
2020
emissions must peak

2040–2050
achieve net-zero emissions

the future
maintain negative emissions

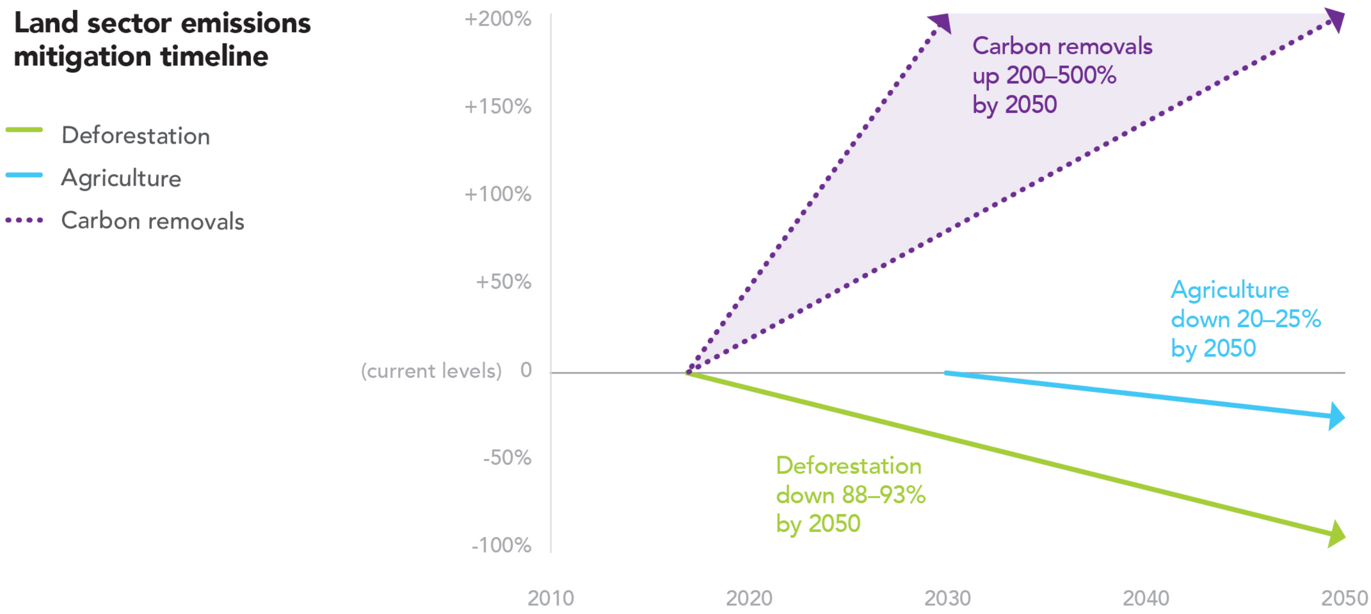
Emissions from all sectors need to decrease by at least 80 to 90 percent and carbon removals need to increase to 5 to 15 Gt CO_2. The land sector can contribute about 25 percent by 2050 of the progress needed to meet the 1.5°C goal. We discuss ten mitigation strategies in this report:

Emissions reductions needed to reach the 1.5°C goal:



- Reduce Deforestation and Degradation
- Restoration of Forests
- Forest Management
- Halt Peatland Burning
- Increase Carbon Sequestration
- Shift to Healthy Diets
- Reduce Food Waste
- Improve Synthetic Fertilizer Production
- Reduce Emissions from Livestock
- Reduce Emissions from Rice Paddies

Land sector emissions mitigation timeline



Contents

1. The Land Sector and the Paris Agreement

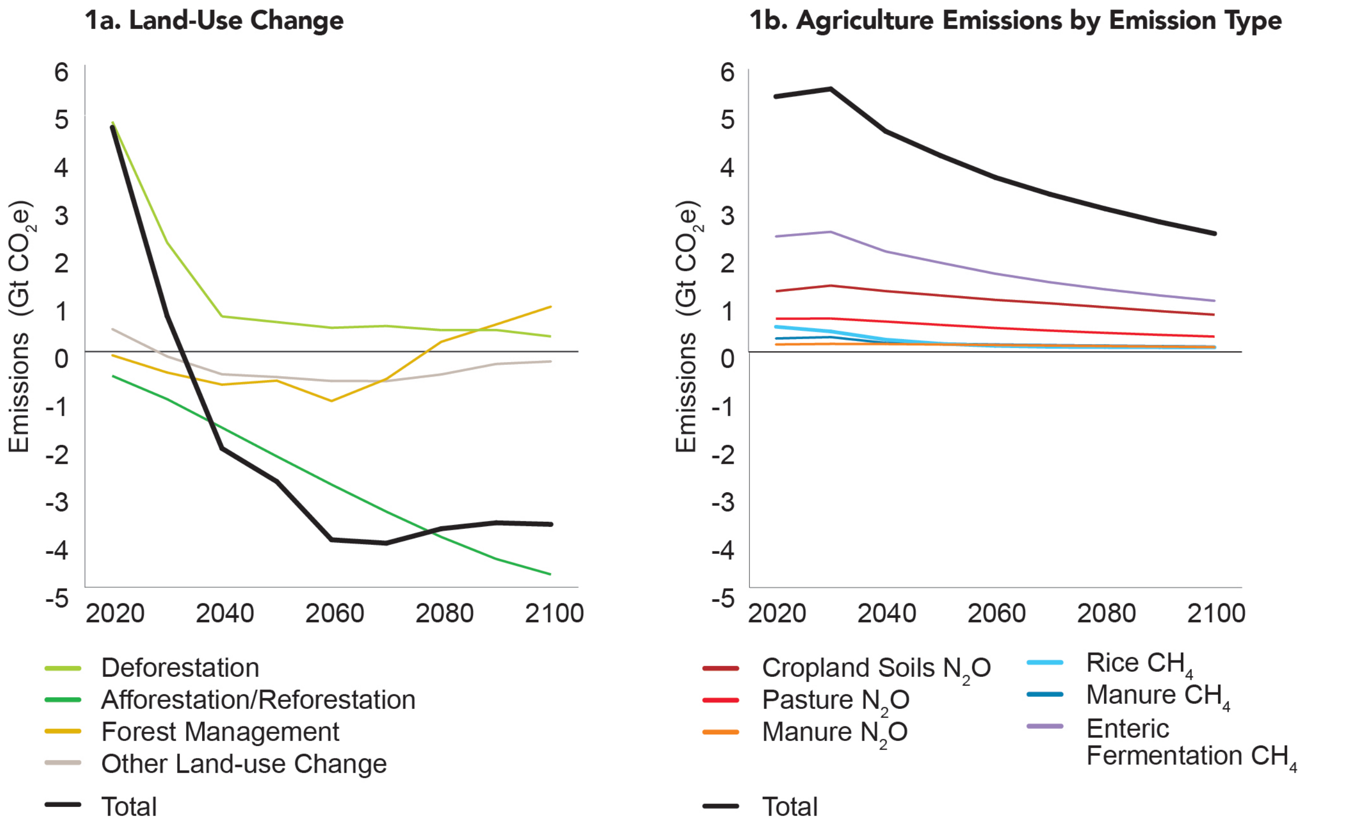
Agriculture, forestry, and other land uses (the land sector) account for about 24 percent of net global greenhouse gases (GHGs).[1] Climate mitigation in the land sector therefore presents a significant opportunity to deliver on the goals set forth by the Paris Agreement of limiting global warming to well below 2°C and encouraging efforts to 1.5°C compared to pre-industrial levels.[2] In addition to contributing to climate change mitigation, forests, and other terrestrial ecosystems provide essential goods and services, such as timber and fiber, biodiversity, air and water purification, and nutrient cycling. Changes in land use also significantly affect the climate by altering water and energy fluxes between the land and the atmosphere.[3]

Delaying action to reduce emissions decreases the likelihood of meeting the Paris Agreement temperature goals. According to the Intergovernmental Panel on Climate Change (IPCC), limiting warming to less than 2°C and 1.5°C with greater than 66 percent likelihood means that global cumulative emissions between 2016 and 2100 cannot exceed 800 gigatonnes of carbon dioxide (Gt CO_2) and 200 Gt CO_2, respectively.[4] At current annual emissions levels of approximately 40 Gt CO_2,[5] the carbon budget for 1.5°C will be exceeded in 4 years (2021), and the carbon budget for 2°C will be exceeded in 19 years (2036) if no mitigation and removal efforts are undertaken.

There is still an opportunity to limit warming to 1.5°C to 2°C, but stringent climate policies and measures that aggressively reduce and remove emissions are needed. Global CO_2 emission pathways must meet three milestones: peak by 2020, reach a net-zero level (balance between emission sources and removals) between 2040 and 2050, and achieve net-negative emissions (greater removals than sources) thereafter to meet a 66 percent probability threshold for 2°C and a 50 percent threshold for 1.5°C of warming.[6] In other words, emissions from all sectors need to decrease by about 80–90 percent and carbon removals need to increase by approximately 5–15 Gt CO_2 per year, so ambitious efforts in the next decade are critical to limiting warming by 1.5°C.[7]

1 Smith et al., 2014; LeQuéré et al., 2016; Baccini et al., 2017. Net emissions include gross emissions from land use change and agriculture + regrowth forest, whereas sequestration includes regrowth forest (managed sinks) and residual sinks. The 24 percent of net emissions correspond to 11 $GtCO_2e$ of emissions. The land sector emits 25–38 percent (10–15 $GtCO_2e$) in gross emissions and sequesters about 20–30 percent of total anthropogenic emissions.
2 Art 4.1 Paris Agreement UNFCCC, 2015.
3 Alkhama, R. & Cescatti, A., 2016. The authors found that forest loss and resulting changes in evapotranspiration and energy fluxes between 2003–12 increased air temperature equating to about 18% of CO_2 emissions from land-use change.
4 Carbon emission quotas through 2011 were taken from the IPCC AR5 Synthesis report and the 2012–16 cumulative emissions from The Global Carbon Budgets estimates were subtracted from the IPCC values (39.9 in 2016, 41.1 in 2015, 40.2 in 2014, 39.4 in 2013, and 39.0 in 2012, in Gt CO_2). Note that this does not include non-CO_2 emissions, which currently make up between 20 and 25 percent of climate forcing emissions. Source: Clarke & Jiang 2014; Le Quéré et al., 2016.
5 Le Quéré et al., 2016.
6 Analysis based on Rockström et al., 2017; Rogelj et al., 2015; Sanderson et al., 2016; Walsh et al., 2017 in Roe et al., (forthcoming).
7 Roe et al., (forthcoming).

Figure 1: Land-use change and agriculture emissions



Land-use change (1a) and Agriculture emissions by emission type (1b) in 1.5°C scenario in Gt CO_2e a year from GLOBIOM model. Forest management includes forests which are managed for timber and bioenergy (BECCS). Emissions from forest management increase after 2060 because gains from BECCS are not accounted for in the land sector but rather the energy sector. A/R represents areas afforested and /or reforested after 2000. Other land-use change is from grasslands, savannahs, wetlands and abandoned agricultural lands.

