Background Analytical Study

Forests and Climate Change

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Background study prepared for the fourteenth session of the United Nations Forum on Forests

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In response to paragraph 31 of resolution 13/1, the UN Forum on Forests Secretariat commissioned three background analytical studies on the contribution of forests to the achievement of the Sustainable Development Goals under review by the High-level Political Forum on Sustainable Development in 2019 in consultation with the Bureau of the fourteenth session of the Forum, taking into account the thematic priorities of the fourteenth session. The studies are: (a) Forests and climate change; (b) Forests, inclusive and sustainable economic growth and employment; and (c) Forests, peaceful and inclusive societies, reduced inequality and inclusive institutions at all levels.

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1 Introduction

The purpose of this paper is to provide background analysis on the critical role played by healthy and resilient forests in climate change mitigation and adaptation.

As the largest storehouse of carbon after the oceans, forests already absorb and store about 30 per cent of current levels of carbon emissions from fossil fuels and industry into their biomass, soils and wood products, and have the potential to store much more. At present, however, about 12 per cent of global greenhouse gas emissions are estimated to derive from deforestation, a process which is itself made more acute by the impacts of climate change. Forests can also help communities adapt to the impacts of climate change, stabilising and cooling local climates, including water flow and rainfall.

References to climate change occur in several places in the United Nations Strategic Plan for Forests 2017–2030 (UNSPF) agreed by the UN General Assembly in 2017, and its Global Forest Goals (GFGs). The box below reproduces the GFGs which explicitly reference climate change, and those which are directly relevant even while they do not mention climate change; the implications are discussed further in Sections 4, 5 and 6 (in practice, virtually all the GFGs are of some relevance).

UN Strategic Plan for Forests 2017–2030: Global Forest Goals[1]

1. Reverse the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of addressing climate change.

   1.1 Forest area is increased by 3 per cent worldwide.

   1.2 The world's forest carbon stocks are maintained or enhanced.

   1.3 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.

   1.4 The resilience and adaptive capacity of all types of forests to natural disasters and the impact of climate change is significantly strengthened worldwide.

2. Enhance forest-based economic, social and environmental benefits, including by improving the livelihoods of forest dependent people.

   …

   2.5 The contribution of all types of forests to biodiversity conservation and climate change mitigation and adaptation is enhanced, taking into account the mandates and ongoing work of relevant conventions and instruments.

3. Increase significantly the area of protected forests worldwide and other areas of sustainably managed forests, as well as the proportion of forest products from sustainably managed forests.

   …

[1] Resolution adopted by the Economic and Social Council on 20 April 2017: United Nations strategic plan for forests 2017–2030 and quadrennial programme of work of the United Nations Forum on Forests for the period 2017–2020 (E/RES/2017/4, July 2017).

3.3 The proportion of forest products from sustainably managed forests is significantly increased.

4. Mobilize significantly increased, new and additional financial resources from all sources for the implementation of sustainable forest management and strengthen scientific and technical cooperation and partnerships.

…

5. Promote governance frameworks to implement sustainable forest management, including through the United Nations forest instrument, and enhance the contribution of forests to the 2030 Agenda for Sustainable Development.

…

5.2 Forest law enforcement and governance are enhanced, including through significantly strengthening national and subnational forest authorities, and illegal logging and associated trade are significantly reduced worldwide.

The Sustainable Development Goals (SDGs) are also relevant. Agreed by the UN General Assembly in 2015 as the core of the 2030 Development Agenda, *Transforming our World: the 2030 Agenda for Sustainable Development*, SDG 13 deals explicitly with climate change (see box).

Sustainable Development Goal 13. Take urgent action to combat climate change and its impacts [2]

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

13.2 Integrate climate change measures into national policies, strategies and planning.

13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

This paper provides an overview of the interaction between forests and climate change. Section 2 examines the roles forests play in regulating the global and local climate, the impacts of forests on climate change and the impacts of climate change on forests. Section 3 analyses the treatment of forests, including the measurement of forest-related greenhouse gas emissions and sinks, in the international climate agreements. Section 4 discusses a range of mitigation options: ways in which forests and forest policy can help to reduce the rate of climate change. Section 5 discusses adaptation: measures through which forests can help societies adapt to the impacts of climate change and ways in which forests themselves may need to be assisted to adapt to climate change. Section 6 discusses key requirements underlying the success of all the measures examined in Sections 4 and 5: the need for financial support and improvements in forest governance. Section 7 provides some brief conclusions, in particular on the synergies between the climate agreements and UNSPF and its Global Forest Goals.

[2] Ibid.

2 Background: forests and climate change

2.1 Role of forests and their ecosystem services in climate systems: carbon

Forests play a critical role in the Earth's climate system, in a number of different ways. Most importantly for global climate change, they capture carbon dioxide from the atmosphere and convert it, through photosynthesis, into living biomass: tree trunks, roots, branches and leaves. Forests also store carbon in forest soils, absorbed through leaf litter, woody debris and roots; whether these inputs are sequestered in the soil matrix or biodegraded and returned to the atmosphere as carbon dioxide, and if so at what rate, depends on complex interactions involving soil minerals, plants and soil organisms, and organic components, all influenced by factors such as local climatic conditions and forest management.

Estimates of the carbon stored in the world's forests vary significantly. In 2000 the Intergovernmental Panel on Climate Change (IPCC) estimated a total volume of 1,100 gigatonnes (Gt, or billion tonnes).[3] This amount is 1.3 times larger than the carbon stored in fossil fuel reserves (estimated at about 800 Gt), and more than the carbon already added to the atmosphere as a consequence of human activities since 1870 (about 600 Gt).[4] In 2010 the Food & Agriculture Organisation (FAO) estimated a smaller total carbon stock of 652 Gt of carbon: 44 per cent in live biomass, 5 per cent in dead wood, 6 per cent in litter and 45 per cent in the soil.[5]

Another study, published in 2011, using bottom-up estimates of carbon stocks and fluxes based on inventory data and long-term field observations, estimated 861 ± 66 Gt carbon, with a similar breakdown: 42 per cent in live biomass, 8 per cent in dead wood, 5 per cent in litter and 44 per cent in soil.[6] According to this latter study, geographically, 55 per cent is stored in tropical forests, 32 per cent in boreal forests and 14 per cent in temperate forests. Tropical and boreal forests are similar in terms of carbon stock density (242 and 239 tonnes of carbon per hectare, respectively), whereas temperate forests are about 40 per cent lower (155 tonnes / hectare). Although tropical and boreal forests store the most carbon, the biomass-soil interaction is quite different: in tropical forests 56 per cent of carbon is stored in biomass and 32 per cent in soil, whereas in boreal forests, just 20 per cent is stored in biomass and 60 per cent in the soil.

Forests play a role in mitigating climate change by absorbing the carbon dioxide emitted into the atmosphere from human activities, chiefly the burning of fossil fuels for energy and other purposes, into the terrestrial carbon sink (see Figure 2.1 – biosphere). It has been estimated that since 1750, forests (and other vegetation, but mainly forests) have been responsible for about half of the carbon emissions naturally sequestered from the atmosphere; the rest has been absorbed by the oceans.[7] Together, forests

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[3] Robert T. Watson et al, *IPCC Special Report on Land Use, Land-Use Change And Forestry* (IPCC, 2000).

[4] Sandro Federici, Donna Lee and Martin Herold, *Forest Mitigation: A Permanent Contribution to the Paris Agreement* (Climate and Land Use Alliance, November 2018).

[5] FAO, *Global Forest Resources Assessment 2010.*

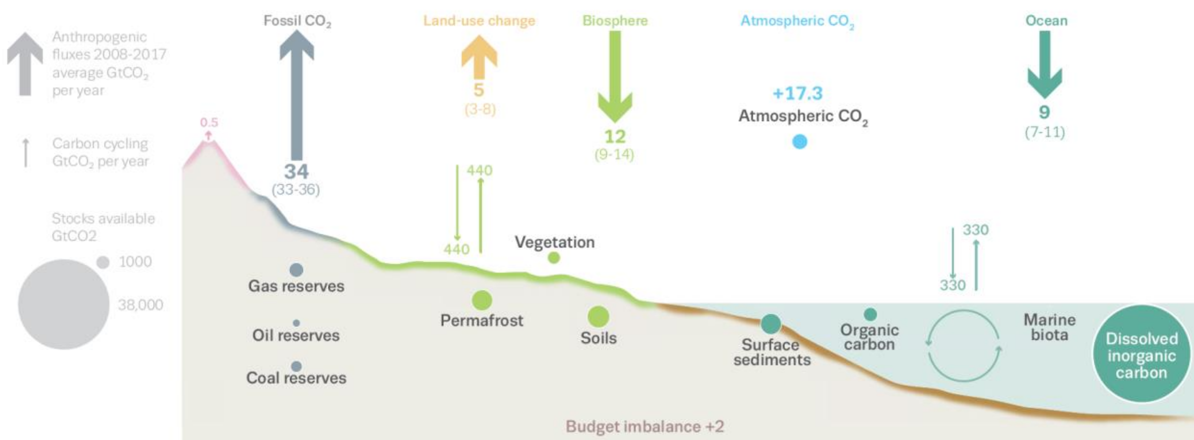
[6] Yude Pan et al., 'A Large and Persistent Carbon Sink in the World's Forests', *Science* 333, 988 (2011).

[7] P. Ciais et al., '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 University Press, 2013).

and oceans form a natural buffer against climate change (though increasing concentrations of carbon dioxide in seawater gradually acidify the oceans, with negative impacts on marine life).

Conversely, deforestation contributes to climate change (see Figure 2.1 – land-use change). When forests are burned or cleared for uses such as cropland, pasture, infrastructure or urbanisation, the net flow of carbon from the atmosphere into the forest ends, both in the present and for the entire projected future lifetime of the trees. Deforestation also causes the release of the stock of carbon that has accumulated, both in the trees themselves and in the forest soil. The speed of release of the carbon depends on how the forest is cleared and what the wood is used for: clearance by burning or for use as bioenergy causes an immediate, or almost immediate, release of carbon into the atmosphere, whereas harvesting for wood products, such as timber for construction, panels, furniture or paper, will trap some of the carbon in the product for its lifetime, which ranges from a few years for paper to, potentially, many decades for other wood products (see further in Section 4.5). Forest biomass left in the forest, such as twigs, branches or stumps left after harvesting, will decay and eventually release its stored carbon into the atmosphere; this process can take years or decades, depending on the type of residue and the local climatic conditions (hot or cold, wet or dry, etc.).

Fig 2.1 Schematic representation of the overall perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2008–2017[8]



The net impact on the climate also depends on what replaces the cleared forest. If selectively harvested rather than clear-cut, forest can regenerate naturally; trees can also be replanted through active forest management. More commonly, however, especially in recent decades in the tropics, forest has been cleared completely, particularly for agriculture (confirmed by several recent studies as the main global driver of deforestation) for both domestic consumption and export markets, and also for mining, infrastructure development and urban expansion. A 2018 study identified the five drivers most strongly associated with gross global tree cover loss over the period 2001–15:[9]

- Commodity-driven deforestation (27 per cent) – permanent conversion of forest for the expansion of commodities such as palm oil, soy, beef, minerals and oil and gas. These areas are not likely to be reforested.

[8] Source: Corinne Le Quéré et al, 'Global carbon budget 2018', *Earth System Science Data* 10 (2018).
[9] Philip G. Curtis et al, 'Classifying drivers of global forest loss', *Science* 361:6407 (2018).

- Forestry (26 per cent) – loss within managed forests and tree plantations, which are expected to regrow after harvest.
- Shifting agriculture (24 per cent) – loss, primarily in tropical regions, through clearance and burning for short-term cultivation of subsistence crops. These forests may or may not grow back, depending on the cultivation practices.
- Wildfires (23 per cent) – loss from fires; trees are likely to regenerate gradually over time. Over this period (2001–15) this loss was concentrated in the northern forests of Canada and Russia.
- Urbanisation (0.6 per cent) – loss from urban expansion; considered permanent, concentrated mainly in the eastern United States.

The impact of deforestation on the climate also varies with the type of forest.[10] Self-evidently, clearance of tall, dense forests produces more carbon emissions per unit of land area than clearing low, sparse forests. Deforestation has a particularly severe impact when it takes place on carbon-rich peat soil. Peat swamps contain up to 2,000 tonnes of carbon per hectare, an order of magnitude greater than tropical forests. When stripped of their protective forest cover and drained of water, previously inundated peat soil is left exposed above the water table, where it oxidizes and decays, releasing carbon into the atmosphere. It also becomes highly flammable; clearance of peat forests creates a high chance of fires that can last for decades. Peatlands cover just 3 per cent of global land area, but store 20–25 per cent of all soil carbon. There is a similar story with mangrove forests, which store an average of 1,000 tonnes of carbon per hectare in their soils, and are currently being cleared faster than tropical forests, for shrimp farms, tourism and other uses.

Forest degradation – as opposed to full deforestation – also affects climate change. In forests that are left standing, logging, wood fuel extraction, fires and grazing typically reduce carbon stocks faster than they can naturally recover. Although the data is uncertain, a 2015 study suggested that emissions from forest degradation were a quarter of those from deforestation in the decade 2001–10, increasing to one third of those from deforestation in the period 2011–15, with substantial variation across countries.[11] As well as causing climate change, forest degradation can be a precursor to outright deforestation: the construction of roads for logging or mining activities, for example, makes it easier for people to gain access to forests and subsequently convert them completely to agriculture.

Scale of impacts of forest growth and deforestation on climate change

The impact of forests on atmospheric concentrations of carbon dioxide will be the net outcome of the carbon absorbed by forest growth (the carbon sink) and the carbon emitted from deforestation and forest degradation (emissions). Figure 2.2 shows estimates for the period since 1900: forests account for most of the land-use change emissions (yellow) and almost all of the land sink (green). The growth in net emissions into the atmosphere (light blue), causing global warming, can be clearly seen.

[10] All figures in this paragraph: Frances Seymour and Jonah Busch, *Why Forests? Why Now? The Science, Economics, and Politics of Tropical Forests and Climate Change* (Center for Global Development, 2016).
[11] Sandro Federici et al, 'New estimates of CO2 forest emissions and removals: 1990–2015', *Forest Ecology and Management* 352 (2015).

Table 2.3 provides estimated figures for the different components since the 1960s, based on a review of recent studies. In 2017 forests absorbed an estimated 3.8 billion tonnes of carbon, about 38 per cent of emissions from fossil fuel use and industry. At the same time, land-use change accounted for 12 per cent of total climate-forcing emissions. The equivalent figures for the decade to 2017 were 30 per cent and 14 per cent.

Fig 2.2 Graphical representation of the global carbon budget as illustrated in Figure 2.1[12]

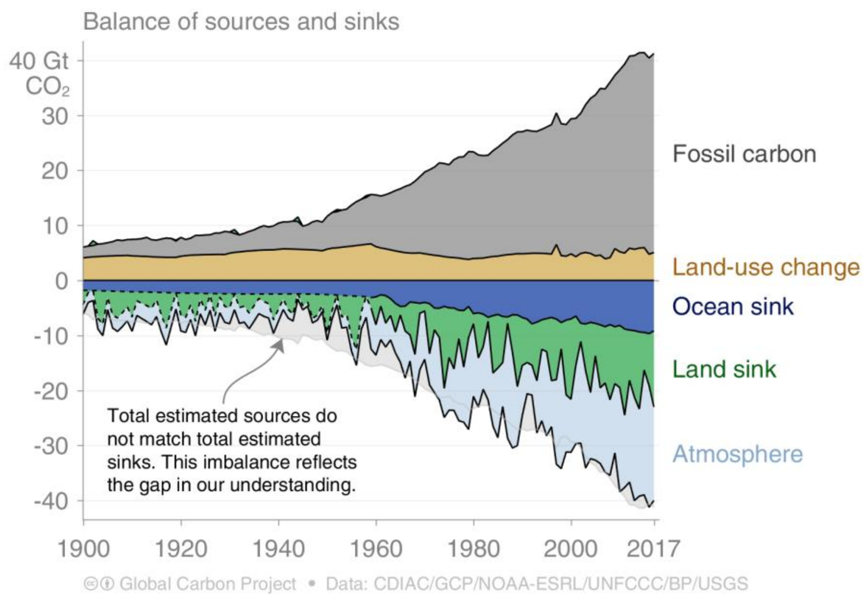


Table 2.3 Decadal mean in the five components of the anthropogenic carbon budget[13]

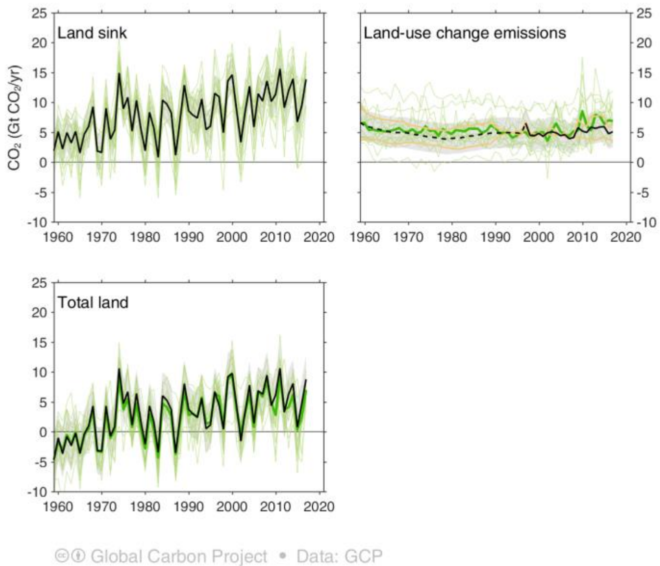
	Mean ($GtC\,yr^{-1}$)						
	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2008–2017	2017
Total emissions ($E_{FF}+E_{LUC}$)							
Fossil CO_2 emissions (E_{FF})	3.1 ± 0.2	4.7 ± 0.2	5.4 ± 0.3	6.3 ± 0.3	7.8 ± 0.4	9.4 ± 0.5	9.9 ± 0.5
Land-use change emissions (E_{LUC})	1.5 ± 0.7	1.2 ± 0.7	1.2 ± 0.7	1.4 ± 0.7	1.3 ± 0.7	1.5 ± 0.7	1.4 ± 0.7
Total emissions	4.7 ± 0.7	5.8 ± 0.7	6.6 ± 0.8	7.6 ± 0.8	9.0 ± 0.8	10.8 ± 0.8	11.3 ± 0.9
Partitioning							
Growth rate in atmospheric CO_2 concentration (G_{ATM})	1.7 ± 0.07	2.8 ± 0.07	3.4 ± 0.02	3.1 ± 0.02	4.0 ± 0.02	4.7 ± 0.02	4.6 ± 0.2
Ocean sink (S_{OCEAN})	1.0 ± 0.5	1.3 ± 0.5	1.7 ± 0.5	2.0 ± 0.5	2.1 ± 0.5	2.4 ± 0.5	2.5 ± 0.5
Terrestrial sink (S_{LAND})	1.2 ± 0.5	2.1 ± 0.4	1.8 ± 0.6	2.4 ± 0.5	2.7 ± 0.7	3.2 ± 0.7	3.8 ± 0.8
Budget imbalance							
$B_{IM}=E_{FF}+E_{LUC}-(G_{ATM}+S_{OCEAN}+S_{LAND})$	(0.6)	(−0.3)	(−0.3)	(0.2)	(0.2)	(0.5)	(0.3)

Note that this figure contains figures for carbon, not carbon dioxide, unlike Figures 2.1 and 2.2. One Gt carbon = 3.664 Gt carbon dioxide.

