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Economics in Context Initiative

Forests and Climate: Economics and Policy Issues

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An ECI Teaching Module on Social and Environmental Issues in Economics

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NOTE – terms denoted in bold face are defined in the KEY TERMS AND CONCEPTS section at the end of the module.

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1. INTRODUCTION: THE ROLE OF FORESTS IN GLOBAL CLIMATE CHANGE

Global climate change is the result of a rapid increase in atmospheric carbon dioxide and other greenhouse gases (GHGs), resulting from human activities. Increased emissions and accumulations of these gases have unbalanced the atmospheric cycles that have maintained a stable planetary temperature range. An important component of this problem, in addition to industrial emissions, is the loss in the capacity of forests and other ecosystems to store carbon and to contribute to balancing cycles of carbon dioxide, methane, and other greenhouse gases.

The urgency of the problem has been addressed by scientists for decades. Since the 1990s, the Intergovernmental Panel on Climate Change (IPCC) has regularly summarized the state of the art of scientific research on this issue through regular detailed reports. Its sixth assessment, published in 2021 warned more strongly than ever about the urgency of the problem, concluding that "Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide (CO_2) and other greenhouse gas emissions occur in the coming decades"[1].

Exceeding 1.5°C of temperature increase would significantly increase projected and potentially catastrophic outcomes including: "increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost. . . Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels."[2] This warning from scientists led to the goals of no more than 2°C of warming, with a more ambitious target of no more than 1.5°C, being adopted at the Paris Agreement on Climate Change in 2015, and reaffirmed at the Glasgow Climate Conference of 2021.

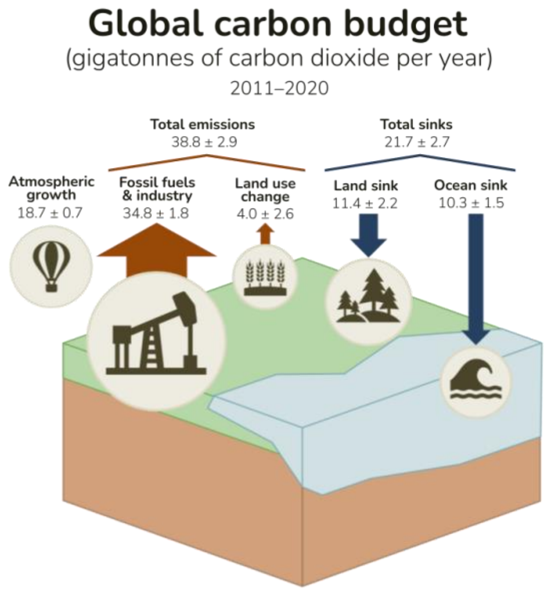
The reality of climate change has already become evident through the increased prevalence of climatic events previously considered as "once-in-a-century" occurrences, but now being experienced at a much higher frequency and amplitude. Droughts, heat waves, mega-wildfires destroying forests in Siberia, Australia, California, and elsewhere, as well as unusually strong hurricanes, typhoons, tropical storms, and floods have occurred particularly in 2020 and 2021, in the Global North as well as in the Global South, devastating entire regions and impacting millions of people.[3]

[1] IPCC, 2021.
[2] Ibid.
[3] ABC News, *Year in Climate*, 2021.

Addressing climate change means not only drastically decreasing human-created global emissions, but also implementing policies to promote "natural climate solutions" that increase the potential of ecosystems to store carbon.

Terrestrial and ocean ecosystems have maintained a rough carbon balance for millennia, but this has been altered by emissions from human activities. Figure 1 depicts the global carbon budget, expressed in Gigatons (or billions of tons, Gt) of carbon dioxide (see Box 1 on measurement of emissions in carbon or in CO_2).

Figure 1. *Global Carbon Budget (Gigatons of carbon dioxide per year),* 2011-2020



Source: Figure adapted from Global Carbon Budget, Global Carbon Atlas 2021. Consulted at http://www.globalcarbonatlas.org/en/content/global-carbon-budget

Each year, human industrial and fossil fuel emissions, as well as land use changes such as deforestation, release close to 39 Gt of CO2into the atmosphere. Some of these emissions are absorbed by planetary "sinks". "Land sink" refers to terrestrial ecosystems, which absorb about 11.4Gt of CO_2 (about 33% of annual emissions), while ocean sinks absorb an additional 10.3 Gt of CO_2.

Current greenhouse gases emissions have far exceeded the earth's capacity to store carbon in forests, oceans and living and dead biomass. The role of oceans as a carbon sink has buffered climate change, but has also caused their acidification, which poses grave threats to marine ecosystems. Since total emissions exceed the sink capacity, there is an annual net increase in atmospheric carbon dioxide of about 19 Gt per year.

The solution to the problem lies in reducing human-created carbon emissions while significantly increasing carbon absorption capacity. Most climate policy discussions focus on reducing emissions. A growing body of scientific research, however, shows the potential of terrestrial ecosystems including forests, mangroves, wetlands, croplands, grasslands, as well as currently degraded or barren lands, to become more potent carbon sinks that draw down excess CO_2 from the atmosphere and help to reverse climate change. There is increasing evidence that ambitious goals to mitigate climate change, such as those set by the Intergovernmental Panel on Climate Change and affirmed by the climate conferences in 2015 in Paris and 2021 in Glasgow, cannot be met without a substantial contribution from increased absorption of CO_2 by forests, wetlands, and soils.[4]

This module presents some of the most recent scientific findings on forests and wetlands, while a companion module presents findings on soils, agriculture, and land management.[5] Together, they examine strategies that could reshape these sectors to combat climate change, and what challenges such a transition might pose.

Box 1: MEASURING GREENHOUSE GAS EMISSIONS

Greenhouse gases (GHGs) include naturally occurring gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), as well as industrially produced gases such as hydrofluorocarbons, among others. Carbon dioxide is the most prevalent GHG, and in order to aggregate all GHG emissions, scientists often convert other GHGs to their equivalents in emissions of CO_2. The heat-trapping potentials of CH_4 and N_2O are much higher than that of CO_2. One ton of methane has a global warming potential of 25 tons of CO_2, and so is equivalent to 25 tons of CO_2 in terms of its climate change impact. One ton of nitrous oxide is equivalent to 298 tons of CO_2. The total warming potential of various greenhouse gases can thus be expressed in tons of carbon dioxide equivalent or CO_2e.

One frequent source of confusion is the difference between expressing emissions in tons of carbon or in tons of CO_2. A molecule of CO_2 includes one atom of carbon plus two atoms of oxygen. The atomic weight of carbon is 12, and the atomic weight of oxygen is 16, therefore the total weight of the CO_2 molecule is 44. The ratio of the weight of the CO_2 molecule compared to the weight of the carbon atom is 44/12 = 3.66. Thus measurements expressed in terms of CO_2 must be divided by 3.66 to obtain the measure of the same quantity in carbon.

For instance, in 2021 total global emissions of greenhouse gases reached 36.4 gigatons of CO_2, which can also be expressed as 36.4/3.66 = 9.93 gigatons of carbon.

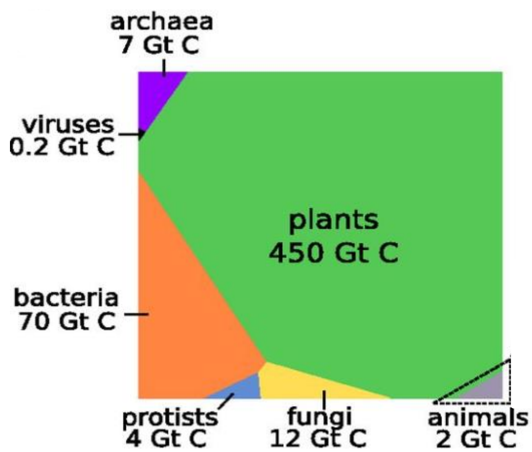
[4] IPCC, 2018.
[5] Codur, Harris and Fay, 2022.

1.1 Understanding the Carbon Cycle

Carbon is the building block of life. It is stored in living beings, including plants, animals, and other life forms. When they die and decompose, carbon is used by other living beings or deposited in the soil as "organic carbon."[6] The upper few feet of soils contain a repository of 2300 Gt of carbon, the largest carbon sink on Earth.

Living beings on earth contain 550 Gt of embedded carbon. This is primarily composed of plants and trees (450 Gt), followed by bacteria (70 Gt), fungi (12 Gt) and single-celled archaea (7 Gt) that are primarily located in deep subsurface environments. The animal kingdom (including human beings and livestock) represents only a global biomass of 2Gt of Carbon (see Figure 2).

Figure 2: *The distribution of biomass on earth (in Gigatons of Carbon)*



Source: Bar-On, Phillips and Milo, 2018.

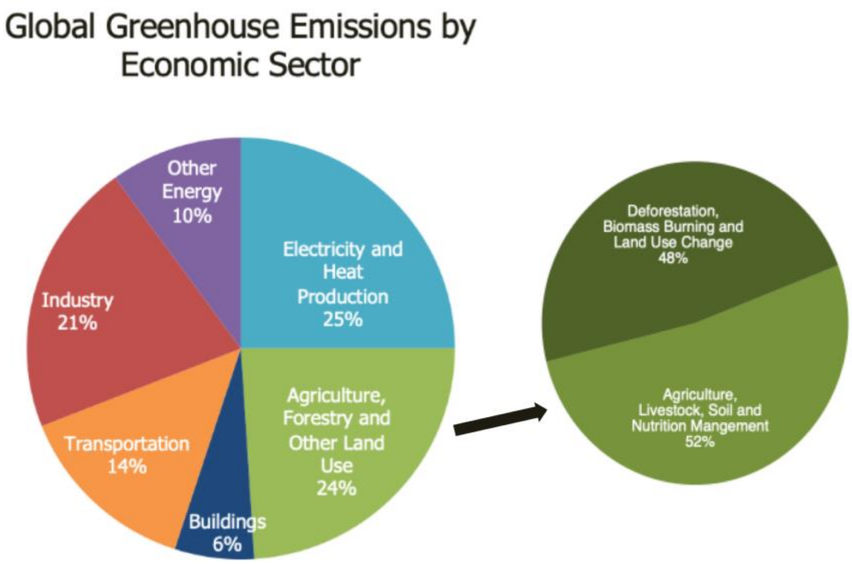
Agriculture and forestry have drastically altered terrestrial pools of carbon through human activities such as deforestation, biomass burning, soil cultivation, and drainage of wetlands. Global land use changes have contributed to a depletion of more than 320 Gt of carbon in the past 10,000 years[7]. Of this amount, 180 Gt have been released into the atmosphere since 1750 through the burning of fossil fuels.[8]

[6] Millions of years of carbon deposits have produced fossil carbon, which made the coal and oil contained in the earth' crust. These, along with natural gas (methane), constitute the fossil fuels whose exploitation in the past 200 years has unleashed unprecedented amounts of carbon dioxide into the atmosphere.
[7] Ruddiman, 2003.
[8] Lewis et al., 2005.

Due to current global land and forest management practices, agriculture (cropland and grazing), land use, and forestry are significant net contributors to climate change. The United Nations Convention on Climate Change (UNFCCC) refers to non-industrial sources of greenhouse gas (GHG) emissions as AFOLU, or Agriculture, Forestry and Other Land Use.

In 2014, AFOLU was globally responsible for 10 to 12 Gigatons of carbon dioxide equivalent (= 2.7 to 3.3 Gt of Carbon) which represented 24% of all emissions of greenhouse gases (Figure 3).

Figure 3. *AFOLU's greenhouse gases emissions*



Source: IPCC 5th assessment (2014).
Note: This graph is based on IPCC's 5th assessment (2014).
The AFOLU data have not been updated in the 6th assessment of the IPCC published in 2021.

These emissions come mostly from:

1. *Deforestation and land use change, such as the conversion of forests into grasslands or croplands, or conversion of croplands into suburban/urban areas* – at a level of 4.3 to 5.5 Gt CO_2 eq. per year (1.2 to 1.5 Gt of Carbon)
2. *Agricultural emissions from livestock, soil and nutrient management* – at a level of 5.0 to 5.8 Gt CO_2 eq. per year (1.36 to 1.58 Gt of Carbon).[9]

[9] Data from the Intergovernmental Panel on Climate Change (IPCC 5th report, 2014).

These sectors, instead of being part of the problem, could become part of the solution if all actors took part in a global reassessment and reform of agriculture, grazing and forestry practices.

Restoring forests could significantly increase the amount of carbon stored in plant biomass and forest soils. Regenerating soils would draw down carbon from the atmosphere into soil ecosystems, with a net benefit both to climate and agricultural productivity (see detailed discussion in Agriculture and Climate module).[10]

Together, these regenerative approaches could stabilize and eventually even contribute to reversing climate change, as shown by research compiled by scientists at the National Academy of Sciences. By 2030 the climate mitigation capacity of forests, agricultural lands and grasslands, and wetlands could be enhanced to store up to an additional 17Gt of CO_2 per year 5 Gt of CO_2 per year, and 2.5 Gt of CO_2 per year, respectively.[11]

In this module, we will analyze the role of forests in these climate mitigation efforts. We will examine challenges, including the drivers of deforestation, both in the Global North and South, and policies to reduce deforestation and promote the expansion of forests and wetlands, including national and international efforts and the role of local communities.

2. THE STATE OF THE WORLD'S FORESTS

2.1 What is a Forest?

Although *forest* is a common term, there is no universally recognized definition. Different approaches to definition include:

- Administrative definitions are based on legal designations of land.
- Land use definitions are based on the primary purpose that the land serves (for instance land that is used primarily for production of timber).
- Land cover definitions define forests based on the type and density of vegetation growing.[12]

None of these institutional definitions are concerned with ecological considerations, including whether a forest is primary – i.e. untouched by logging activities – or secondary, which means already logged or disturbed in significant ways.[13] But from an ecological point of view, and also in terms of carbon storage potential, the type of forest is important.

[10] Codur, Harris and Fay, 2022.
[11] Griscom at al., 2017.
[12] IPCC 2014 Land Use, Land-Use Change and Forestry (LULUCF)
[13] Rainforest Journal, "Differences between primary and secondary rainforest," July 14, 2013.

In ecological terms, a forest is a diverse ecosystem that includes a wide variety of trees and other plants. Recent research has shed light on the complexity of forest ecosystems, and how trees communicate underground, through their roots, which are connected to each other by way of the mycorrhizal fungi, which scientists have humorously nicknamed the "wood wide web."