The mitigation goals countries have communicated as part of their Nationally Determined Contributions (NDCs) under the Paris Agreement currently fall short of the needed reductions. The cumulative mitigation contemplated under the countries' NDCs would still result in 2.5°C to 3°C of warming by 2100.[8] To meet the Paris Agreement goals, more ambitious efforts from all countries will be required. Greater emission reductions need to be achieved faster.

According to our modeling assessment, land-sector emissions must peak around 2020 and decline by about 85 percent through 2050 to meet the Paris Agreement goals.[9] We modeled land-sector transformation and related GHG emissions (CO_2, methane and nitrous oxide)

8 Schleussner et al., 2016.

9 To provide higher resolution on 1.5°C and 2°C trajectories in agriculture and forestry, we modeled land sector development trajectories optimizing least-cost pathways. We used the GLOBIOM Integrated Assessment Model. GLOBIOM (Global Biosphere Management Model, http://www.globiom.org) is a partial equilibrium model developed by the International Institute for Applied Systems Analysis. It integrates the agricultural, bioenergy, and forestry sectors and draws on comprehensive socioeconomic and geospatial data. It accounts for the 18 most important crops globally, a range of livestock production activities, forestry commodities, first- and second-generation bioenergy, and water. Production is spatially explicit and takes into account land, management, and weather characteristics. The market equilibrium is solved by maximizing the sum of producer and consumer surplus subject to resource, technological, and political constraints. We used RCP 1.9 to model 1.5°C and RCP 2.6 to model 2°C.

Box 1: The Price of Mitigation

Scientists rely on theoretical carbon prices to model global emission reduction scenarios. These prices are largely theoretical since they fail to take into account either local circumstances or the co-benefits of action. All the mitigation actions presented in this study carry substantial benefits outside the scope of the study, including improvements in public and environmental-health outcomes.

The costs of not implementing the mitigation actions (i.e. the cost of inaction on climate-change mitigation) are also significant. Inaction risks major interruptions to current patterns of human settlement and subsequent economic upheaval that cannot be easily quantified. Sectoral financial models also fail to forecast rapid technological developments that render model assumptions invalid along their extended timelines. Consequently, projected costs of the proposed mitigation actions are not presented here due to several significant sources of uncertainty in applying specific financial measures to a given measure or set of measures.

reductions driven by an increasing carbon price to limit warming to 1.5°C. Meeting the Paris goals requires a dramatic reduction in gross GHG emissions (measured as CO_2 equivalent—CO_2e) from deforestation and agriculture, and a significant increase in carbon removals from afforestation and reforestation (A/R) and forest management. In the 1.5°C scenario, CO_2 emissions from land-use change fall precipitously from 2020 and become net negative around 2030 due to avoided deforestation and A/R expansion (Figure 1a). Agricultural non-CO_2 emissions composed primarily of enteric fermentation, manure, and rice cultivation begin to decline around 2030, due to production efficiencies and diet shifts (Figure 1b).

While most analyses and literature focus on CO_2 emissions, powerful, short-lived greenhouse gases (methane, black carbon, HFCs, and ground-level ozone), account for almost half of current global warming effects. These gases remain for a shorter period in the atmosphere and have a disproportionate effect on global warming. Many of the gases are also local pollutants with negative effects on human health and ecosystems. Agriculture accounts for 56 percent of methane emissions, or 27 percent of total short-lived gases.[10] Reducing short-lived gases would produce more rapid GHG reductions in the near term, which may offset some delays in reducing or sequestering CO_2 emissions. The greatest impact would be in meeting the 2°C goal, as reaching the 1.5°C goal will rely almost solely on continued reductions in CO_2 emissions.[11]

10 Smith et al., 2014; Montzka et al., 2011.
11 Rogelj et al., 2015.

2. Negative Emissions

Limiting warming to 1.5°C requires substantial mitigation and a significant concurrent increase in carbon sinks.[12] The removal of carbon from the atmosphere creates negative emissions that are essential for achieving a carbon balance in the atmosphere. A large portion of removals depends on the extensive use of land.[13] Options that rely exclusively on natural solutions include enhanced carbon removal by ecosystem restoration, A/R, sustainable forest management, and conservation agriculture. These activities, including the substitution of high-emission construction materials (e.g. steel, concrete) with wood-based construction supplied from the expansion of A/R, could significantly enhance the impact of the related removals if pursued at scale.

A number of less mature technologies include engineered carbon sinks. Such sinks can be created through biochar generation in soils, and bio-energy with carbon capture and storage (BECCS). BECCS generates energy and relies on the subsequent storage of CO_2 in geological reservoirs. Compared to natural options, the environmental and social trade-offs of BECCS can be significant.[14] BECCS has yet to be demonstrated as viable or deployed at scale. Nonetheless, the IPCC has estimated the mitigation potential of BECCS at 2–10 Gt CO_2 a year.[15] In fact, a significant majority of the IPCC-reviewed 2°C scenarios incorporated significant negative emissions, including through BECCs.[16] The climate-modeling community appears to be making a large assumption that not only will the BECCS technology be available at scale, but that the land sector will deliver a significant portion of the energy sector's emissions reductions.[17]

The large potential mitigation gains with BECCS must be assessed in the context of the risks, uncertainties, and tradeoffs that come with an aggressive expansion of bioenergy. This risk increases with the scale of deployment. According to some models, the potential negative emissions from BECCS would require 300 to 700 million hectares of land (a range equivalent to the area of India at the low end and Australia at the high end).[18] BECCS can lead to land conversion that would pit climate change measures against food security and the conservation of biodiversity, watersheds, and natural ecosystems.[19] There is also uncertainty about the technology's viability at scale.[20] Yet bioenergy could drive positive impacts if deployed on degraded lands or as part of agroforestry systems.[21] Further, negative emissions will be necessary in the future, and thus research and investment in negative emissions technologies in the next few years will be critical for future piloting and deployment.

12 Rockström et al., 2017; Rogelj et al., 2015; Sanderson et al., 2016; Walsh et al., 2017.
13 Ibid.
14 Field & Mach, 2017.
15 Smith et al., 2015.
16 Clarke & Jiang, 2014; Smith et al., 2015; Roe et al., (forthcoming).
17 Anderson & Peters, 2017.
18 Schleussner et al., 2016; Smith et al., 2015.
19 Field & Mach, 2017; Creutzig et al., 2015.
20 Anderson & Peters, 2017.
21 Creutzig et al., 2015.

3. The Mitigation Potential of the Land Sector

We assessed the mitigation potential of measures that reduce emissions from agriculture, forests, wetlands, diets, and food systems, as well as their contribution to meeting the 1.5°C goal.[22] We calculated the technical mitigation potential, which includes the full range of emissions reductions and carbon sequestration possible with current technologies without economic and political constraints.[23] On the supply side, we focused on land-use change (e.g. reduced deforestation), natural carbon-sink enhancement (e.g. forest restoration), agriculture (e.g. reduced fertilizer use), and biofuels; on the demand side, we looked at food waste and food loss, diets (e.g. reduced meat consumption), and building materials (e.g. increasing demand for timber as a building material). Given that we combined estimates from multiple studies and sources, there are a range of methodologies reflected that may not be directly comparable or additive. We therefore produced separate estimates for the supply side and the demand side, while aggregated categories were designed to avoid the potential double-counting of mitigation opportunities.

Our bottom-up analysis of mitigation potential results in an estimate of potential emission reductions of 9.64 to 25.15 Gt CO_2e a year from the supply side, i.e. reducing land-use conversion and agriculture emissions, and increasing natural carbon sinks (Figure 2). Increased A/R and reduced deforestation are the activities that provide the largest mitigation potential at 2.7 to 16.8 Gt CO_2e a year combined. Harnessing the mitigation potential from land-use change (includes forests, peatlands, and degradation) and carbon removals from A/R, agroforestry, forest management, and wetland restoration alone could make the land sector carbon negative by approximately 6 Gt CO_2e a year (higher-end estimate) based on current emissions, if the entire technical mitigation potential were realized. However, this potential considers neither costs nor socio-political realities, and the A/R feasibility will largely depend on locating suitable and available land that does not result in food insecurity. In agriculture, the largest potential for GHG reductions comes from the improved management of croplands and pastures (0.3 to 1.5 Gt CO_2e a year) and the reduction of methane emissions from enteric fermentation (0.94 to 1.03 Gt CO_2e a year). Considering cost and feasibility, 1 Gt CO_2e a year of total agricultural mitigation (non-CO_2 emissions) seems possible.[24]

On the demand side, we estimate 2.85 to 10.8 Gt CO_2e a year of mitigation potential from reducing food loss and waste, shifting diets, and increasing demand for wood products. Shifting to healthier diets and reducing food waste provide significant mitigation at approximately 2.15 to 5.8 Gt CO_2e a year and 0.38 to 4.5 Gt CO_2e a year, respectively. Additionally, demand-side interventions generally provide co-benefits, as they reduce competition for and pressure on

22 The mitigation potential was assessed by synthesizing published literature and data and updating the IPCC-AR5 list with newer data and additional categories, based on Roe et al. (forthcoming).