[12] Source: Le Quéré et al, 'Global carbon budget 2018'.
[13] Source: ibid.

As can be seen, emissions from land use change, including forestry, have remained roughly constant over the period since 1960: deforestation in the tropics has been largely counteracted by growth in boreal and temperate regions (see further below). The annual terrestrial carbon sink has grown, though this has been subject to considerable variability, particularly during El Niño events, which cause a significant reduction. Figure 2.4 shows the net outcome of sink and emissions.

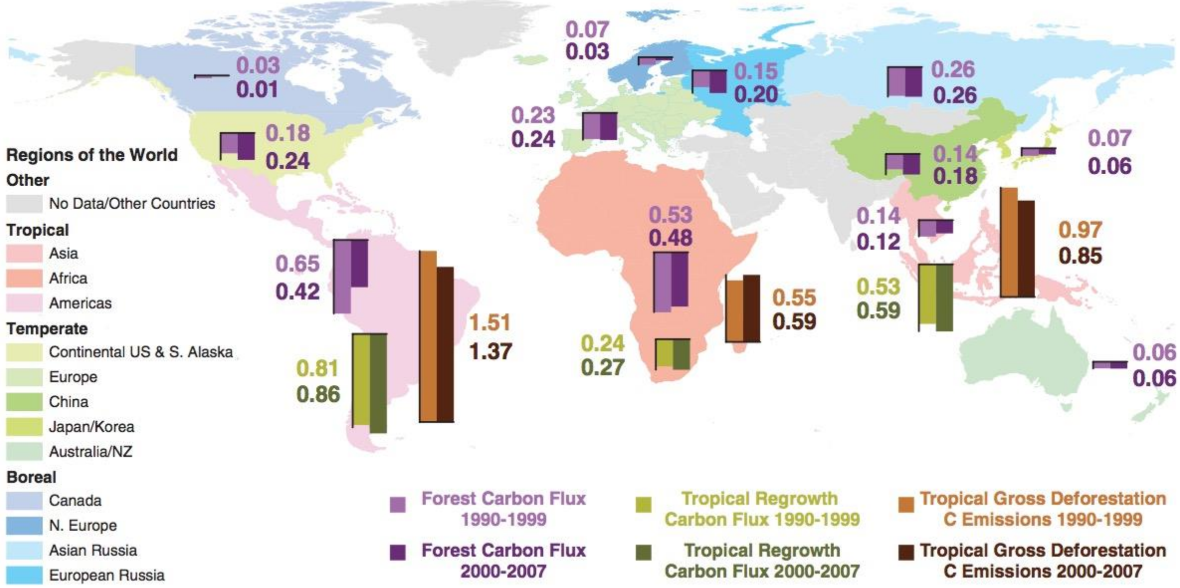
Fig 2.4 Terrestrial carbon sink, 1960–2017[14]



A more detailed analysis of the average annual change in the carbon stock of established forests, and the annual average emissions from deforestation and forest degradation (using data from 1990–99 and 2000–07) showed important regional differences (see Figure 2.5), as well as confirming that non-forest ecosystems were neither a major source nor a major sink over these two periods.[15]

[14] Source: ibid.
[15] Pan et al., 'A Large and Persistent Carbon Sink in the World's Forests'.

Fig 2.5 Carbon sinks and sources (Gt carbon per year) in the world's forests, 1990–2007



Coloured bars in the downward-facing direction represent carbon sinks, whereas bars in the upward-facing direction represent carbon sources (emissions). Light and dark purple = global established forests (boreal, temperate, and intact tropical forests); light and dark green = tropical regrowth forests after anthropogenic disturbances; and light and dark brown = tropical gross deforestation emissions. Note these are figures for carbon, not carbon dioxide.

Boreal forests, on average, showed little difference between the two time periods, but this masked significant changes within the region: increases in forest cover in European Russia and northern Europe counteracted a sharp fall in Canadian managed forests, mostly due to intensified wildfires and insect outbreaks. The carbon sink in temperate forests increased by 17 per cent in 2000–07 compared to 1990–99, due in particular to forest growth in the United States (slightly offset by higher drought stress and increased mortality from insects and fires in the western US) and China, where the biomass sink almost doubled thanks to an intensive national afforestation and reforestation programme.

In contrast, the tropical forest carbon sink uptake fell by 23 per cent between the two time periods in the study as a result of deforestation reducing intact forest area, together with a severe drought in the Amazon region in 2005. This was partly offset by an increase in the carbon sink in tropical regrowth, i.e. forests recovering from deforestation, logging, or abandoned agriculture, which represented about 30 per cent of the total tropical forest area. The combined tropical forest area, both intact and regrowth, on average accounted for about 70 per cent of the gross carbon sink in the world's forests (about 4.0 Gt carbon per year). However, given the equally significant gross emissions from tropical deforestation, tropical forests were in effect nearly carbon-neutral. The net global increase in the forest carbon sink resides mainly in temperate and boreal forests.

It should be noted that all these estimates are subject to considerable uncertainty and data gaps. There are also significant differences between data reported from independent studies and national greenhouse gas emission reports. The most recent IPCC report estimated net land-use emissions (most of which are from forests) for 2000–09 as about 1.09 Gt of carbon per year, whereas countries collectively reported net emissions closer to 0.25 Gt carbon.[16] There are several reasons for this anomaly, including differences between all changes in forest carbon fluxes, including both natural and anthropogenic changes (which is what the IPCC reports cover) and anthropogenic changes only (i.e. fluxes from managed forest, which should be the only ones included in national reports); a lack of capacity to conduct detailed measurements; differences in data sets and definitions; and the complexity of attempting to measure carbon stocks in above and below-ground biomass, deadwood, litter, soil etc.

2.2 Other roles of forests and their ecosystem services in climate systems

Forests affect climate systems in many other ways than carbon storage. In particular, forests play important roles in producing and regulating the world's temperatures and fresh water flows. Indeed, one paper published in 2017 argued that carbon sequestration should be seen merely 'as one co-benefit of reforestation strategies designed to protect and intensify the hydrologic cycle and associated cooling'.[17]

Forests contribute to atmospheric moisture and rainfall patterns over land through evapotranspiration: evaporation from soil and plant surfaces and transpiration of water by plants.[18] On average, at least 40 per cent of rainfall over land originates from evapotranspiration. The resulting atmospheric moisture is circulated by winds across the Earth's continents and oceans. This cross-continental production and transport of atmospheric moisture – 'precipitation recycling' – can promote and intensify the redistribution of water across terrestrial surfaces.

Forest loss and degradation reduce evapotranspiration, with implications for rainfall thousands of kilometres downwind. In addition, by affecting the Earth's surface albedo, temperature, and surface roughness, forests alter moisture and heat fluxes between terrestrial surfaces and the atmosphere. Trees and forests also lead to more intense rainfall through the biological particles (fungal spores, pollen, bacterial cells and biological debris) they release into the atmosphere, which accelerates condensation of atmospheric moisture. Climate modellers have predicted that large-scale deforestation may reduce rainfall in some regions by as much as 30 per cent, and this can lead to feedback effects including slower forest growth, drought, die-off and fires.

Large, continuous areas of forest drive the atmospheric circulation that brings rainfall to continental interiors, according to the 'biotic pump' theory first postulated in 2007. Under this theory, through transpiration and condensation forests actively create low-pressure regions that draw in moist air from the oceans, generating prevailing winds capable of carrying moisture and sustaining rainfall far within continents. Deforestation may therefore cause significant changes in wind patterns and rainfall, though this can be reversed by reforestation.

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[16] Sandro Federici et al, *GHG fluxes from forests: An assessment of national GHG estimates and independent research in the context of the Paris Agreement* (Climate and Land Use Alliance, June 2017).

[17] David Ellison et al, 'Trees, forests and water: Cool insights for a hot world', *Global Environmental Change* 43 (2017) 51–6. Unless otherwise noted, this section draws primarily on this paper.

[18] David Ellison, *Forests and Water* (Background analytical study prepared for the thirteenth session of the United Nations Forum on Forests, April 2018).

Forests also influence local temperatures, providing a cooling effect through transpiration and shade. This can be particularly important in cities, where trees can help to counteract the urban heat island effect.[19] Additional regional and global cooling derives from the fact that through emissions of reactive organic compounds, forests can increase low-level cloud cover and raise reflectivity – though clouds can also contribute to warming. Under more cloud-free skies, at high latitudes and particularly in winter, forests reduce the earth's albedo and can thus contribute to local warming. The net effect of forests on regional and global climate warming and cooling depends on the combined impact of the rate and magnitude of evapotranspiration and carbon accumulation, changes to surface and cloud albedo, as well as land-cover-change impacts on aerosols and reactive gases; these are complex relationships which are difficult to model.

Forests regulate water supplies in many ways. High-altitude forests can intercept fog and cloud droplets, which may account for up to 75 per cent of total catchment run-off. Where such forests have been removed, the atmospheric moisture present in clouds may move on to other locations, affecting local downstream water supplies. Loss of tree cover also promotes soil degradation that reduces soil infiltration and water retention capacity, and in turn reduces groundwater reserves that maintain dry-season water flows.

Because of their capacity to store and recycle water, forests help to moderate flooding. Conversely, removing trees leads to soil compaction and hardening, soil erosion (especially in mountainous areas), transpiration loss, reduced infiltration and increased run-off, thereby promoting floods. In general, mixed-species forests are more effective in regulating water supplies and moderating floods than monocultures: through variations in rooting depth, strength and patterns, different species aid each other through water uptake, water infiltration and erosion control.

For all these reasons, trees growing in or near agricultural fields can provide regulating services that reduce the vulnerability of crops to climate variations; agroforestry and silvopastoral systems (where degraded open, treeless pastures are converted into richer and more productive environments through planting trees and shrubs interspersed among fodder crops) can thus improve the stability and productivity of agriculture.[20] Tree roots explore soil deeply for water and nutrients, which can benefit crops during droughts – though planting the right trees is vital; some species, such as eucalyptus, deplete soil moisture. Trees can also improve fertility and protect soils from erosion by increasing soil organic matter, porosity, infiltration and soil cover. Shade trees can control temperature and humidity and protect against winds and storms, and can improve the resilience of shade crops such as coffee or cocoa.

2.3 Impacts of climate change on forests

Forests are subject to several natural disturbances irrespective of climate change, including fires, droughts, storms, snow and ice, insect infestation and disease. A recent major example was the mountain pine beetle epidemic in the 1990s and 2000s in British Columbia. The largest such infestation ever recorded, over 18 million hectares of forest (almost a third of total forest area in the province) was affected to some extent,

[19] Bruno Locatelli, 'Ecosystem Services and Climate Change', in Marion Potschin et al (eds.), *Routledge Handbook of Ecosystem Services* (Routledge, 2016).
[20] Ibid.

resulting in a loss of more than half the area's merchantable pine volume by 2012.[21] In the long run, events such as these are not necessarily negative, however: disturbances help to increase landscape heterogeneity, foster greater species diversity and initiate ecosystem renewal or reorganisation.

However, climate change has the potential to increase both the frequency and the intensity of most of these disturbances, possibly exceeding forest ecological resilience and resulting in permanently altered forests or shifts to non-forest ecosystems. The year 2018, for example, saw a sharp increase in forest fires in temperate and boreal regions, with extensive and long-lasting wildfires in the US, Siberia, Australia and Europe. In California, 14 of the 20 largest wildfires on record have occurred over the past 15 years, and on average fires now burn more than twice the area they did in the 1980s and 1990s.[22] Although climate change is not the only factor behind this, fuel aridity – a combination of temperature and precipitation – explains about 75 per cent of the year-to-year variations in burned area (see Figure 2.6).

Countries in northern Europe in the summer of 2018 saw between 20 and 200 times the ten-year average area burned.[23] A study in 2014 suggested that should global warming continue, outside the tropics fires (caused primarily by climate change) could become the most important driver of deforestation, more significant than any other cause, such as the conversion of forestlands to agriculture.[24] In the tropics, in contrast, climate change seems to have reduced the area burned over the past 50 years, due, in part, to wetter conditions – though the impacts of climate change on tropical forests have been less extensively studied than on boreal and temperate forests.

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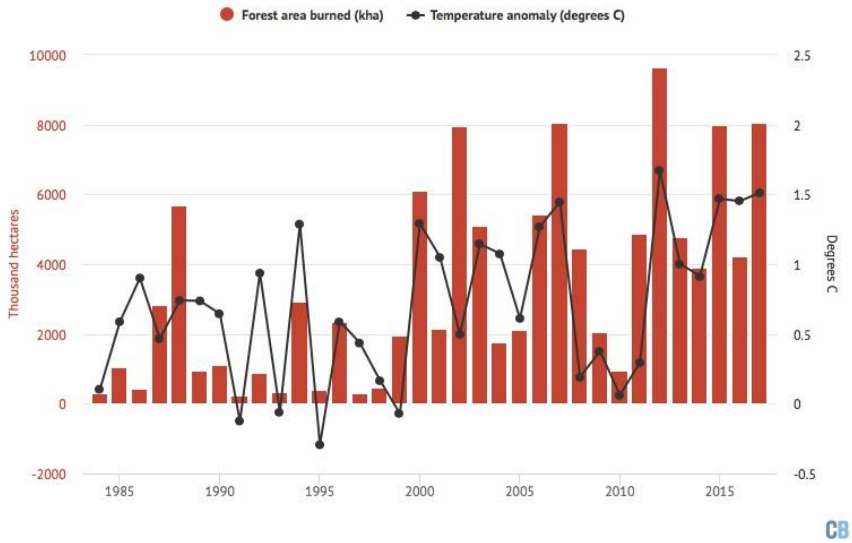
[21] Natural Resources Canada, 'Mountain pine beetle factsheet' (nd); https://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13397.

[22] Carbon Brief, 'Factcheck: How global warming has increased US wildfires' (9 August 2018); https://www.carbonbrief.org/factcheck-how-global-warming-has-increased-us-wildfires.

[23] Stefan H. Doerr & Cristina Santín, 'Why wildfires are breaking out in the 'wrong' countries', BBC News (31 July 2018); https://www.bbc.co.uk/news/world-44941999.

[24] Jia Yang et al, 'Spatial and temporal patterns of global burned area in response to anthropogenic and environmental factors: Reconstructing global fire history for the 20th and early 21st centuries', *JGR: Biogeosciences*, Vol. 119, Issue 3 (March 2014).

Fig 2.6 Forest area burned, and spring/summer temperatures, western US[25]



Red bars show western US forest area burned (in thousand hectares). Black line shows March–August temperature anomalies relative to a 1961–90 baseline period for the US west of 102 degrees longitude.

Forest fires are important not just because of their impact on forest area and future growth but also because they release significant quantities of greenhouse gases into the atmosphere. This includes not just carbon dioxide but also methane and nitrous oxide, both of which have greater impacts on global warming than carbon dioxide. In developed countries non-carbon-dioxide fire emissions represent about 10–12 per cent of total carbon-dioxide-equivalent fire emissions (equivalent data is largely lacking in developing countries).[26]

Table 2.7 lists the effects of climate change identified in a recent comprehensive review of the scientific studies.[27] Direct effects are defined as the unmediated impacts of climate variables on disturbance processes; examples include changes in the frequency or severity of wind events and drought periods, changes in lightning activity or climate-mediated changes in the metabolic rates of pests and pathogens. Indirect effects are changes in disturbances through climate effects on vegetation and other ecosystem processes not directly related to disturbances, such as an alteration of the disturbance susceptibility through a change in tree species composition, size, density (which may affect, for example, the quantity of fuel available for burning) and distribution, as well as changes in tree-level vulnerability (for example, changes in soil anchorage of trees against wind due to variation in soil frost). Interaction effects are defined as linked or compounding relationships between disturbance agents, such as an increased risk of bark beetle outbreaks resulting from wind disturbance (which create large amounts of effectively defenceless breeding material supporting the build-up of beetle populations) or drought (weakening tree defences against beetles).

[25] Source: Carbon Brief, 'Factcheck: How global warming has increased US wildfires'.

[26] Federici et al, *GHG fluxes from forests.*

[27] Rupert Seidl et al, 'Forest disturbances under climate change', *Nature Climate Change* (31 May 2017).