> Tree roots extend a long way, more than twice the spread of the crown. So the root systems of neighboring trees inevitably intersect and grow into one another… fungi act as intermediary to guarantee quick dissemination of news. These fungi operate like fiber-optic Internet cables. Their thin filaments penetrate the ground, weaving through it in almost unbelievable density. One teaspoon of forest soil contains many miles of these "hyphae". Over centuries, a single fungus can cover many square miles and network an entire forest. The fungal connections transmit signals from one tree to the next, helping the trees exchange news about insects, drought, and other dangers.
>
> —Peter Wohlleben, The Hidden Life of Trees: What They Feel, How They Communicate, Discoveries from a Secret World. 2018 (Greystone Books)

Tree plantations are often made up of a single species (monoculture). A monoculture plantation might be defined as forest on an administrative, land use, or land cover point of view, but it does not meet the ecological criteria of being a diverse ecosystem. For example, a monoculture plantation of eucalyptus dehydrates and acidifies the land and prevents anything else from growing, which can lead to desertification. Monoculture plantations by definition are not diverse ecosystems, since they are composed of the same species, and consequently do not provide habitat for diverse flora and fauna. They have been described by ecologists as "green deserts".

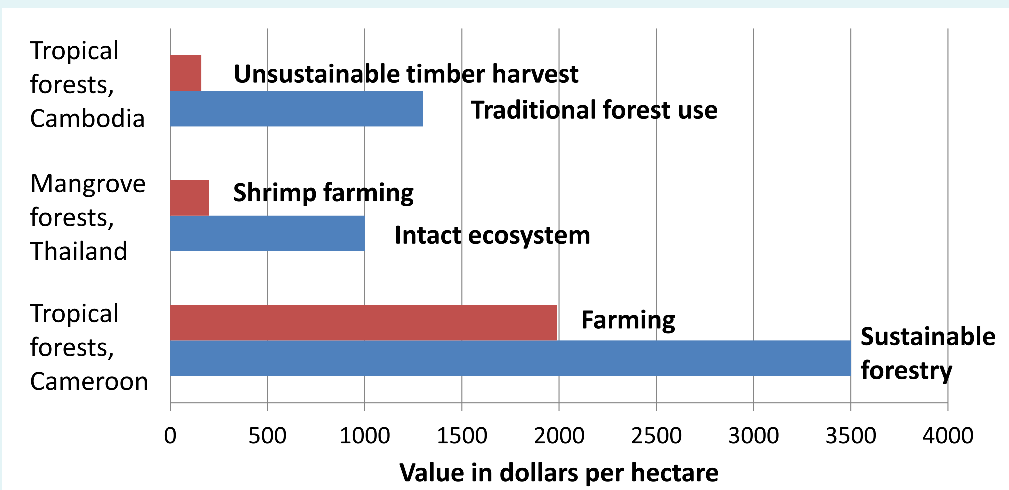
Forests can also be described according to their functions. The 2015 FAO Global Forest Resources Assessment examined changes in the world's forests between 1990-2015. They found that 31% of forests globally are used directly for economic production.[14] Close to one third of forests globally are designated for the provision of vital ecological services, such as soil and water conservation, as well as ecosystem and sociocultural services (see Box 2).

[14] FAO, 2015.

BOX 2: SOCIAL AND ECOLOGICAL FUNCTIONS OF FORESTS

"Forests are more than just carbon, they are home to local communities, and they provide essential ecosystem services beyond carbon storage. Forest resources directly support the livelihoods of 90% of the 1.2 billion people living in extreme poverty and are home to nearly 90% of the world's terrestrial biodiversity. Indigenous and forest-dependent peoples are stewards of their forests, providing the rest of humanity with vital ecosystem services (ES). Also, forests provide ecosystem services such as watershed protection, water flow regulation, nutrient recycling, rainfall generation and disease regulation that all will be negatively affected by the recent global deforestation and forest degradation trends."[15]

The total economic value of forests includes all these services, as well as other benefits such as recreation opportunities and the existence value of simply knowing that pristine forests are preserved. Some economists have attempted to measure the total economic value of intact forest ecosystems. While converting all these benefits to monetary units is subject to both methodological and ethical concerns, policy makers can potentially use this information to assess forest policies. In particular, the economic value of preserving forests can be compared to extractive uses such as timber or agricultural development.



The results of several studies suggest that the benefits of preserving forests often exceed the benefits of extractive uses. For example, a study of Mediterranean forests found that in some countries, nonmarket benefits such as carbon storage, watershed protection, and recreation, are greater than the combined economic values from timber, fuelwood, and grazing. Other research

[15] Parker et al., 2009.

(see figure above) has found that the benefits of intact or sustainably managed forest ecosystems exceed the value of unsustainable uses in Cambodia, Thailand, and Cameroon.[16]

An attempt to estimate the economic value of the world's forest ecosystems found that forests provide about $5 trillion in total annual value to humanity, with only about 20% of these benefits derived from extractive uses. Economic benefits from forests includes the ecosystem services provided without cost, such as nutrient cycling, erosion control, climate regulation and waste treatment.[17]

2.2 The Role of Forests in the Carbon Cycle

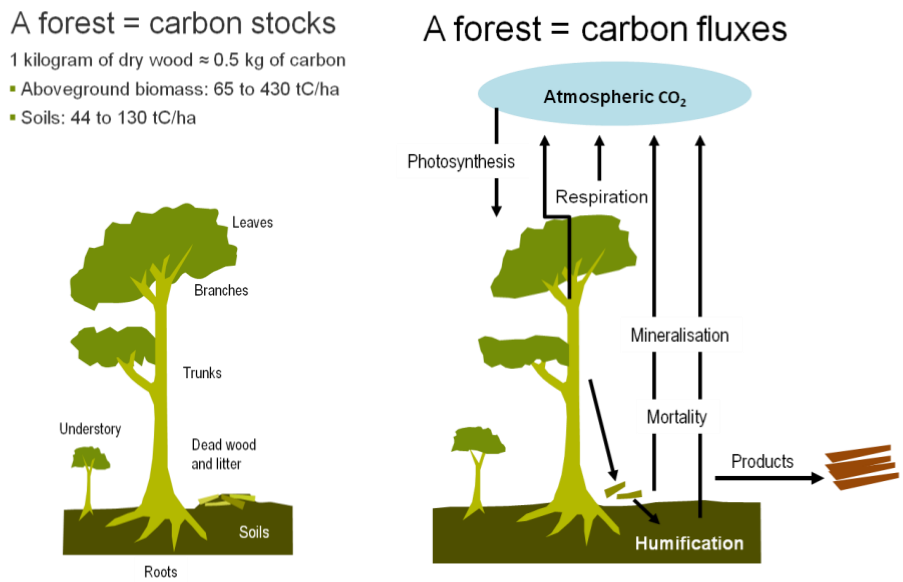
Forests can affect the global carbon cycle in two different ways:

1. *Forests as **carbon stocks***: a forest, like any other ecosystem, accumulates carbon from the atmosphere by breaking down carbon dioxide into carbon and oxygen, using solar energy. The carbon thus generated is stored in tree trunks, branches, leaves, and other parts of plants, as well as in soils as living and dead biomass. The dry biomass of a tree is about 2 tons, which can contain around 1 ton of carbon. A tropical wet forest can store up to 430 tons of carbon per hectare in aboveground biomass.[18]
2. *Forests as **carbon fluxes***: forests also affect the carbon cycle through the carbon fluxes they generate. Through the process of photosynthesis and using sunlight, leaves absorb CO_2 from the atmosphere (inbound flux). This stored carbon will be distributed to the plant and transferred to soil when leaves and branches fall down and decompose. Part of this CO_2 will return to the atmosphere through respiration and soil mineralization (outbound flux). The **net absorption flux** is the difference between the inbound and outbound.[19] This concept is represented in Figure 4 below.

As a forest grows, the net flux is an inbound flux, meaning that CO_2 is removed from the atmosphere. This process is called **carbon fixation**, absorption or removal and the ecosystem is called a **carbon sink**. On the other hand, if the stock decreases (in a decaying or burning forest), an outbound flux increases atmospheric greenhouse gas emissions. The process is called carbon emission and the ecosystem is then called a **carbon source**.

[16] Millennium Ecosystem Assessment, 2005.
[17] Costanza et al. 1997.
[18] CIFOR, 2009.
[19] Ibid.

Figure 4. *Forests as carbon stocks and carbon fluxes*



Source: CIFOR, 2009.

Depending on whether forest cover is expanding or contracting, large regions of the world can be net carbon sources (contributing to climate change) or net carbon sinks (reducing climate change).

Climate change in the past has been related to the evolution of global forest cover. For instance, when the discovery of the Americas by Europeans led to the near annihilation of native populations, abandoned agricultural lands were reclaimed by tropical forests. This phenomenon caused a significant reduction in the level of atmospheric CO_2 (as more carbon was stored in tropical forests), which in turn may have caused the little Ice Age of the 16th and 17th centuries.[20]

Figure 5a shows that during the twentieth and early twenty-first centuries, forested areas in South and Central America, Africa, and South and Southeast Asia have become major sources of atmospheric carbon due to forest loss and degradation. As shown in Figure 5b, forests in Europe, the former USSR, China, and the United States are no longer major carbon sources, and in the case of the U.S., Europe, and more recently China have become net carbon sinks.

China's transition from being a major net carbon source to being a carbon sink is mainly due to afforestation projects developed in the past decade as a result of serious environmental damage, including massive flooding, that resulted from earlier forest degradation (See Box 3 for more information on China reforestation).

[20] Yirka, 2011.

***Figure 5a.** Annual Net Flux of Carbon to the Atmosphere from Land Use Change, South America, Africa, and Asia: 1850-2005*

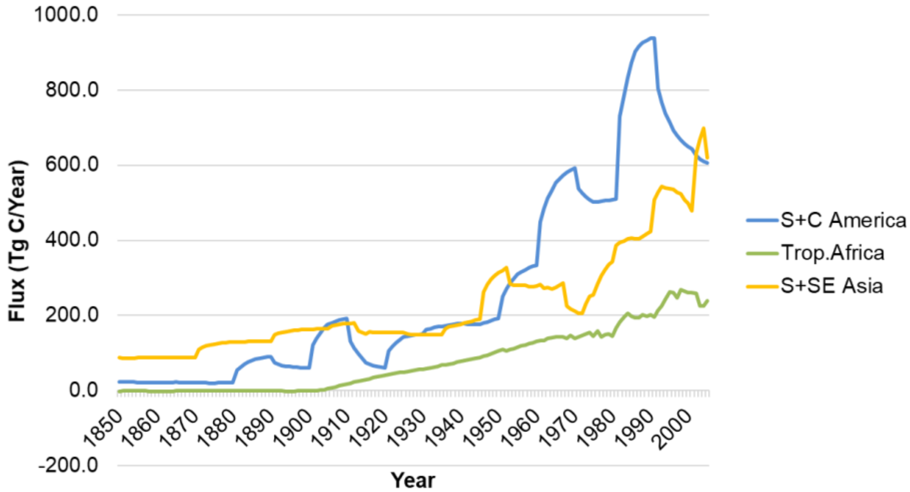
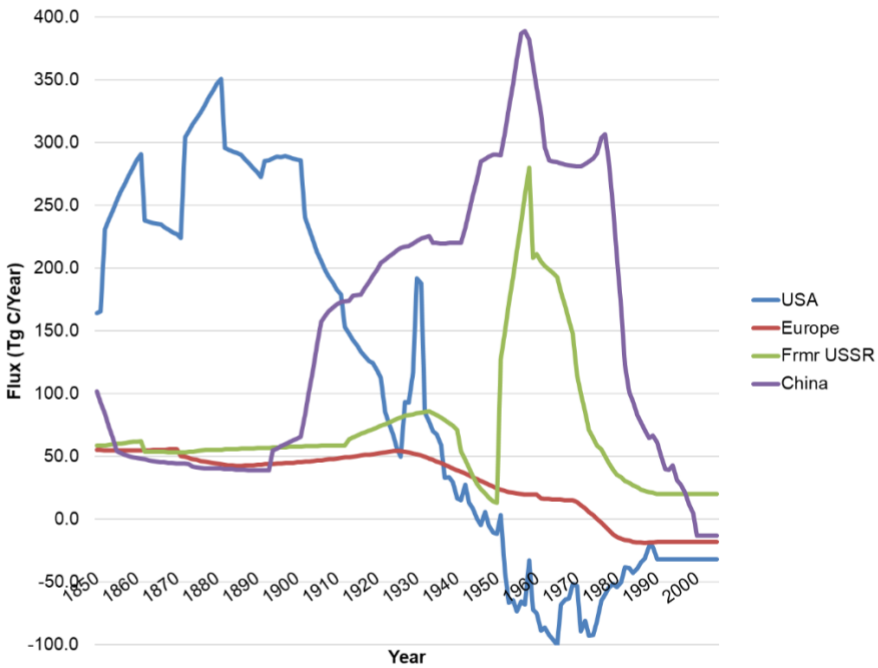


***Figure 5b.** Annual Net Flux of Carbon to the atmosphere from land use change, Europe, China, Former USSR, and USA: 1850-2005*

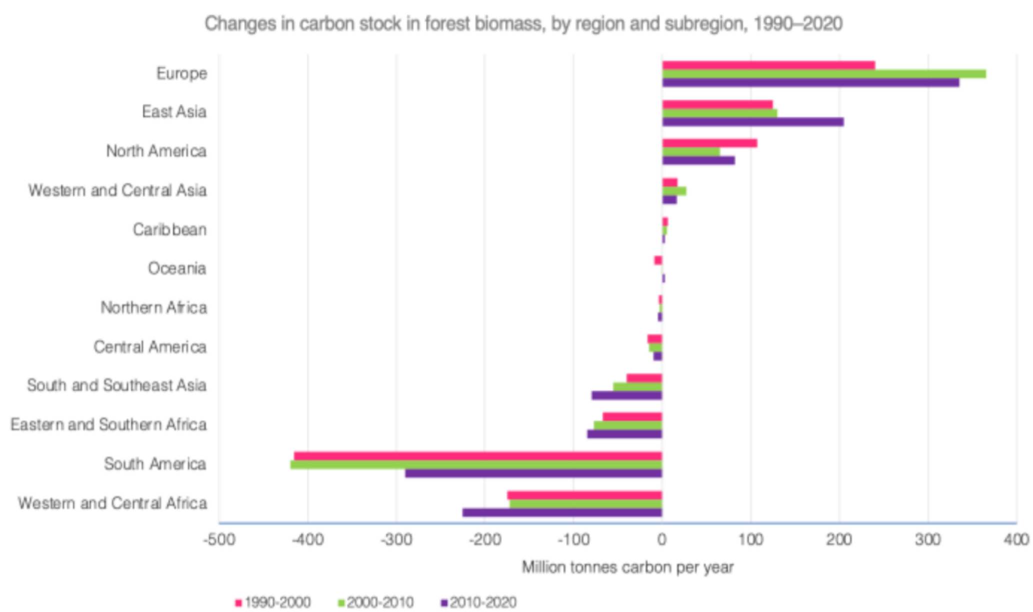


Source: Houghton 2008.[21]

[21] Data are accessible at https://cdiac.ess-dive.lbl.gov/trends/landuse/houghton/houghton.html

Figure 6 shows the continued changes in the carbon stock of forest biomass up to 2020. Europe, East Asia, and North America's forests continue act as net carbon sinks. Deforestation in South and Southeast Asia (especially in Indonesia, as a result of palm oil plantations) has led to increasing losses in carbon stocks in these areas. The largest net forest losses are in South America and Africa, with deforestation increasing in Africa in recent decades.