23 We synthesized published literature and data and updated the IPCC-AR5 list with newer data and additional categories.

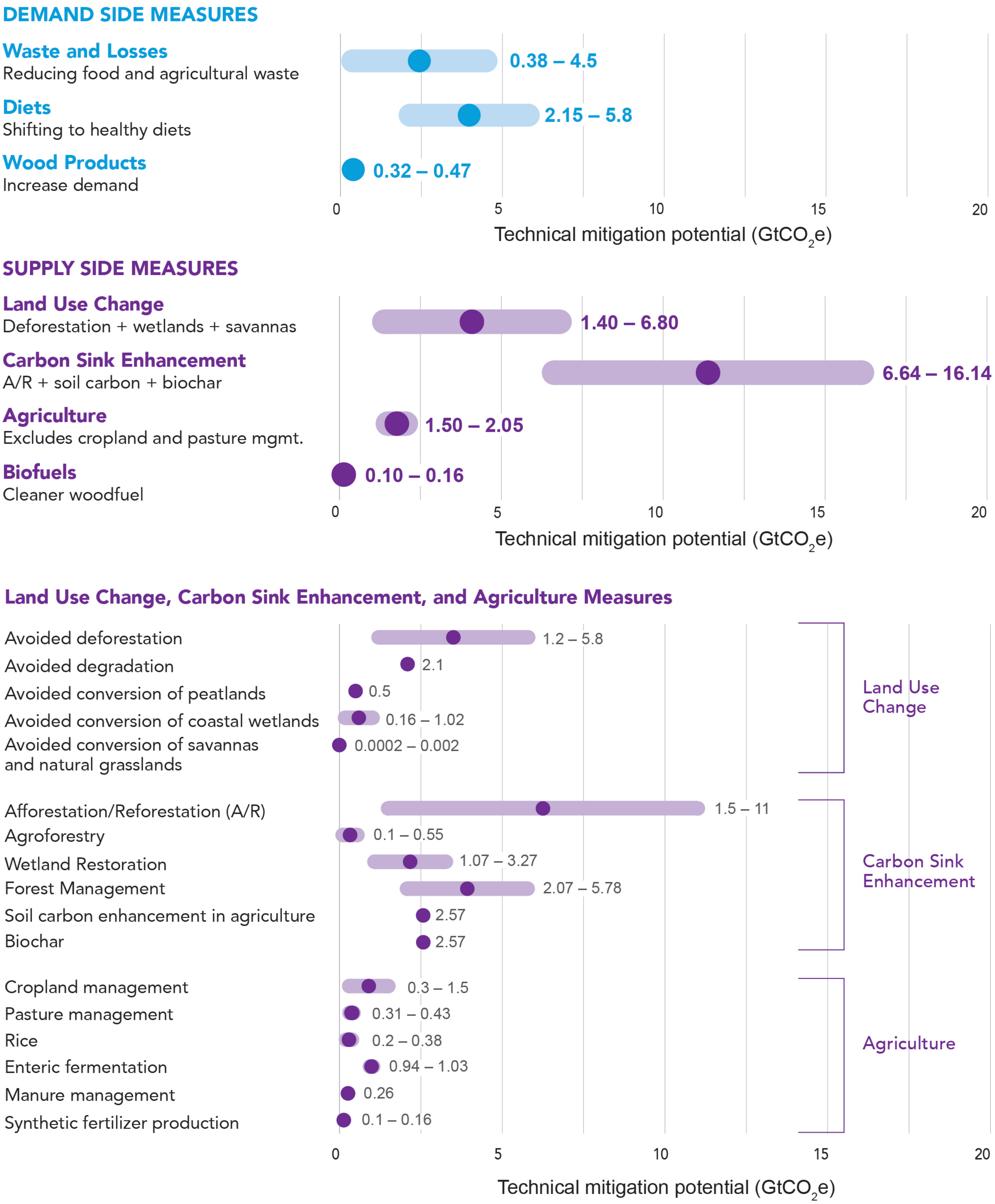
24 Wollenberg et al., 2016.

land, water, and other inputs in contrast to most supply-side measures that require more land and/or inputs.[25]

The top 40 countries with the highest technical mitigation potential represent 91 percent of deforestation emissions, 83 percent of livestock emissions, and 84 percent of cropland emissions.[26] Looking at countries with the currently highest land emissions and trends (cropland, livestock, deforestation, restoration commitments, food waste and loss, and beef consumption) allows us to identify priority regions and countries for mitigation. The 40 countries with the highest combined land sector emissions (crops, livestock and deforestation) are illustrated in Figure 3, with Brazil, China, the EU India, Indonesia, and the US emitting the most.

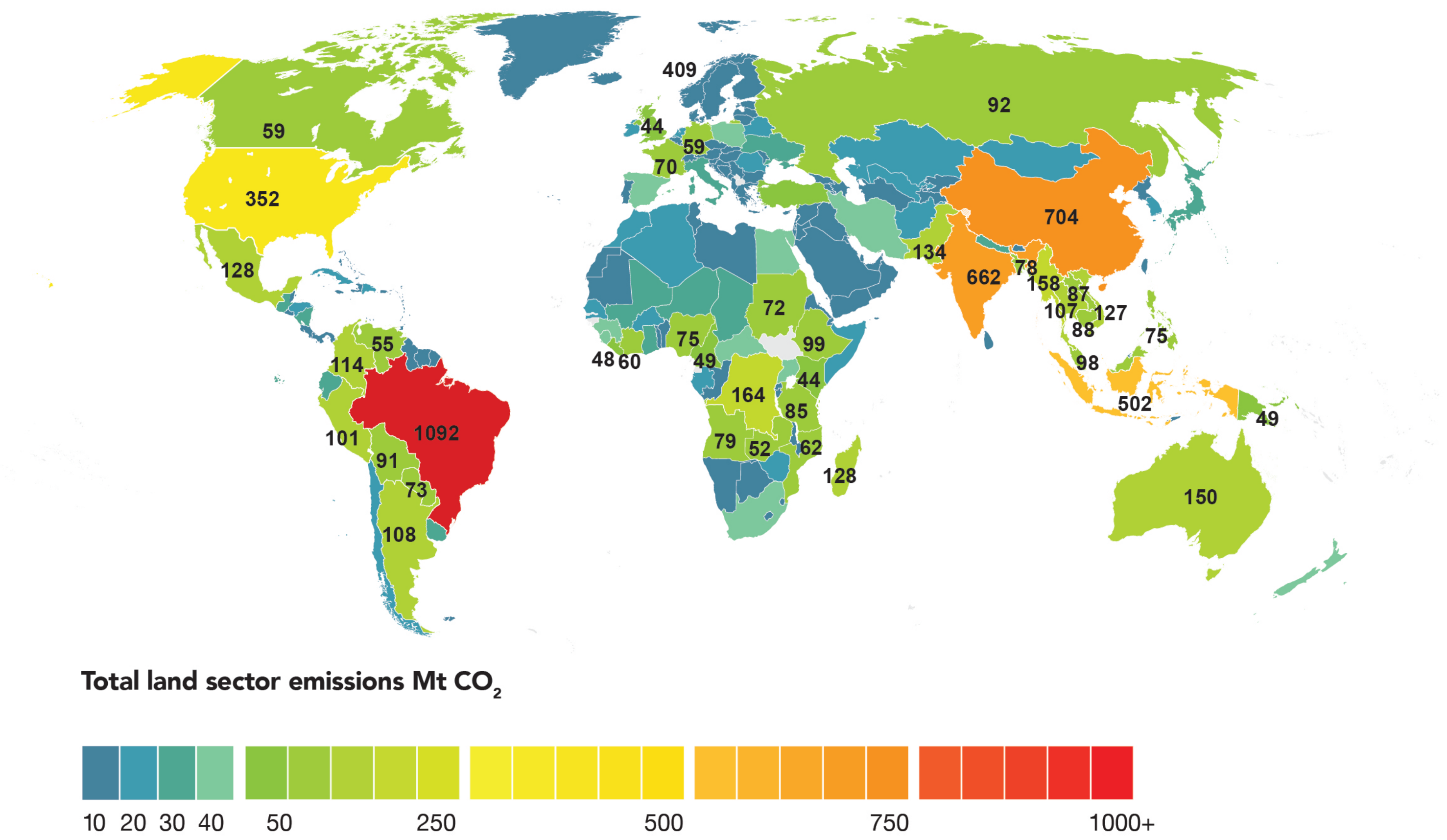
25 Smith et al., 2014.
26 Includes the EU as a region.

Figure 2: Technical mitigation potential by activity type, measured in Gt CO_2e a year based on a range of low to high estimates The synthesized data from literature represent a range of methodologies which may not consider plausibility or be directly comparable or additive with other estimates. The calculation of aggregate mitigation potentials are noted in the table.



Sources: Anderson et al., 2015; Bailis et al., 2015; Bajzelj, 2014; Bernoux & Paustian, 2015; Busch et al., 2016; Carter et al., 2015; Climate Action Reserve 2014; Crooks et al., 2011; Dickie et al., 2014; FAO, 2016; Hawken, 2017; Henderson et al., 2015; Herrero et al., 2015; Herrero et al., 2016; Hooijer et al., 2010; Houghton, 2013; Hristov et al., 2013; Joosten & Couwenber, 2009; Kindermann et al., 2008; Lenton, 2014; Nabuurs et al., 2007; Paustian et al., 2016; Pearson et al., 2017; Pendleton et al., 2012; Smith & Bustamante 2014; Smith et al., 2015; Smith, 2016; Sohngen, 2009; Stehfest et al., 2009; Tilman et al., 2014; Woolf et al., 2010; Zarin et al., 2016; Zhang et al., 2013; Zomer et al., 2016.

Figure 3: Land sector (croplands, livestock, and deforestation) emissions by region Emissions increase from blue to red and are measured in Mt CO_2e a year. Top emitting EU countries as well as the EU region are listed separately. The agriculture and livestock emissions represent the five-year average between 2010 and 2014 from FAOSTAT, and the deforestation emissions represent the five-year average between 2011 and 2015 from Global Forest Watch Climate. Source: Climate Focus analysis based on FAOSTAT 2015 and GFW 2016.



AFRICA	
DRC	164
Madagascar	128
Ethiopia	99
Tanzania	85
Angola	79
Nigeria	75
Sudan	72
Mozambique	62
Côte d'Ivoire	60
Zambia	52
Cameroon	49
Liberia	48
Kenya	44

ASIA	
China	704
India	662
Indonesia	502
Myanmar	158
Pakistan	134
Vietnam	127
Thailand	107
Malaysia	98
Laos	88
Cambodia	87
Bangladesh	78
Philippines	75
Papua New Guinea	49

LATIN AMERICA	
Brazil	1092
Mexico	128
Colombia	114
Argentina	108
Peru	101
Bolivia	91
Paraguay	73
Venezuela	55

OTHER COUNTRIES	
EU	409
US	352
Australia	150
Russia	92
France	70
Canada	59
Germany	59
UK	44

4. Feasibility of Mitigation Action

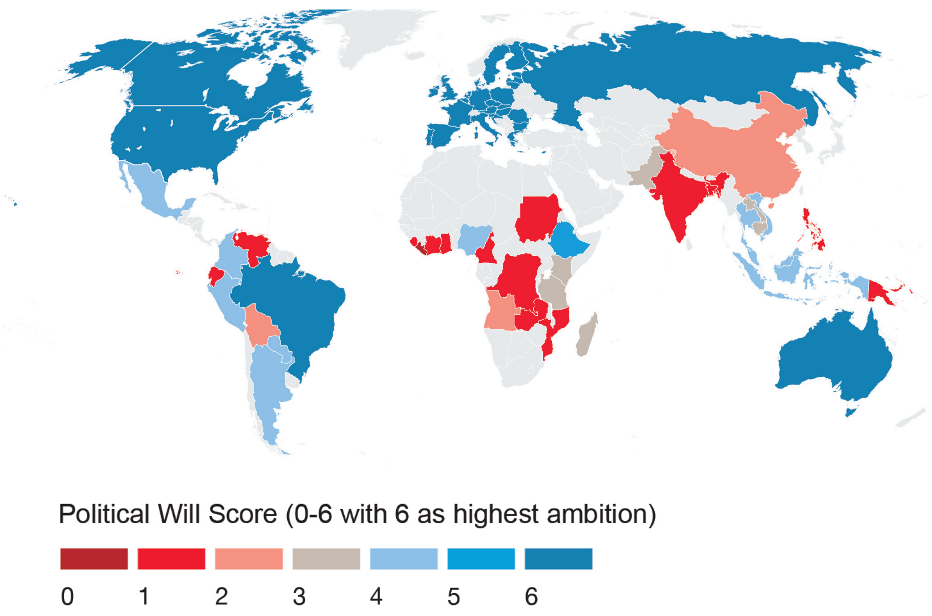
The 1.5°C goal in the land sector calls for a transformation of global landscapes, agricultural systems, and diets. Realizing that transformation will require both political consensus and support to strengthen the capacity of countries to implement the required measures. To gauge the likelihood of successful mitigation action in key countries, we assessed the following criteria for the top emitting countries with the highest mitigation emissions and potential:

- The **political will** to realize this potential;
- The **ability** to implement mitigation policies.