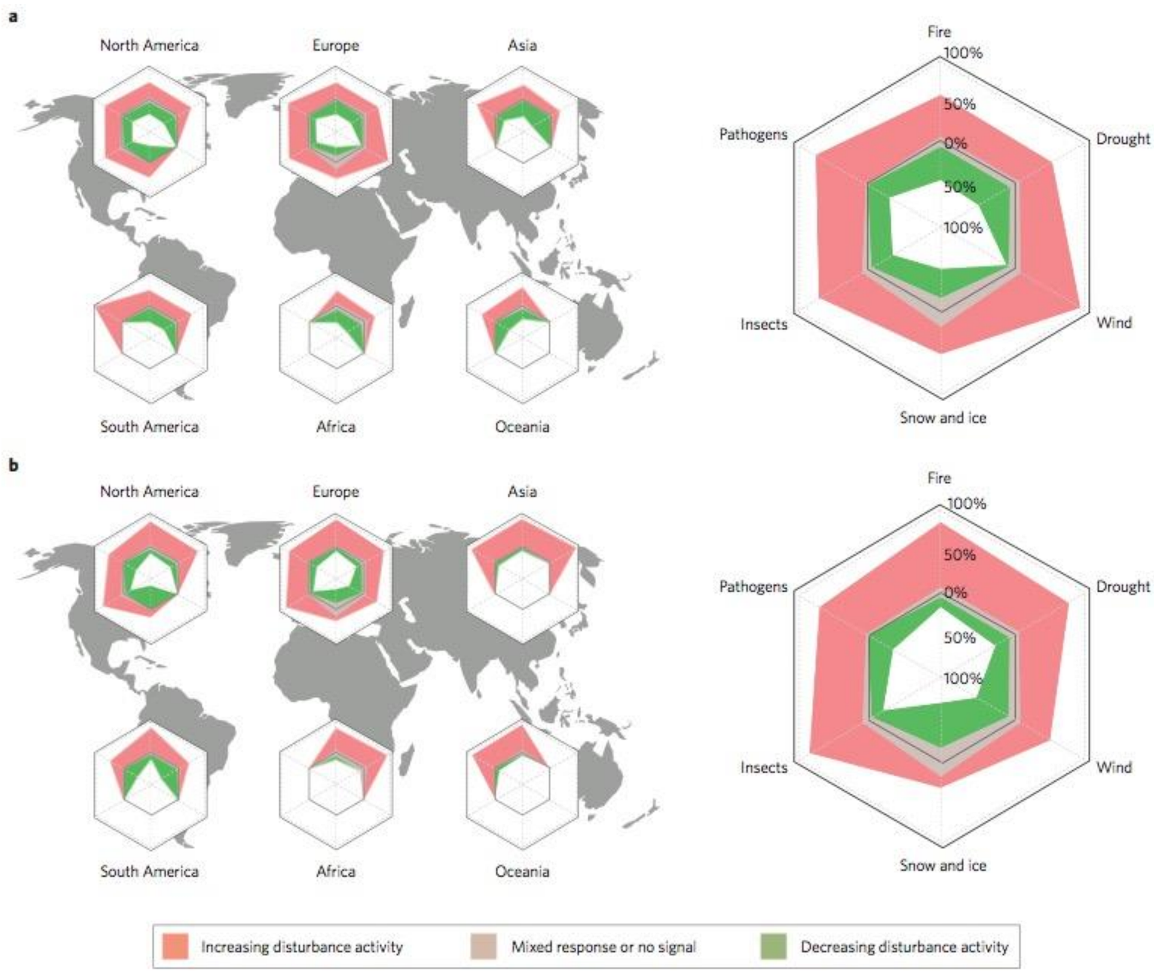
Table 2.7 Important processes through which climate influences forest disturbances[28]

Disturbance agent	Direct effects: climate impact through changes in …	Indirect effects: climate impact through changes in …	Interaction effects: climate impact through changes in …
Fire	Fuel moisture Ignition (for example, lightning activity) Fire spread (for example, wind speed)	Fuel availability (for example, vegetation productivity) Flammability (for example, vegetation composition) Fuel continuity (for example, vegetation structure)	Fuel availability (for example, via wind or insect disturbance) Fuel continuity (for example, avalanche paths as fuel breaks)
Drought	Occurrence of water limitation Duration of water limitation Intensity of water deficit	Water use and water-use efficiency (for example, tree density and competition) Susceptibility to water deficit (for example, tree species composition)	Water use and water-use efficiency (for example, insect-related density changes) Susceptibility to water deficit (for example, fire-mediated changes in forest structure)
Wind	Occurrence of strong winds Duration of wind events Intensity of wind events (for example, peak wind speeds)	Tree anchorage (for example, soil frost) Wind exposure (for example, tree growth) Wind resistance (for example, tree species composition)	Wind exposure (for example, insect disturbances increases canopy roughness) Soil anchorage (for example, pathogens decrease rooting stability) Resistance to stem breakage (for example, pathogens decrease stability)
Snow and ice	Snow occurrence Snow duration Occurrence of freezing rain	Exposure of forest to snow Avalanche risk	Avalanche risk (for example, through gap formation by bark beetles)
Insects	Agent metabolic rate (for example, reproduction) Agent behaviour (for example, consumption) Agent survival	Host distribution and range Agent–host synchronization (for example, budburst) Host defence (for example, carbohydrate reserves)	Host presence and abundance Host resistance and defence (for example, through changes in drought)
Pathogens	Agent metabolic rate (for example, respiration) Agent abundance	Host abundance and diversity Host defence	Agent interaction and asynchrony Agent dispersal (for example, through vector insects)

The analysis also suggested that at the global scale, disturbances from five of these six agents are likely to increase in a warming world; the only one not increasing is snow and ice. Warmer and drier future conditions are likely to lead to an increase in fires, drought and insect activity. Warmer and wetter conditions still see increases in these disturbance agents, but of a lower intensity, together with a higher likelihood of wind disturbance and pathogen activity. As would be expected, impacts vary with geography; Figure 2.8 illustrates the regional breakdown. The analysis concluded by noting that some of the indirect effects of climate change can be mitigated, at least to a certain extent, by appropriate forest management regimes – for example by modifying forest composition and structure – but that direct effects are much more difficult to counter.

[28] Source: ibid.

Fig. 2.8 Global disturbance response to changing temperature and water availability[29]



Radar surfaces indicate the distribution of evidence (% of observations) for increasing or decreasing disturbance activity under (a) warmer and wetter and (b) warmer and drier climate conditions. The large radar plots to the right summarise the responses over all continents. Only direct and indirect climate effects are considered here.

Set against these impacts, there are some potential positive effects of climate change on forests. These include the carbon fertilisation effect: increased growth rates caused by higher concentrations of atmospheric carbon. Studies suggest that elevated carbon levels can encourage increases in leaf area, the rate of photosynthesis per leaf area, and carbon stored below-ground in roots and soil.[30] Higher concentrations of carbon dioxide also cause leaves to open their stomata less wide, so less water evaporates and the trees go on growing longer in times of relative drought or in the heat of the day. One study of global changes in leaf area, based on satellite observations, suggested that up to half of the Earth's vegetation-covered land was now 'greener' than 30 years ago, mostly due to rising levels of carbon dioxide

[29] Source: ibid.

[30] R. Ceulemans et al, 'Effects of CO2 Enrichment on Trees and Forests: Lessons to be Learned in View of Future Ecosystem Studies', *Annals of Botany* 84: 577–590 (1999); Randall J. Donohue, 'Impact of CO2 fertilization on maximum foliage cover across the globe's warm, arid environments', *Geophysical Research Letters* 40 (May 2013).

from human activity.[31] Another suggested that higher carbon dioxide levels were accelerating the growth of forests in British Columbia by one to three per cent a year.[32]

Other studies, however, have cast doubt on these effects, at least in tropical forests. One study of tree growth in Bolivia, Cameroon and Thailand suggested that while water-use efficiency had improved, as expected, there was no evidence for any concurrent acceleration of individual tree growth.[33] It was thought that the most likely explanation was that forest growth was not limited by the availability of carbon dioxide, but by nutrients in the soil such as phosphate, and possibly by the availability of water.

Forest growth may also be promoted by the improved bio-availability of nitrogen originating from the combustion of fossil fuels, biomass burning or agricultural fertilisation. This impact is probably most important in Europe and the eastern US, both because of the larger quantities of nitrogen emissions in these regions and because many of those forests are nitrogen-limited.[34] A 2015 study that modelled fluxes at 68 forest sites estimated that 19 ± 29 per cent of the observed increases in the carbon sink were due to nitrogen deposition effects, with larger effects in temperate and tropical forests.[35]

It has also been argued that forest growth may be promoted by a longer 'growing season' – i.e. longer periods of warm temperatures, at least in cold climates. In fact, however, despite a large number of studies on the topic, no standard for measuring the beginning, middle or end of a growing season has emerged, leading to wildly diverging conclusions from the available data.[36] In any case, on a global scale, the negative impacts described above are likely to overwhelm any positive effects from carbon dioxide fertilisation or nitrogen deposition.[37]

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[31] Zaichun Zhu et al, 'Greening of the Earth and its drivers', *Nature Climate Change* volume 6 (2016).

[32] Vivek K. Arora et al, 'Potential near-future carbon uptake overcomes losses from a large insect outbreak in British Columbia, Canada', *Geophysical Research Letters* 43 (March 2016).

[33] Peter van der Sleen et al, 'No growth stimulation of tropical trees by 150 years of CO2 fertilization but water-use efficiency increased', *Nature Geoscience* volume 8 (2015).

[34] J. G. Canadell et al, 'Factoring out natural and indirect human effects on terrestrial carbon sources and sinks', *Environmental Science & Policy,* 10:4 (2007).

[35] K. Fleischer et al, 'Low historical nitrogen deposition effect on carbon sequestration in the boreal zone', *J. Geophys. Res. Biogeosci.* 120 (2015).

[36] David M. Barnard, John F. Knowles et al, 'Reevaluating growing season length controls on net ecosystem production in evergreen conifer forests', *Scientific Reports* 8:17973 (December 2018).

[37] Carbon Brief, 'Rising CO2 has 'greened' world's plants and trees' (25 April 2016); https://www.carbonbrief.org/rising-co2-has-greened-worlds-plants-and-trees.

3 Forests in the climate agreements

3.1 Reporting and accounting for forest carbon stocks and emissions

Given the importance of forests to climate change, both as carbon sinks and sources of emissions, it has long been recognised that some form of measuring and accounting for changes in forest area should be included in the international climate agreements. Article 4 of the UN Framework Convention on Climate Change (UNFCCC), agreed in 1992, includes the commitment to promote the sustainable management, conservation and enhancement of sinks of greenhouse gases, including biomass, forests and oceans, and other terrestrial, coastal and marine ecosystems. It also includes the commitment of all parties to publish national inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases. This includes inventories of emissions and removals from land use, land use change and forestry (LULUCF). Annex I (developed) countries submit national inventory reports annually, while developing countries include their inventories in their national communications, which all parties must submit every four years, and a summary in their biennial update reports. Guidelines for these reports have been developed and are periodically updated.[38]

Simple to describe, this reporting of emissions from the LULUCF sector is challenging to carry out in practice. As discussed in Section 2, the size of forest carbon stocks is very difficult to estimate. Annual changes in stocks of carbon are relatively small compared with the total size of the stock; a small uncertainty in assessing a change in the carbon stock can thus result in a large uncertainty in assessing the annual change in emissions. In addition it is often difficult, and sometimes impossible, to distinguish changes that occur naturally – for example from forest fires, droughts or disease – from those caused by human activity, though the UNFCCC and the Kyoto Protocol deal only with anthropogenic emissions and removals.

This is particularly important when it comes to *accounting* for changes in sinks and emissions against climate targets relative to a baseline period, as in the Kyoto Protocol – as opposed to simple *reporting* not connected to a target or baseline – since it is human activity that climate regulation is attempting to influence. For example, if a country were to choose a baseline year during which its forests had been particularly badly affected by natural disturbances, it could then gain considerable credits from natural forest regrowth, reducing the incentive to cut its emissions from energy or industrial uses.

Against this background, the IPCC and parties to the UNFCCC and Kyoto Protocol have engaged in a long and continuing effort to account accurately for changes in forest carbon (and other elements of the LULUCF sector) and create incentives for increasing, or at least avoiding reducing, the size of the forest carbon sink, and also to promote the wider use of wood products (to replace, e.g., concrete, plastics and metals in

[38] 'Reporting of the LULUCF sector by Parties included in Annex I to the Convention'; https://unfccc.int/topics/land-use/workstreams/land-use--land-use-change-and-forestry-lulucf/reporting-of-the-lulucf-sector-by-parties-included-in-annex-i-to-the-convention. The national inventory reports are available at https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2018.

buildings) while at the same time avoiding opportunities to dilute national climate goals.[39] Arguments have been put forward, mainly by NGOs, that carbon sinks such as forests should not be included at all in accounting, or accounted for in separate pillars from other sectors, but so far they remain in the accounting frameworks.

This discussion continues under the Paris Agreement, signed in 2015. All parties to the agreement, whether developed or developing countries, are required to prepare Nationally Determined Contributions (NDCs) setting out their commitments to reduce greenhouse gas emissions and their plans for meeting these commitments. These NDCs may include actions to increase carbon sinks in the LULUCF sector (see further below), and the most recent climate conference (CoP-24), in Katowice in December 2018, agreed a set of rules for the details required to be included (except for the rules governing a possible market mechanism, possibly including forest-related activities, where agreement was not possible and the discussion was postponed to 2019). This includes measures relating to consistency of scope and coverage, definitions, data sources, metrics, assumptions and methodological approaches, and the provision that once a source, sink or activity is included in the NDC, it should continue to be included in the future – implying that once carbon sinks and emissions from forests are included in an NDC, they must continue to be measured and, accordingly, managed.[40] This may help to resolve some of the problems identified above in Section 2.1, including the difficulties in measuring emissions and sinks and distinguishing between anthropogenic actions and natural impacts.

3.2 Forests in the Paris Agreement

Article 5 of the Paris Agreement encourages parties to pursue various actions in regards to forests:

1. Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d), of the Convention [the UNFCCC], including forests.
2. Parties are encouraged to take action to implement and support, including through results-based payments, the existing framework as set out in related guidance and decisions already agreed under the Convention for: policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries; and alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivising, as appropriate, non-carbon benefits associated with such approaches.

[39] For a good summary, see Joachim H. A Krug, 'Accounting of GHG emissions and removals from forest management; a long road from Kyoto to Paris', *Carbon Balance and Management* 13:1 (2018). For a longer discussion of the issues, see Sandro Federici, Donna Lee and Martin Herold, 'Forest Mitigation: A Permanent Contribution to the Paris Agreement?' (Climate and Land Use Alliance, October 2017).
[40] 'Proposal by the President – Informal compilation of L-documents, Version 15/12/2018 19:27', Annex II, paras 2 and 3; https://unfccc.int/sites/default/files/resource/Informal%20Compilation_proposal%20by%20the%20President_rev.pdf.

As noted above, parties to the agreement are required to submit NDCs outlining their commitments, targets and plans of action.[41] For all countries other than the least developed and small island developing states, these must include baselines against which their commitments can be measured. Sections 4 and 5 of this paper review the possible options countries face for forest-related actions on mitigation and adaptation; the remainder of this section looks at what parties have so far committed to in their NDCs. Mostly these were included in the intended NDCs (INDCs) submitted in the run-up to the Paris conference in December 2015, which became NDCs once the party concerned had ratified the agreement; submission of new or updated NDCs (under the new rulebook) is next due by 2020.

By November 2018 181 of the (so far) 184 parties to the Paris Agreement had submitted their first NDC and one party its second. Eighty per cent of the NDCs include LULUCF-related actions in their commitments to mitigation and 58 per cent include specific policies and measures for forestry.[42] A lack of concrete information on approaches and methods for accounting emissions and removals from land-use categories, however, makes it difficult to compare these commitments and derive an overall estimate of the potential global impact (the new rulebook may help to resolve this). Only a small number (17 per cent) include a measurable LULUCF target. The most frequently referenced policies and measures are afforestation/reforestation, forest management and a reduction in deforestation. Several developing countries' targets are conditional on the receipt of adequate financial assistance.

Fifty-nine per cent of the NDCs refer to forestry in climate adaptation plans and 12 per cent include specific adaptation measures for the forestry sector, though in general quantitative targets against which adaptation measures could be judged are not included. The synergies between adaptation and mitigation are frequently highlighted.

As noted above, there is a wide degree of variation of the way in which forest-related targets are included in the NDCs. They may be fully included in the country's overall emissions target, partially included through different accounting rules, or considered separately with special mitigation actions. Estimated abatement costs for forest-related mitigation activities are highly uncertain, ranging from less than $1 to over $800 per tonne.

Ignoring these problems and attempting to measure the impact of the aggregated commitments (using a range of assumptions), one analysis of the full implementation of the NDCs (conditional and unconditional) estimated they would lead to a reduction in net LULUCF emissions by 0.5 ± 0.3 Gt CO_2e per year by 2020 and 0.9 ± 0.4 Gt CO_2e per year by 2030, both compared to 2010 levels (see Figure 3.1).[43] Net LULUCF emissions fall to a total of 2.0 – 2.6 Gt CO_2e per year by 2030, about half of projected emissions under business as usual (3.7 – 5.1 Gt CO_2e per year). (Four countries – the Democratic Republic of the Congo (DRC), Indonesia, the US and the Russian Federation – together account for about 70 per cent of the substantial increase in projected business-as-usual global LULUCF emissions by 2030.)

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[41] Available at https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx.

[42] Information on this section drawn from Nicklas Forsell et al, 'Assessing the INDCs' land use, land use change, and forest emission projections', *Carbon Balance and Management* 11:26 (2016); Giacomo Grassi et al, 'The key role of forests in meeting climate targets requires science for credible mitigation', *Nature Climate Change* 3227 (February 2017); *Sectoral implementation of nationally determined contributions: Forestry and land-use change* (NDCs) (GIZ, May 2017); Lee and Sanz, *UNFCCC Accounting for Forests*; Krug, 'Accounting of GHG emissions and removals from forest management'.

[43] Forsell et al, 'Assessing the INDCs' land use, land use change, and forest emission projections'.

Detailed analysis of the NDCs show that the largest absolute reductions, compared to business as usual, are expected from Indonesia (mainly from a reduction in deforestation and reduced emissions from peat oxidation) and the US (though avoiding the projected business-as-usual reduction in the carbon sink), followed by Brazil (through implementation of the Forest Code and achieving zero illegal deforestation in the Amazon), China (mainly through afforestation), Ethiopia (through an increase in the forest carbon stock and forest land protection), Gabon (through governance improvements and more coherent planning) and DRC (through afforestation and reforestation measures). Together, these parties account for about 84 per cent of the total global expected reduction in net LULUCF emissions by 2030. At the global level, the LULUCF sector is expected to contribute as much as 20 per cent of the full mitigation potential of all the conditional and unconditional NDC targets.

Fig 3.1 Business-as-usual (red) and NDC (green) projections of global net LULUCF emissions to 2030[44]

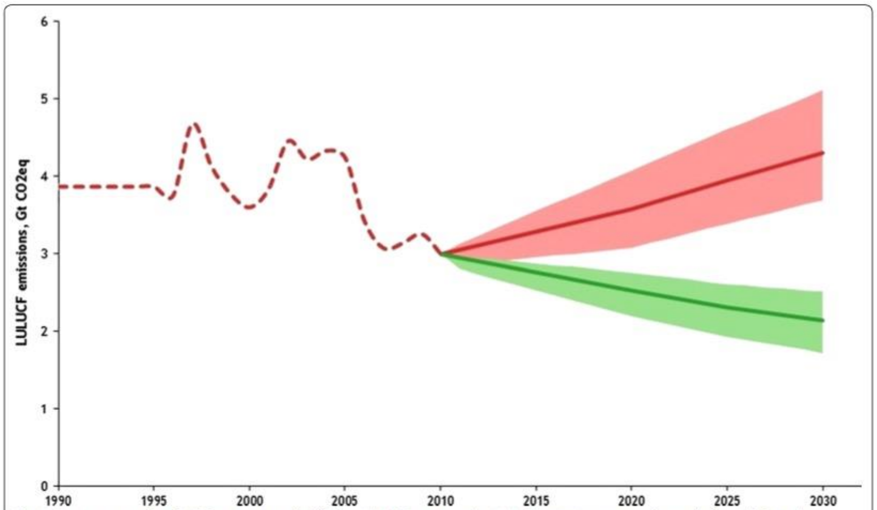


Fig. 2 Business-as-usual and INDC projections of global net LULUCF emissions. Net LULUCF emissions expected to result from INDC implementation, compared to national business-as-usual projections based on official national data as provided in the INDCs [1] and National Communications [2]

Another analysis, taking into account projected growth in national carbon sinks as well as the expected fall in LULUCF emissions, estimated that implementation of the NDCs would turn the LULUCF sector globally from a net anthropogenic source in 1990–2010 (estimated at 1.3 ± 1.1 CO_2e per year) to a net sink by 2030 (up to −1.1 ± 0.5 CO_2e per year), and together provide about a quarter of total emission reductions planned in countries' NDCs.[45] Given the large uncertainties around how parties estimate and account for their emissions and removals from the LULUCF sector, however, considerably more information will be required in future NDC submissions for a proper evaluation.