Figure 6. *Changes in Carbon Stock in Forest Biomass, 1990-2020*



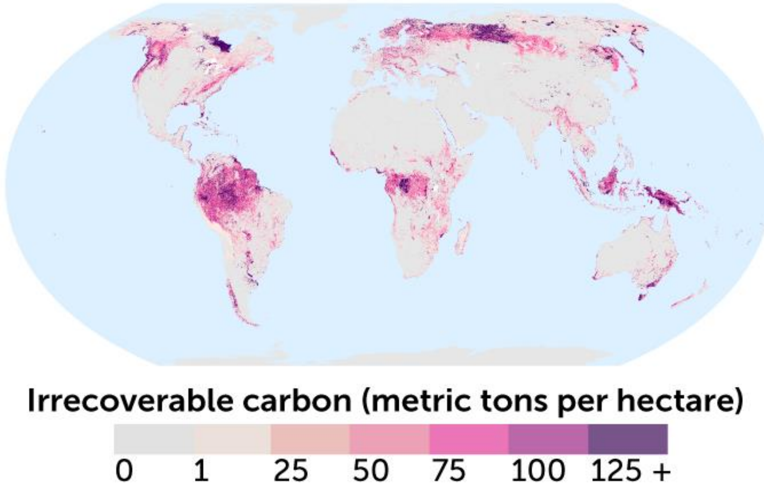
Source: FAO 2020 Global Forests Resources Assessment, Figure 24 (p. 53)
https://www.fao.org/3/ca9825en/ca9825en.pdf

Scientists have mapped out key ecosystems, especially carbon-rich forests and peatlands, that humanity cannot afford to destroy if climate catastrophe is to be avoided. These areas store 139 Gigatons (Gt) of carbon in trees, plants, and soils, which are "irrecoverable", meaning that natural regeneration would not be able to compensate for their loss by 2050 (see Figure 7).

During the last decade, 4 Gt of this irrecoverable carbon has been released into the atmosphere through wildfire, logging, and farming. The major remaining stores of carbon are in forests and peatlands in the Amazon Forest, Russia, the Congo Basin, Canada, and Australia.[22]

[22] Noon et al., 2021.

Figure 7. *Irrecoverable Carbon Stores across the Planet*



Source: Noon et al, 2021.

2.3 Scale of World Forest Coverage and Forest Loss

More than half (54%) of the world's forests are only in 5 countries: the Russian Federation, Brazil, Canada, the U.S.A, and China. In 1990 the world had 4236 million ha (hectares) of forest areas; by 2020 this area had decreased to 4059 million ha, with the largest losses in the tropics, particularly in South America and Africa.

An estimated 420 million ha of forest (mostly primary forests) was lost through deforestation between 1990 and 2020, although the rate slowed over the period. During that same period, forested areas have expanded by about 240 million ha (mostly planted forests). The difference is a net forest loss of 178 million ha during the past three decades. Figure 8 presents changes in forest area during the period 1990-2020.

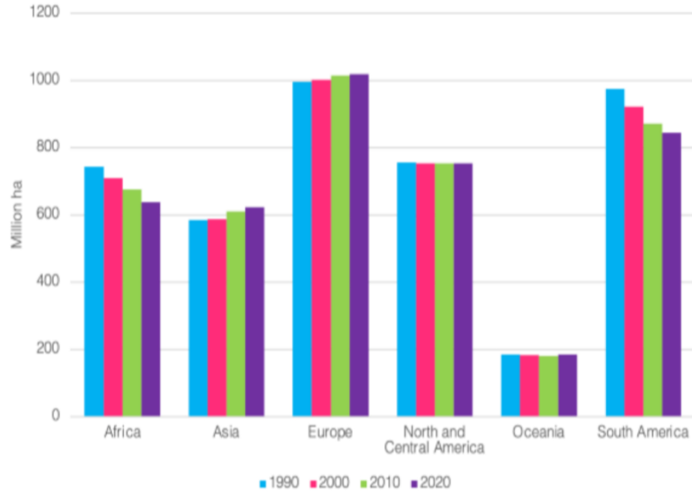
The rate of net forest loss declined from 7.8 million ha per year in the decade 1990–2000 to 5.2 million ha per year in 2000–2010 and 4.7 million ha per year in 2010–2020.[23] This aggregate of 4.7 million ha per year of loss of forest area in the past decade hides a very diverse situation when comparing different continents (see Figure 9).[24]

Africa's annual rate of net forest area was 3.9 million hectares in the 2010s, a rate of loss that has been steadily increasing since the 1990s. South America's annual rate of net forest loss was 2.6

[23] FAO, 2020.
[24] Lipton, 2020.

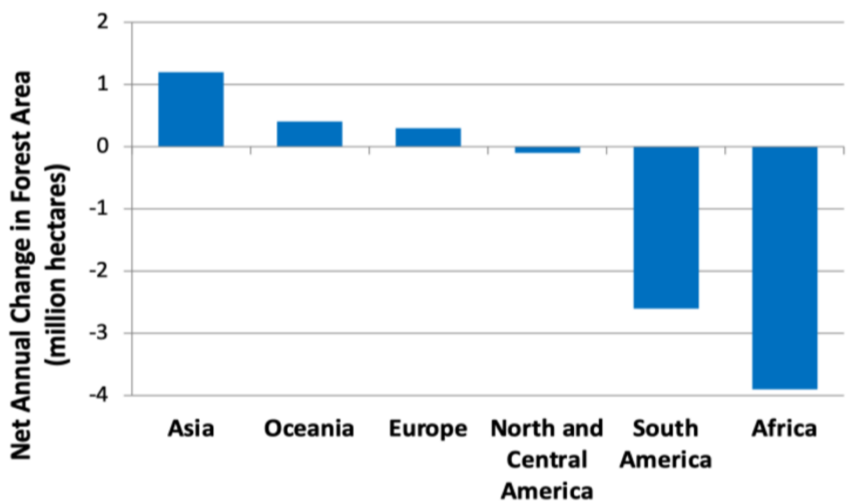
million hectares, half of what it was in the prior decade, but the rate of deforestation of the Amazon Forest has increased again in the last few years under the Bolsonaro government in Brazil (see section 3.2a.).

Figure 8. *Annual net forest area by region, (millions of ha), 1990 to 2020.*



Source: FAO 2020 assessment, Figure 7 (p. 17), https://www.fao.org/3/ca9825en/ca9825en.pdf

Figure 9. *Net Change in Forest Area 2010-2020*



Source: FAO 2020 assessment, Figure 7 (p. 17), https://www.fao.org/3/ca9825en/ca9825en.pdf

When looking at losses and gains in forest areas, it is also important to note that these definitions include any kind of forested area, including many that do not qualify as complex and diverse ecosystems. Afforestation in China of large parts of previously deforested lands and croplands has been done in a very "industrial" way, planting millions of the same tree species, in straight-lined plantations (see Box 3 on China). Reforestation efforts need to be conducted with a more holistic and systemic approach so that they not only provide carbon storage but also meet all other criteria of ecological and social uses of forests (see section 2.1).

In addition, although China is increasing its own forested land, its giant economy is one of the main drivers of deforestation *outside* of China, and especially in Africa, where the total accumulated export of wood from the Congo Basin (Cameroon and Republic of Congo) to China doubled between 2001 and 2015, often used in Chinese factories to make low-cost furniture for the US market.[25]

BOX 3: AFFORESTATION AND REFORESTATION IN CHINA

China has long suffered from severe problems of soil erosion and flooding due to loss of forest cover. An estimated 2 to 4 billion tons of silt flows into the Yangtze and Yellow Rivers annually, and periodic floods cause hundreds of deaths and huge economic losses. This has motivated the Chinese government to undertake the largest reforestation project in the world, through the "Grain-for-Green" Program launched in 1999, by paying farmers to restore forests and grasslands where they had previously planted crops – in order to protect against flooding and landslides.

In the 1950s and 60s, China had one of the highest net forest carbon emission rates in the world (see Figure 7b) – this rate has fallen to zero around 2005 and then has become negative (net carbon storage). Overall tree cover grew by 32% between 2000 and 2015. Today 22% of the country is covered in forest, compared with 19% in 2000 - and $100 million has been spent between 2008 and 2018 on afforestation efforts. China has continued its afforestation efforts during the covid-19 pandemics, stepping up its efforts in 2021 in a bid to become the world leader in conservation.

However afforestation mostly came from turning former croplands into monoculture tree plantations – forests with only one type of tree, mainly fast-growing trees which are non-native and therefore unsuitable for local wildlife. In effect, these types of forests are empty of wildlife, also called "green deserts". In the meantime, native forests have actually decreased by 6% because people continued to clear native forests to make way for tree plantations. "This creates a perverse incentive to establish tree plantations and displace native forests," said Fangyuan Hua, co-lead author of a study in *Biological Conservation*.[26]

Sources: Hua et al., 2018; Liu and Pharr, 2018; Lie, Feldman, and Daily, 2011; Kelly and Huo, 2013.

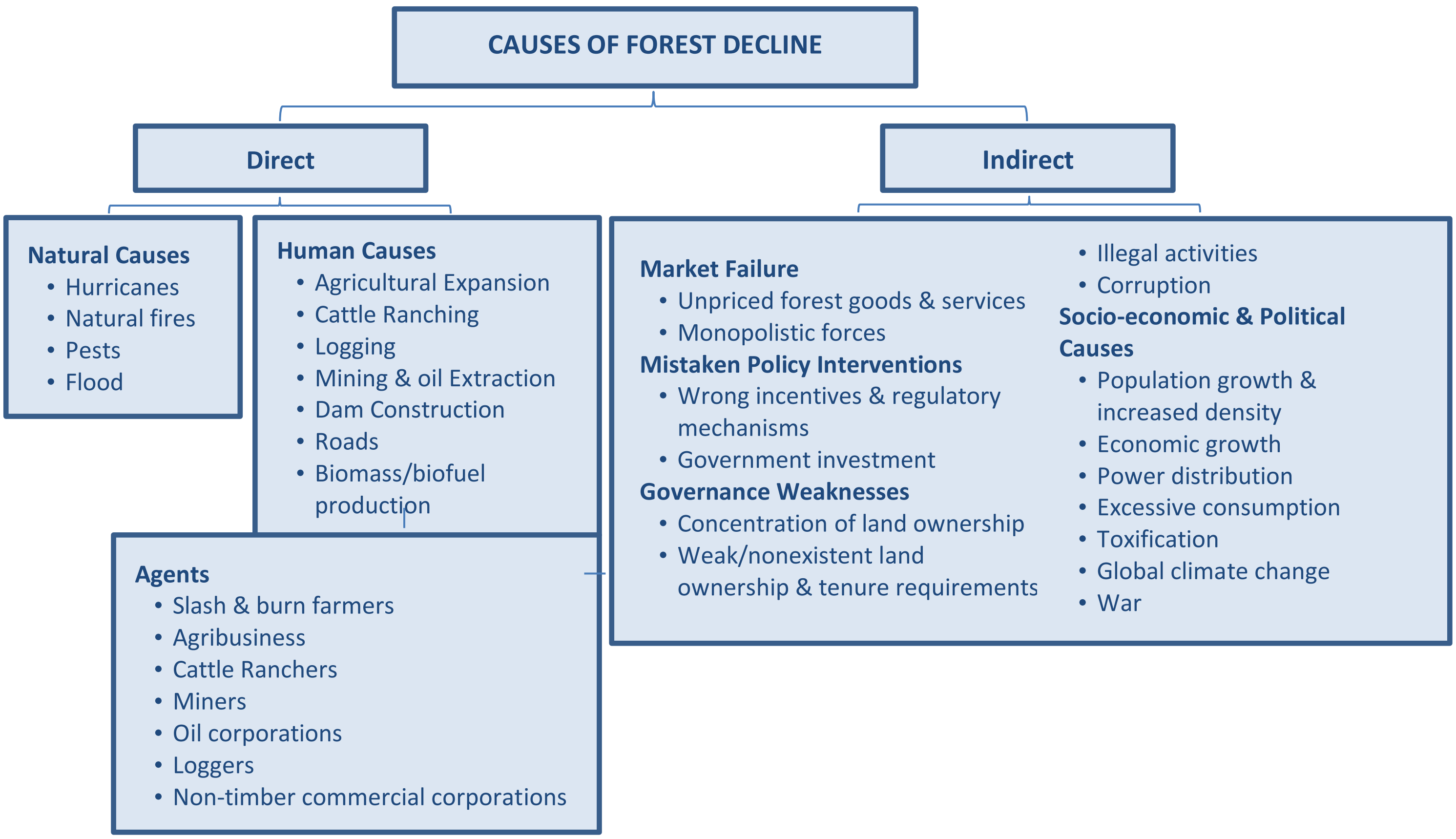
[25] Fuller et al., 2019.
[26] Erickson-Davies, 2018.

3. WHAT CAUSES DEFORESTATION?

The main driver of deforestation is large-scale agricultural development to meet global demand for four commodities: beef, soybean, palm oil, and wood products (pulp and timber). These four products are responsible for 3.8 million hectares of deforestation annually, with a lesser amount accounted for by coffee, rubber, cocoa and sugar.[27]

Other economic incentives for deforestation include **market failures** and destructive **government policies** such as subsidies for logging, road-building, and agricultural exports. A new leading cause of deforestation is the production of biomass for electricity generation. The complex patterns that lead to forest loss are shown in Figure 10.