Political Will

As a proxy for political commitment, we analyzed the land-sector goals that countries included in the NDCs (Figure 4). We assessed the NDCs of the 40 countries to determine their political ambition to mitigating their greenhouse gas emissions. Countries that communicated domestic, economy-wide, and absolute emissions limitation and reduction targets demonstrated the highest level of political will in our analysis. Following this group are countries with relative targets that are measured against business-as-usual scenarios and include the land sector. The next set of countries with at least some demonstrable level of political commitment listed mitigation actions that involve the land sector. The score of ambition was reduced downwards if the (full) land-use commitment was conditional upon receiving international finance.

Figure 4: Political will of the top 40 emitting countries[27] While the US scores high due a quantifiable economy-wide emissions target, its political will has been put into question by the administration's decision to withdraw from the Paris Agreement.



27 Countries that specified economy-wide targets quantifiable in terms of emissions reductions (ERs) received an initial score of 6; those that did not designate total ERs but land-use targets received a score of 4; and countries that did not enumerate quantifiable ERs but instead mentioned activities, policies, or measures for land use earned a score of 2. Countries that received an initial score of either 4 or 6 had their value reduced by 2 points if their targets were either intensity-based or relative to a Business as Usual scenario. All countries whose action was at least in part conditional on international finance had their scores reduced by 1 point. Thus, the total range of final scores was 0–6.

All of the countries identified as priorities for mitigation action have submitted their NDCs, although the US' intention to exit the Paris Agreement also means the withdrawal of its NDC.[28] Brazil, Canada, the EU, Russia, and the US have committed to economy-wide, absolute, and unconditional emissions reduction targets. Brazil is the only developing country that has set an absolute and unconditional mitigation target. Other large developing countries, such as China, Colombia, India, Peru, and Vietnam, have adopted relative economy-wide targets.

Ability to Implement

The ability to implement measures depends on a country's resources, institutional capacity, and governance. For our purposes, we deem the ability of a government to implement policies to be positively correlated with (i) government capacities; and (ii) access to finance. These two indicators help us to assess whether political will can translate into political action.

Countries with high institutional capacity, existing infrastructure, and relevant policies have been shown to deploy climate change mitigation activities more effectively.[29] We assume that the ability to implement mitigation activities correlates with good governance, expressed by high rankings in World Bank governance indicators (Figure 5). Some countries' low governance scores leave doubt for successful fulfillment of their commitments. The top-ranking 25 percent of countries include Australia, France, Germany, Malaysia, the UK, and the US, while the DRC, Liberia, Madagascar, and Myanmar by contrast performed poorly in terms of government effectiveness.

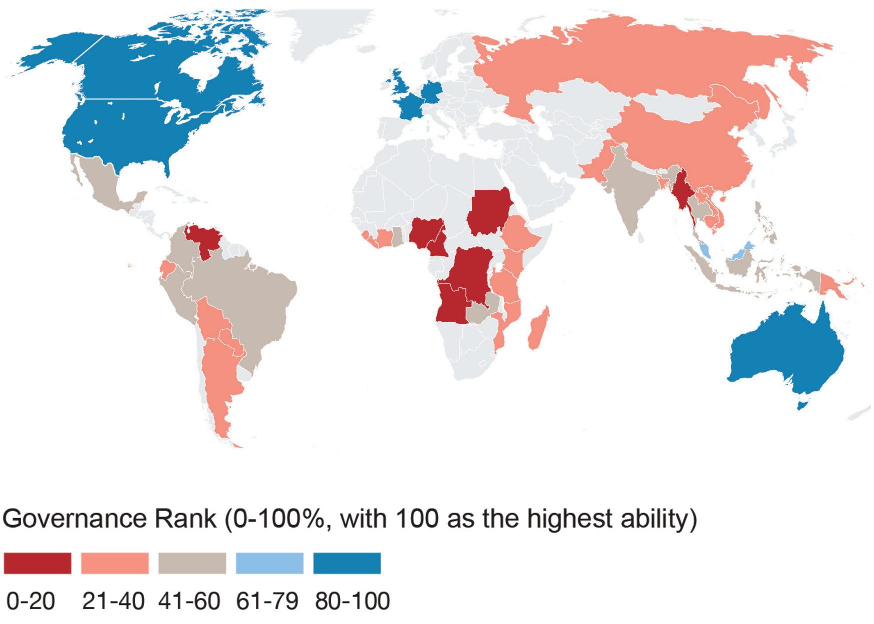


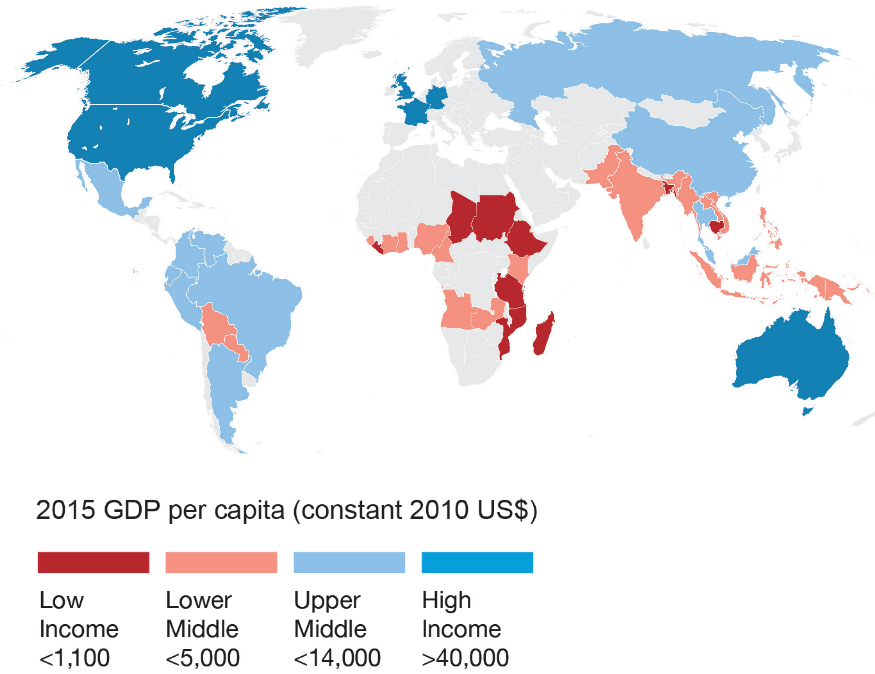
Figure 5: 2014 Percentile Rank (0–100%) of governance indicators for the top 40 emitting countries
Source: Climate Focus analysis based on World Bank, 2017 (data from 2014)

28 On August 4, 2017, the US administration submitted a communication to the United Nations announcing to withdraw from the Paris Climate Change Agreement as soon as it is possible to do so. US Department of State, 2017.

29 Forest Investment Programme, 2014.

The ability of a country to achieve emission reductions depends in part on its ability to mobilize adequate finance. Per capita incomes and the quality of governance are strongly positively correlated across countries.[30] Gross Domestic Product (GDP) per capita can serve as a rough proxy for the ability of a country to mobilize finance. Among the countries identified as priorities for mitigation actions, GDP per capita differs significantly (Figure 6).

Figure 6: GDP per capita for the top 40 emitting countries in USD
Source: Climate Focus analysis based on World Bank, 2017 (data from 2014)



"No excuses" versus "Dependent on Assistance"

Considering the technical mitigation potential as well as feasibility of action, countries can be grouped according to their impact, ability to act, and need for support and assistance.

High-income countries with large mitigation gains that have "no excuses" to delay action: Australia, Canada the EU, and the US

Developed countries with large mitigation potential, high governance indicators, and access to finance must step up their action and reduce land sector emissions as quickly as possible. Main areas of action include diet shifts, reduced food waste, restoration and A/R, reduced enteric fermentation, and improved crop-land management, fertilizer use, and production.

Upper-middle-income countries that have high mitigation potential and are essential for a 1.5°C pathway: Brazil and China

Brazil and China make up approximately 25 percent of global land-sector emissions (agriculture, livestock, and deforestation), and in their NDCs have manifested strong political will in favor of climate action. However, both countries face governance-related challenges and important intertwined socio-economic interests. Brazil is a leading exporter of agricultural commodities (e.g. soy and beef) while China is concerned about long-term food security.

30 Kaufmann & Kraay, 2002.

Lower-middle-income countries that have high mitigation potential and are vital for achieving a 1.5°C pathway: India and Indonesia

India and Indonesia have the third and fourth highest land-sector emissions after Brazil and China, yet formulate less ambitious climate goals and face significant barriers to implementation. Land-sector mitigation in both countries is essential for achieving the Paris Agreement. Indonesia will have to reduce deforestation and peatland emissions while India will have to reduce emissions from its cattle herds and rice fields. Considering their governance and development challenges, both countries require international support to achieve these goals.

Other upper-middle-income countries that have important mitigation potential: Argentina, Colombia, Malaysia, Mexico, Paraguay, Peru, Russia, and Thailand

Upper-middle-income countries from Latin America and Asia, as well as Russia have significant mitigation potential, and many of them are committed to action. They should be able to follow through on their ambition, in some cases with financial assistance, and in other cases with some civil society pressure.

Low-income and high-potential countries that require high levels of assistance: Bolivia, Cambodia, the Democratic Republic of Congo, Laos, Madagascar, and Myanmar

Bolivia, Cambodia, DRC, Laos, Madagascar, and Myanmar are important countries for international climate goals but unlikely to live up their potential without significant financial, technical, and capacity assistance. All listed countries have some confirmed commitment to climate action but lack the ability to follow through independently.

Regional programs for lower-middle-income countries in Asia and West Africa

Regional assistance programs could help groups of countries to implement interventions that combine adaptation and mitigation goals. In Sub-Saharan Africa, where smallholders are particularly vulnerable to the impacts of climate change, long-term investment in soil fertility (and soil organic carbon) is critical for food security and climate mitigation alike. In Asia, where around 90 percent of rice is grown, regional programs are needed that support improved agricultural rice practices, including land preparation, seedling practice, fertilizer application and water management. These offer significant GHG mitigation potential.