3.3 The climate agreements and the UN Strategic Plan for Forests

As can be seen from the summary in Section 1, the Global Forest Goals of the UN Strategic Plan for Forests are directly relevant to the achievement of climate mitigation and adaptation targets. Specific policies and

[44] Source: ibid.

[45] Grassi et al, 'The key role of forests in meeting climate targets requires science for credible mitigation'.

measures are explored in detail in Sections 4 and 5. Since the adoption of the UNSPF in April 2017, countries have been encouraged to bring these together by publishing ‘voluntary national contributions’, or VNCs, aimed at achieving the Global Forest Goals and targets.

By January 2019, ten countries (Ecuador, Ghana, Guatemala, Jamaica, Liberia, Madagascar, Morocco, New Zealand, Slovak Republic and Ukraine) had done so.[46] A wide range of measures and targets were featured, including targets for reductions in emissions, the restoration of degraded forests and the planting of new trees; measures to strengthen the frameworks for sustainable forest management, the establishment of community forestry, the improvement of the protection of land rights and tenure; the implementation of forest monitoring and timber tracking systems; and commitments to provide finance, either from domestic or international sources. Explicit links are made to the UNSPF Global Forest Goals, and also often to international frameworks and agreements such as the Paris Agreement, the Sustainable Development Goals and the Aichi Biodiversity Targets of the Convention on Biological Diversity.

[46] Available at https://www.un.org/esa/forests/documents/un-strategic-plan-for-forests-2030/vncs/index.html.

4 Forests and climate mitigation

Countries aiming to mitigate climate change – i.e. reduce greenhouse gas emissions or increase their rate of absorption into carbon sinks – through actions related to forests face several different options, most of which are reflected in the UNSPF Global Forests Goals (see box).

Global Forest Goals relevant to climate mitigation

1. Reverse the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of addressing climate change.

    1.1 Forest area is increased by 3 per cent worldwide.

    1.2 The world's forest carbon stocks are maintained or enhanced.

    1.3 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.

    …

3. Increase significantly the area of protected forests worldwide and other areas of sustainably managed forests, as well as the proportion of forest products from sustainably managed forests.

    …

    3.3 The proportion of forest products from sustainably managed forests is significantly increased.

Many other international declarations have been made with similar objectives. These include, for example, the New York Declaration on Forests, agreed at the UN Climate Summit in September 2014;[47] progress against the Declaration's targets is monitored by the NYDF Assessment Partners, an independent network of civil society groups and research institutions, with the goal of producing annual evaluations of progress toward meeting the goals.[48] Most recently, the Katowice Declaration on Forests for Climate, which was endorsed at the meeting of the parties to the UNFCCC and the Paris Agreement in December 2018, acknowledged that: 'forests are a key component to achieve the goals of the Paris Agreement'.[49] It underscores the key role forests must play in limiting temperature rise to 1.5˚C, and highlights the need to reduce emissions from deforestation and forest degradation, mindful of concerns about equity, sustainability and efforts to eradicate poverty; though unlike the UNSPF Global Forest Goals and the New York Declaration, it does not contain any quantified targets.

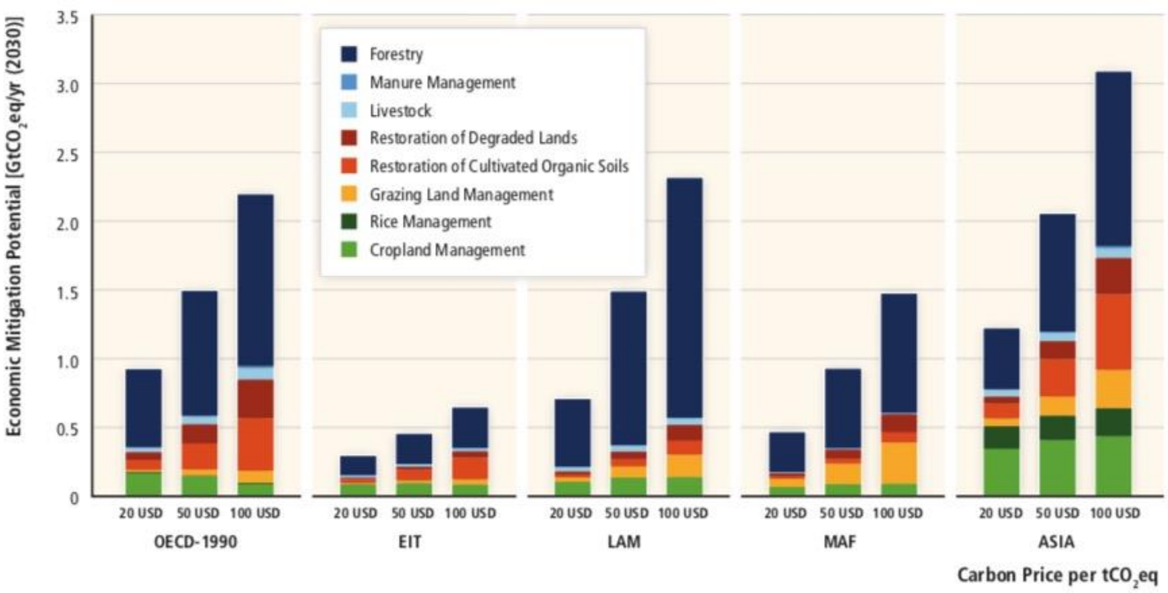
The main forest-related mitigation options are reviewed in the rest of this section: reducing pressures on forests through the various REDD+ initiatives (Section 4.1), and, more specifically, from agriculture, the main global driver of deforestation (4.2); promoting sustainable forest management (4.3); increasing the area of forests through reforestation, afforestation and forest landscape restoration (4.4); increasing the

[47] See https://nydfglobalplatform.org.
[48] See http://forestdeclaration.org
[49] Available at
https://cop24.gov.pl/fileadmin/user_upload/Ministerial_Katowice_Declaration_on_Forests_for_Climate_OFFICIAL_ENG.pdf.

value of forests through expanding markets for wood products (4.5); and using wood for bioenergy – though here current policy developments may have the potential to accelerate rather than mitigate climate change (4.6).

Several studies have attempted to estimate the scale of potential mitigation options. In 2014, the IPCC estimated ranges of mitigation potentials for different carbon prices of: 0.01 – 1.45 $GtCO_2e$ (at a carbon price of up to US$20/$tCO_2e$); 0.11 – 9.5 $GtCO_2e$ (at up to US$50/$tCO_2e$); and 0.2 – 13.8 $GtCO_2e$ (at up to US$100/$tCO_2e$); as can be seen, these are very wide ranges. Figure 4.1 shows the IPCC's regional breakdown based on 2007 studies (including mitigation potentials from agriculture); in the two regions mostly comprising industrialised countries (OECD and EIT in Figure 4.1), the majority of the potential emissions savings derived from forest management, with most of the rest from afforestation; in the Latin American and Middle East and Africa regions, avoiding deforestation was the main contributor; and in the Asia region, all three components – forest management, afforestation and avoiding deforestation – were significant.

Fig. 4.1 Economic mitigation potentials in the Agriculture, Forests and Land Use (AFOLU) sector by region[50]



A more recent calculation of the potential of forest-related climate mitigation options is summarised in Figure 4.2, taken from a paper published by the Climate Land Ambition and Rights Alliance in 2018.[51] This argued that the top priority should be avoiding further loss and degradation of primary forests, protecting and restoring peatlands and protecting grasslands; together these measures could avoid emissions of 6.1 Gt CO_2eq a year (compared to total global emissions, in 2017, of 53.5 $GtCO_2e$), and roughly equal to current levels of emissions from land-use change (see Table 2.3 in Section 2.1).

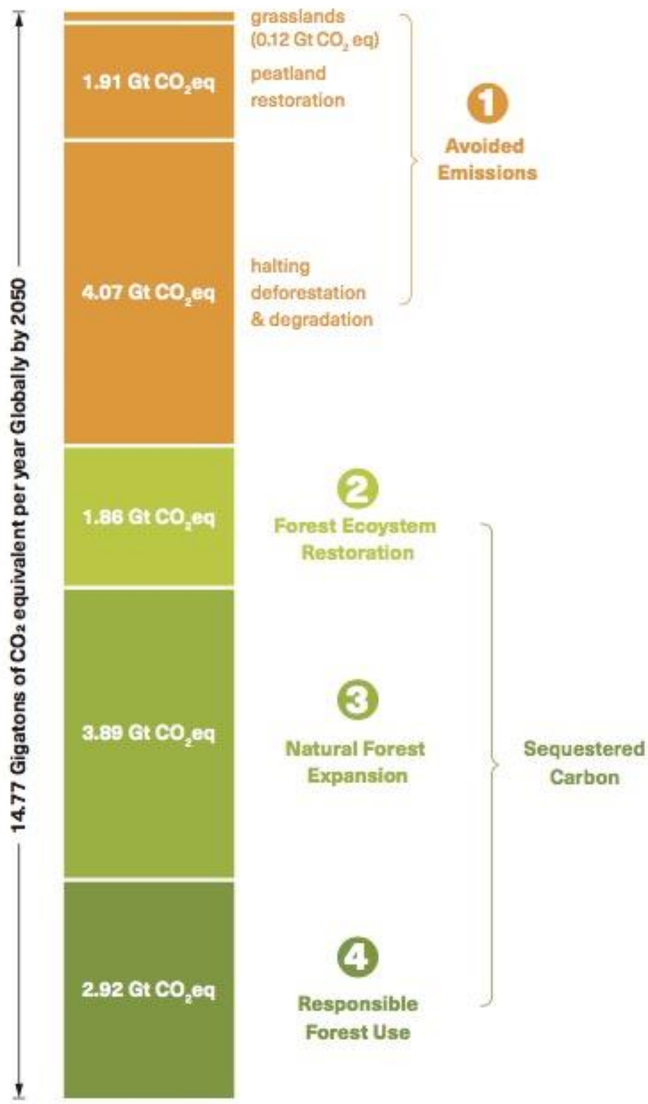
[50] Source: O. Edenhofer et al, *Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 2014).

[51] Kate Dooley et al., *Missing Pathways to 1.5°C: The role of the land sector in ambitious climate action* (Climate Land Ambition and Rights Alliance, 2018). See also Bronson W. Griscom et al, 'Natural climate solutions', *PNAS* 16 October 2017.

Forest ecosystem restoration, involving restoring one-quarter of degraded natural forest cover globally (600 million hectares) would restore primary forest characteristics, increasing the area of primary forests to 50 per cent of the global forest area, and increase the size of the global carbon sink by an estimated 1.9 $GtCO_2e$ per year. Promoting the expansion of natural forests (as opposed to planting monoculture tree plantations), aiming to restore 350 million hectares by 2030, would absorb a further 3.9 $GtCO_2e$ per year.

Finally, ensuring the responsible use of forests, including improved management for timber, non-timber forest products, and ecological values, lengthening rotation times and reducing harvest rates, could lead to significant increases in forest carbon stocks and biodiversity in temperate and boreal production forests. In tropical forests, responsible use was assumed to mean no commercial extraction of timber, given that over 50 per cent of biomass in those forests resides in valuable hardwood trees that take centuries to regrow. This would absorb a further 2.9 $GtCO_2e$ per year.

Fig 4.2 Climate mitigation potential of forest-related climate mitigation options[52]



These last three categories of measures together results in an increase in the carbon sink of 8.67 $GtCO_2e$ (2.37 GtC) per year, about two-thirds of the 2017 total terrestrial sink (see Table 2.3 in Section 2.1). Adding all the measures together results in net global emissions falling by 14.8 $GtCO_2e$ (about 4 GtC) per year by 2050, equivalent to more than a quarter of current global emissions. This can be compared with the impact of the full implementation of the Paris Agreement NDCs discussed in Section 3.2, which estimated a potential reduction in net LULUCF emissions by 0.9 ± 0.4 Gt CO_2e per year by 2030 (the estimates above relate to 2050).

Unlike the IPCC report, the study did not attempt any economic analysis, but argued that many of the mitigation options it outlined would be relatively low cost. It should be noted, however, that many of these

[52] Source: Dooley et al., *Missing Pathways to 1.5°C*.

activities, including in particular forest ecosystem restoration and natural forest expansion, are assumed to take place in tropical forests, currently areas which are characterised by poor levels of forest governance and weak law enforcement. Implementing the type of measures discussed below in Section 6.2 is therefore of vital importance, as well as the provision of financial support, as discussed in Section 6.1.

4.1 Reducing pressures on forests: REDD+

Clearly, the starting point for forest-related climate mitigation options should be to reduce the pressures on existing forests. For most of the last ten years, the bulk of climate-related forest spending by both donors and forest countries has been devoted to a set of activities initially called 'reducing emissions from deforestation' (RED) and now expanded to 'reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries' (REDD+).[53]

REDD+ is a simple concept which is proving difficult in practice to implement. It is intended to act as a performance-based mechanism, encouraging countries to reduce emissions from deforestation and forest degradation through creating a financial value for the carbon stored in forests, thus offering incentives to keep trees standing and increasing the opportunity costs of deforestation, counteracting the drivers of deforestation such as conversion for agriculture. First introduced to the climate change negotiations in 2005, by the Coalition of Rainforest Nations, the concept formed part of the UNFCCC's Bali Action Plan agreed in 2007, which included the aim of: 'halting forest cover loss in developing countries by 2030 at the latest and reducing gross deforestation in developing countries by at least 50 per cent by 2020 compared to current levels'.[54]

Issues such as the scope of the concept, means of measuring, reporting and verifying emissions, the rights of indigenous peoples, and financing and institutional arrangements were debated over the following years, culminating in the Warsaw Framework for REDD+, agreed in 2013.[55] Under the Framework, in order to qualify for results-based finance, a developing country must have in place the following elements:

- A national strategy or action plan for reducing forest-based emissions.
- A system for monitoring and reporting forest cover change and associated emission reductions.
- A baseline (reference level) against which progress in reducing emissions will be measured.
- A safeguards information system for reporting on how measures to protect against environmental and social harm are being implemented.

Support is made available in three phases:

1. 'Readiness' activities, including building stakeholder capacities, developing measuring, reporting and verification systems, and supporting increased understanding of drivers of deforestation and the development of national strategies.

[53] Definition taken from Bali Action Plan (UNFCCC Decision 1/CP13), para 1 (b) (iii).
[54] Ibid.
[55] See https://unfccc.int/topics/land-use/resources/warsaw-framework-for-redd-plus.

2. The investment phase, scaling up policies and measures designed to address the direct and indirect drivers of deforestation and forest degradation.
3. Performance-based payments for verified reductions in emissions.

Donor countries have to date pledged billions of dollars to developing countries for REDD+ activities (see further in Section 6.1). Most has been dedicated to the first two phases. Among other outcomes, this has assisted in the development of forest monitoring capacities, a prerequisite for evidence-based forest policy; to date 39 countries, accounting for about 70 per cent of the forest area in developing countries, have submitted a forest, or forest emissions, reference level, most at the national level.[56]

Progress with the third phase has been slower. According to the REDD+ Web Platform maintained by the UNFCCC, just four countries – Brazil, Colombia, Ecuador and Malaysia – have reported verified reductions in emissions and only Brazil has reported receiving payments as a result[57] (though since 2016 Colombia has also received payments through the REDD Early Movers Programme jointly funded by Germany, Norway and the UK). The total reduction in emissions reported by these four countries currently amounts to 6.3 $GtCO_2e$ over the ten years from 2006 to 2015 (although only Brazil reported results for all ten years), almost entirely from Brazil. The total verified emissions savings for which Brazil received payments was much smaller, at 0.19 $GtCO_2e$ over the ten years.

The specific activities funded to reduce emissions cover a wide range of measures and vary from country to country; they often take the form of sub-national, or 'jurisdictional', projects. In Colombia, for example, in a programme funded by the REDD Early Movers Programme, the government has committed to increase productivity in the cattle sector and reverse the expansion of pastureland for cattle (currently the main cause of most of the deforestation in the Colombian Amazon); establish public-private partnerships with businesses that are committed to zero deforestation, for commodities including milk, cocoa, coffee and rubber; establish 2.5 million hectares of new protected areas; increase payments for ecosystem services to local communities in rural areas; strengthen indigenous peoples' sovereignty over their territories by supporting their own management plans and assisting in land planning; and strengthen efforts against illegal logging, illegal mining and illegal cultivation.[58]

Similarly, investment from the same programme for the Brazilian states of Acre and Mato Grosso is intended to increase the capacity of local environmental protection authorities; build the capacity and track record of new deforestation-friendly industries, particularly in beef and soy production; help those industries to reach production volumes and standards sufficient to attract capital investment; significantly reduce emissions from deforestation; increase the intensity of agricultural and forest-based production; and strengthen the livelihoods and resilience of the poorest communities.[59]

The first results-based payments from a multilateral institution (as opposed to a bilateral initiative such as the REDD Early Movers Programme) was approved in February 2019, when the Green Climate Fund

[56] See https://redd.unfccc.int/fact-sheets/forest-reference-emission-levels.html
[57] https://redd.unfccc.int/info-hub.html.
[58] See summary at https://www.regjeringen.no/en/topics/climate-and-environment/climate/climate-and-forest-initiative/kos-innsikt/colombia/id2459245/.
[59] Department for Business, Energy and Industrial Strategy (UK), 'International Climate Finance Extension Business Case for Investment in the REDD for Early Movers (REM) Programme' (September 2017); https://aidstream.org/files/documents/REM-Business-Case-Extension-20180322030336.pdf.

allocated US$96.5 million to Brazil for its success in reducing emissions from deforestation in the Amazon region in 2014 and 2015. The Brazilian government has stated that it intends the payments to be used to help implement the country's NDC, including developing a pilot environmental services incentives programme for the conservation and recovery of native vegetation (Floresta+), and strengthening the implementation of the national REDD+ strategy.[60]

Almost all forest-rich developing countries have been involved in various REDD+ programmes and activities. In addition to the development of techniques for the measurement of forest resources and their related emissions, and the verified emissions reductions, mentioned above, impacts have included a general raising of the profile of the need to invest in forests in order to reduce emissions. In general, however, REDD+ programmes have been slower to develop than many of their proponents originally anticipated. Their implementation has faced major methodological, practical and political challenges, including the definition of reference levels; systems of measuring, reporting and verifying reductions in emissions; problems of leakage, where a reduction in deforestation in one area may simply lead to an increase in deforestation in another, and of permanence, the need to guarantee the protection of the trees throughout their growing lifespan; the implementation of safeguards to ensure that REDD+ activities do not negatively effect the benefits forests provide to local communities and indigenous peoples; and governance and law enforcement, the lack of which in many countries can fatally undermine the intentions of REDD+ programmes (see Section 6). While many of these issues are addressed in the Warsaw Framework, operationalising them, particularly in countries with poor standards of forest governance and low levels of capacity, has not proved easy.