Figure 10. *Causes of Forest Decline*



Source: Adapted from Contreras-Hermosilla, 2000.

[27] Union of Concerned Scientists, 2016.

3.1 Deforestation vs. Degradation: The Value of Intact Forest Systems

It is important to distinguish between deforestation and degradation. Deforestation is the complete removal of a forested area due to a change in land use, such as from forest to agriculture or urban development. Deforestation has resulted in the loss of 35% of the Earth's pre-agricultural forest cover in the last three centuries.

Degradation (specifically anthropogenic, or human-driven, degradation) includes all human actions that are known to cause physical changes in a forest that lead to declines in ecological function. These may be changes in physical structure, species composition, diversity, abundance and functional organization compared with a forest's natural state. Pressure on forests can result from fires, logging, forest fragmentation, and other human activities, especially at a large scale and industrial intensity.[28]

Forests that have not been degraded are called *intact forests*. Aside from the ecological value of intact forests as habitats for rich biodiversity, intact forests are vital to climate mitigation. Intact forests store more carbon than logged, degraded or planted forests in ecologically comparable locations. They also regulate local and regional weather patterns and diminish the impact of heavy rain events by decreasing runoff and reducing the negative consequences of climate extremes. Additionally, intact forests have lower burning rates, thereby reducing the impact of fires on both humans and animals.

Unfortunately, intact forests are in the minority. An estimated 82% of global forests show evidence of significant degradation.[29] Figure 11 illustrates the regional reduction of intact forest land area and cause of change, and Table 1 illustrates the percent decrease in each region.

It is crucial that the preservation of intact forests be given special consideration when considering forest preservation policies (Box 4). Degradation must be addressed in addition to deforestation in order to improve both the carbon storage capacity and the biodiversity of the earth's forests. Both deforestation and degradation contribute to global warming, and in a vicious circle, climate change accelerates deforestation, as more frequent droughts and heat waves of unprecedented severity are increasingly causing massive wildfires devastating forests on all continents, including the West Coast of Canada and the United States, Siberia, and Australia.[30] In addition, the loss of wetlands is a major issue, since established wetlands and peatlands represent one of the largest pools of existing carbon storage (see Box 5).

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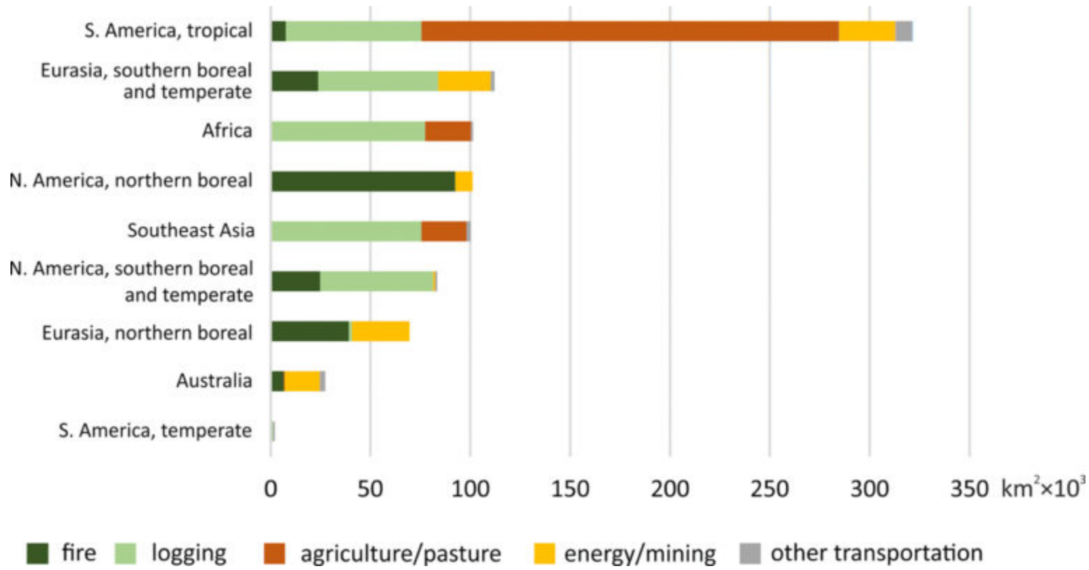
[28] Watson et al., 2018
[29] Ibid.
[30] ABC News, 28 December 2021.

Figure 11. *Regional Reduction of Intact Forest Land Area and Causes, 2000-2013*



Source: Potapov et al. 2017.

Table 1. *Percent Decrease in Intact Forests, 2000-2013*

Region	% Intact Forest Loss
South America, tropical	7.3%
Eurasia, southern boreal and temperate	9.1%
Africa	10.1%
North America, northern boreal	3.3%
Southeast Asia	13.9%
South America, southern boreal and temperate	15.5%
Eurasia, northern boreal	4.4%
Australia	21.9%
South America, temperate	1.3%

Source: Potapov et al., 2017.

BOX 4. MATURE FORESTS ARE BEST FOR CARBON STORAGE

Scientists concede that there are still many gaps in their knowledge of the role of forests as carbon sinks. A new paradigm is emerging in forest sciences, based on the realization that old mature forests continuously store more carbon, with about half in the soil and half in living trees. [31]

New research from a team of 98 scientists in 21 countries and territories has found that the largest 1 percent of trees in mature and old forests contain about 50 percent of forest biomass worldwide.[31] This observation challenges established forest management practices, which are based on a relatively fast turnover. Generally, trees are cut and replaced before they reach 50 to 60 years of age.[32] Such practices prevent forests from developing older trees that would store more carbon. They also contribute to disturbing forest soils, which then rapidly lose carbon due to decay of organic material.

For example, a clear-cut replanted with conifer seedlings in the Pacific Northwest may continue to emit CO_2 for as long as 20 years. The young trees are sequestering carbon, but the accelerated soil decay caused by deforestation releases carbon at a higher rate. One 70 to 80-year-old tree may store as much carbon as about 100 20-year-old trees.[31] These scientific findings indicate that forests should be minimally disrupted whenever possible in order to enhance their capacity to sequester carbon from the atmosphere.

BOX 5. THE CRUCIAL CONTRIBUTION OF WETLANDS

Many civilizations, from ancient China to modern Europe and the United States, have considered wetlands as useless and have dried them up to reclaim them for human needs. Globally, the total cumulative loss of natural wetlands is estimated at 54 to 57%. Only recently has the critical role of wetlands been fully understood and emphasized by scientists.

Wetlands include areas of marsh, fen, peatland, with water that is static or flowing, fresh, brackish or salt, including areas of marine water (mangroves). Wetlands are essential to many forms of life, comprising a wide range of ecosystems that support many species populations, as well as providing ecological, hydrological, physiographical, and cultural functions and services.

These functions include a critical role in moderating climate. Approximately 20–30% of the world’s soil carbon is stored in wetlands, and this is a crucial factor for maintaining long-term climate stability. Wetlands cool surrounding areas, store flood waters, store and provide water and buffer both coastal and inland storms, and hence are essential to shorter-term and more localized aspects of climate resilience.

Natural wetlands typically absorb more carbon than they release. But as the climate warms wetland soils, microbial metabolism increases, releasing additional greenhouse gases. In addition, draining or disturbing wetlands can release soil carbon very rapidly. For these reasons, it is essential to protect natural, undisturbed wetlands. In some types of wetlands, it can take decades to millennia to develop soil conditions that support net carbon accumulation. Other types, such as new saltwater wetlands, can rapidly start accumulating carbon.

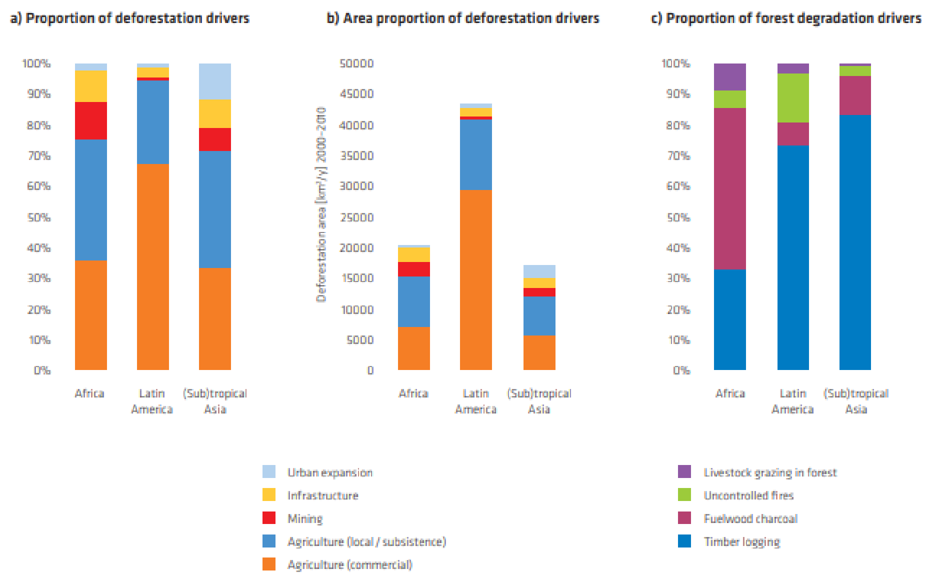
Until recently, wetlands have received little attention from climate scientists and policymakers. Climate considerations are often not integrated into wetland management. This is a critical omission, which was pointed out in the Scientists' Second Warning to Humanity, a statement endorsed by an unprecedented 20,000 scientists. Leading scientists have proposed including the rights of wetlands to be protected as key natural sanctuaries in international law, through a Universal Declaration of the Rights of Wetlands.

Sources: Finlayson et al., 2019; Moomaw, 2018b; Moomaw et al., 2018; Ramsar Convention, 2018; Nahlik and Fennessy, 2016; Millennium Ecosystem Assessment, 2005; Davies et al., 2021.

3.2 Deforestation in the Global South

Figure 12 depicts drivers of deforestation during the first decade of the century (graphs a and b) and forest degradation (graph c) in Africa, Latin America, and Subtropical Asia. Deforestation indicates a change in land use, such as from forests to croplands.

Figure 12. *Drivers of Deforestation and Forest Degradation*



Source: Kissinger, Herold and De Sy, 2012.

Graph a shows that agriculture is a leading cause of deforestation. Commercial and local and subsistence agriculture combine to cause more than 90% of the deforestation in Latin America, and more than 70% of the deforestation in both Africa and Subtropical Asia. Local and subsistence agriculture predominate in Africa and subtropical Asia, while commercial agriculture predominates in Latin America.

Graph b shows the rate of deforestation in each region, measured in km^2/year. Latin America has the fastest rate of deforestation (approximately 43,000 km^2/year), of which 40,000 km^2/year are due to agriculture. Smaller amounts of land are lost to mining, urban expansion, and infrastructure.

Graph c examines the causes of forest degradation, which vary by region. Timber logging leads in Latin America and subtropical Asia, and fuelwood charcoal leads in Africa. Other causes of forest degradation include livestock grazing and uncontrolled fires.

3.2.a Politics and Deforestation in Brazil

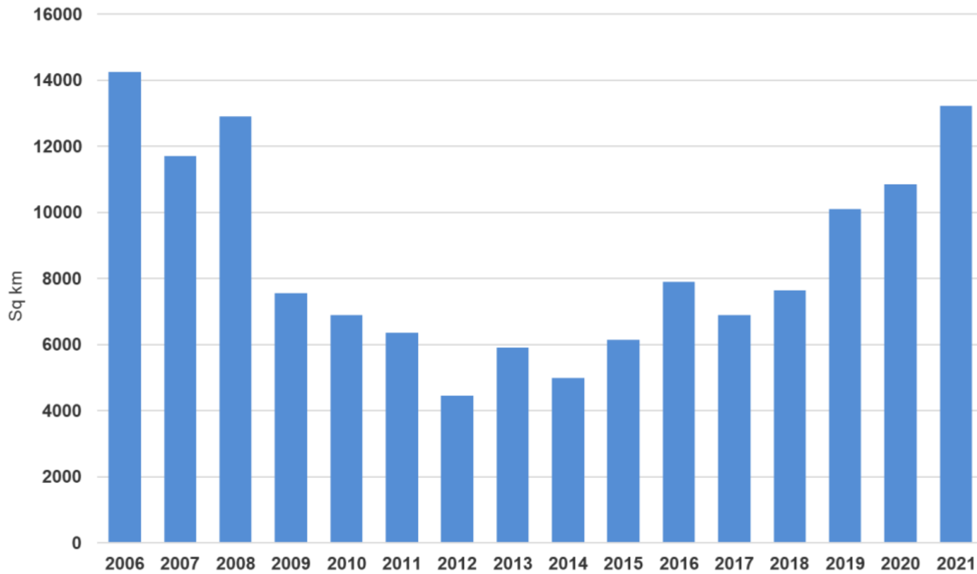
The case of Brazil is particularly instructive. Rates of deforestation were very high from the 1950s to the 1990s. In the late 1990s the government of President Cardoso launched the first national program to halt deforestation. President Lula ramped up these efforts in 2002, and President Dilma Roussef continued efforts to protect Brazil's forests. These efforts were multifaceted, and included:

1. The Brazilian Association of Vegetable Oil Industries and the National Association of Cereal Exporters signed a moratorium on soy in 2006. They pledged not to buy any soybeans produced on Amazon lands that were deforested after June 24, 2006.
2. In 2009, the four largest slaughterhouses announced they would sign on a moratorium to only purchase cattle from ranchers registered with the rural environmental land registry.
3. The Brazilian government expanded indigenous reserves and protected areas.
4. Local and Federal government prioritized the reduction of deforestation through increased enforcement efforts, fines for illegal deforestation, and preventing bank loan and credit distribution to individuals with pending fines related to illegal deforestation.
5. Brazil established the Amazon Fund, a bilateral agreement with Norway to further decrease its rate of deforestation through mechanisms inspired by the REDD+ framework (see section 4 below).

These measures contributed to a significant decrease in the deforestation of Amazonia from 2007 to 2014 (see Figure 13). Brazil was unanimously lauded at the international level for its efforts, and planned to reduce deforestation by 80% before 2020.