5. Roadmap Towards the 1.5°C Climate Goal

Drawing on our technical and feasibility assessments, we propose an emissions reductions roadmap for the land sector. We have developed a carbon budget based on our modeled timeline of peaking emissions by 2020, reducing emissions by approximately 85 percent by 2050, and achieving net negative emissions thereafter; we then propose priority interventions for 2017–50 according to their mitigation potential and feasibility of implementation. The proposed carbon budget and pathway translates to a contribution of the land sector to about 25 percent of global CO_2e emissions reductions needed by 2050 to limit warming to 1.5°C. This pathway is only for the land sector, and is therefore contingent on similarly ambitious emissions reductions trajectories from other sectors (e.g. energy, industry, transport) to deliver on the Paris Agreement.

Land-based mitigation activities interact strongly with each other. They also have an impact on delivery of ecosystem services and biophysical conditions (e.g. land competition, radiative cooling/warming, albedo, crop yields, livelihoods, pollution, water-use and provision, and biodiversity). We considered the various risks and tradeoffs and aimed to maximize co-benefits and no-regret measures when selecting interventions. Furthermore, we sought to avoid reliance on undeveloped negative emissions technologies, and instead focused on earlier and deeper emissions reductions to increase the likelihood of limiting warming to 1.5°C or 2°C.

Priority Measures to 2020

Using the outlined carbon budget and emissions pathway, we propose the following roadmap of priority measures to 2050.

1 **Reduce deforestation and degradation, including conversion of mangroves,** in Latin America—in particular Bolivia, Brazil, Colombia, Paraguay, and Peru—by 25 percent by 2020 [~265 Mt CO_2 per year], 50 percent by 2025 [~265 Mt CO_2 per year], 70 percent by 2030 [~215 Mt CO_2 per year], 80 percent by 2040 [~105 Mt CO_2 per year], and 95 percent by 2050 [~160 Mt CO_2 per year], in Southeast Asia—in particular—Cambodia, Indonesia, Laos, Malaysia, Myanmar, and Vietnam—by 40 percent by 2030 [~335 Mt CO_2 per year], 80 percent by 2040 [~335 Mt CO_2 per year], 90 percent by 2050 [~85 Mt CO_2 per year], and in Africa—in particular Angola, Côte d'Ivoire, the DRC, Liberia, Madagascar, and Mozambique—by 20 percent by 2030 [~150 Mt CO_2 per year], 50 percent by 2040 [~225 Mt CO_2 per year], and 85 percent by 2050 [~260 Mt CO_2 per year].

2 **Prioritize restoration of forests** in upper- and middle-income countries with large historic and current forest areas—particularly Australia, Brazil, Canada, China, Colombia, India, Mexico, Peru, Russia, Southeast Asia, and the US—between 2020 and 2030 [~1500 Mt CO_2 per year] and in less developed countries—such as the DRC Guatemala, Honduras, Madagascar, and Malawi—between 2030 and 2050 [~500 Mt CO_2 per year].

3 **Improve forest management, including the sustainable management of agroforestry and plantation forests** in developed, forested countries—particularly Australia, Canada, the EU, and the US—by 2020 [250 Mt CO_2 per year], in upper-middle and middle-income countries—particularly Brazil, China, Colombia, Peru, Russia—and by 2025 [450 Mt CO_2 per year]; in middle- and lower-income countries—including India, Indonesia, and Sub-Saharan Africa—by 2030 [200 Mt CO_2 per year].

4 **Halt peatland burning and restore degraded and drained peatlands** in Indonesia and Malaysia by 2020 [~320 Mt CO_2e per year] and by 2030 [~400 Mt CO_2e per year].

5 **Shift to healthy diets (reduced meat, especially beef, consumption)** in China by 2020, in Australia, Canada, the EU and the US by 2025 and in Latin America—particularly Argentina, Brazil, Colombia, and Mexico—and Russia by 2030 [estimate of ~300 Mt CO_2e by 2030 and ~500 Mt CO_2e by 2050].

6 **Reduce food waste and food losses** in upper- and middle-income countries—particularly China, the EU, and the US—by 2025, in Latin America, Southeast Asia, and Sub-Saharan Africa after 2030 [estimate of ~200 Mt CO_2e by 2030 and 1000 Mt CO_2e per year by 2050].

7 **Increase soil and pasture carbon sequestration** in areas with high carbon losses—particularly Australia, China, the EU, India, Latin America, Sub-Saharan Africa, and the US. [200 Mt CO_2 per year by 2030 and 600 Mt CO_2 per year by 2050].

8 **Improve synthetic fertilizer production and efficiency**—particularly in Canada, China, the EU, India, Pakistan and the US—reducing emissions by 2030 [180 Mt CO_2e per year] and 2050 [200 Mt CO_2e per year].

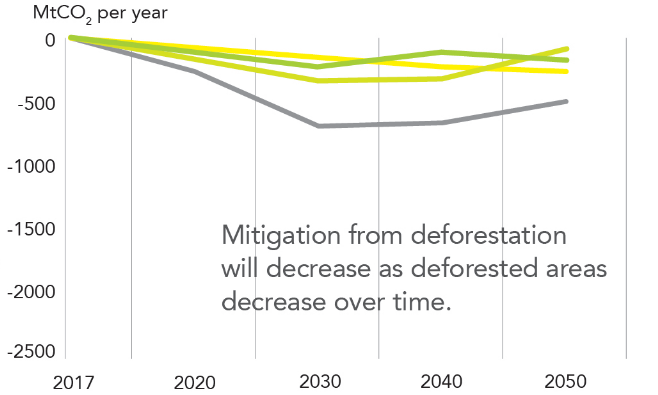
9 **Reduce emissions from rice paddies**—particularly in Bangladesh, China, India, Indonesia, Myanmar, Philippines, Thailand, and Vietnam—by 30 percent by 2030 [90 Mt CO_2e per year] and 70 percent by 2050 [205 Mt CO_2e per year].

10 **Reduce emissions from livestock (enteric fermentation and manure)** —particularly in Brazil, China, the EU, India, and the US—by 20 percent by 2040 [120 Mt CO_2e per year] and 30 percent by 2050 [180 Mt CO_2e per year].

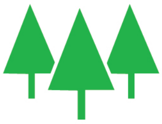
Overview of Action for Priority Countries

REDUCE DEFORESTATION AND DEGRADATION, incl. conversion of mangroves

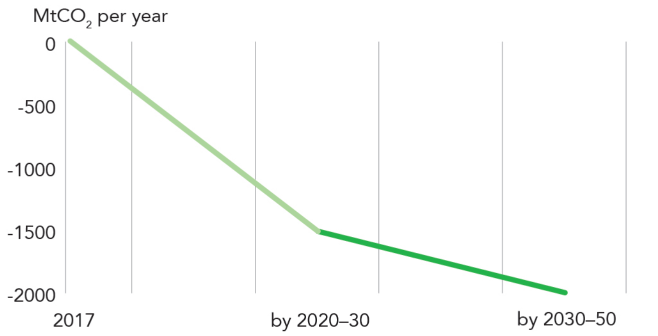
- **Latin America** (Bolivia, Brazil, Colombia, Paraguay, Peru)
- **Southeast Asia** (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Vietnam)
- **Africa** (Angola, Cote d'Ivoire, DRC, Liberia, Madagascar, Mozambique)
- **Total**



RESTORATION OF FORESTS

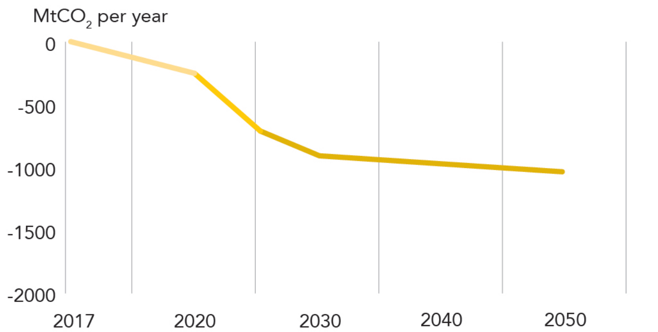


- **upper- and middle-income countries** (Austalia, Brazil, Canada, China, Colombia, India, Mexico, Peru, Russia, Southeast Asia, US)
- **less developed countries** (DRC, Guatemala, Honduras, Madagascar, Malawi)



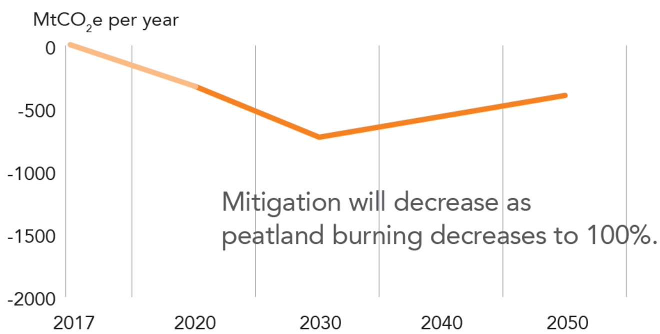
FOREST MANAGEMENT incl. sustainable mgmt. of agroforestry and plantation forests

- **developed countries** (Australia, Canada, EU, US)
- **upper-middle- and middle-income countries** (Brazil, China, Colombia, Peru, Russia)
- **middle- and lower-income countries** (India, Indonesia, Sub-Saharan Africa)



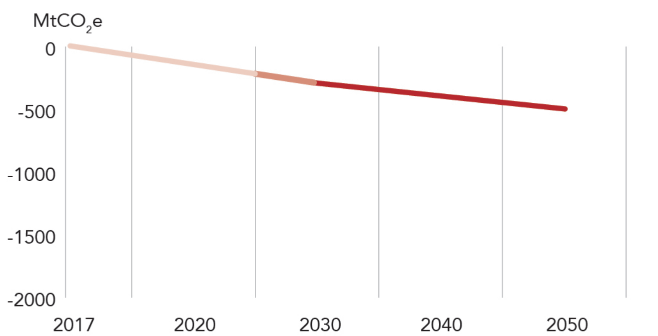
HALT PEATLAND BURNING and restore degraded and drained peatlands

- **halt peatland burning** (Indonesia, Malaysia)
- **restore degraded and drained peatlands**



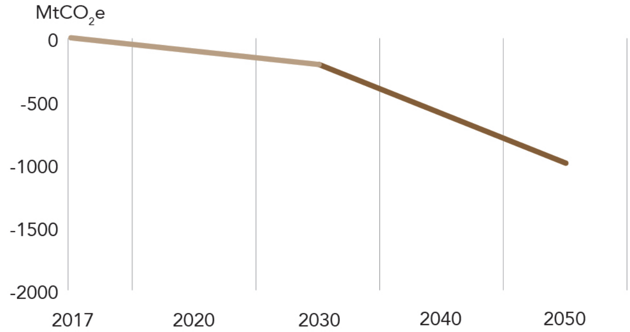
SHIFT TO HEALTHY DIETS (reduced meat, esp. beef, consumption)