On top of this, there is evidence to suggest that REDD+ activities have often failed to engage local stakeholders, such as forest communities or local governments, to drive systemic policy reforms or to change the political economy of the forest sector; in most countries it is still more profitable to replace forests with agriculture than it is to keep them standing.[61] In addition, the flow of private-sector finance from global forest carbon markets that many proponents of REDD+ originally anticipated has so far largely failed to materialise, partly because of the difficulties outlined above and partly because of the failure of any global emissions trading or offset system to emerge under the international climate agreements. At least 90 per cent of the financing pledged to date for REDD+ programmes has derived from public sources.[62] Inevitably, this source is always likely to be limited in scope; and, as discussed in Section 6.1, flows of finance overall are so far inadequate to achieve the objectives of REDD+.

4.2 Reducing pressures on forests: agricultural commodity supply chain initiatives

Another approach to reducing the pressures on forests is to focus on the drivers of deforestation throughout the supply chain, from production to consumption – chiefly agriculture, the main global driver of forest clearance for at least the last two decades. As noted in Section 2.1, a 2018 study estimated that commodity-driven deforestation (mainly, though not only, for agriculture) accounted for 27 per cent of gross global tree cover loss over the period 2001–15, and short-term cultivation of subsistence crops for a

[60] https://www.greenclimate.fund/projects/fp100

[61] See, e.g., Arild Angelsen, 'REDD+: What should come next?' in Scott Barrett, Carlo Carraro and Jaime de Melo, *Towards a Workable and Effective Climate Regime* (CEPR Press, 2015); Wolfram Dressler et al, 'Learning From 'Actually Existing' REDD+: A Synthesis of Ethnographic Findings', *Conservation and Society* 2018.

[62] Marigold Norman and Smita Nakhooda, *The State of REDD+ Finance* (CGD and ODI, May 2015).

further 24 per cent.[63] A detailed study for the European Commission, published in 2013, estimated that 53 per cent of the global deforestation experienced from 1990 to 2008 was due to agricultural expansion.[64] Livestock (mainly cattle) pasture accounted for 46 per cent and crops for animal feed for a further 11 per cent. The remaining 43 per cent was due to crop production, including soybeans (19 per cent), maize (11 per cent), oil palm (8 per cent), rice (6 per cent) and sugar cane (5 per cent). The rapid expansion of soy and palm oil production since 2008 mean that these figures will be under-estimates of the situation today.

In general, the returns earned on investment in agricultural expansion are much greater than in leaving trees standing or managing them for timber production, though it is not always the case that deforestation occurs directly as a result of agricultural expansion. In some cases the land may be converted to agriculture after deforestation has occurred as a result of government policies promoting economic growth or rural development – as has historically been the case, for example, in Brazil.

The increasing liberalisation of trade policy has clearly affected the extent and magnitude of deforestation. Globalised demand allows 'the drivers of deforestation to be mobile' and the 'forces of the market to move them around the world,'[65] creating an ever-increasing incentive to convert forests into more profitable uses. Nevertheless, it is still true that the bulk of deforestation from agriculture is the result of domestic use in the producing country; in the European Commission study, about one-third of the deforestation embodied in crop production, and just 8 per cent of the deforestation embodied in ruminant livestock products, was traded internationally.[66] Oil crops such as soy and palm oil accounted for the majority (almost two-thirds) of the deforestation embodied in exported crop commodities. While South American countries had experienced approximately one-third of total global deforestation, they accounted for almost two-thirds of the global trade in crop products associated with deforestation, largely due to exports of soy, mainly to China.

A significant proportion of clearance of forests for agriculture has been illegal in nature. A comprehensive survey published by Forest Trends in 2014 concluded that 49 per cent of total tropical deforestation between 2000 and 2012 was due to illegal conversion for commercial agriculture. Nearly one quarter (24 per cent) was the direct result of illegal agro-conversion for export markets.[67] Brazil and Indonesia together accounted for 75 per cent of the global area of tropical forest estimated to have been illegally converted for commercial agriculture over this period. In Brazil, where cattle and soy had been the main drivers, at least 90 per cent of deforestation for agriculture in the Amazon was estimated to be illegal. In Indonesia, at least 80 per cent of deforestation for commercial agriculture – mostly palm oil – and timber plantations was estimated to be illegal.

Both private companies and governments have responded to the growing evidence of these impacts of agriculture on deforestation, and have adopted a variety of declarations and commitments to the objective of zero deforestation or zero net deforestation. This includes in particular:

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[63] Curtis et al, 'Classifying drivers of global forest loss'.

[64] European Commission (2013), *The Impact of EU Consumption on Deforestation: Comprehensive analysis of the impact of EU consumption on deforestation*. Technical Report - 2013 – 063. Brussels: European Commission.

[65] Boucher, D., May-Tobin, C., Lininger, K. and Roquemore, S. (2011), *The Root of the Problem: What's Driving Deforestation Today?* Union of Concerned Scientists, 2011), pp. 9.

[66] Unless otherwise noted, all figures in this section: European Commission (2013), pp. 22–36.

[67] Sam Lawson et al, *Consumer Goods and Deforestation: An Analysis of the Extent and Nature of Illegality in Forest Conversion for Agriculture and Timber Plantations* (Forest Trends, September 2014), p. 2.

- The Consumer Goods Forum, which in 2010 adopted a target of achieving zero net deforestation in its membership's supply chains by 2020 for a number of key commodities, including soy, cattle, palm oil and paper and pulp.[68]
- The Tropical Forest Alliance 2020, a global partnership formed in 2012 with the aim of reducing the tropical deforestation associated with the sourcing of commodities such as palm oil, soy, beef, and paper and pulp.[69]
- The New York Declaration on Forests agreed in 2014 includes the commitment to support and help meet the private-sector goal of eliminating deforestation from the production of agricultural commodities by no later than 2020.
- Action by a wide range of individual companies producing, trading and using agricultural commodities. Commitments to eliminate or reduce deforestation in corporate supply chains have become common in companies trading in and using palm oil and cocoa (and timber) in Europe and North America; they are less common for other key commodities such as beef, soy, maize or rubber, though they are beginning to appear.[70] A number of European countries have seen the emergence of industry alliances aimed at ensuring the entire national market is supplied by certified sustainable palm oil by a target date, and some are now emerging on sustainable (or deforestation-free) soy.

The implementation of these commitments rely heavily (though not exclusively) on certification schemes such as those of the Roundtable on Sustainable Palm Oil (RSPO), Round Table on Responsible Soy (RTRS), Rainforest Alliance and others. Consumer goods companies in particular, positioned at the end of the supply chain with no direct relationship to producers, often have little option but to rely on sourcing certified products as the main means of fulfilling their commitments. Uptake of certification schemes has steadily increased; market penetration is highest for timber, palm oil, cocoa, coffee and tea, though much less well developed for beef, soy and other forest risk commodities. In turn this has focused attention on the standards used by the certification schemes and the extent to which they are enforced in practice. Particularly in the case of for palm oil, many companies have started to adopt additional criteria on top of the RSPO standard, the most commonly used, due to concerns over its impact. In turn this is placing pressure on RSPO to revise its principles and criteria to more effectively tackle deforestation.

Some countries have developed and promoted their own national standards in preference to those of external organisations. This includes in particular the Indonesian Sustainable Palm Oil (ISPO) and Malaysian Sustainable Palm Oil (MSPO) schemes; the two countries between them produce about 80 per cent of the global supply of palm oil. In Brazil, local and international companies joined together to impose, from 2006, a moratorium on the purchase of soy grown on lands deforested after July 2006 in the Brazilian Amazon or on farms using indentured or forced labour and, from 2009, a moratorium on the purchase of cattle from ranches on recently deforested and indigenous land.

Action by governments has so far been less common than action by companies. The Malaysian state of Sabah is something of an exception, having committed in 2015 to achieve RSPO certification for all crude

[68] https://www.theconsumergoodsforum.com/initiatives/environmental-sustainability/key-projects/deforestation/
[69] https://www.tfa2020.org
[70] http://supply-change.org/

palm oil produced within the state by 2025.[71] A number of regions and districts in Indonesia are working with RSPO towards similar targets, recognising possible weaknesses in the ISPO scheme and its lack of recognition by companies and governments outside Indonesia.

Action by consumer countries has also so far been limited mainly to the provision of development aid to support deforestation-free agriculture, both through bilateral programmes such as the UK's Partnerships for Forests programme, which mainly supports a series of public-private partnerships, and multilateral initiatives such as the World Bank's BioCarbon Fund Initiative for Sustainable Forest Landscapes. Two examples of REDD+ projects tackling agricultural drivers of deforestation, in Colombia and Brazil, are mentioned above in Section 4.1. Some European governments, however, are beginning to use demand-side measures to promote markets for sustainable, or deforestation-free, commodities, sometimes through joint action with industry, and to exclude particular commodities from their procurement policies or regulations governing biofuels (a major source of demand for palm oil and soybean oil, and biodiesel made from these feedstocks). Examples include the UK (on palm oil and soy), Belgium (cocoa) and Norway (palm oil); at the EU level, sustainability criteria for transport biofuels are still being finalised which seem likely to restrict the market for palm oil and soy.

In March 2018 the European Commission published a feasibility study on options for the EU and its member states to tackle the EU's impact on global deforestation.[72] Proposals included greater support for deforestation-free agriculture in producer countries, the wider use of public procurement policy in EU member states, the adoption of a due diligence regulation for forest risk commodities, and greater scrutiny of investments in agriculture in producer countries. In November 2018 the Commission announced that it would publish specific proposals for a way forward in the second quarter of 2019. This was partly thanks to pressure from the Amsterdam Declaration Partnership, a group of European countries aiming to promote and coordinate action on sustainable commodity supply chains.

In November 2018 the French government published an action plan to deal with imported deforestation, including proposals to stop importing products linked to deforestation and unsustainable agriculture by 2030, to help companies meet their own deforestation goals and to encourage financiers to take environmental and social issues into account for investment decisions.[73]

4.3 Sustainable forest management

As well as reducing the pressures on forests from alternative uses of the land such as agriculture, any strategy for increasing carbon uptake by forests and reducing the rates of deforestation and forest degradation must also include sustainable management of existing forests. The idea of sustainable forest management (SFM), an attempt to reflect the environmental and social as well as economic benefits provided by forests, become widely accepted after the UN Conference on Environment and Development

[71] John Payne, 'Introduction to Sabah Jurisdictional Approach for Sustainable Palm Oil Production' (Sabah Jurisdictional Certification Steering Committee, 2016), http://rt14.rspo.org/ckfinder/userfiles/files/PC4_4_2%20Datuk%20Dr%20John%20Payne.pdf.

[72] See http://ec.europa.eu/environment/forests/studies_EUaction_deforestation_palm_oil.htm.

[73] Ministère de la Transition Écologique et Solidaire, *Stratégie Nationale de Lutte Contre la DéForestation Importée 2018–2030* (November 2018); https://www.ecologique-solidaire.gouv.fr/sites/default/files/2018.11.14_SNDI_0.pdf.

in 1992 (the 'Earth Summit' in Rio de Janeiro), which first saw international commitment to the concept of sustainable development more broadly.

SFM covers a wide range of issues; as defined by Forest Europe, and since adopted by the FAO; it is:

> The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems.[74]

The UN Forest Instrument (formerly known as the Non-Legally Binding Instrument on All Types of Forests), agreed under the auspices of the UN Forum on Forests (UNFF) in 2007, identifies seven key thematic elements of SFM: extent of forest resources, biological diversity, forest health and vitality, productive functions of forest resources, protective functions of forest resources, socio-economic functions, and the legal, policy and institutional framework.[75] More precise definitions of SFM inevitably vary from region to region, since the types of forests, the needs of the populations who live in and around them, and the social, economic, environmental and political contexts in which their protection and management are set also vary regionally. This has led to a series of processes to define principles, criteria and indicators for SFM for particular regions, including, for example, those of the African Timber Organisation, the International Tropical Timber Organisation (ITTO), the Montreal Process on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests, and the Pan-European Forest Process on Criteria and Indicators for Sustainable Forest Management (the Helsinki Process of Forest Europe).

(It is worth noting that the term 'sustainable management of forests' used in the REDD+ context (see Section 4.1) is not quite the same as what is normally meant by SFM, focusing as it does on the application of forest management practices for the primary purpose of sustaining constant levels of carbon stocks over time.[76] There has been much debate over the extent to which the REDD+ approach provides adequate incentives for the other – primarily economic and social – elements of SFM.)

Beyond these overarching global and regional agreements and documents, the concept of SFM has been incorporated very widely in national legislation, action plans and procurement policies, development assistance programmes and projects, business strategies, NGO campaigns and forest certification schemes, with detailed definitions often being drawn from these international processes. Although it is undoubtedly true that the concept of SFM may be appealed to more frequently than it is implemented in reality, it has had a major impact on policy-making and practices relevant to the world's forests.

Managing forests to maximise carbon uptake and carbon storage, however, is not necessarily the same as SFM techniques used to maximise production for high-quality commercial wood products, which is the context in which they are normally applied. In fact the literature displays little consensus on the most appropriate regime for maximising carbon uptake and mitigating climate change.

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[74] 'General Guidelines for the Sustainable Management of Forests in Europe' (Resolution H1 of the Second Ministerial Conference on the Protection of Forests in Europe, 16–17 June 1993, Helsinki), para D; available at http://www.mcpfe.org/files/u1/helsinki_resolution_h1.pdf

[75] Food & Agriculture Organisation, *State of the World's Forests 2007* (FAO, 2007), p. 3.

[76] 'Sustainable management of forests and REDD+: Negotiations need clear terminology' (FAO, nd).

What is probably the most widely accepted view is that active forest management enhances carbon uptake, both because the rate of carbon uptake slows as forests mature, net primary productivity declines and natural mortality increases, and also because unmanaged forests increase the chance of massive carbon losses from disturbances such as fire, insects or disease infestations.[77] Harvesting mature trees and replanting should therefore increase the rate of carbon uptake, as well as generating timber for wood products.

Other studies suggest, however, that this is not necessarily true, particularly in old-growth forests, though it may be in plantations (possibly because of lower soil nutrient availability in plantations compared to natural forests). Many studies have shown that mature trees absorb more carbon than younger trees, mainly because of their much higher number of leaves, which enable greater absorption of carbon dioxide from the atmosphere.[78] As a 2014 study concluded, 'for most species mass growth rate increases continuously with tree size. Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree.'[79] While there will be a difference between the carbon sequestration rate of individual trees versus the entire forest, a 2008 study concluded that: 'in forests between 15 and 800 years of age, net ecosystem productivity (the net carbon balance of the forest including soils) is usually positive.'[80] The higher rate of carbon uptake of older trees is only partially offset by their higher mortality rates, and it should be possible to reduce this by management for conservation, e.g. by removing diseased or dead trees.

This conclusion is supported by other studies suggesting that, far from accelerating carbon uptake, harvesting may in fact bring it to a temporary halt. One study reviewing the impacts of forest disturbances (including harvesting, fires, storms and insect infestation) throughout the US concluded that in most cases the forest did not return to its status as a carbon sink for at least 10, and sometimes as much as 20, years, partly due to the large soil carbon losses associated with the event.[81] (The impacts are likely to be much larger for clear-cutting than for selective felling.) Similarly, a model-based study of forest carbon storage in the north-eastern US compared different types of forest management and concluded that the highest rate of carbon uptake and storage was achieved simply by leaving the forest alone: 'The results supported both our first hypothesis that passive management sequesters more carbon than active management, as well as our second hypothesis that management practices favouring lower harvesting frequencies and higher structural retention sequester more carbon than intensive forest management.'[82]

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[77] See, e.g., Hektor, B., Backéus, S. and Andersson, K., 'Carbon balance for wood production from sustainably managed forests', *Biomass and Bioenergy*, 93 (2016), or the studies reviewed and summarised in 'Maximising carbon storage through sustainable forest management' (American Hardwood Export Council, nd).
[78] See, for example, Luyssaert, S. et al, 'Old-growth forests as global carbon sinks', *Nature,* 455 (2008); Lewis, S. et al, 'Increasing carbon storage in intact African tropical forests', *Nature,* 457 (2009); Bellassen, V. and Luyssaert, S., 'Carbon sequestration: Managing forests in uncertain times', *Nature,* 506 (2014); Stephenson, N. L. et al, 'Rate of tree carbon accumulation increases continuously with tree size', *Nature* 507 (2014); Craggs, G., *The Role of Old-Growth Forests in Carbon Sequestration* (Future Directions International, 2016). Over 60 studies showing the same phenomenon are summarised in 'Forests (Growth Rates of Old vs. Young Trees) – Summary', *CO2 Science* (2014).
[79] Stephenson, 'Rate of tree carbon accumulation increases continuously with tree size'.
[80] Luyssaert, 'Old-growth forests as global carbon sinks'.
[81] Amiro, B. D. et al, 'Ecosystem carbon dioxide fluxes after disturbance in forests of North America', *Journal of Geophysical Research*, 115 (2010)).
[82] Nunery, J.S., and Keeton, W.S., 'Forest carbon storage in the northeastern United States: Net effects of harvesting frequency, post-harvest retention, and wood products', *Forest Ecology and Management*, 259:8 (2010).

Similarly, a recent study of carbon storage in forests in the US state of Oregon concluded that lengthening harvest cycles on private lands and restricting harvesting on public lands, together with reforestation and afforestation, had the potential to increase the net ecosystem carbon balance by 56 per cent by 2100, with the first two actions contributing the most.[83] (Co-benefits included improved water availability and a greater range of biodiversity, primarily from increased forest area, age, and species diversity.) SFM strategies may therefore need to be adapted to incorporate management practices primarily aimed at enhancing forest carbon stocks rather than producing production-grade timber – e.g. silvicultural treatments (tending operations, enrichment of gaps, etc.), species selection, modification of rotation cycles, planting densities, and thinning frequencies. This of course needs to be balanced against measures designed to encourage the greater use of wood products (see below, Section 4.5), but the Oregon study concluded that increasing forest carbon stocks on public lands would reduce emissions more than storage in wood products, since the residence time is more than twice that of wood products.[84]

On the other hand, a recent study of European forests using a complex computer model to calculate the amount of carbon, energy and water trapped or released by managing a forest, concluded that any climate benefits from carbon sequestration through forest management could be reinforced, counteracted or offset entirely by concurrent changes in surface albedo, land-surface roughness, emissions of biogenic volatile organic compounds, transpiration and sensible heat flux, meaning that forest management could offset carbon emissions without actually halting global temperature rise.[85] Examining a number of different pathways, the study concluded that managing forests with the objective of reducing near-surface air temperature, primarily by converting evergreen to deciduous forests, would also reduce the atmospheric carbon growth rate, though not by much, and would also reduce the wood available for harvest.