Priorities shifted when President Dilma Rousseff was impeached during the 2016 political crisis. The new government cut funding for environmental monitoring and enforcement, and advanced legislation to reduce protected areas and indigenous lands,[31] backing up the political agenda of the powerful "ruralist" voting bloc in National Congress, which promoted resuming massive plans for highways, dams, and other infrastructure in Amazonia, which all contribute to increased deforestation.[32]

Figure 13. *Deforestation in the Brazilian Amazon, 2006-2021*



Source: Brazil's national space research institute INPE, quoted in Mongabay, https://news.mongabay.com/2021/11/amazon-deforestation-unexpectedly-surges-22-to-highest-level-since-2006/

The 2018 election of Jair Bolsonaro significantly worsened the situation. The Bolsonaro administration quickly announced plans to combine Brazil's Agriculture and Environment Ministries into one government body, ensuring that production would take priority over conservation.[33] Bolsonaro also announced plans to pull Brazil from the Paris Climate Agreement, but later said Brazil would remain as long as he is able to open up the AAA corridor, a large stretch of land from the Andes to the Amazon and the Atlantic.

Deforestation rates have risen sharply, and by 2021 had reached the same level as in 2006, with more than 13000 square kilometers of rainforest cleared from August 2020 to July 2021 (Figure

[31] Butler, 2018.
[32] Fearnside, 2017.
[33] Watts, 2018.

13). According to a scientific study by the National Institute for Space Research in Brazil, the Amazon Forest has already turned into a net carbon emitter (emitting more CO_2 than it absorbs).[34]

Activists and environmentalists are fighting back, nationally and internationally, against the severe abuse of the Amazon Forest and to defend the rights of indigenous people.[35] In September 2021, 5000 indigenous women representing 170 tribes, converged on Brasília to demonstrate against Bolsonaro's attempts to open up large tracks of indigenous territories to commercial exploitation, a policy that indigenous people call an "extermination effort". In the words of one of their leaders: "Our struggle is for survival, for life, for the forest and for our children. So we will resist. In spite of all the attacks from the government, we are resisting, and we will continue to resist."[36]

3.2.b The Role of Rural Communities: the case of India

India successfully reversed its once-high rates of deforestation and stabilized its forest cover through innovative policies that have driven action at all levels of society. India's forests were under assault during the colonial era and the first decades of its independence. In the late 1970s, popular pressure and the mobilization of rural communities through the Chipko movement forced a change in policy, with India's government enacting the landmark National Forest Policy Act of 1988. This replaced the country's prioritization of commercial plantations with an emphasis on the importance of conservation and local engagement with forest management.

Village communities work with an officer from the state's Forest Department to create a localized micro-plan for forest management and cooperate on program implementation and monitoring.[37] Villages and the government each received a share of the income from timber and non-timber forest products (NTFPs) harvested from the area. Currently, 22 million hectares of forest are managed cooperatively by community groups and state governments. India's reforestation efforts are an example of an approach where the government responded to the will of the people and included rural populations in forest governance.[38]

3.3 Biomass and Deforestation in the Global North

The production of biomass as a substitute for coal is, together with logging, one of the main causes of deforestation in the northern hemisphere. In Europe, "biomass power" is now often counted and subsidized as zero-emissions renewable energy. European countries have turned decommissioned coal power plants into wood-burning power plants. Each year, millions of trees (in particular in

[34] Carrington, 2021.
[35] Wallace, 2018.
[36] Philipps and Milhorance, 2021.
[37] Ravindranath and Sudha, 2004.
[38] Union of Concerned Scientists, 2014.

the US Southeast) are cut and chopped into wood pellets that are exported to Europe to fuel these plants.

Scientists have criticized this labeling of biomass as a “carbon-neutral” fuel. Biomass emits more carbon than coal at the smokestack, in addition to the carbon released by logging, processing logs into pellets, and transporting them overseas. Large scale tree cutting disrupts ecosystems and threatens biodiversity. Burning wood also releases several other local pollutants into the air. Finally, biomass is only very slowly renewable, as it takes many decades to regrow the trees that have been cut. [39]

Solar panels can produce 100 times as much power per acre as biomass, but in 2021 Europe’s economy generated more energy from burning wood than from wind and solar combined.[40]

Photo: Forests across the US Southeast are being clear-cut for wood pellets as biofuel in Europe (source: Dogwood Alliance, 2017).

A petition to the European Parliament signed by close to 800 scientists from around the world warned about the fallacy of considering biomass as a promising response to the climate crisis. They called for a complete revision of the EU’s energy policy to recognize that burning biomass worsens climate change.[41]

Despite outcry from the scientific community, the EU continues to advocate for biomass as “renewable, sustainable and carbon neutral.” Several EU countries rely on biomass to meet their carbon emission goals, as pledged in their Nationally Determined Commitments (NDCs) which they signed as part of the Paris Agreement on Climate Change in 2015.

Biomass power is currently a $50 billion industry, and global demand for wood pellets is growing at a rate of about 15% annually. 73% of the demand comes from Europe. The UK is the leading importer, and offers $1 billion a year in subsidies to wood-burning power plants.[42] One of the leading exporters of wood pellets is the USA, where this industry is contributing to the deforestation of North Carolina and other states in the Southeast.[43]

[39] Moomaw, 2018a; Sterman et al., 2022.
[40] Grunwald, 2021.
[41] Letter from Scientists to the EU Parliament regarding Forest Biomass, 2018.
[42] Ballard, 2017.
[43] Dogwood Alliance, 2017.

In February 2021, more than 500 scientists and economists wrote to President Biden to warn that converting wood into power contributes to global warming, destroys forests and biodiversity, and is an inefficient way to generate energy.[44] Despite this, a 2022 Forest Service plan was estimated to lead to a quadrupling of logging in North Carolina's Pigah-Nantahala National Forest, one of the US's most popular forests along the Appalachian trail.[45] Whether the U.S. and Europe will modify their biomass policies to give greater weight to scientific opinion still remains to be seen.

4. FORESTS AND CLIMATE POLICY

One of the outcomes of the twenty-sixth Conference of the Parties on Climate Change (COP26), which met in November 2021 in Glasgow, Scotland, was the Glasgow Declaration on Forests and Land Use, signed by 141 countries representing over 90% of the world's forested land, committing to end deforestation by 2030.[46] This pledge was met with skepticism by critics including representatives of indigenous peoples, whose livelihoods are at risk along with the forests themselves. A major question for the future is the extent to which countries can follow up on their stated commitments.

To achieve this pledge, a major expansion would be needed in current policies for forest preservation. The existing framework, known as REDD+ (Reduction of Emissions from Deforestation and Degradation) has been in place since 2009, and has been implemented by 64 countries, with mixed results.[47] An examination of the structure and implementation of REDD+ is important to understand the possibilities for achieving more ambitious goals.

4.1 The Structure of REDD+

In 1997, the United Nations Framework Convention on Climate Change (UNFCCC) made deforestation and forest degradation in developing countries a priority through the establishment of REDD (Reduction of Emissions from Deforestation and Degradation). The Copenhagen Accord (2009) acknowledged the urgent need to act on reducing emissions from deforestation and forest degradation and revamped REDD, which then became REDD+. Its objectives were to prevent deforestation and forest degradation while creating incentives for reforestation and afforestation (planting forests in areas that were previously not forested).

The REDD+ mechanism encourages countries to protect their forests by offering them credits for maintaining the carbon stored in forests. It also offered access to carbon markets to sell those credits, giving an incentive to governments to protect, restore and sustainably manage forests.

[44] Moomaw, 2018a; Sterman et al. 2022; Grunwald, 2021.
[45] Boyle, 2022.
[46] Einhorn and Buckley, 2021; Glasgow Leaders' Declaration on Forests and Land Use, 2021.
[47] United Nations Climate Change, 2021.

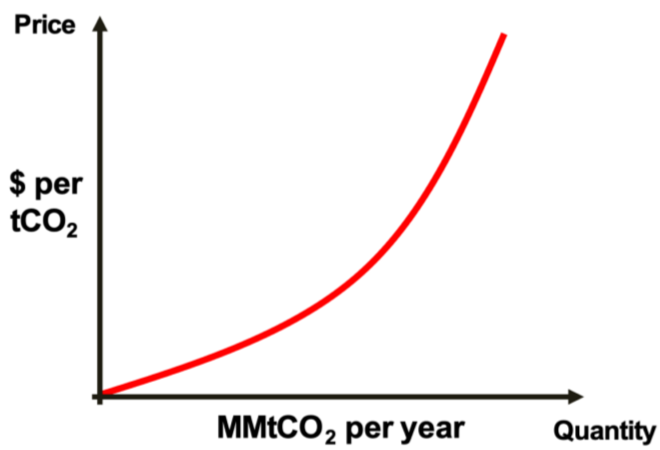
The framework was completed in 2015 and REDD+ became a central part of the Paris Agreement on Climate Change in that year.

There are three phases in REDD+ programs: readiness, implementation, and payment for results. More than $4 billion have been spent to support REDD+ readiness since the beginning of the REDD+ program.[48] The 64 partner countries of REDD+ programs include 28 African countries, 19 countries in the Asia-Pacific Region (China is not included), and 17 countries in Latin America and the Caribbean.[49]

4.2 The Economic Framework of REDD+

The structure of costs is extremely important in determining whether investments in REDD+ are worthwhile, and where the greatest benefit in terms of reduced emissions can be obtained. In some case, emissions can be reduced at relatively low cost, but other options will require a higher price per ton of CO_2 reduced. At some point, the costs of further reduction will become very high, when the best opportunities have already been exploited. This results in a supply curve for emissions reduction with an upward-curving shape, as shown in Figure 14.

Figure 14. *REDD+ supply curve*



Source: Adapted from Estimating the Costs of Reducing Forest Emissions (Wertz-Kanounnikoff 2008).

The costs of REDD+ include **opportunity costs**, (the forgone profits from alternative land uses such as cash crops, food crops, or timber); and **transaction costs**, which include costs borne by the government to establish and administer the scheme, and costs to individual landowners to

[48] https://globalforestatlas.yale.edu/amazon/conservation-initiatives/redd
[49] Data from October 2018 as seen on the UN-REDD website https://www.unredd.net/regions-and-countries/regions-and-countries-overview.html

participate in the program. In addition, there will be costs for reforestation and afforestation including planting and labor and capital costs to maintain newly forested areas.

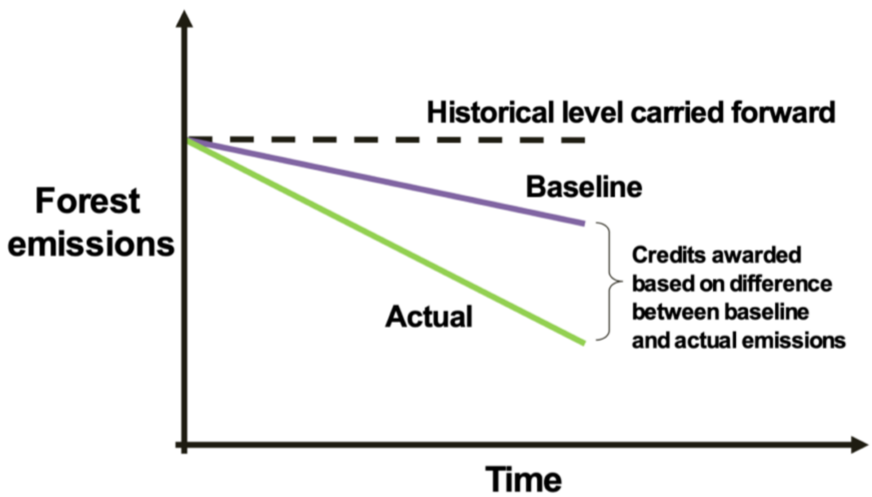
Marginal costs tend to rise over time because the lowest-cost opportunities are adopted first, usually involving land of lower productivity. Although model projections vary, it appears that up to 2-3 billion tons of CO_2 reduction per year can be obtained at relatively low cost per ton.[50]

Since carbon stored in forests is not a traditional economic good, it is necessary to create a market for forest carbon in a way that accurately represents actual carbon storage and is not open to manipulation or abuse. A number of issues arise in designing effective mechanisms.

Establishing a Baseline

An important issue is the establishment of a **baseline** for emissions reduction. The point of REDD+ is to increase carbon storage, so credit should not be given for emissions reduction that would have occurred anyway. Analysis of a country's historical emissions rate, as well as current conditions and policies, can indicate what this baseline should be. Credits can then be awarded based on reductions below this baseline (Figure 15), subject to additional criteria related to **additionality**, **permanence**, and **leakage**.

Figure 15. *Illustration of baseline credit system*



Source: Adapted from Eliasch, 2008.

[50] Wertz-Kanounnikoff, 2008.

1- Additionality

Establishing a credible baseline helps to deal with the problem of **additionality** − would emissions have been reduced or carbon stored even if a given program had not been carried out? Any reductions that earn credits should be additional to reductions that would have occurred in the absence of active policy. As well as comparing overall national projects to a baseline, evaluating individual projects will be important to establish additionality.

2- Permanence

Because climate change is a long-term problem, it is important that REDD+ programs produce lasting results. Participants should structure incentives for long-term preservation so that forests are not later destroyed or converted to other land uses. Countries that receive REDD+ funds should be held liable if they abandon forest preservation projects or permit land use conversion.[51]

3- Leakage

Suppose a country accepts REDD+ credits to preserve a large tract of forest. The forest is placed off limits to logging, and its preservation is certified by independent authorities. That sounds like a success. But the removal of one area of forest from logging may increase logging pressure in other areas. This is **leakage.** It is important to take account of the possible effects of leakage in evaluating any forest conservation program.[52] Leakage can occur at various scales: farm-level, local/regional, national or international. The problem of leakage is particularly complicated to address. One of the earliest REDD projects, the Noel Kempff Reserve in Bolivia, has been condemned for failing to prevent deforestation outside of the park's borders.[53]

Guyana has been particularly successful in preventing leakage. In this Amazonian country, deforestation rates are still very low and large amounts of forest remain. Therefore, it could have been particularly vulnerable to leakage as loggers and ranchers could have moved from Brazil to neighboring Guyana to compensate for their restrained ability to deforest the Amazon in Brazil, where stricter regulations prevailed for 15 years. Guyana's government signed a REDD+ partnership with Norway in 2009 to get compensated up to $250 million over five years in proportion to its success in keeping its deforestation rate low. Because Guyana has kept deforestation rates low, funds from Norway have composed almost 3 percent of Guyana's GDP per year, during the first phase of this REDD+ program.[54]

[51] Angelsen 2008.
[52] Murray 2008.
[53] Pearce, 2010.
[54] Union of Concerned Scientists, 2014, Chapter 3.