- **China**
- **Australia, Canada, EU, US**
- **Latin America** (Argentina, Brazil, Colombia, Mexico) **and Russia**



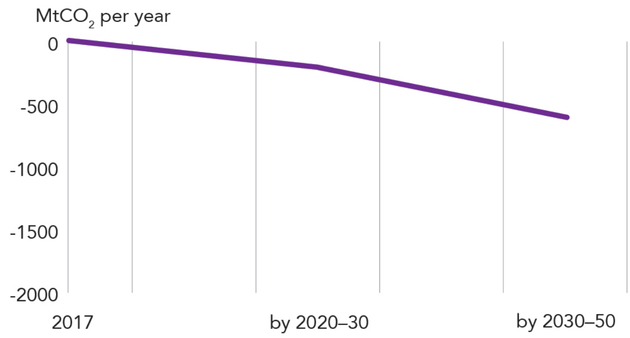
REDUCE FOOD WASTE and food losses

- upper- and middle-income countries (China, EU, US)
- Southeast Asia and Sub-Saharan Africa

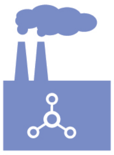


INCREASE CARBON SEQUESTRATION (soil and pasture)

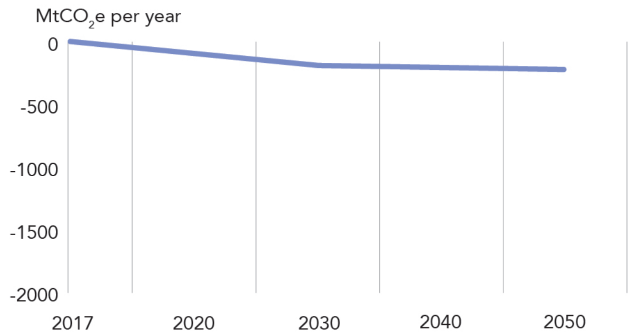
- Australia, China, EU, India, Latin America, Sub-Saharan Africa, US



IMPROVE SYNTHETIC FERTILIZER PRODUCTION and efficiency

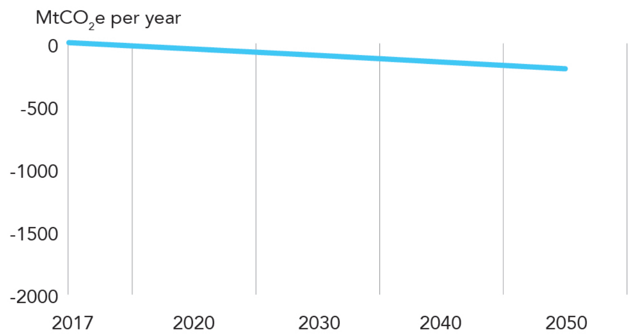


- Canada, China, EU, India, Pakistan, US

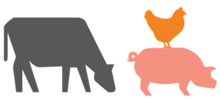


REDUCE EMISSIONS FROM RICE PADDIES

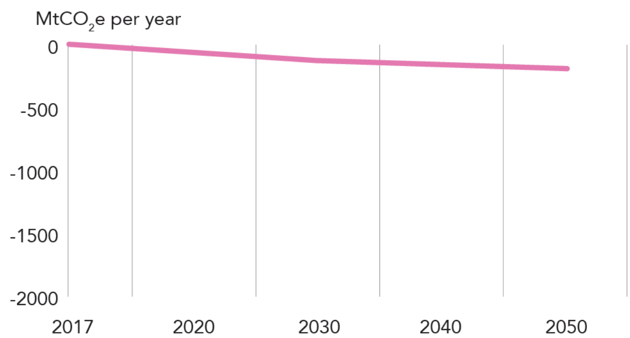
- Bangladesh, China, India, Indonesia, Myanmar, Philippines, Thailand, Vietnam



REDUCE EMISSIONS FROM LIVESTOCK (enteric fermentation and manure)



- Brazil, China, EU, India, US



1. Reduce deforestation and degradation, including the conversion of mangroves…

Reducing deforestation and forest degradation has the potential to mitigate 2.15 to 5 Gt CO_2 a year, with the higher estimate representing a complete end to deforestation.[31] Agriculture, primarily via commodity-driven agribusiness, drives 50–80 percent of tropical deforestation, whereas illegal logging drives the majority of degradation.[32] Forests and wetlands can be spared and conserved through direct activities (e.g., land planning, protected areas, law enforcement, and supply-chain interventions), and indirect activities (e.g., agricultural intensification to increase yields and reduce conversion pressure, consumer pressure to remove deforestation from commodity-supply chains, reducing food waste to increase yields, and shifting diets to reduce demand for commodities that cause deforestation). Reducing deforestation has significant co-benefits from forest conservation: biodiversity, radiative cooling from increased evapotranspiration, and water and air purification. Despite global pledges and efforts to reduce deforestation over the last decade, the global annual rate of gross tree cover loss rose by an average of 35 percent between 2014 and 2016 compared to a 2001–13 baseline period.[33] Associated carbon emissions are also on the rise; more than one-quarter (26.3 percent) of all tree cover loss globally in the year 2016 occurred in Brazil and Indonesia alone.[34] Average annual emissions from tropical deforestation over the years 2014–16 were 25 percent higher than over the historical average benchmark period (2001–13).[35] Action to combat tropical deforestation is as urgent as ever.

…in Latin America—in particular Bolivia, Brazil, Colombia, Paraguay, and Peru—by 25 percent by 2020, 50 percent by 2025, 70 percent by 2030, 80 percent by 2040, and 95 percent by 2050…

Latin America is home to about half of the world's remaining tropical forests, and it also has some of the highest deforestation rates in the world.[36] Brazil achieved steep reductions in deforestation between 2005–15, but official government data indicate that deforestation rates in the Amazon were 29 percent higher in 2016 than in the previous year.[37] The main drivers of deforestation and degradation in Latin America—the production of soy and beef and illegal logging —need to be addressed. Achieving moderate efficiency gains in pasture-based beef production could reduce cattle-driven deforestation by sparing around 58 million of hectares of land by 2030, an area larger than France, if adequate governance mechanisms prevented increases in productivity from leading to more expansion.[38] Cutting deforestation by 50 percent by 2025 and by 95 percent by 2050 compared to current levels would correspond to a reduction of 265 million tons of CO_2 a year (Mt CO_2 a year) and 160 Mt CO_2 a year,

31 Harris et al., 2012; Hansen et al., 2013; Federici et al. 2015; Smith et al., 2014; Zarin et al., 2016; Pearson et al., 2017.
32 Henders et al., 2015; De Sy et al., 2015.
33 Climate Focus, 2017.
34 Climate Focus, 2017.
35 Ibid.
36 Hansen et al., 2013; Federici et al. 2015.
37 Estimate of the Brazilian Space Agency (INPE), http://www.inpe.br/noticias/noticia.php?Cod_Noticia=4344.
38 Assuming a baseline with stable productivity, and that a doubling of productivity is achieved on half of the pasture area by 2030. Source: Climate Focus calculations based on Federation of Industries of the State of São Paulo, 2016.

respectively. Such emissions reductions amount to a cumulative savings of over 25 million hectares of tropical rainforests saved in Latin America.

…in Southeast Asia—in particular in Cambodia, Indonesia, Laos, Malaysia, Myanmar, and Vietnam—by 40 percent by 2030, 80 percent by 2040, 90 percent by 2050, and…

Southeast Asian countries have among the highest rates of deforestation in the world, especially between 2010 and 2014, and are linked to palm oil, timber, and rubber.[39] In Indonesia, despite the 2011 moratorium on new concessions in primary forests and peatlands, 537,294 ha of tree cover and 928,765 ha were lost in 2013 and 2014, respectively.[40] Deforestation has continued in the region despite efforts to reduce the illegal trade of timber with China (i.e. from P.R. Laos). As a result, illegal logging has shifted to other countries in the Mekong basin.[41]

Driving a wedge between the commodities that support the economies of the region and the deforestation they produce is vital to protecting the natural resources that will help realize the Paris Agreements goals. The political will to protect forests is present, but as the evidence has shown, converting that will into positive results on the ground has proven difficult.[42] However, protecting the tropical forests of Southeast Asia remains a global priority. Preventing deforestation in Southeast Asia due to palm oil cultivation alone would help protect nearly 300 thousand hectares of forests, mangroves, and peatlands lost every year.[43] In Southeast Asia, reducing land conversion by 40 percent by 2030 and 80 percent by 2040 compared to current levels would reduce emissions by 335 Mt CO_2 a year and 85 Mt CO_2 a year, respectively. This would protect more than 35 million hectares of forests in Southeast Asia with high biodiversity value.

…in Africa—in particular Angola, Côte d'Ivoire, the DRC, Liberia, Madagascar, and Mozambique—by 20 percent by 2030, 50 percent by 2040, and 85 percent by 2050

Due to a rapid expansion in commercial agriculture (palm oil, sugar, and cocoa), deforestation rates in West Africa have increased sharply over the last decade and particularly over the last five years.[44] Two-thirds of the world's cocoa is grown in Africa, with the majority produced by Côte d'Ivoire and Ghana. West Africa lost 2.3 million hectares of forest to cocoa cultivation between 1988 and 2007, and deforestation continues across an ever-diminishing area of forest in the region.[45] Sustainable intensification paired with the protection of remaining forests, harmonizing and securing of land-titles, land planning, and enforcement of laws are all essential strategies to halt deforestation in West Africa. Considering existing governance challenges, we anticipate that halting deforestation in Africa will require more assistance and time. We consider a 20 percent decrease by 2030 and an 85 percent decrease of deforestation rates by 2050 feasible. This would save 150 Mt CO_2 a year by 2030 and 260 Mt CO_2 a year by 2050. It would also translate to over 30 million hectares of forests saved.

39 Climate Focus, 2016.
40 Global Forest Watch, 2017.
41 Forest Trends, 2017.
42 Climate Focus, 2016.
43 Henders et al., 2015.
44 Ordway et al., 2017.
45 Gockowski and Sonwa, 2010; Tropical Forest Alliance 2020, 2017.

2. Prioritize restoration of forests…

Forest restoration entails the enhancement of natural carbon sinks, an essential climate change strategy. As well as promoting negative emissions, its benefits include protection of biodiversity, an increase in agricultural productivity, and an improvement in climate resilience. These benefits may accrue from interventions including afforestation, reforestation, or planting more trees on farms. Afforestation, the conversion of non-forested land into forests, and reforestation, restoring and replanting deforested or degraded forests, have a large technical mitigation potential of 1.5–11 Gt CO_2 a year. Agroforestry is a land-management system that combines above-ground biomass (e.g., trees or shrubs) with crops and/or livestock, and can include fruit or timber trees for harvest, windbreaks, riparian buffers, and silvopasture. Some measures depend on land suitability and availability, and may increase pressure on natural (biodiversity) and agricultural systems (food provision), as well as water and nutrient resources. If done on a large scale, these land-use changes may also change cloud cover, albedo, and water availability, which could feed back into the climate. Further, permanence and leakage effects may reduce the future effectiveness of these measures.