It is, accordingly, difficult to reach firm conclusions about the appropriate form of forest management to maximise carbon uptake and storage; and in any case these are likely to vary with the type of forest, ecosystem and local climate.

4.4 Increasing forest cover

Alongside managing existing forests more sustainably, measures can be taken to increase the area of forest cover and, therefore, the global carbon sink. The UNSPF Global Forest Goals, the New York Declaration and the Sustainable Development Goals all call for, and in some cases set targets for, increasing forest area, Global Forest Goal 1.1 by 3 per cent worldwide by 2030. Accordingly, increasing attention is being paid in many countries to strategies for reforestation (defined by FAO as the re-establishment of forest through planting and/or deliberate seeding on land classified as forest), afforestation (the same activities, taking place on land that, until then, was not classified as forest), and the restoration of degraded forests.

Such initiatives have a long history. In the 1930s and 1940s nearly 3 billion trees were planted in the US by the Civilian Conservation Corps, one of the public works relief programmes established under the New Deal in the wake of the Great Depression. A more recent example is the Green Belt Movement, founded

[83] Beverly E. Law et al, 'Land use strategies to mitigate climate change in carbon dense temperate forests', *PNAS* 115:14 (April 2018).
[84] Ibid.
[85] Sebastiaan Luyssaert et al, 'Trade-offs in using European forests to meet climate objectives' *Nature* 562 (2018).

by Nobel laureate Wangari Maathai in 1977, which saw 51 million trees planted in Kenya. In Korea, a massive tree-planting programme by national and local governments added 11 billion trees between 1961 and 2008. In Tanzania, the Kwimba Reforestation Project in the 1990s resulted in 6.4 billion trees planted to replace tree cover lost due to local use for firewood. The Great Green Wall for the Sahara and Sahel Initiative, proposed by the African Union in 2007, aims to plant a 15 km-wide 7,700 km-long barrier of trees across the continent to halt the advance of the Sahara and to reverse the spread of desertification through the Sahel region. So far it is claimed that 15 per cent of the trees have been planted, largely in Senegal, with 4 million hectares of forest land restored. In 2018 New Zealand announced a target of planting 1 billion trees over the next ten years, representing a doubling in the current commercial replanting rate.

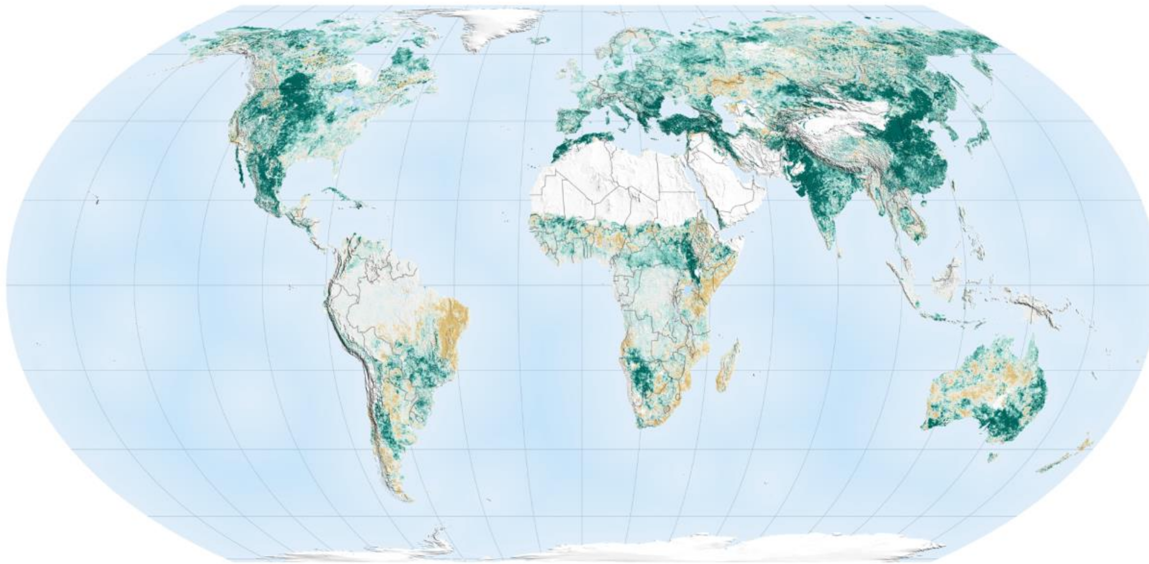
Inspired by Wangari Maathai's example, in 2006 the UN Environment Programme (UNEP) launched its Billion Tree Campaign. Its initial target was the planting of one billion trees in 2007, which was achieved by November that year. One year later, in 2008, the campaign's objective was raised to 7 billion trees by the time of the Copenhagen climate change conference in 2009; that target was achieved three months before the conference. In December 2011, after more than 12 billion trees had been planted, UNEP formally handed management of the programme over to the Plant-for-the-Planet Foundation.[86] As of December 2018, over 15 billion trees had been planted, and the Foundation has now set a target of 1,000 billion trees by 2050.

China has seen the largest and most sustained programme of reforestation and afforestation, after the devastating Yangtze River floods in 1998 highlighted the dangers of deforestation. The country gradually introduced strict bans on logging in primary forests, a massive programme of expansion of forest reserves, and large-scale afforestation initiatives. For many years China has accounted for more afforestation than the rest of the world combined; on average 5 million hectares has been planted each year, resulting in an increase in forest cover of 9 per cent over the past 30 years. China is now home to about 79 million hectares of planted forest, more than a quarter of the world's total. For the period 2016–20 the government aims to increase forest cover further, from 21.7 per cent of land area to 23 per cent. A recent study concluded that China and India together had accounted for a third of the increased greening of the Earth's surface that has been observed over the last two decades (which in total account for a 5 per cent increase in global leaf area since 2000), even though they represent just 9 per cent of the planet's land area (see Figure 4.3).[87] In China, 42 per cent of the increase in leaf area has been due to forest programmes, and 32 per cent to agricultural expansion and intensification (whereas 82 per cent of the increase in leaf cover in India is due to agriculture).

[86] See https://www.plant-for-the-planet.org/en/home.

[87] Chi Chen et al, 'China and India lead in greening of the world through land-use management', *Nature Sustainability*, 11 February 2019.

Fig 4.3 Trend in annual average leaf area 2000–17 (per cent per decade)[88]



Some of China's experiences, however, highlight the challenges of afforestation programmes. The Three Norths Shelterbelt Development Programme initiated in 1978 – commonly called the 'Great Green Wall' – was designed to plant nearly 35 million hectares of new forest in a band stretching 4,500 km across northern China, with the aim of reversing centuries of desertification. By 2011, however, 85 per cent of the new plantings had failed, because the non-native species used could not tolerate local conditions.[89] Even though they had been selected to thrive in arid regions, in practice they depleted soil moisture and died, along with native vegetation which they deprived of water. Smaller-scale programmes using native species (and sometimes grasses rather than trees) proved more successful.

In general, if not properly managed, afforestation and reforestation efforts risk the production of monocultures that not only lack plant diversity but also reduce the number of available habitat types for animal species and diminish local biodiversity; they can also result in the introduction of non-native and potentially invasive species, reduced stream flow, and lost revenue from agriculture. The overall figures for the expansion of plantations quoted above may in fact be misleading, as studies have shown that planted forest is often far less dense than natural forest. As one study of the Chinese afforestation programme concluded, 'If the definition of "forest" follows FAO criteria (including immature and temporarily unstocked areas), China has gained 434,000 km^2 between 2000 and 2010. However, remotely

[88] Source: NASA Earth Observatory, https://www.nasa.gov/feature/ames/human-activity-in-china-and-india-dominates-the-greening-of-earth-nasa-study-shows.

[89] Shixiong Cao et al, 'Excessive reliance on afforestation in China's arid and semi-arid regions: Lessons in ecological restoration', *Earth Sciences Review* 104:4, February 2011.

detectable gains of vegetation that non-specialists would view as forest (tree cover higher than 5 m and minimum 50 per cent crown cover) are an order of magnitude less (33,000 km^2).'[90]

The concept of forest landscape restoration has recently emerged as a new approach to managing the dynamic and often complex interactions between the people, natural resources and land uses that comprise a landscape. It makes use of collaborative approaches to harmonise the many land-use decisions of stakeholders, with the aims of restoring ecological integrity and enhancing the development of local communities as they attempt to increase and sustain the benefits they derive from the management of their land.[91] This approach is embedded in the Bonn Challenge of the International Union for the Conservation of Nature (IUCN), which aims to bring 150 million hectares of degraded and deforested land into restoration by 2020, and 350 million hectares by 2030, generating an estimated US$84 billion per year in net benefits, including through trade in forest products, as well as providing watershed protection, improved crop yields and climate mitigation.

This approach is, in effect, now gradually being implemented through the Great Green Wall for the Sahara and Sahel Initiative, where the initial emphasis on tree planting is giving way to an array of land use practices, including using simple water harvesting techniques, and protecting trees that emerge naturally on farms rather than clearing them to make room for crops.[92] The Korean experience mentioned above was actually achieved by increasing tree cover in degraded forests rather than by planting new forests; over the past 60 years the stocked forest area (with tree cover greater than 30 per cent) has significantly increased, as has total growing stock, even though total forest area in Korea has in fact declined.[93]

As argued in the study cited in the introduction to this section, forest ecosystem restoration may have significant potential for climate mitigation (see Figure 4.2 above).[94] The restoration of one-quarter of degraded natural forest cover globally (600 million hectares) would restore primary forest characteristics, increasing the area of primary forests to 50 per cent of the global forest area, and increase the size of the global carbon sink by an estimated 1.9 $GtCO_2e$ per year – equivalent to about 3.5 per cent of total global emissions in 2017. Promoting the expansion of natural forests – as opposed to planting monoculture tree plantations – aiming to restore 350 million hectares by 2030, would absorb emissions equivalent to a further 7.3 per cent of the global total.

4.5 Increasing the value of forests: promoting sustainably produced wood products

Increasing the use of harvested wood products can contribute to climate change mitigation in two ways: through increasing the carbon stock (fixed in the products) and through replacing products manufactured

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[90] Ahrends A, Hollingsworth PM, Beckschafer P, Chen H, Zomer RJ, Zhang L, Wang M, Xu J., 'China's fight to halt tree cover loss'. *Proc. R. Soc. B* 284: 20162559. 2017

[91] FAO, 'Forest Restoration and Rehabilitation', at http://www.fao.org/sustainable-forest-management/toolbox/modules/forest-restoration-and-rehabilitation/basic-knowledge/en/

[92] Jim Morrison, 'The "Great Green Wall" Didn't Stop Desertification, but it Evolved Into Something That Might', *Smithsonian Magazine* 23 August 2016; https://www.smithsonianmag.com/science-nature/great-green-wall-stop-desertification-not-so-much-180960171/#AgmZGcsGhGIf2kRo.99

[93] Michael Wolosin, *Large-scale Forestation for Climate Mitigation: Lessons from South Korea, China, and India* (Climate and Land Use Alliance, 2017).

[94] Dooley, *Missing Pathways to 1.5°C: The role of the land sector in ambitious climate action*.

from greenhouse-gas-intensive materials such as concrete or brick, metals or plastics. Using wood in this way thus both directly reduces greenhouse gas emissions and raises the value of forests, potentially encouraging greater investment and greater efforts at protection.

The extent to which carbon can be fixed in wood-based products of course varies with the product. Estimates of the fate of cleared wood and the timing of atmospheric carbon emissions for 169 countries, published in 2012, suggested that 30 years after forest clearance the percentage of carbon stored in wood products and landfills ranged from about 0 per cent to 62 per cent globally.[95] For more than half (90) of these countries, less than 5 per cent of carbon remained after 30 years, whereas for about 20 per cent (34), more than 25 per cent remained in storage. Higher storage rates resulted primarily from a greater percentage of long-lived products such as wood panels and lumber, and tended to occur in countries with predominantly temperate forests. Lower storage rates were associated with a greater fraction of non-merchantable wood and the greater use of wood for energy and paper production, which tended to occur in countries with predominantly tropical forests.

A number of studies have attempted to measure the carbon savings from using wood to substitute for non-wood products. A survey of research published in 2004 suggested that replacing concrete or brick with timber in construction would save between 0.7 and 1 tonne CO_2e per cubic metre; and replacing glass, plastics or metals with wood products in packaging would save between 1.1 and 4.0 kg CO_2e per kg for packaging made from virgin wood and between 0.1 and 2.1 kg CO_2e per kg for packaging made from recycled wood materials.[96] These figures relate to emissions over the maximum lifetime of the material, and did not account for the carbon fixed in the product.

A more recent survey of research suggested an average substitution effect of 1.2 kg carbon / kg carbon – i.e. for each kilogram of carbon in the substituting wood products, there was an average emission reduction of approximately 1.2 kg carbon.[97] Combining both these elements – the kilogram of carbon fixed in the wood product plus the reduction in emissions from the substitution – gives a net mitigation effect of about 2.2 kg of carbon per kg of wood product. This studies showed a wide range of outcomes, depending on the wood product, the technology considered and the methods used to estimate emissions.

Most of the studies referred to the use of wood in construction – replacing brick, concrete or stone, or plastics, e.g. in window frames – though not at new developments such as the use of cross-laminated timber, now used for buildings up to 14 storeys (55 metres) tall (with higher ones planned). Relatively few studies examine the use of wood in packaging, furniture, chemicals or textiles (using wood-based fibres such as viscose, lyocell or modal in place of cotton or synthetic fibres), or in emerging new technologies, such as the production of biomaterials from biorefineries or the use of nanotechnology, for example in intelligent wood-based and paper-based products incorporating nano-sensors to measure forces, loads, moisture levels, temperature, pressure, chemical emissions or attack by wood-decaying fungi. The research was also largely based on studies in northern Europe and North America; very few studies looked at developing countries, or even countries in southern Europe.

[95] J. Mason Earles, Sonia Yeh and Kenneth E. Skog, 'Timing of carbon emissions from global forest clearance', *Nature Climate Change*, September 2012.
[96] Hannah Reid et al, *Using Wood Products to Mitigate Climate Change: A Review of Evidence and Key Issues for Sustainable Development* (IIED, 2004).
[97] Pekka Leskinen et al, *Substitution effects of wood-based products in climate change mitigation* (EFI, 2018).

It is difficult to extrapolate from this research to economy-wide effects, though some attempts have been made. A study in Japan, looking primarily at increased use of wood in construction and energy, estimated potential savings of 8.4 MtC per year in 2050, equivalent to 2.4 per cent of Japan's 2015 carbon dioxide emissions.[98] A scenario developed for the UK estimated potential savings of 4 MtCO_2e per year by 2050 from the greater use of wood in construction, equivalent to just under 1 per cent of UK 2016 emissions.[99] A model applied to the EU estimated that efforts to increase both the lifespan and the recycling rate of wood products (not including substitution effects) could raise the emission savings from 58 MtCO_2e per year under business as usual to 68 MtCO_2e per year.[100]

This potential wider use of wood products of course comes on top of expanding demand for wood products simply from population growth and urbanisation (which tends to increase demand for wood used in construction while reducing it for wood used for energy).[101] It will be important, then, to design policy measures aimed at increasing the use of wood to ensure it is sourced from sustainably managed and harvested forests (bearing in mind the discussion above about maximising forest carbon stocks). The potential savings will also vary significantly with the extent to which products are recovered, reused and recycled. The 'cascading' approach, which aims to maximise resource efficiency, implies that wood should be used in the following order of priority: wood-based products, extending their service life, reuse, recycling, bio-energy and disposal.

4.6 Wood for energy

Biomass-based energy (mainly wood, though also agricultural residues) is the oldest source of consumer energy known to humans, and is still the largest source of renewable energy worldwide, accounting for an estimated 8.9 per cent of world total primary energy supply in 2014.[102] Most of this is consumed in rural areas of non-industrialised or less industrialised parts of the world for cooking and heating, usually on open fires or in simple cookstoves;[103] in Africa, for example, biomass accounts for almost two-thirds of total primary energy supply.[104] These traditional uses of wood for energy are important in helping to ensure access to energy for poor families and communities, but they also often have negative impacts through emissions of particulates, which contribute both to premature deaths, through degrading air quality, and to climate change.

Soot, or 'black carbon', is a powerful contributor to global warming because of its effectiveness at converting solar radiation to heat and affecting cloud formation, regional circulation and rainfall patterns; when deposited on ice and snow, black carbon and co-emitted particles reduce surface albedo and heat

[98] Chihiro Kayo et al, 'Climate change mitigation effect of harvested wood products in regions of Japan', *Carbon Balance and Management* 10:24 (2015).
[99] *UK Climate Action Following the Paris Agreement* (Committee on Climate Change, 2016).
[100] Pau Brunet Navarro et al, 'The effect of increasing lifespan and recycling rate on carbon storage in wood products from theoretical model to application for the European wood sector', *Mitig Adapt Strateg Glob Change*, September 2016.
[101] For a longer discussion, see Duncan Brack, *Sustainable Consumption and Production of Forest Products: Background study prepared for the thirteenth session of the United Nations Forum on Forests* (April 2018).
[102] *Renewables 2016: Global Status Report* (United Nations Environment Programme, 2016).
[103] For a fuller discussion, see Gary Bull, *Forests and Energy: Background study prepared for the thirteenth session of the United Nations Forum on Forests* (April 2018).
[104] Elizabeth Cushion, Adrian Whiteman and Gerhard Dieterle, *Bioenergy Development: Issues and Impacts for Poverty and Natural Resources Management* (World Bank, 2010).

the surface.[105] While it has other sources, including diesel engines, coal, kerosene and forest fires, in 2015 household uses, mainly of biomass, accounted for 58 per cent of black carbon emissions. Various initiatives are under way to replace traditional cooking and heating with clean-burning biomass stoves or alternative sources of energy, eliminating kerosene lamps and so on. Biomass use for energy tends to fall as population income rises and the degree of urbanisation increases.

Alongside these traditional uses, the use of wood for electricity generation and heat in modern, non-traditional, technologies has grown rapidly in recent years, particularly in the EU, which is the main global source of demand as a result of its overall targets for renewable energy; most EU member states subsidise the use of biomass (and other renewables) in various ways. This rapid growth in demand has exceeded production from the EU's own forest resources and led to a sharp rise in imports, particularly of wood pellets from the US, Canada and Russia. Though small in comparison to the global trade in wood products, trade in wood pellets has been one of the fastest growing categories since the commodity was first identified separately in trade statistics, in 2012.[106] Outside the EU, wood is mainly used for energy in industrial uses, for example in pulp and paper mills, though consumption for electricity and heat is also growing particularly in Japan and Korea.