Estimating emissions from deforestation

In estimating emissions reduction, it is important to consider both the type of forest involved and the potential alternative uses of the land. For example, converting tropical forest to soybean, maize or rice potentially produces 60% more emissions than conversion to oil palm. The IPCC greenhouse gas (GHG) accounting method[55] includes two approaches to estimating carbon stock changes: (i) the stock-based or stock-difference approach; and (ii) the process-based or gain-loss approach (See Box 6).[56]

BOX 6. TWO ACCOUNTING METHODS TO ESTIMATE CARBON STOCK CHANGES

Stock-difference approach: This method estimates the difference in carbon stocks in a particular pool at two moments in time. It can be used when carbon stocks in relevant pools have been measured and estimated over time, such as in national forest inventories. This approach is suitable for estimating emissions caused by both deforestation and degradation, and it can be applied to all carbon pools.

Gain-loss approach: This approach estimates the net balance of additions to and removals from a carbon pool. In the REDD+ context, depending on how ecosystem rehabilitation is treated, gains result from growth and carbon transfer between pools (e.g. biomass pool to a dead organic matter pool due to disturbance). Hence, losses result from carbon transfer to another pool and emissions due to harvesting, decomposition or burning

4.3 Lessons from twelve years of REDD+

Twelve years after the initiation of REDD+ programs, researchers admit that "we don't have a very good sense of which interventions work well, when they work well, and why they work well", as expressed by Arun Agrawal, from the University of Michigan, in a report surveying 19 reviews of different types of interventions, assessing over 1200 research articles spanning over 3 billion hectares of land.[57] Agrawal and his colleagues found that in most cases the data was too "patchy" to make any general claims. Center for International Forestry Research scientist Amy Duchelle and her co-authors concluded that "recent research has not yet measured up to the importance of REDD+ in terms of scope, depth, and analytic sophistication," and stressed that "as forest-rich

[55] IPCC, 2006.
[56] Wertz-Kanounnikoff et al., 2008.
[57] Evans, 2018.

countries refine their climate action plans post 2020, there is an urgent need for more reliable evidence on the impacts of REDD+ to date to guide their choices."[58]

While researchers have not yet been able to identify trends specific to successful REDD+ programs, experts have identified the following critical factors for the sustainability of governance systems in general:

1. ***Collaborative relationships***. The integration between top-down and bottom-up approaches and the inclusion of local rural communities in decision-making is a key component of successful reforestation projects.
2. ***Supportive policies.*** Law enforcement and sanctions have an important role in keeping deforestation behaviors at bay and regulating them.
3. ***Adaptive management.*** Management schemes should adapt to different circumstances and not be rigidly defined with an immutable top-down approach.
4. ***Responsive macro-institutional frameworks***. International institutions must provide a responsive framework and continuous support for local efforts.

An example of the importance of these four aspects, is illustrated by the Great Green Wall in the Sahel, an international initiative of afforestation which originally adopted a "top-down" approach that failed to achieve its ambitious goals, and is now being replaced with an approach focused on the needs of the local communities and indigenous people (see Box 7).

BOX 7. THE GREAT GREEN WALL

The region of the Sahel − the biogeographic zone between the Sahara and the savannah that stretches from the Atlantic Ocean to the Red Sea and includes, from West to East: Senegal, Burkina Faso, Mali, Niger, Nigeria, Cameroon, Chad, and Sudan − has been heavily impacted by recurrent periods of droughts since the 1970s.

In 2007, The Great Green Wall Initiative was announced by the African Union (AU). Funded by the EU, the World Bank and the United Nations, the wall was first planned as a barrier of vegetation across the Sahel region of northern sub-Saharan Africa. Its ambition was to grow an 8,000km long and 15km wide forest across the entire width of Africa, from Senegal to Djibouti, to stop the progression of the Saharan desert southward. By 2030, the GGW initiative aimed to restore 100 million hectares of currently degraded land, sequester 250 million tons of carbon and create 10 million jobs in rural areas.

[58] Ibid.

The project is significantly behind schedule. In 2020, the Great Green Wall was only 4% complete ahead of its planned 2030 completion date. Various analyses showed that top-down approaches of merely replanting trees and shrubbery was not an appropriate strategy to fix issues of poor land management. Re-designing the Great Green Wall with a focus on a bottom-up approach led to a new agenda, uncovering and encouraging indigenous farming techniques, including agroforestry, water harvesting, and regenerative agriculture, which are specifically suited to their area and local geology.

This new approach notably builds on successful local initiatives, as illustrated by the story of Yacouba Sawadogo, a farmer from Burkina Faso, who, in the space of 40 years, singlehandedly restored 30 ha of once degraded land, through the application of the traditional technique of “zaï” by which he continuously planted trees which eventually became a forest. Called “the man who stopped the desert”, he received the 2018 Right Livelihood Award (considered as an alternative Nobel Prize) and inspired thousands of other farmers in Burkina Faso and beyond to adopt similar methods of agroforestry.

Sources: UNCCD, 2016*;* Bove, 2021; Right Livelihood, 2018.

Disruptive ecological impacts of REDD+

Through REDD+, forest owners or managers earn credits for 'avoided deforestation' or reforestation, which can then be traded in international carbon markets or through other mechanisms. This includes “carbon offset” programs, in which companies or individuals buy forested land under a REDD+ program, and/or land to reforest, in order to compensate for their own carbon emissions. Unfortunately, many reforestation efforts use unsound methods, such as monoculture plantations of one single species of tree. These plantations may require heavy use of agrichemicals that pollute the environment, kill native animals, and ultimately lead to "green deserts" that lack biodiversity[59] (for example in China – see Box 3).

Other potentially harmful effects of REDD+ schemes on the ecosystems include increased pressure on non-REDD+ forests (leakage effect) and a lack of protection for ecosystems that have low carbon sequestration potential but high biodiversity.

Impacts of REDD+ on forest-dependent communities

Indigenous peoples and local communities (IPLCs − ethnic groups who are descended from and identify with the original inhabitants of a given region) own, manage, use or inhabit over a quarter of the world's land.[60] In 2000, 200 million people lived in forest-dependent communities.[61] This includes indigenous communities with centuries-old customs and symbiotic relationships with the forests. Forest-dependent communities steward approximately 80% of the planet's biodiversity and ecosystems, with legal ownership of at least 11% of the world's forestland,[62] making the roles of these communities critical to global conservation efforts.[63]

REDD+ mechanisms can jeopardize forest dependent communities that do not have formal tenure or ownership of their ancestral forestland. Where tenure is unclear, forest ownership may be "recentralized" and sold by the federal government to private corporations looking to offset their carbon emissions.[64] This often leads to the expulsion of forest-dependent communities from land they have protected for generations (see Figure 16).

Cases of land grabbing facilitated by REDD+ mechanisms have been documented around the world. "Carbon cowboys" profit from the value of carbon and carbon market speculation in indigenous forests.[65] Without proper community consultation, national guidelines, and social safeguards, "carbon pirates" can convince communities to sign away their land and carbon rights.[66]

In response to these problems, indigenous communities of the Amazon region presented an alternative to the international REDD+ framework. Their framework rewards indigenous

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[59] Beder, 2014.

[60] Daley, 2018.

[61] There are debates on how to define the term "forest dependent communities" as shown in the survey by Newton et al. (2016); here we are using a strict definition that includes only communities whose livelihoods rest entirely on the products of the forest which they live in.

[62] Bayrak and Marafa, 2016.

[63] Bove, 2021.

[64] Global Forest Atlas, Yale University.

[65]Asia Indigenous Peoples Pact, 2010.

[66] Espinoza Llanos and Feather, 2018.

communities for their role in forest conservation. While conventional REDD+ proposals generally target areas of high deforestation risk, the proposed framework would advocate payments for areas with secure conservation status, such as indigenous reserves. Indigenous communities could then use payments to facilitate land titling and tenure clarification.

Figure 16. *Posters of Indigenous People Protests against REDD schemes*

Source: http://ggjalliance.org/posters

Although opponents have targeted REDD+ as a whole, analysts have shown that these flaws are not inherent to the design of the REDD+ policies and could be amended, if the mechanism was monitored and managed at the national scale, with the proper safeguards to protect and respect indigenous rights.[67] Forest-dependent communities should be treated as key stakeholders in any future REDD+ schemes.

To address these concerns, the United Nations framework of the REDD+ has been significantly modified by introducing the following safeguards. (Note that items c, d, and e directly respond to the demands of indigenous peoples and the NGOs that represent them.) These safeguards are intended to insure:

a) That actions complement or are consistent with the objectives of national forest programmes and relevant international conventions and agreements;
b) Transparent and effective national forest governance structures, taking into account national legislation and sovereignty;
c) Respect for the knowledge and rights of indigenous peoples and members of local communities, by taking into account relevant international obligations, national

[67] Cannon, 2019.

circumstances and laws, and noting that the United Nations General Assembly has adopted the United Nations Declaration on the Rights of Indigenous Peoples;

d) The full and effective participation of relevant stakeholders, in particular indigenous peoples and local communities;
e) That actions are consistent with the conservation of natural forests and biological diversity, ensuring that the actions are not used for the conversion of natural forests, but are instead used to incentivize the protection and conservation of natural forests and their ecosystem services, and to enhance other social and environmental benefits;
f) Actions to address the risks of reversals;
g) Actions to reduce displacement of emissions

Source: UNFCCC, REDD+ Web Platform, https://redd.unfccc.int/fact-sheets/safeguards.html

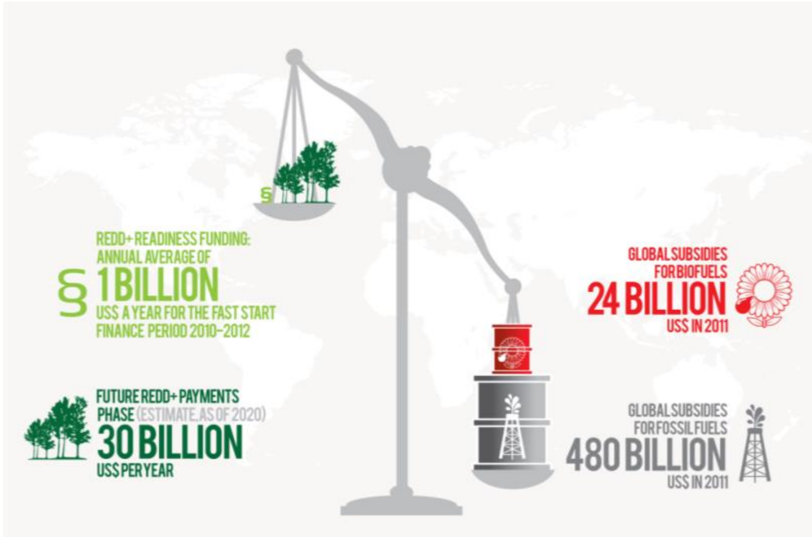
Beyond REDD+, the Glasgow Climate Pact, signed in November 2021, seems to have finally taken into account these recommendations. This international document acknowledges in its opening paragraphs the key role of indigenous people in the preservation of nature and ecosystems, and in its article 38, it "*emphasizes* the importance of protecting, conserving and restoring nature and ecosystems to achieve the Paris Agreement temperature goal, including through forests …, while ensuring social and environmental safeguards". [68] At least on paper, this suggests that the known problems with counterproductive impacts of REDD+ could be overcome to achieve more effective forest protection.

REDD+ Funding

Despite the best intentions of the REDD+ framework to improve methodology and practices, the amount of REDD+ funding has remained inconsistent with the severity of the problem it is intended to address. Since 2007, hundreds of REDD+ pilot projects and programs have emerged. In the majority of cases, results-based payments to local landholders have barely gained traction, in part due to unstable REDD+ financing.[69] At the global level, the funding for REDD+ amounted to $323 million in 2018, though it was supposed to be scaled up to $1 billion a year. [70] This amount is dwarfed in comparison with the $24 billion spent annually on biofuel subsidies and $480 billion dollars spent annually on fossil fuel subsidies (Figure 17).

[68] Washington Post, November 13, 2021.
[69] Sills et al. 2014; Simonet, 2015.
[70] Hang, 2018.

Figure 17. *REDD+ Funding vs. Global Subsidies for Biofuels, and Fossil Fuels*



Source: Mulder, 2014, in REDD+ Academy Asia Pacific.

When funding was available, it was often inadequate to encourage forest protection. Payments may be competitive in places that are remote and lack infrastructure. In areas with better transportation networks, however, alternative land uses such as soy and palm cultivation are likely to be more profitable than carbon payments.[71] In this case, the opportunity cost (see section 4.2) of not deforesting is much higher than the carbon credits offered, which hinders the chance of success. More research is necessary to identify whether REDD+ initiatives can provide sufficient economic incentives to stop landowners from deforesting.

At COP26 in Glasgow, the Global Forest Finance Pledge by 12 countries (including the United States and several European nations, as well as the EU) provides $12 billion for forest-related climate finance between 2021 and 2025. This includes $1.7 billion specifically dedicated to support Indigenous Peoples and Local Communities, to advance their forest tenure rights and recognize their role as guardians for forests and nature.[72]

Protecting indigenous land rights might be the most efficient policy to protect forests and biodiversity. Indigenous communities are at the frontline of movements against deforestation, agroindustry plantations, rampant resource extraction and harmful infrastructure development. A 2016 study in Bolivia found that deforestation rates in the Bolivian Amazon were up to three times lower in tenured indigenous areas than they were elsewhere.[73]

[71] Union of Concerned Scientists, 2014.
[72] UN Climate Change Conference UK 2021, November 2, 2011.
[73] Veit and Ding, 2016.

Indigenous land management yields significant economic benefits as well. Carbon sequestration, biological pest control and regulating water and air quality are critical ecological services which provide an aggregate value of USD$1.16 trillion each year to the global economy, all of which is derived from indigenous-managed land.

The financial sector has joined the global effort to stop deforestation through a coalition of 30 leading financial institutions, (collectively with over $8.7 trillion in assets under management), which have committed $7.2 billion to the Global Forest Finance Pledge and to eliminate agricultural commodity-driven deforestation from their portfolios by 2025.[74] This redirecting of global investments away from some the main causes of deforestation (cattle ranching, logging, soy production, palm oil, cocoa, and other agricultural uses), could have significant impacts on slowing down deforestation rates, if truly implemented.