Countries and private entities have committed under the New York Declaration of Forests to restore 350 million hectares of forests by 2030, adding another 200 million hectares to the 2020 Bonn Challenge goal.[46] In 2017, Bonn Challenge pledges add up to 156 million hectares, equal to 45 percent of the 2030 goal. Of this total, 94 million hectares are pledged for 2020 and 62 million hectares for 2030.[47] The majority of countries' NDCs also included restoration (122 of 165). Nonetheless, only 20 percent include quantifiable targets which, if pledged to the Bonn Challenge, would equal 12 percent of the total 350-million-hectare goal.[48] Some NDC targets might overlap with Bonn Challenge commitments. In sum, while many countries have made forest restoration commitments for 2020 and 2030, implementation needs to be supported and accelerated.

…in upper- and middle-income countries with large historic and current forest areas—particularly Australia, Brazil, Canada, China, Colombia, India, Mexico, Peru, Russia, Southeast Asia, and the US—between 2020 and 2030…

Restoration priority countries have large biophysical opportunities both in terms of the carbon density of restored forests and the area suitable for restoration. In Latin America, this includes restoration in Brazil, Colombia, Mexico, and Peru. For Brazil and Mexico alone, the World Resources Institute and IUCN suggest a restoration opportunity that exceeds 400 million hectares.[49] Forests in these countries could be replanted and more trees brought onto active farms and pasturelands. Another priority region is Southeast Asia, where countries like Indonesia have estimated opportunities over 60 million hectares. The main restoration activities to be considered in Latin America and Asia are reforestation and agroforestry due to the large areas deforested

46 Bonn Challenge, 2017.
47 Climate Focus, 2017.
48 Climate Focus, 2017. Only quantifiable commitments expressed in hectares have been considered for estimating this figure, summing 42.5 million hectares. Quantifiable commitments represent 3.39 Gt CO_2e.
49 WRI & IUCN, 2014.

and degraded for agriculture. Restoration of forests in the Americas and Asia is equivalent to removing approximately an EU's worth of emissions from electricity generation.[50] Furthermore, in China and India restoration opportunities are estimated at over 550 million hectares, and India has already pledged to restore 21 million hectares. In developed countries like Australia, Canada, Russia, and the US, there is ample opportunity for forest restoration through reforestation and natural regeneration of historically and recently deforested areas. We anticipate that restoration efforts in the countries with the highest potential could sequester approximately 1.5 Gt CO_2 a year by 2030.

…and in less developed countries—such as the DRC, Guatemala, Honduras, Madagascar, and Malawi—between 2030 and 2050…

Another 500 Mt CO_2 a year of annual GHG emissions can be saved through restoration efforts in developing countries in Central America and Sub-Saharan Africa. These restoration efforts often have strong sustainable development and adaptation benefits as they open new sources of income and prevent soil degradation and erosion. Many of these less developed countries have committed to restore millions of hectares through reforestation and agroforestry that will help countries contend with the stresses brought on by widespread deforestation and degradation.

3. Improve forest management, including the sustainable management of agroforestry and plantation forests…

Forested lands, especially those managed for commercial purposes, cover around 264 million hectares of land and have the potential to absorb around 2 to 5.78 Gt CO_2 a year from the atmosphere.[51] Managed forests provide vital economic support for communities that depend on their products, and supply the world with important commodities (timber, paper, bioenergy) which will increase in importance in the context of climate change mitigation. Improving forest management includes extending rotation cycles between harvests, reducing damage to remaining trees when harvesting, reducing logging waste, implementing soil-conservation practices, fertilization, and using wood more efficiently.

…in developed, forested countries—particularly Australia, Canada, the EU, and the US—by 2020

Improved forest management practices in developed countries have to be prioritized, given the importance of the forestry industry to these economies and their governments' ability to implement policies. Large companies like Weyerhaeuser manage around 11 million hectares of forests in the US and Canada alone and have certified their entire timberland portfolio.[52] Given the concentration of the industry in many countries, just a few actors in these countries have the ability to realize the projected emissions reductions. While forest ownership is more dispersed in Europe and forest management a long-standing practice, management practices often fail to integrate climate concerns.

50 CAIT Climate Data Explorer, 2015.
51 FAO, 2010.
52 Weyerhaeuser, 2017.

Research shows that traditional forest-management methods have to be improved to yield climate benefits.[53]

...in upper-middle- and middle-income countries—particularly Brazil, China, Colombia, Peru, and Russia—by 2025

China has embarked on major campaigns over the past decade to plant large numbers of trees, both for climate purposes and to prevent desertification.[54] But the mixed results of these campaigns show that this will to act needs an infusion of better forestry science and management techniques to ensure healthy forest growth and high-carbon sequestration potential.[55] The Latin American countries in this group have already expressed a commitment to prevent future deforestation, and given that they produce large and growing quantities of tree crop products such as coffee and palm oil, agroforestry practices may contribute 2.2 million hectares of sustainably managed forest land.

...and in middle- and lower-income countries—including India, Indonesia, and Sub-Saharan Africa—by 2030

Properly managed forests in India and Sub-Saharan Africa could satisfy the need for wood products, especially fuels, while still providing a source for sequestering carbon emissions. Improved agroforestry practices in countries like Ghana and Côte d'Ivoire could turn the millions of hectares devoted to cocoa into substantial carbon sinks.[56] Community forest management provides another strategy that combines the benefits of local development, forest protection, and improved forest management.

4. Halt peatland burning by 2020...

Halting peatland burning would reduce emissions by approximately 320 Mt CO_2e a year, equivalent to more than twice the industrial emissions of the EU.[57] The emissions of Indonesia and Malaysia from land use and land-use change in 2005 alone amounted to the equivalent of burning around 70,000 hectares of peatland forests.[58] In these countries, agricultural production has been growing in the rubber and palm-oil sectors, which has caused large conversions of peatlands, with Indonesia and Malaysia identified as priority countries for mitigation action.

Indonesia has committed to mitigate 29 percent of GHG emissions by 2030 compared to its business-as-usual scenario.[59] But despite recent progress in an extended moratorium on primary forest and peatlands conversion, Indonesia has witnessed an increase in forest fires, which makes it urgent that it curbs deforestation and associated GHG emissions. Per its NDC, Malaysia intends to mitigate, economy-wide, 23 percent of GHGs compared to the base year 2005. Despite this commitment, Malaysia has seen continued growth in palm-oil plantations at the expense of peatlands and forests.

53 Naudts, et al., 2016.
54 Luoma, 2012.
55 Ibid.
56 Kroeger et al., 2017.
57 CAIT Climate Data Explorer, 2015.
58 Agus et al., 2011. Malaysia's NDC cited 2005 emissions due to LULUCF at 25,667,000 tonnes CO_2 equivalent, while Indonesia's cited 1,134,000,000 tonnes CO_2 equivalent.
59 Indonesia, 2015.

…and restore degraded and drained peatlands in Indonesia and Malaysia by 2030

In Southeast Asia, degraded and drained peatlands in Indonesia and Malaysia present a unique opportunity for restoration. Industrial plantations have expanded to cover 4.3 million hectares of peatlands in Indonesia and Malaysia between 2007 and 2015.[60] Restoring degraded peatlands would sequester carbon in the order of 400 Mt CO_2e a year by 2030, equivalent to the annual GHG emissions of Mexico.[61]

5. Shift to healthy diets (reduced meat, especially beef, consumption)…

A shift to healthy, plant-based diets has the potential to reduce these emissions by 2.15 to 5.8 Gt CO_2e a year, with the lower figure representing a healthy diet[62] and the higher figure representing a vegetarian diet.[63] Beef in particular is highly resource-intensive, with the highest GHG, water, land, and energy footprint of all proteins.[64] Reducing or stabilizing beef consumption to healthy levels in Brazil, China, and the US, would result in emission reductions of 472.3 Mt CO_2e a year, equivalent to taking 100 million cars off the road.[65] In addition to reduced emissions, a global dietary shift has environmental, health, and socio-economic co-benefits. A reduction in meat consumption would reduce water use, soil degradation, forest loss and water pollution. It would also reduce mortality rates from chronic diseases associated with the overconsumption of red meats and benefit healthcare systems by reducing associated costs by billions of dollars.[66] A global dietary shift would require both demand-side and supply-side interventions. In addition to policy interventions to reduce beef production and improve the availability of alternative proteins, demand-side measures that change drivers of food choices would be required.

…in China by 2020…

China's shift to a more Western and energy-dense diet is increasing emissions, demand for land, and health-sector costs. While average per capita beef consumption is well below the world average, China is the third largest beef consumer in absolute terms and is projected to steadily increase its beef consumption in the next few decades.[67] China is also projected to become the second largest beef importer in 2017, making it a key global beef trader.[68] Stabilization in per-capita beef consumption in China at today's levels would avoid a 23 percent increase in emissions from beef production.[69] In terms of emissions, avoiding an increase in beef consumption alone would put the country on a path to avoid 70 Mt CO_2e by 2030.[70]

60 Miettinen et al., 2016.
61 CAIT Climate Data Explorer. 2015.
62 Based on Harvard definition of a healthy diet of approximately 0.8g per kilo of body weight. Dickie et al., 2014.
63 Stehfest, 2009; Tilman and Clark, 2014; Bajzelj, 2014; Dickie et al., 2014; Hedenus et al., 2014; and Springmann et al., 2016.
64 Haupt et al., 2017.
65 Ibid.
66 Springmann et al., 2016.
67 USDA, 2017; OECD, 2017.
68 USDA, 2017.
69 Haupt et al., 2017.
70 Ibid.

...in Australia, Canada, the EU, and the US by 2025 ...

Australia, Canada, the EU, and the US have among the highest beef consumption rates in the world, with the US and the EU accounting for more than 25 percent of global consumption. For the US and Canada alone, a 33 percent reduction in per capita beef consumption from the substitution of other proteins would reduce agricultural land and GHG emissions by 15 percent from 1.4 to 1.2 tonnes per capita of CO_2e a year.[71] Given the combined population of these countries, that would be equivalent to preventing the annual GHG emissions of Turkey from entering the biosphere.[72] There is also emerging public awareness and concern over the health and environmental impacts of excessive meat consumption in the EU and the US. While efforts by civil society organizations to shift diets is increasing, decisive political action is still absent.

...and in Latin America—particularly Argentina, Brazil, Colombia, and Mexico—and Russia by 2030.