In general, biomass (mainly wood) is classified as a source of renewable energy in national policy frameworks, benefiting from financial and regulatory support on the grounds that, like other renewables, it is perceived to ne a carbon-neutral energy source. However, it is not carbon-neutral at the point of combustion; if biomass is burnt in the presence of oxygen, it produces carbon dioxide, almost always at a higher rate of carbon per unit of energy than fossil fuels. In addition, its production involves supply-chain carbon emissions from harvesting, processing and transporting the wood. The classification of biomass as carbon-neutral is accordingly increasingly being questioned, and the argument made that its use in reality has negative impacts on the global climate.[107]

This is a complex and contested topic, and a full exploration falls outside the remit of this paper. To summarise the arguments very briefly, however, It is often argued that, despite its higher rate of carbon emissions per unit of energy, the use of woody biomass can be assumed to be carbon-neutral because over time the growth of forests after harvesting absorbs the carbon dioxide emitted on combustion. Estimates of this 'carbon payback period' vary from a few years, for sawmill wastes or forest residues, to decades or centuries for longer-lived forest residues or roundwood. The study of carbon sequestration potential in forests in Oregon mentioned above in Section 4.3, for example, concluded that using wood harvest residues for bioenergy production instead of leaving them in forests to decompose increased emissions for at least 50 years.[108]

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[105] Climate and Clean Air Coalition, 'Black carbon'; http://www.ccacoalition.org/ru/slcps/black-carbon.

[106] Brack, *Sustainable Consumption and Production of Forest Products.*

[107] For a longer discussion of this topic, see Duncan Brack, *Woody Biomass for Power and Heat: Impacts on the Global Climate* (Royal Institute of International Affairs (Chatham House), 2017). For a critique of this report by authors from the IEA Bioenergy technology network, and for the author's response, which between them cover many of the main points under debate, see https://www.chathamhouse.org/sites/les/chathamhouse/publications/2017-04-05-IEABioenergy.pdf and https://www.chathamhouse.org/sites/les/chathamhouse/publications/2017-04-05-ResponsetoIEABioenergy.pdf. Also see European Academies Science Advisory Council, *Multi-functionality and sustainability in the European Union's forests* (German Academy of Sciences, 2017).

[108] Law, 'Land use strategies to mitigate climate change in carbon dense temperate forests'.

The length of this carbon payback period matters, because any short-term growth in carbon emissions increases the likelihood of irreversible climate 'tipping points', and is also likely to be incompatible with the goals of the Paris Agreement, which require near-term peaking in emissions and steep reductions thereafter to net zero by mid-century. Suggestions have therefore been put forward that only wood feedstocks with the shortest carbon payback periods – residues that would otherwise have been burnt as waste or would have been left in the forest or sawmill and decayed rapidly, thus releasing their stored carbon into the atmosphere over a short period – should be eligible for financial and regulatory support. The use of other types of feedstock risks increasing carbon levels in the atmosphere for years or decades.

The second assumption that leads to the common perception that biomass energy is zero-carbon at the point of combustion derives from the international greenhouse gas reporting and accounting frameworks established under the UNFCCC and Kyoto Protocol (see Section 3.1). In order to avoid double-counting emissions from biomass energy within both the energy sector (when the biomass is burned) and the land-use sector (when the biomass is harvested), the rules provide that emissions should be reported within the land-use sector only.

While this approach makes sense for *reporting*, it has resulted in significant gaps in the context of *accounting*, i.e. measuring emissions levels against countries' targets. This largely derives from the different forest management reference levels that parties have been permitted to adopt, which allow emissions to go unaccounted for when a country using biomass for energy imports biomass from a country outside the accounting framework; accounts for its biomass emissions using a historical forest management reference level that includes higher levels of biomass emissions than in the present; or accounts for its biomass emissions using a business-as-usual forest management reference level that (explicitly or implicitly) includes anticipated emissions from biomass energy; these emissions will not count against its national target.

This failure to account fully for biomass energy emissions risks creating perverse policy outcomes: where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel energy sources does, this creates an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions – even where this reduction is not 'real', in the sense that it is not accounted for in any country's land-use sector accounts. The quantity of emissions missing from the international greenhouse gas accounting framework is impossible to calculate precisely, but is likely to be significant. In 2014, countries listed in Annex I to the UNFCCC in aggregate emitted 985 million tonnes of carbon dioxide ($MtCO_2$) from biomass combustion, including an estimated 781 $MtCO_2$ from solid biomass. The latter figure is equivalent to 5.6 per cent of aggregate, economy-wide carbon dioxide emissions from Annex I countries in 2014, and 6 per cent of their total energy emissions.

To date most governments that subsidise biomass energy have not accepted these arguments – an attempt to amend the EU's new Renewable Energy Directive to restrict feedstock use to wastes and residues was defeated in the European Parliament in January 2018 – but these debates seem likely to continue. In any case, further rapid growth of biomass seems unlikely in the future, particularly for electricity, given the rapid fall in the costs of competing renewable sources, particularly solar and wind. The situation for heat, however, is less clear given that competing technologies for low-carbon or renewable heat are much less well established.

Biomass energy growth may also be constrained by increasing competition from other users of wood resources. Although one of the arguments used in support of the use of wood for energy is that this demand increase the return to forest owners on their investments, and encourages them to plant more trees, or avoid deforesting, there is no real evidence to date to suggest this is the case; for example, the area of timberland in the five south-eastern US states which are the main sites of the pellet mills supplying the EU market actually fell between 2011 and 2015, against a general increase in forest cover in the US as a whole.

There is also growing interest in the combination of bioenergy with carbon capture and storage (BECCS) with the aim of providing energy supply with net negative emissions. Both the IPCC's fifth assessment report, published in 2014, and its special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, published in 2018, relied heavily on bioenergy for heat and power, and specifically on BECCS, in most of their scenarios of future mitigation options. However, all the studies that the IPCC surveyed assumed that the biomass was zero-carbon at the point of combustion, which, as discussed above, is not necessarily a valid assumption.

In addition, the slow rate of deployment of carbon capture and storage technology, and the extremely large areas of land that would be required to supply the woody biomass feedstock needed in the BECCS scenarios render its future development at scale highly unlikely. The top end of the projections for BECCS included in the IPCC's fifth assessment report would require an additional 2 billion hectares of forests – an area greater than the total global land area currently planted with agricultural crops (about 1.5 billion hectares in 2015) and about half the total global forest area (about 4 billion hectares).

Wood is not the only potential feedstock for BECCS – energy crops and algae are also being researched, and given the much faster rate of growth of perennial crops such as miscanthus, may well be preferable, if the land is available without displacing food crops – and BECCS is not the only potential negative emission technology.[109] However, the unquestioning reliance on BECCS of so many of the climate mitigation scenarios and models reviewed by the IPCC is of major concern, potentially distracting attention from other mitigation options and encouraging decision makers to lock themselves into high-carbon options in the short term on the assumption that the emissions thus generated can be compensated for in the long term.

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[109] In a presentation of the IPCC's 1.5 degrees report in the UK House of Commons in October 2018, ones of its authors suggested that its scenarios focused so much on BECCS simply because the literature on BECCS was more extensive than that on any other negative emission technology.

5 Forests and climate adaptation

This section looks at forests and adaptation to climate change. This has two dimensions: the role forests and forest policy can play in assisting communities to adapt to the impacts of climate change, and the need for forests themselves to adapt to climate change. As with mitigation, these options are reflected in the UNSPF Global Forests Goals (see box).

Global Forest Goals relevant to climate adaptation

1. Reverse the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of addressing climate change.

   …

   1.4 The resilience and adaptive capacity of all types of forests to natural disasters and the impact of climate change is significantly strengthened worldwide.

2. Enhance forest-based economic, social and environmental benefits, including by improving the livelihoods of forest dependent people.

   …

   2.5 The contribution of all types of forests to biodiversity conservation and climate change mitigation and adaptation is enhanced, taking into account the mandates and ongoing work of relevant conventions and instruments.

5.1 Forests for adaptation

The topic of adaptation to climate change has tended to be of less interest to policy-makers than options for mitigation, but with the recognition that current levels of greenhouse gas emissions have already driven the world to more than a 1 degree C rise over pre-industrial temperatures, and are very likely to result in considerably more, interest in adaptation options is growing. Article 7 of the Paris Agreement commits parties to: 'enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal referred to in Article 2'.[110] Specific commitments to enhancing adaptation include sharing information, experiences and lessons learned, strengthening institutional arrangements, strengthening scientific knowledge and assisting developing countries.

Adaptation to climate change is a different policy challenge to mitigation. While reducing greenhouse gas emissions may often (though not always) be best addressed through top-down global or national approaches with coordinated international action, national targets and broader policy frameworks, adaptation is a process usually best addressed at the local level, with organisations, communities, businesses, households or individuals considering their future climate risks and the benefits and costs of different risk management options.[111] This local action will still, however, require coordination across

[110] Paris Agreement, Article 7 para 1.

[111] Ciurean, R.L., Schröter, D., Glade, T., 'Conceptual Frameworks of Vulnerability Assessments for Natural Disasters Reduction', in John Tiefenbacher (ed.), *Approaches to Disaster Management: Examining the Implications of Hazards* (IntechOpen, 2013).

jurisdictions and levels of government, particularly in the provision of information and the management of cross-boundary issues, for example in food risk, fire management or species conservation.

Forests can help societies adapt to climate variability and change in several ways.[112] Forests provide ecosystem services that contribute to reducing the vulnerability of sectors and people beyond the forestry sector, including provisioning services or ecosystem goods, such as food and fuel; regulating services, such as the regulation of water, local climate or erosion; and cultural services, such as recreational, spiritual or religious services. It is increasingly recognised that the delivery of these services by well-managed ecosystems play a crucial role in efforts to help societies adapt to climate change and significantly reduce social vulnerability. For example, mangroves protect coastal areas against storms and waves, forest products provide safety nets for local communities when agricultural crops fail, and hydrological ecosystem services (such as base flow conservation, storm flow regulation and erosion control) are of importance for buffering the impacts of climate change on water users.

Maintaining nature's capacity to buffer the impacts of climate change is often less costly than having to replace lost ecosystem functions by investment in infrastructure or technology. According to the Economics of Ecosystems and Biodiversity group (TEEB), cost-benefit analyses indicate that public investment should support ecological infrastructure (forests, mangroves, wetlands, etc.) because of their contribution to adaptation to climate change.[113] In many cases, an ecosystem investment can be justified solely on the basis of one valuable service but it becomes even more attractive when the whole range of services is considered. Additionally, ecological infrastructure can often be more adaptive than engineered infrastructure because ecosystem management can be modified more easily in the face of unexpected changes. Ecosystem management can also strive to enhance ecological resilience and facilitate natural adaptation processes, so that ecosystems can adapt to unanticipated environmental changes and continue to deliver services.

Ecosystem-based adaptation strategies accordingly target the conservation or restoration of specific ecosystem services that are crucial for societal adaptation in a particular region.[114] For example, many forests are already managed to ensure a reliable provision of clean water, but management plans and priorities may need to be modified in the future under climate change. Stakeholders might choose to focus on certain goods and services that they value more for their contribution to social resilience. Forest management can evolve towards a better conservation of water in places where the population is particularly vulnerable to changes in water quantity or quality. Such strategies can be cost-effective and generate a variety of environmental, social, economic and cultural co-benefits; they have the potential to align objectives that can otherwise be in conflict, such as poverty alleviation, development, biodiversity conservation, and climate change adaptation and mitigation. In order to ensure that forest ecosystems will be able to contribute to these adaptation strategies, deforestation and forest degradation must be curbed as an important first step.

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[112] Information in this section mainly taken from Risto Seppälä et al (eds.), Adaptation of Forests and People to Climate Change – A Global Assessment Report (IUFRO, 2009); Bruno Locatelli and Emilia Pramova, 'Forests and Adaptation to Climate Change: What is at Stake?', *World Resources Report 2010–2011: Decision Making in a Changing Climate* (WRI, 2011); Brunco Locatelli et al, 'Integrating climate change mitigation and adaptation in agriculture and forestry: opportunities and trade-offs', *WIREs Climate Change* (2015); Seymour and Busch, *Why Forests? Why Now?*; *FAO, Forests and Climate Change* (FAO, nd).

[113] See http://www.teebweb.org

[114] *Issues brief: Ecosystem-Based Adaptation* (IUCN, 2017).

One of the first two adaptation projects accepted in the UNFCCC Adaptation Fund (see below in Section 6), in September 2010, is a good example of this kind of strategy. The project aimed to improve water management and decrease water problems for the poor in the Honduras capital region of Tegucigalpa. It placed a strong emphasis on the role of forests in regulating water and the negative impacts of deforestation in water catchments. According to the project document, ecosystem management, including the creation of protected areas, needed to consider issues of water supply for cities and sensitive ecosystems such as cloud forests. The project developers recognised that there were no mechanisms in place to conserve the forests and green belts, which provided important ecosystem services and were threatened by deforestation and urbanisation.

5.2 Adaptation for forests

As well as helping societies adapt to the impacts of climate change, forests themselves need to adapt to the kind of climate-related impacts reviewed in Section 2.3, including temperature rise, changes in rainfall patterns and water availability, fires, insects and diseases, as well as deforestation and land use change. Forest ecosystems differ in both their sensitivity – the degree to which they are affected by a change in climate, either positively or negatively – and their vulnerability – the extent to which they are able to adapt to these climatic and climate-change-induced changes.

Two broad kinds of adaptation measures can thus be identified: measures that aim to buffer forests from perturbations by increasing their resistance and resilience, and measures that facilitate ecosystem shift or evolution towards a new state that meets the altered conditions.[115]

Buffering measures tend to focus on preventing perturbations, such as fire (by e.g. managing fuel load) and invasive species (by e.g. preventing their spread or removing them). They can also include managing the forest actively after a perturbation, by, for example, assisting the establishment of adapted and acceptable species. These measures might, however, only be effective over the short term, becoming less and less so with accelerating climate-related changes and pressures. Furthermore, there are often high costs associated with such measures due to the intensive management that they require. They are likely to be more efficient when applied to high-value or high-priority conservation forests or to forests with low sensitivity to climate change.

Measures that facilitate ecosystem shift or evolution do not aim to resist changes, but rather to ease and manage the natural processes of adaptation. Resilience is crucial, not necessarily to keep the ecosystem in the same state after a disturbance, but to help it evolve towards a new state that is socially acceptable. Examples of such measures include the reduction of landscape fragmentation, conserving genetic diversity and a large spectrum of forest types for their value and higher resilience, adopting species and genotypes that are adapted to future climates in forest plantations, and planting mixed species and uneven age structure.

Strategies that reduce non-climatic pressures – such as other drivers of deforestation and forest degradation – are critical and can contribute to both buffering and facilitating measures for adaptation.

[115] Bruno Locatelli et al, 'Forests and Adaptation to Climate Change: Challenges and Opportunities', in G. Mery et al (eds.), *Forests and Society – responding to global drivers of change* (IUFRO, 2010).

Forest stakeholders have a central role to play in forest adaptation because they manage forests and depend directly on them and because adaptation must be based on local practices and knowledge; local people know their environment better than outsiders. Institutional changes are often needed to achieve this, for example by increasing local ownership and access to forests, protecting rights of ownership and tenure, and building institutional responsibility for adaptation.

The Tegucigalpa adaptation project mentioned above in Section 5.1 also included measures to promote ‘adaptation for forests’. It aimed to increase connectivity between protected areas around the city, thereby increasing ecosystem resilience as the climate changed. This project is a positive sign of mainstreaming forests into adaptation policies, as well as adaptation into forest management.

6 Underlying requirements: finance and governance

Having reviewed a range of forest-related policy options for climate mitigation and adaptation, this section looks briefly at two key underlying prerequisites for their successful implementation; the provision of financial support, and improvements in forest governance and law enforcement. Once again these are reflected in the Global Forest Goals (see box).

Global Forest Goals relevant to finance and governance

4. Mobilize significantly increased, new and additional financial resources from all sources for the implementation of sustainable forest management and strengthen scientific and technical cooperation and partnerships.

   …

5. Promote governance frameworks to implement sustainable forest management, including through the United Nations forest instrument, and enhance the contribution of forests to the 2030 Agenda for Sustainable Development.

   …

   5.2 Forest law enforcement and governance are enhanced, including through significantly strengthening national and subnational forest authorities, and illegal logging and associated trade are significantly reduced worldwide.

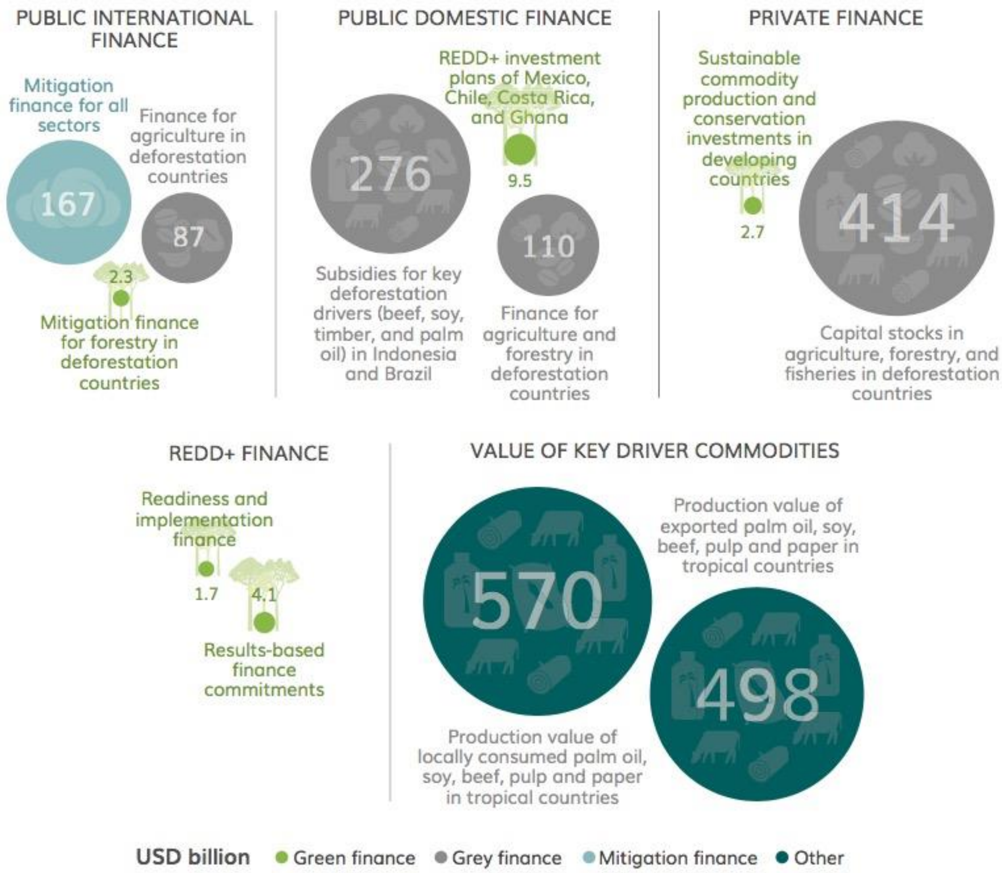
6.1 Finance

Overall, as an analysis published by the NYDF Assessment Partners in 2017 concluded, 'support for the development and implementation of strategies to reduce forest emissions remains insufficient'.[116] At just over 1 per cent of global mitigation-related development funding, the authors of the survey argued that the magnitude of the finance made available was highly disproportionate to both the investment needs and the mitigation potential of the forest sector. Figure 6.1 provides a summary of financial flows from 2010 to 2015.