5. CONCLUSION

It remains to be seen whether the Glasgow Declaration on Forests and Land Use, and the Global Forest Finance Pledge that accompanies it, are sufficient tools to alter the current trends of deforestation, especially of primary forests. These trends have powerful economic and political support, and it is much easier to make a sweeping pledge at a conference than to implement it successfully.

Plans for planting trees may also sound impressive, but as the examples cited above of China and the Great Green Wall show, tree planting may be of limited ecological value if focused on plantations, and may not stand the test of time. Preserving existing forests and sustaining their ecological integrity – called "proforestation" by William Moomaw and colleagues – is both more difficult and more valuable both in terms of carbon storage and ecological sustainability.[75]

It is worth noting the inconsistency in Northern countries' approaches to deforestation, on the one hand cutting down their own primary forests to provide wood pellets to generate electricity, and on the other hand condemning deforestation in Southern developing countries, exerting pressure and offering incentives to halt the degradation of tropical forests. In the South also there are strong pressures to destroy forests for agricultural, mineral, and other development, as the example of recent policy in Brazil shows. To achieve the great potential of forests and wetlands both for carbon storage and ecological sustainability, these perverse economic incentives will have to be overcome, which remains a major challenge.

[74] Race to Zero, November 2, 2021. https://racetozero.unfccc.int/leading-financial-institutions-commit-to-actively-tackle-deforestation/

[75] Moomaw, Masino, and Faison, 2019.

6. KEY TERMS AND CONCEPTS

Additionality – According to the Kyoto Protocol, gas emission reductions generated by Clean Development Mechanism and Joint Implementation project activities must be additional to those that otherwise would occur. Additionality is established when there is a positive difference between the emissions that occur in the baseline scenario, and the emissions that occur in the proposed project.[76]

Afforestation – The process of establishing and growing forests on bare or cultivated land, which has not been forested in recent history.[77]

Baseline – The emission of greenhouse gases that would occur without the contemplated policy intervention or project activity.

Biodiversity – The total diversity and variability of living things and the systems (e.g., coral reefs), of which they are part.[78]

Carbon stocks – The quantity of carbon contained in a “pool”, meaning a reservoir or system which has the capacity to accumulate or release carbon. In the context of forests it refers to the amount of carbon stored in the world’s forest ecosystem, mainly in living biomass and soil, but to a lesser extent also in dead wood and litter.[79]

Carbon flux – A forest - or any ecosystem - is a set of carbon fluxes. Forests absorb carbon dioxide (CO_2) from the atmosphere and transform it into stored carbon through the process of photosynthesis. Other fluxes are emitting CO_2 back into the atmosphere through respiration and soil mineralization. Products exported from the ecosystem, such as wood, are also responsible for carbon fluxes.[80]

Carbon fixation – The process through which carbon dioxide is taken up, removed or absorbed from the atmosphere. It is usually driven by photosynthesis whereby carbon dioxide is converted to solid compounds.

Carbon sink – A natural or artificial storage that accumulates and stores carbon dioxide for a long period through physical or biological processes.

Carbon source – An ecosystem or activity that emits CO_2 to the atmosphere and increases GHG concentration is called a carbon source, and a physical or biological process that releases CO_2 to the atmosphere is called carbon emission.

[76] Coalition for Rainforest Nations, http://www.rainforestcoalition.org/
[77] Ibid.
[78] World Resource Institute glossary, http://www.wri.org
[79] Based on definition by GreenFacts Glossary and FAO.
[80] Forest and Climate Change Toolbox, http://www.cifor.org/fctoolbox/

Carbon tax – A per-unit tax levied on carbon-based fuels in proportion to the amount of carbon dioxide emitted when the fuel is burned.

Carbon trading – A system that allows firms or institutions to trade permits to emit carbon based on an initial allocation or auction of permits. Permits may also be allocated to firms or institutions that engage in carbon reduction or carbon-storing practices, which they can then sell.

Certification – A process of validation by an independent authority; in the case of carbon permits, a certification that an activity or process reduces carbon by a certain amount, or removes a certain amount of carbon from the atmosphere

Leakage – That portion of cuts in greenhouse-gas emissions that may reappear in other areas or countries not bound by carbon limits. For example, multinational corporations may shift factories from developed countries to developing countries to escape restrictions on emissions.[81]

Market failures – Situations where the allocation of goods and services by a free market is not efficient due to the breakdown of price mechanism caused by factors such as establishment of monopolies or existence of externalities including environmental costs.

Marginal cost – The change in total cost when the quantity produced is increased by one unit. In other word, it is the cost of producing one more unit of output.

Net absorption flux – The difference between inbound (photosynthesis) and outbound fluxes (respiration and mineralization) is the net absorption flux.

Offset – In a carbon trading scheme, a credit issued for a process that reduces carbon emissions or stores carbon. Offsets can be purchased by firms that emit carbon in an equal amount to the carbon they wish to emit, as an alternative to reducing their emissions.

Opportunity cost – The cost of an alternative that must be forgone in order to pursue a certain action. In other word, the benefits could have been received by taking an alternative action.

Reforestation – This process increases the capacity of the land to sequester carbon by replanting forest biomass in areas where forests have been previously harvested.

Transaction cost – A cost incurred in making an economic exchange.

[81] UNFCCC Glossary.

7. DISCUSSION QUESTIONS

1. How significant are forests and agriculture in global climate change? What roles do they play in the emissions and absorption of carbon dioxide and other greenhouse gases? Why do you think that forests and agriculture have played a relatively small role until recently in policies to combat climate change?

2. What economic principles are important in the formulation of policies to mitigate carbon emissions through forestry and agricultural practices? What important patterns of costs are relevant and what do they indicate about the potential of forests and agriculture to mitigate climate change? What market processes may strengthen or undermine policies for carbon reduction through forestry and agriculture?

3. Are biofuels a positive or a negative factor in climate policy? How would you distinguish the different impacts of different biofuels and what might this imply for policies regarding biofuels, including the use of subsidies?

8. WEB LINKS

1. **http://www.cifor.org/**
The Center for International Forestry Research is a nonprofit, global facility dedicated to advancing human wellbeing, environmental conservation and equity that conducts research on the use and management of forests in less-developed countries. For quick access to the online library use: http://www.cifor.org/online-library/browse.html and for slide presentations on a variety of topics related to forests and climate change see http://www.cifor.org/fctoolbox/ For a recent evaluation of REDD+ see https://www.cifor.org/knowledge/publication/7045/# and https://www.cifor.org/knowledge/publication/5202/

2. **https://sites.tufts.edu/gdae/soils-forests-and-biomass-policy/**
A selection of articles from the Tufts University Global Development and Environment Institute on soils, forests, and biomass policy, including information about the unique carbon storage value of mature forests and wetlands.

3. **https://redd.unfccc.int**
Homepage for the United Nations Framework Convention on Climate Change REDD+ program, including information on current REDD+ programs listed by country at https://redd.unfccc.int/info-hub.html

4. **https://www.fao.org/redd/en/**
The Food and Agriculture Organization of the United Nations homepage on REDD+, with information on national forest inventories and management systems.

5. **https://ukcop26.org/the-global-forest-finance-pledge/**
Full text of the Global Forest Finance Pledge from the 26th Conference of the Parties to the U.N. Framework Convention on Climate Change (COP26) in Glasgow, 2021, with discussion on the background and significance of the pledge at https://unfccc.int/news/cop26-pivotal-progress-made-on-sustainable-forest-management-and-conservation

9. REFERENCES

ABC News. 2021. *Year in Climate*: Extreme weather events prove climate change is already here, 28 December. https://abcnews.go.com/US/year-climate-extreme-weather-events-prove-climate-change/story?id=81771045

Angelsen, Arild. 2008. *Moving ahead with REDD: Issues, options and implications.* Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Asia Indigenous Peoples Pact. 2010. REDD+ Implementation in Asia and the Concerns of Indigenous Peoples. Chiang Mai, Thailand. Available online: https://www.iwgia.org/images/publications/0654_REDD_Plus_Implementation_in_Asia_and_the_Concerns_of_Indigenous_Peoples.pdf

Ballard, Allison. 2017. "Wood pellet demand, opposition growing", *Coastal Review*. https://www.coastalreview.org/2017/10/wood-pellet-demand-opposition-growing/

Bar-On Yinon M., Rob Phillips and Ron Milo. 2018. "The Biomass distribution on Earth". *Proceedings of the National Academy of Sciences.* May 21. 115(25) 6506-6511. https://www.pnas.org/doi/full/10.1073/pnas.1711842115

Bayrak, Mucahid Mustafa, and Lawal Mohammed Marafa. 2016. "Ten Years of REDD+: a Critical Review of the Impact of REDD+ on Forest-Dependent communities", *Sustainability*, 2016, 8(7), 620. https://www.mdpi.com/2071-1050/8/7/620/htm

Beder, Sharon. 2014. "Carbon offsets can do more environmental harm than good", *The Conversation*, 28 May. https://theconversation.com/carbon-offsets-can-do-more-environmental-harm-than-good-26593

Bellassen, Valentin and Sebastiaan Luyssaert. 2014. "Carbon Sequestration; Managing Forests in Uncertain Times," *Nature* 506, issue 7487, 12 February. https://www.nature.com/news/carbon-sequestration-managing-forests-in-uncertain-times-1.14687

Bove, Tristan. 2021. "The Great Green Wall is Failing, but its Legacy could Still be a Success", *Earth.org*, March 24th, 2021. https://earth.org/the-great-green-wall-legacy/

Boyle, Louise. 2022. "Plans to quadruple logging in the US's most popular forest – months after Biden's COP26 reforestation pledge", *The Independent*, 25 January. https://www.independent.co.uk/climate-change/news/forest-trees-deforestation-carbon-biden-b1999661.html#comments-area

Butler, Rhett A. 2018. "Deforestation skyrockets in the Amazonian rainforest", 25 July. https://news.mongabay.com/2018/07/deforestation-skyrockets-in-the-amazon-rainforest/

Cannon, John. 2019. "REDD+ more competitive than critics believe, study finds". *Mongabay*, 12 September. https://news.mongabay.com/2019/09/redd-more-competitive-than-critics-believe-study-finds/

Carrington, Damian. 2021. "Amazon rainforest now emitting more CO2 than it absorbs", *The Guardian*, 14 July.

Codur, Anne-Marie, Jonathan Harris, and Kayleigh Fay. 2022. *Agriculture and Climate: Economics and Policy Issues*, Boston University Economics in Context Initiative (ECI) teaching module https://www.bu.edu/eci/education-materials/teaching-modules/

Coleman, Eric A. et al. 2021. "Limited effects of tree planting on forest canopy cover and rural livelihoods in Northern India" *Nature Sustainability*, Vol 4, November: 997–1004,

Contreras-Hermosilla, Arnoldo. 2000. "The underlying causes of forest decline." Center for International Forestry Research. https://www.cifor.org/publications/pdf_files/OccPapers/OP-030.pdf

Costanza, Robert, et al., 1997. "The value of the world's ecosystem services and natural capital." *Nature* 387 (6630): 253-60.

Center for International Forestry Research (CIFOR), World Agroforestry Center and USAID. 2009. Forest and Climate Change Toolbox, [PowerPoint presentation]. In: Forest and Climate Change Toolbox: Topic 2 Section B. 2009-20-11. https://www2.cifor.org/fcctoolbox/

Daley, Jason. 2018. "Indigenous Peoples Manage One Quarter of the Globe, which is Good News for Conservation", *Smithsonian Magazine*, July 23.
https://www.smithsonianmag.com/smart-news/indigenous-people-manage-one-quarter-globe-which-good-news-conservation-180969689/

Davies Gillian T. et al. 2021. "Towards a Universal Declaration of the Rights of Wetlands", *Marine and Freshwater Research*, 72, 593–600.

Dogwood Alliance. 2017. "Our Forests, Our Strength" https://www.dogwoodalliance.org/2017/11/n-c-forests-are-under-assault-gov-cooper-should-help/

Einhorn, Catherin and Chris Buckley. 2021. "Global Leaders Pledge to End Deforestation by 2030", *The New York Times*, November 10.
https://www.nytimes.com/2021/11/02/climate/cop26-deforestation.html;

Eliasch, Johan. 2008. *Climate change: Financing global forests: The Eliasch Review*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/228833/9780108507632.pdf

Erickson-Davis, Morgan. 2018. "Study reveals China's new forests aren't really forests", *Mongabay*, 7 June. https://news.mongabay.com/2018/06/study-finds-chinas-new-forests-arent-really-forests

Espinosa Llanos, Roberto, and Conrad Feather. 2018. "A Marathon, not a Sprint: the role of International Climate Finance in securing indigenous lands in Peru: Progress, setbacks and challenges." Forest Peoples Program and AIDESEP.
https://www.forestpeoples.org/sites/default/files/documents/A_marathon_print.pdf

Evans, Monica. 2018. "Governing Forests for Sustainability, What Works?", *Forest News*, Special Issue, 9 October 2018.
https://forestsnews.cifor.org/58113/governing-forests-for-sustainability-what-works?fnl=en&utm_source=CIFOR+Website&utm_medium=Slide+show+bar&utm_campaign=Forests+News

Food and Agriculture Organization of the United Nations (FAO). 2020. Global Forest Resources Assessment, main report, available at https://www.fao.org/3/ca9825en/ca9825en.pdf Digital report with main findings at: https://www.fao.org/forest-resources-assessment/2020/en/

FAO. 2015. Global Forest Resources Assessment: how are the world's forests changing? Second edition. https://www.fao.org/3/i4793e/i4793e.pdf

FAO. 2010. Global Forests Resources Assessment. Food and Agriculture Organization of the United Nations.