The potential contributions of these countries is significant given their high per-capita meat consumption.[73] Brazil is the largest country in this group in terms of population and has one of the highest beef consumption rates per capita in the world at around 25 kg per person per year.[74] Just reducing per-capita consumption by 25 percent, which would still be more than three times the current world average, would result in avoided emissions of nearly 100 million tons of CO_2e by 2030.

6. Reduce food waste and food losses

Approximately one-third of all food produced is lost or wasted in the value chain.[75] In developing countries, losses mainly occur post-harvest as a result of financial and technical limitations in production techniques, storage and transport.[76] In contrast, losses in the developed world are mostly incurred by end consumers. Globally, reduced food loss and waste has the potential to reduce 0.38 to 4.5 of $GtCO_2e$ a year, with the higher estimate representing a 50 percent decrease in food waste from projected baseline emissions in 2050.[77] Co-benefits of reducing food losses and waste include overall efficiency gains in food value chains and increased food security, reduced pressure on land, forests and water resources, decreased consumer costs, and improved food availability. Cutting current food-waste levels in half, it would decrease the 60 percent of food needed to meet 2050 demand down to 22 percent,[78] making the reduction of food waste a potentially leading strategy to achieve global food security. Interventions to reduce food loss and waste would vary across regions given the causes of food loss and waste. While in industrialized countries and regions, interventions at the food services, retail and consumer level including shifting consumption practices may be more impactful, in Sub-Saharan Africa, and South and Southeast Asian countries improved production, handling and storage practices are important to curb food loss. In Latin America, both improved

71 Ranganathan et al., 2016.
72 CAIT Climate Data Explorer, 2015.
73 FAO, 2015.
74 Climate Focus calculations based on OECD, 2017.
75 FAO, 2013.
76 Dickie et al., 2014.
77 Bajzelj, 2014; Dickie et al., 2014; Hawken, 2017.
78 Lipinski et al., 2013.

production practices and changes in consumption practices are necessary to reduce food loss and waste. We estimate an emission reduction potential of approximately 200 Mt CO_2e a year by 2030 and 1 Gt CO_2e a year by 2050.

…in upper- and middle-income countries—particularly China, the EU, and the US—by 2025…

As these regions have high levels of food waste and relatively higher feasibility of mitigation action, they are prioritized for early action. In China, USD 32 billion worth of food is thrown away by end-consumers every year, enough to feed 200 million people.[79] North American consumers waste approximately 1,500 calories per person per day, compared to about 750 in Europe. A 50 percent reduction in food waste in North America would equate to emissions savings of 1.7 Gt CO_2e a year through avoided agricultural emissions and emissions from land-use change.[80] In these regions, there is a growing public concern over food waste and government policies and programs to reduce food waste are already in place. In addition, civil society organizations and the private sector have to increase action to reduce food waste.

…in Southeast Asia and Sub-Saharan Africa after 2030

While per-capita food loss is low in Southeast Asia, the carbon footprint from total food lost is among the highest, with most losses occurring during production, handling and storage.[81] Interventions in Sub-Saharan would therefore be highly impactful in increasing food supply. This is especially important because the agricultural sector accounts for the majority of livelihoods in these regions, and because food supply will become more challenging for its rapidly growing population and demand. Interventions to intensify and diversify production and improve handling and storage practices could significantly reduce food loss.

7. Increase soil and pasture carbon sequestration in areas with high carbon losses—particularly Australia, China, the EU, India, Latin America, Sub-Saharan Africa, and the US

A substantial amount of soil carbon has been released into the atmosphere due to agricultural practices and land-use changes.[82] Sequestering carbon in agricultural systems through conservation agriculture practices (including reduced tillage, crop residue management, use of perennials or deeper rooted cultivars, organic amendment,[83] and fire management), and pasture management (including managing stocking rates, timing and rotation of livestock, higher productivity grass species or legumes, and nutrient management) have the technical potential to mitigate 2.57 Gt CO_2 a year.[84] Storing carbon by converting biomass into recalcitrant biochar to use for soil amendment also has the potential to mitigate another 2.57 Gt CO_2 a year.[85] While soil carbon and biochar have a large mitigation potential, there continues to be a great deal of uncertainty in the science of soil carbon,

79 China Daily, 2013.
80 Climate Focus calculations based on Raganathan et al., 2016.
81 Dickie et al., 2014.
82 Sanderman et al., 2017.
83 Organic amendment refers to organic fertilizer, such as biochar.
84 Smith, 2016.
85 Ibid.

specifically on issues of saturation and permanence based on soil, climate, and activity type.[86] While the carbon sequestration potential of soil still has uncertainties, there is still a large opportunity to restore degraded agricultural land and enhance carbon removal. It is also well-known that enriching soils with organic matter increases the fertility and resilience of soils.

Enhancing the health and carbon content of soils in Sub-Saharan Africa and India will increase the yields in and resilience of grazing and agricultural lands and reduce poverty caused by degraded soils. Australia, China, the EU, Latin America, and the US have large areas of degraded agricultural lands with high restoration and carbon storage potential. We estimate a mitigation potential of about 600 Mt CO_2e a year by 2050. To put that in perspective, this level of avoided emissions would be equivalent to eliminating 20 percent of annual GHG emissions within the EU-15.[87]

8. Improve synthetic fertilizer production and efficiency—particularly in Canada, China, the EU, India, Pakistan, and the US—reducing emissions by 2030 and 2050.

China, the EU, the US and, to a lesser extent, India are the global hotspots for nitrogen overuse and account for almost 80 percent of agricultural soil nitrous oxide emission.[88] Although the drivers of overuse vary in these countries, they all have potential to benefit from improved production efficiency. The US and the EU have highly industrialized, high-input, agricultural systems while China and India are aggressively intensifying their agricultural systems. Over the last few decades, China has become the global hotspot for overuse of synthetic fertilizers. Most farmers in China could reduce fertilizer application rates by 30–60 percent without harming yields.[89]

China also has a large opportunity for reducing emissions on the production side, and the country has already taken steps in that direction. The *12th Five Year Plan for the Fertilizer Industry*, issued by the Ministry of Industry and Information Technology, aims to eliminate inefficient producers, and includes the target for 2015 that more than 80 percent of N-fertilizers will be produced in large and medium enterprises and more than 70 percent of phosphate fertilizer in large-scale enterprises.

Improving fertilizer production and application can avoid emissions of 200 Mt CO_2e a year by 2050, an amount equivalent to the annual industrial process GHG emissions within the EU.[90]

86 Ibid.
87 CAIT Climate Data Explorer, 2015. The EU-15 are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.
88 Dickie et al. 2014.
89 Ju et al., 2009.
90 CAIT Climate Data Explorer, 2015.

9. Reduce emissions from rice paddies—particularly in Bangladesh, China, India, Indonesia, Myanmar, Philippines, Thailand, and Vietnam—and by 30 percent by 2030 and 70 percent by 2050…

Paddy-rice cultivation is a major source of methane emissions, responsible for about 11 percent of all GHG emissions from the agricultural sector,[91] exceeding the total annual energy emissions of Australia.[92] Rice farming has both high emissions and mitigation potential due to the amount of rice grown in flooded fields. The top rice-producing countries— Bangladesh, China, India, Indonesia, Myanmar, Philippines, Thailand, and Vietnam—account for more than 85 percent of global rice emissions[93] and regional programs could reduce emissions through improved water management. Many of the interventions used to reduce rice emissions are complementary with productivity gains, such as adding irrigation to better control water, which allows for double cropping. Switching to low-emissions practices could save 90 Mt CO_2e a year by 2030 and 205 million tonnes of CO_2e emissions by 2050, a quantity equivalent to nearly four times the annual GHG emissions of Denmark.[94]

10. Reduce emissions from livestock (enteric fermentation and manure)—particularly in Brazil, China, the EU, India, and the US—by 20 percent by 2040 and 30 percent by 2050.

Emissions from ruminant enteric fermentation accounts for 35 percent of total GHG emissions from the agriculture sector, the majority of which comes from beef and dairy cattle.[95] Latin America, a global hotspot for beef production, was responsible for 33 percent of global emissions from enteric fermentation from beef cattle in 2014. Of the enteric fermentation emissions in Latin America, 60 percent came from Brazil, home to the largest cattle herd in the world.[96] Measures to reduce enteric fermentation include improving feed quality, genetics, and vaccines. Efforts to improve feed quality in Latin America and India, the world's largest dairy producer, have begun, yet need to continue and expand. In India, even marginal increases in animal productivity through improved feeding would have important livelihood and food security benefits for millions of farmers and consumers, while simultaneously decreasing the emissions intensity of livestock products (approximately 70 Mt CO_2e a year). Reducing emissions from ruminant enteric fermentation by 30 percent could generate 180 Mt CO_2e a year by 2050, a saving equivalent to the industrial process emissions of all countries in Sub-Saharan Africa.[97]

Livestock manure and urine account for roughly one-quarter of direct agricultural GHG emissions. The highest manure management emission reduction potentials are in China, India, the US, and the EU. Measures to manage manure include anaerobic digestion for energy use, composting as a nutrient source, reducing storage time, and changing livestock diets. Improved manure management practices have important co-benefits, including reducing water and air pollution and increased yields and income from nutrient and energy inputs produced.

91 FAO, 2014.
92 CAIT Climate Data Explorer, 2015.
93 FAO, 2015.
94 Ibid.
95 Ranganathan et al., 2016.
96 Moncada-Laines et al., 2017.
97 Ibid.

6. Concluding Remarks

The proposed roadmap seeks to highlight the importance of the land sector in delivering on the Paris Agreement targets and present an ambitious yet feasible emissions pathway for 1.5°C. It focuses on actions that maximize positive tradeoffs and avoid relying on relatively risky and untested technologies.

Investments in science and monitoring capacities remain essential to monitor progress. Land-sector emissions (especially land fluxes and sinks) remain difficult to measure with certainty. Further complicating things, various scientific studies and national reports to the UNFCCC use different methodologies, carbon pools, and definitions—making the monitoring of progress challenging. Effort should be taken by the scientific community and practitioners to achieve greater transparency and comparability on land-based carbon flux and sink estimates.[98]

The roadmap shows that no single strategy—and no single country—is sufficient. Success can only be achieved if a panoply of mitigation strategies is deployed immediately and in parallel around the globe. Developed countries have to implement mitigation strategies without delay and support developing countries in their efforts. Collaboration and the pursuit of a common vision will be key.

Action in the land sector contributes significantly to sustainable development. Our roadmap not only helps to achieve global climate goals, but also furthers a series of sustainable development goals. Reduced deforestation and peatland burning preserves habitats essential for halting biodiversity loss. Forest conservation is essential for clean air and water provision. Reduced food loss/waste, improved diets and reduced emissions from livestock support global food security goals, while healthy diets promote better public health outcomes. These are just some of the roadmap's synergies with other development goals.

98 Federici et al., 2016.

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