The report estimated the flows of 'green finance' aligned with forest and climate goals, and compared them with 'grey finance', which had an unclear but potentially negative impact on forests. Overall, total green finance for Goals 8 and 9 of the New York Declaration (which promises financial support for preparing and implementing strategies to reduce emissions (Goal 8) and rewards for reducing emissions (Goal 9)) had reached roughly US$20 billion since 2010. This was dwarfed by the US$777 billion in grey finance for the land sector that influenced forests but which was not clearly aligned with forest and climate goals – mainly for agriculture. As can be seen in Figure 6.1, the production value of four key agricultural commodities in tropical countries (palm oil, soy, beef and pulp and paper) exceeds US$1 trillion, illustrating the large economic incentives in the sectors that drive deforestation.

[116] Franziska Haupt et al, *Progress on the New York Declaration on Forests: Finance for Forests – Goals 8 and 9 Assessment Report* (Climate Focus, 2017).

Fig. 6.1 Forest-related finance flows 2010–15[117]



REDD+

As noted in Section 4.1, for most of the last ten years, the bulk of climate-related forest spending by both donors and forest countries has been directed to REDD+ activities. A variety of international institutions and initiatives have evolved to channel REDD+ funding to developing countries, including three World-Bank-administered funds (Forest Investment Programme, Forest Carbon Partnership Facility and BioCarbon Fund Initiative for Sustainable Forest Landscapes) and the UN-REDD partnership. In 2017 the Green Climate Fund – which is intended to be the main financial mechanism of the Paris Agreement – also began to draw up plans for its own REDD+ financing activities; activities it has supported so far include the results-payments to Brazil discussed in Section 4.1. Several donor countries maintain sizeable bilateral REDD+ programmes and some are increasingly collaborating in deploying their support – for example, Germany, Norway and the UK in particular through the REDD Early Movers Programme.

Assessing the exact amount pledged to or delivered by the various REDD+ institutions, bilateral donors and host countries is difficult. One analysis published in 2015 estimated that US$10 billion had been pledged

[117] Source: ibid.

(though most had not been disbursed) by 2014.[118] The NYDF Assessment Partners report in 2018 estimated that US$1.7 billion had been delivered for the first two stages and US$4.1 billion pledged for results-based finance, plus a further US$10 billion of domestically sourced investment planned for the next four to ten years in middle-income countries.[119] As noted in Section 4.1, a global private-sector forest carbon market has not so far developed; at least 90 per cent of the financing pledged to date has derived from public sources.[120] Section 4.1 discusses the challenges and future prospects of REDD+ initiatives in more detail.

Private funding

In addition to these primarily public sources of funding, some private funding has also been available. A tiny amount (in relative terms) has been provided through voluntary carbon markets – individuals and institutions offsetting their own carbon-emitting activities by purchasing offsets from carbon-reducing projects elsewhere. In 2016 voluntary buyers paid US$191 million to offset 63.4 $MtCO_2e$; of this, US$67 million and 13.1 $MtCO_2e$ related to forestry and land use.[121] While these voluntary markets have grown in size rapidly, future prospects are uncertain, depending on the relationships that develop with national targets and compliance markets, and also, possibly, with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) adopted by the International Civil Aviation Organisation in 2016.[122]

Larger sums have been made available through impact investment markets relevant to forests. Seeking environmental and social benefits in addition to monetary returns, cumulative green finance commitments by investors are estimated at US$3.3 billion for Latin America, Asia, and Africa between 2009 and 2015, including 44 per cent for sustainable forest and timber activities and 35 per cent for sustainable agriculture.[123]

As with public sources, green private investment is only a fraction of grey finance in the sectors that drive deforestation. FAO estimates place the total value of private investment (capital stocks) in 'business-as-usual' farming, forestry, and fisheries sectors in forest countries in recent years at a cumulative US$414 billion.[124] However, this volume of investment is, at least in principle, capable of being 'greened'. Financial institutions are increasingly adopting policies that address deforestation risks, but progress is slow and piecemeal and often not consistently applied or independently monitored.

Finance for adaptation

The UNFCCC's Adaptation Fund was established as long ago as 2001, though it was not officially launched until 2007.[125] Since 2010 it has committed US$532 million to climate adaptation and resilience activities, including supporting 80 specific adaptation projects. The Fund is financed in part by government and

[118] Norman and Nakhooda, *The State of REDD+ Finance*.
[119] Haupt et al, *Progress on the New York Declaration on Forests: Finance for Forests.*
[120] Norman and Nakhooda, *The State of REDD+ Finance*.
[121] Kelley Hamrick, *Unlocking Potential: State of the Voluntary Carbon Markets 2017* (Forest Trends, 2017).
[122] Kelley Hamrick and Melissa Gallant, *Voluntary Carbon Markets: Outlooks and Trends January to March 2018* (Forest Trends, 2018).
[123] Haupt et al, *Progress on the New York Declaration on Forests: Finance for Forests*
[124] Ibid.
[125] https://www.adaptation-fund.org.

private donors, and also from a 2 per cent share of proceeds of Certified Emission Reductions issued under the Kyoto Protocol's Clean Development Mechanism projects. To date the only forest-related project the Adaptation Fund appears to have supported is the 'Ecosystem-Based Adaptation at Communities of the Central Forest Corridor in Tegucigalpa' project referred to above in Section 5, which has had US$4.4 million allocated.[126]

Other multilateral and bilateral donors also make financial support available for adaptation, however. This includes the Green Climate Fund, the Forest Carbon Partnership Facility and several of the major donors mentioned above. Since there are in reality many overlaps between forest-related mitigation and adaptation activities, many projects in fact aim to achieve both.[127]

6.2 Forest governance

Along with the provision of sufficient financial and capacity-building support, the other essential prerequisite for the successful implementation of almost all of the measures outlined above in Sections 4 and 5 is adequate standards of forest governance – yet the forest sector as a whole has long been characterised, in many countries, by severe and long-lasting weaknesses in governance and law enforcement, leading to widespread illegal activity, including logging, forest clearance and illegal export. This is the result of several factors:

- *Overlapping or unclear resource ownership and usage rights* are a major underlying driver, and accordingly, the profile of land tenure issues has risen considerably in recent years. Despite widespread recognition of this issue's importance in the literature and global policy debate, efforts to address the dispossession of local communities and to resolve the conflict between national and customary law on property rights have been slow and uneven.
- *The degree of stakeholder participation in policy-making* significantly shapes the nature and extent of illegal activity. Studies suggest that in the right circumstances, initiatives to involve local stakeholders, such as local communities and NGOs, in decisions over the management and protection of forests can contribute to a reduction in illegal exploitation.[128] This also requires high levels of transparency and access to information. In many countries this is very far from the norm: basic information, such as forest concession boundaries or logging quotas, may never be made publicly available, vested interests and elites have captured the government agencies involved, at national or local levels, and the interests of local communities are marginalised or ignored entirely.
- *State criminality and deep-rooted corruption*, in some cases endemic to the conduct of business in the sector rather than a deviation from the norm, is a necessary precondition for the magnitude

[126] See https://www.adaptation-fund.org/project/ecosystem-based-adaptation-communities-central-forest-corridor-tegucigalpa/.
[127] Locatelli et al, 'Integrating climate change mitigation and adaptation in agriculture and forestry'.
[128] *Evaluation of the EU FLEGT Action Plan (Forest Law Enforcement Governance and Trade) 2004–2014* (Terea, S-for-S, Topperspective, 27 April 2016); https://ec.europa.eu/europeaid/evaluation-eu-flegt-action-plan-forest-law-enforcement-governance-and-trade-2004-2014_en; Christine Overdevest and Jonathan Zeitlin, *Experimentalism in Transnational Forest Governance: Implementing EU Forest Law Enforcement Governance and Trade (FLEGT) Voluntary Partnership Agreements in Indonesia and Ghana* (Amsterdam Centre for Contemporary European Studies, SSRN Research Paper 2016/02).

of illegal activity; the actors involved may include central and local government officials, state-owned enterprises, the military and other enforcement agencies.[129]

- *Failures of enforcement* often stem from factors related to endemic corruption, including bribery, fraud, abuse of office, extortion, and cronyism.[130] Weak managerial capacity in the government agencies responsible for the oversight of forests is common, and can be both a cause and symptom of entrenched corruption.
- *Policy failure* at the macro or micro level can also create incentives and scope for illegal activity. At the macro level, this may result from a failure to address major threats to sustainable resource management. Encroachment of agriculture is a key culprit – if forestry policy is set in isolation from agricultural policy, the resulting incoherence may create perverse incentives; as noted above, clearance of forests for agriculture is now the main global driver of deforestation, and much of this may itself be illegal. Macro-level policies also need to account for trends such as population pressure increasing the demand for land for agriculture, livestock, and infrastructure, at the expense of forests, as well as the similar pressures posed by climate change. At the micro level, inappropriate regulations (sometimes due to regulatory capture) may distort incentives, for instance by making it more profitable to engage in illegal than in legal forest exploitation, or by making compliance impracticably difficult. Unnecessary complexity or inconsistency of regulations also creates a plethora of opportunities for bribery of officials.

Weaknesses in forest governance as a root cause of illegal logging have been recognised at the international level at least since the first Forest Law Enforcement and Governance (FLEG) ministerial meeting in Indonesia in 2001, and have led to a series of actions by producer and consumer countries aiming at improving governance, including in particular the EU's Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan, adopted in 2003. The bilateral Voluntary Partnership Agreements (VPAs) with timber-producing countries lie at the heart of the FLEGT action plan. By January 2019, VPAs had been concluded with nine countries and negotiations were under way or about to start in a further eight. Although the main aim of the VPAs is to ensure that only legal timber products can be exported from the partner country to the EU (and other destinations), which falls outside the scope of this paper, in many cases the process of negotiating the VPAs has itself led to improvements in forest governance.

An independent evaluation of the FLEGT action plan published in 2016 concluded that its main achievement was a significant improvement in governance.[131] Similarly, a 2016 study of the VPA processes in Ghana and Indonesia concluded that the they had:

> … resulted in significant improvements in forest governance in both countries, including measurable declines in illegal logging … the VPA implementation process has led in both countries to substantially increased participation by civil society and other stakeholders in forest governance, greater transparency and accountability of forestry administration, and heightened recognition of community rights. In both countries, too, the VPA process has focused attention on protecting the needs and livelihoods of small producers in the transition to the new timber legality regime … the VPA process has contributed to reducing arbitrary

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[129] Aksel Sundström, 'Understanding Illegality and Corruption in Forest Governance', *Journal of Environmental Management* 181 (2016).
[130] *Uncovering the Risks of Corruption in the Forestry Sector* (Interpol, 2016).
[131] *Evaluation of the EU FLEGT Action Plan.*

> administrative discretion in forest governance, including the award of concessions and harvesting permits, while creating new mechanisms for exposing corruption across the supply chain, whose effectiveness can be expected to grow as the monitoring, reporting, and review provisions of their timber legality assurance schemes kick into full gear with the onset of FLEGT licensing.[132]

It is generally recognised, however, that the FLEGT initiative has had less success in addressing questions of land tenure and human rights. This is a matter of substantial importance; much of the world's remaining tropical forests are occupied by indigenous peoples and traditional communities, and studies suggest that such areas see deforestation rates significantly lower than other government-controlled lands.[133] Only 10 per cent of these areas are legally under indigenous and community ownership, however; so securing community land and management rights represents a potentially effective, efficient and equitable climate action that governments can undertake to protect forests and increase the size of the global carbon sink.[134]

More broadly, the active participation and commitment of local communities is likely to be the single most crucial factor in determining how forests are used in the future. Implementation of the various options discussed above, including forest restoration, efforts to reduce deforestation, management for carbon storage and increased production of sustainably harvested wood products, requires the understanding and consent of local communities, which in turn requires effective protection of their rights and a genuine voice in decision-making processes.

These are important lessons for most of the policies and measures discussed above in Sections 4 and 5. In many countries, initiatives to halt deforestation, promote sustainable forest management, reforestation, afforestation, forest landscape restoration and the sustainable use of wood products will not succeed unless standards of governance are adequate to ensure the lasting positive impact of the programmes in question. As a 2018 survey of standards of governance put it, 'While not sufficient to address deforestation by itself, good forest governance is a necessary condition for forest protection and sustainable land use.'[135]

These issues are increasingly recognised in the international efforts to combat deforestation and protect forests, including the UNSPF's Global Forest Goad 5, the New York Declaration (which includes the commitment to 'strengthen forest governance, transparency and the rule of law, while also empowering communities and recognising the rights of indigenous peoples, especially those pertaining to their lands and resources') and the Katowice Declaration (which recognises 'the role of indigenous peoples and local communities in conserving and sustainably managing forests for the benefit of present and future generations').

Nevertheless, although standards of governance are often incorporated as required safeguards in many aid programmes and the requirements of the REDD+ institutions, the evidence suggests that only limited progress is being made in improving it; the survey concluded that:

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[132] Overdevest and Zeitlin, *Experimentalism in Transnational Forest Governance.*

[133] *A Global Baseline of Carbon Storage in Collective Lands: Indigenous and local community contributions to climate change mitigation* (Rights and Resources Initative, September 2018).

[134] Dooley, *Missing Pathways to 1.5°C: The role of the land sector in ambitious climate action.*

[135] Darragh Conway et al, *Improving Governance to Protect Forests: Empowering People and Communities, Strengthening Laws and Institutions – New York Declaration on Forests Goal 10 Assessment Report* (NYDF Assessment Partners, 2018).

> Improvements in forest governance remain too slow to have a measurable impact on reducing deforestation. There is progress in increasing transparency around forests, improving law enforcement, and expanding demand-side measures to address illegal logging in a number of countries. However, these improvements fall short of what is needed to address the vast governance challenges that continue to allow deforestation and inhibit efforts to improve forest conservation and management.[136]

Further efforts will therefore be necessary if the measures discussed in the rest of this paper are to be effective.

[136] Ibid.

7 Conclusions and recommendations

Global climate change is not under control. While the full implementation of the Paris Agreement's NDCs should limit total annual global emissions in 2030 to 53–56 $GtCO_2e$, keeping warming below 2˚C requires reducing emissions to 40 $GtCO_2e$ on average; to limit warming to 1.5˚C, emissions would need to fall to 24 $GtCO_2e$ per year.[137]

Against these targets, the potential contribution of forest-related mitigation options – halting deforestation and forest degradation, promoting sustainable forest management, increasing the area of forests through reforestation, afforestation and forest landscape restoration and increasing the value of forests through expanding markets for wood products – is significant. While the actions in the current NDCs are estimated to lead to LULUCF emissions falling by about 0.9 $GtCO_2e$ a year by 2030, full implementation of the ambitious programme of activities discussed in Section 4 in this paper could lead to a reduction in emissions of an estimated 15 $GtCO_2e$ a year by 2050, potentially closing the current 'emissions gap', at least to the level needed to keep warming below 2˚C.

Any policy affecting forests has the potential to affect forest-related carbon emissions and sinks, and a full listing would take many pages. In outline, however, key policies and measures include the following:

- Agreement on consistent means of measuring and accounting for changes in forest-related greenhouse gas emissions and sinks and distinguishing between anthropogenic actions and natural impacts, for inclusion in the NDCs under the Paris Agreement. Among other things, this should permit a more accurate analysis of the impact of the NDCs on forests and related emissions and sinks. Greater investment in the capacity to measure these changes is also required.
- Encouragement for countries to commit to voluntary national contributions aimed at achieving the UNSPF Global Forest Goals and targets, alongside and coherent with their NDCs.
- Measures aimed at reducing current rates of deforestation and degradation, including (though not limited to) measures designed to reduce pressures from conversion to agriculture – particularly illegal conversion – including the development of production techniques not associated with deforestation, and measures designed to promote the consumption of zero-deforestation and/or sustainable products.
- The research and promotion of means of sustainable forest management designed to maximise carbon storage in forests (recognising that these may not necessarily be the same as SFM techniques aimed at maximising production of wood products).
- Support for reforestation and afforestation initiatives, focusing on holistic approaches to natural forest landscape and ecosystem restoration, sensitive to local conditions and local communities, rather than expanding plantations of monocultures unsuited to local ecosystems and climates.
- Measures to promote the sustainable production and consumption of long-lived forest products, in construction and other uses.

Unlike many other climate mitigation options, these measures do not require any invention or commercialisation of new technologies; although techniques for sustainable forest management, forest

[137] *Emissions Gap Report 2018* (UN Environment, November 2018).

restoration, and making and using wood products will undoubtedly continue to evolve, we already largely know how to achieve these forest-related activities, at least in technical terms. They are also not likely to be expensive, compared to many other mitigation options.

The role forests can play in adaptation to the impacts of climate change is also important: forests can help societies adapt to climate variability and change in several ways, providing ecosystem services that can significantly reduce social vulnerability. Key policies and measures include:

- Ecosystem-based adaptation strategies designed to target the conservation or restoration of specific ecosystem services that are crucial for societal adaptation in a particular region.
- Strategies to assist forests to adapt to the impacts of climate change, through measures that either increase their resistance and resilience or facilitate ecosystem shift or evolution towards a new state that meets the new conditions.

Underlying all of these measures are two prerequisites for the successful implementation: the provision of adequate sources of funding, and ensuring adequate standards of governance. Key measures include:

- A significant increase in financial support for forest-related mitigation activities from the current 1 per cent of global mitigation-related development funding; and a commensurate increase in funding for forest adaptation activities.
- Support for improvements in forest governance and law enforcement, including in particular the clarification of land tenure and access rights and support for community land and forest management.

Although progress is being made in many countries, it is not yet sufficient. What is lacking so far is finance, effective governance and political will. Until each of these three barriers is overcome, forests will not contribute their full potential to limiting global warming, or deliver any of the other co-benefits of these actions, which include watershed management, local climatic regulation, biodiversity protection, poverty alleviation – and assistance to communities and nations to adapt to the impacts of climate change that are already inevitable.

The Global Forest Goals of the UN Strategic Plan for Forests set out a clear direction for forest-related mitigation and adaptation options. If nations fail to meet them, the overall cost of climate mitigation efforts will rise, global warming will take longer to limit, and the impacts of climate change will be more severe.

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