FAO. 2003. World agriculture: Towards 2015/2030: An FAO perspective. London: Earthscan Publication Ltd. https://www.fao.org/publications/card/en/c/a6c6e4a7-ff1c-5c35-be85-8b2e032036e7/

Fearnside, Philip. 2017. "Deforestation of the Brazilian Amazon", *Environmental Science*, Sept 2017. Available at Oxford Research Encyclopedias. https://oxfordre.com/view/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-102

Finlayson Colin Maxwell et al. 2019. "The Second Warning to Humanity – Providing a Context for Wetland Management and Policy." *Wetlands* Volume 39, pp.1–5. https://scientistswarning.forestry.oregonstate.edu/

Fuller, Trevon L. et al. 2019. "Assessing the impact of China's timber industry on Congo Basin Land Use Change", *Royal Geographical Society*, Volume 51, Issue 2, June. https://rgs-ibg.onlinelibrary.wiley.com/doi/pdf/10.1111/area.12469

Glasgow Leaders' Declaration on Forests and Land Use, UN Climate Change Conference UK. 2021. https://ukcop26.org/glasgow-leaders-declaration-on-forests-and-land-use/

Global Forest Atlas, Yale University https://globalforestatlas.yale.edu/amazon/conservation-initiatives/redd

Griscom, Bronson W. at al. "Natural Climate Solutions." 2017. Proceedings of the National Academy of Sciences, October 31, vol. 114, N°44 http://www.pnas.org/content/pnas/114/44/11645.full.pdf

Grunwald, Michael. 2021. "The "green energy" that might be ruining the planet." *Politico*, March 26. https://www.politico.com/news/magazine/2021/03/26/biomass-carbon-climate-politics-477620

Global Carbon Atlas. 2021. Consulted at http://www.globalcarbonatlas.org/en/content/global-carbon-budget

Hang, Christi. 2018. "Where REDD+ money goes – and doesn't go." *Forest News*, 6 June.

Houghton, Richard A. 2008. Carbon Flux to the atmosphere from land-use changes: 1850-2005. *TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., USA.* Data are accessible at https://cdiac.ess-dive.lbl.gov/trends/landuse/houghton/houghton.html

Hua, Fangyuan et al. 2018. "Tree plantations displacing native forests: The nature and drivers of apparent forest recovery on former croplands in Southwestern China from 2000 to 2015." *Biological Conservation* 222:113-124, June. Quoted in Science Daily, May 2018.

Intergovernmental Panel on Climate Change (IPCC). 2021. Sixth Assessment Report: Working Group 1: The Physical Science Basis. https://www.ipcc.ch/report/ar6/wg1/

IPCC Special Report, 2018. *Global Warming of 1.5°C*, https://ipcc.ch/report/sr15/

IPCC. 2014. Fifth Assessment Report, Working Group 3: Mitigation of Climate Change: https://www.ipcc.ch/report/ar5/wg3/

IPCC. 2014. Land Use, Land-Use Change and Forestry (LULUCF) https://unfccc.int/topics/land-use/workstreams/land-use--land-use-change-and-forestry-lulucf

IPCC. 2007. *Climate Change 2007: Synthesis report.* Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC) Secretariat.

IPCC. 2006. IPCC Guideline for National Greenhouse Gas Inventories, Vol. 4, Agriculture, Forestry and other Land Use, accessible at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Kelly, Peter, and Xuexi Huo. 2013. "Land retirement and nonfarm labor market participation: an analysis of China's sloping land conversion program." *World Development* vol. 48, issue C, 156-169. https://econpapers.repec.org/article/eeewdevel/v_3a48_3ay_3a2013_3ai_3ac_3ap_3a156-169.htm

Kindermann, Georg, et al. 2008. "Global cost estimates of reducing carbon emissions through avoided deforestation." *Proceedings of the National Academy of Sciences* 105 (30).

Kissinger, Gabrielle, Martin Herold, and Veronique De Sy. 2012. "Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers." Lexeme Consulting, Vancouver Canada, August.

Letter from Scientists to the EU Parliament regarding Forest Biomass. 2018. https://www.euractiv.com/wp-content/uploads/sites/2/2018/01/Letter-of-Scientists-on-Use-of-Forest-Biomass-for-Bioenergy-January-12-2018.pdf

Lewis Simon L. et al. 2005. "Tropical forests and atmospheric CO_2: Current conditions and future scenarios." Pages 147–153 in Schellnhuber, HJ, ed. *Avoiding Dangerous Climate Change*. Cambridge University Press.

Li, Jie, Marcus Feldman, Shuzhuo Li, and Gretchen Daily. 2011. "Rural household income and inequality under the Sloping Land Conversion Program in western China." *Proceedings of the National Academy of Sciences*, April 25. 108 (19) 7721-7726 http://www.pnas.org/content/early/2011/04/20/1101018108.short

Lipton, Gabrielle. 2020. "4.06 billion remaining hectares and other new numbers on forests… But what do they mean?" *Landscape News*, 14 May. https://news.globallandscapesforum.org/44355/4-06-billion-remaining-hectares-and-other-new-numbers-on-forests-but-what-do-they-mean/

Liu, Lu and Clarissa Pharr. 2018. "China is reforesting land the size of Ireland. Here's what that looks like." *Washington Post*, June 1.

Luyssaert, Sebastiaan et al. 2008. "Old-growth Forests as Carbon Sinks." Nature 455, 213–215. https://www.nature.com/articles/nature07276

Millennium Ecosystem Assessment. 2005. "Ecosystems and Human Wellbeing: Wetlands and Water Synthesis." Washington, DC: World Resources Institute.

Moomaw William. 2018a. "The EPA says burning wood to generate power is 'carbon-neutral'. Is that true?" *The Conversation*, May 8.

Moomaw William. 2018b. "What the world needs now to fight climate change: more swamps." *The Conversation*, September 12.

Moomaw, William R., Susan A Masino, and Edward K. Faison. 2019. "Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good." *Frontiers in Forests and Global Change*. https://www.frontiersin.org/articles/10.3389/ffgc.2019.00027/full

Moomaw, William et al., 2018. Wetlands in a changing climate: science, policy and management. *Wetlands* 38, 183–205.

Mulder, Ivo. 2014. "The Economics of REDD+." in *REDD+ Academy Asia Pacific*, 18 November. https://www.unredd.net/documents/global-programme-191/redd-academy-3509/redd-academy-asia-pacific-2014-october-27-november-7-yogyakarta-indonesia-3607/redd-academy-asia-pacific-presentations-3616/13656-11-the-economics-of-redd-ivo-mulder-13656.html

Murray, Brian C. 2008. Leakage from an avoided deforestation compensation policy: Concepts, empirical evidence, and corrective policy options. Nicholas Institute for Environmental Policy Solutions, Duke University. Durham, NC. https://nicholasinstitute.duke.edu/climate/policydesign/leakage-from-an-avoided-deforestation-compensation-policy-concepts-empirical-evidence-and-corrective-policy-options

Newton, Peter, et al. 2016. "Who are forest-dependent people? A taxonomy to aid livelihood and land use decision-making in forested regions", *Land Use Policy*, Volume 57, 30 November, pp. 388-395. https://www.sciencedirect.com/science/article/pii/S0264837716300497

Noon, Monica L. et al. 2021. "Mapping the Irrecoverable Carbon in Earth's Ecosystems," *Nature Sustainability* https://www.nature.com/articles/s41893-021-00803-6

North Carolina Forestry Association, "Forest Management Basics". https://www.ncforestry.org/teachers/forest-management-basics/

New York State Department of Environmental Conservation, "Trees: The Carbon Storage Experts." https://www.dec.ny.gov/lands/47481.html

Parker, C., A. Mitchell, M. Trivedi, and N. Mardas. 2009. "The little REDD+ book: A guide to governmental and non-governmental proposals for reducing emissions from deforestation and degradation." https://globalcanopy.org/wp-content/uploads/2020/12/LRB_en.pdf

Pearce, Fred. 2010. "Will REDD Preserve Forests or merely provide a Fig Leaf?", *Yale Environment 360*, May 27. https://e360.yale.edu/features/will_redd_preserve_forests_or_merely_provide_a_fig_leaf

Potapov et al. 2017. "The last frontiers of wilderness: tracking loss of intact forest landscapes from 2000 to 2013" *Science Advances* 13 January, Vol. 3, Issue 1. http://advances.sciencemag.org/content/3/1/e1600821/tab-figures-data

Nahlik, A. M., and Fennessy, M. S. 2016. "Carbon storage in US wetlands." *Nature Communications* 7, 13835.

Philipps, Tom and Flavia Milhorance. 2021. "Indigenous warrior women take fight to save ancestral lands to Brazilian capital." *The Guardian*, 10 September. https://www.theguardian.com/world/2021/sep/10/indigenous-warrior-women-brazil-ancestral-lands-protest

Race to Zero. 2021. "Leading Financial Institutions commit to actively tackle Deforestation", November 2. https://racetozero.unfccc.int/leading-financial-institutions-commit-to-actively-tackle-deforestation/

Rainforest Journal. 2013. "Differences between primary and secondary rainforest," July 14.

Ramsar Convention on Wetlands. 2018. "Global Wetland Outlook: State of the World's Wetlands and Their Services to People." Ramsar Convention Secretariat: Gland, Switzerland.

Ravindranath N.H. and P. Sudha, 2004. *Joint Forest Management in India*. Universities Press.

Right Livelihood. 2018. Yacouba Sawadogo, Awarded 2018 "For turning barren land into Forest and demonstrating how farmers can regenerate their soil with innovative use of indigenous and local knowledge". https://rightlivelihood.org/the-change-makers/find-a-laureate/yacouba-sawadogo/

Ruddiman, William F. 2003. "The anthropogenic greenhouse era began thousands of years ago." *Climate Change* 61: 261-293.

Sathaye, J., W. Makundi, L. Dale, P. Chan, and K. Andrasko. 2006. "GHG mitigation potential, costs and benefits in global forests: A dynamic partial equilibrium approach." *The Energy Journal*, Vol. 27, Special Issue: Multi-Greenhouse Gas Mitigation and Climate Policy, pp. 127-162. International Association for Energy Economics.

Scher, Sara J. and Sajal Sthapit. 2009. *Mitigating climate change through food and land use.* Word Watch Institute, Report 179. https://biochar-international.org/news/worldwatch-report-mitigating-climate-change-through-food-and-land-use/

Sills, Erin O. et al. 2014. "REDD+ on the ground. A case book of subnational initiatives across the globe." *Center for International Forestry Research.* November. https://www.cifor.org/knowledge/publication/5202/

Simonet, Gabriella. 2015. "REDD+ Projects in 2014: an overview based on a new database and typology." *Climate Economics Chair Information and Debates.* Volume 32. July 1.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, and C. Rice. 2008. "Greenhouse gas mitigation in agriculture." *Philosophical Transactions of the Royal Society B: Biological Sciences* 363 (1492).

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, and C. Rice. 2007. "Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture." *Agriculture, Ecosystems & Environment* 118 (1-4): 6-28.

Soares-Filho, B. S., D. C. Nepstad, L. M. Curran, G. C. Cerqueira, R. A. Garcia, C. A. Ramos, E. Voll, A. McDonald, P. Lefebvre, and P. Schlesinger. 2006. "Modelling conservation in the amazon basin." *Nature* 440 (7083): 520-3.

Sohngen, B., and R. Sedjo. 2006. "Carbon sequestration costs in global forests." *Energy Journal*: 109-26.

Sterman, John, William Moomaw, Juliet N. Rooney-Varga, and Lori Siegel. 2022. "Does Wood Bioenergy Help or Harm the Climate?" *Bulletin of the Atomic Scientists*, May 10. https://thebulletin.org/premium/2022-05/does-wood-bioenergy-help-or-harm-the-climate/

United Nations Climate Change. 2021. "COP26: Pivotal Progress made on Sustainable Forest Management and Conservation", 10 November https://unfccc.int/news/cop26-pivotal-progress-made-on-sustainable-forest-management-and-conservation

UN Climate Change Conference, UK. 2021. COP26 IPLC Forest Tenure Joint Donor Statement. https://ukcop26.org/cop26-iplc-forest-tenure-joint-donor-statement/

UN Convention to Combat Desertification (UNCCD). 2016. "The Great Green Wall: Hope for the Sahara and the Sahel." https://www.unccd.int/sites/default/files/documents/26042016_GGW_ENG.pdf

UNEP. 2009. *Towards Sustainable Production and use of Resources: Assessing Biofuels*. https://www.unep.org/resources/report/towards-sustainable-production-and-use-resources-assessing-biofuels

UNFCCC. 2007. *Investment and financial flows to address climate change*. UNFCCC, Bonn, Germany.

Union of Concerned Scientists. 2016. "What's Driving Deforestation?" Feb 8. https://www.ucsusa.org/resources/whats-driving-deforestation

Union of Concerned Scientists. 2014. "Deforestation Success Stories: Tropical Nations where Forest Protection and Reforestation Policies have worked." September 3. https://www.ucsusa.org/resources/deforestation-success-stories

University of Montana, "Largest 1% of trees make up half of mature forest biomass worldwide." https://news.umt.edu/2018/05/051018tree.php

Wallace, Scott. 2018. "Brazil's new president Jair Bolsonaro promised to exploit the Amazon – but can he?" *National Geographic*, October 31. https://www.nationalgeographic.com/environment/article/brazil-president-jair-bolsonaro-promises-exploit-amazon-rain-forest?loggedin=true

The Washington Post. 2021. "The Glasgow Climate Pact, annotated." November 13. https://www.washingtonpost.com/climate-environment/interactive/2021/glasgow-climate-pact-full-text-cop26/

Veit, Peter and Helen Ding. 2016. "Protecting Indigenous Land Rights makes Good Economic Sense." World Resources Institute, October 7. https://www.wri.org/insights/protecting-indigenous-land-rights-makes-good-economic-sense

Watson, James E.M. et al. 2018. "The exceptional value of intact forest ecosystems." *Nature ecology & evolution* 2, 599-610. https://pubmed.ncbi.nlm.nih.gov/29483681/

Watts, Jonathan. 2018. "Fears for Amazon as Bolsonaro plans to merge environment and agriculture ministries." *The Guardian*, Thursday 1 November.

Wertz-Kanounnikoff, S. 2008. "Estimating the costs of reducing forest emissions." *A Review of Methods*.

Wertz-Kanounnikoff, S., L. V. Verchot, M. Kanninen, and D. Murdiyarso. 2008. "How can we monitor, report and verify carbon emissions from forests?" *Moving ahead with REDD: issues, options, and implications*, Bogor, Indonesia, Center for International Forestry Research (CIFOR) Chapter 9, 87-98.

Wohlleben, Peter. 2018. *The Hidden Life of Trees: What They Feel, How They Communicate, Discoveries from a Secret World.* Greystone Books.

Yirka, Bob. 2011. "Research team suggests European Little Ice Age came about due to reforestation in New World." https://phys.org/news/2011-10-team-european-ice-age-due.html