Macroeconomic impacts of land use change and forest loss

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Abstract:

This paper analyses the implications of land-use change and forest loss to economies and financial systems. It builds on the evidence advanced by the joint NGFS-INSPIRE study group, the Conceptual Framework by the NGFS Nature Task Force, and the work on nature scenarios that environmental risks, such as the loss of biodiversity and deforestation, could have significant macroeconomic and financial stability implications. The paper offers a closer look at deforestation as a driver of nature loss, paying attention to the nexus between forest ecosystems with economic and social dimensions. It outlines potential transmission channels from deforestation and land-use change to economic and financial risks. In doing so, it also discusses the reasons behind persistent deforestation despite decades of global efforts to stop it, and examines key pressures on forests from economic and governance dimensions. The paper then discusses future areas of research and policy considerations to reduce and halt financial activity that drives deforestation.

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Introduction

Deforestation and land-use change are critical environmental issues that have far-reaching implications for economies and financial systems. The increasing awareness of these implications has been significantly shaped by the work of the Network for Greening the Financial System (NGFS) and the International Network for Sustainable Financial Policy Insights, Research, and Exchange (INSPIRE) study group. Their research highlights the profound macroeconomic and financial stability risks posed by environmental degradation, particularly the loss of biodiversity (NGFS & INSPIRE, 2021), including as a result of widespread deforestation.

Building on the Conceptual Framework by the NGFS Nature Task Force and nature scenarios developed by NGFS and other scholars, this paper delves into the specific role of deforestation as a driver of nature loss. It examines the intricate connections between forest ecosystems and their economic and social dimensions, by providing evidence on the links between forest loss and a host of economic and social factors such as impacts to health, productivity and livelihoods. By outlining potential transmission channels from deforestation and land-use change to economic and financial risks, this paper aims to elucidate the complex mechanisms through which environmental degradation can destabilise economic systems.

Despite global efforts spanning decades, deforestation persists, driven by various economic and governance pressures. This paper seeks to explore the reasons behind the continued prevalence of deforestation, considering factors such as agricultural expansion, illegal logging, and inadequate enforcement of environmental regulations. Understanding economic pressures, as well as the governance amplifiers facilitating deforestation, is crucial for developing effective strategies to mitigate deforestation and its associated risks.

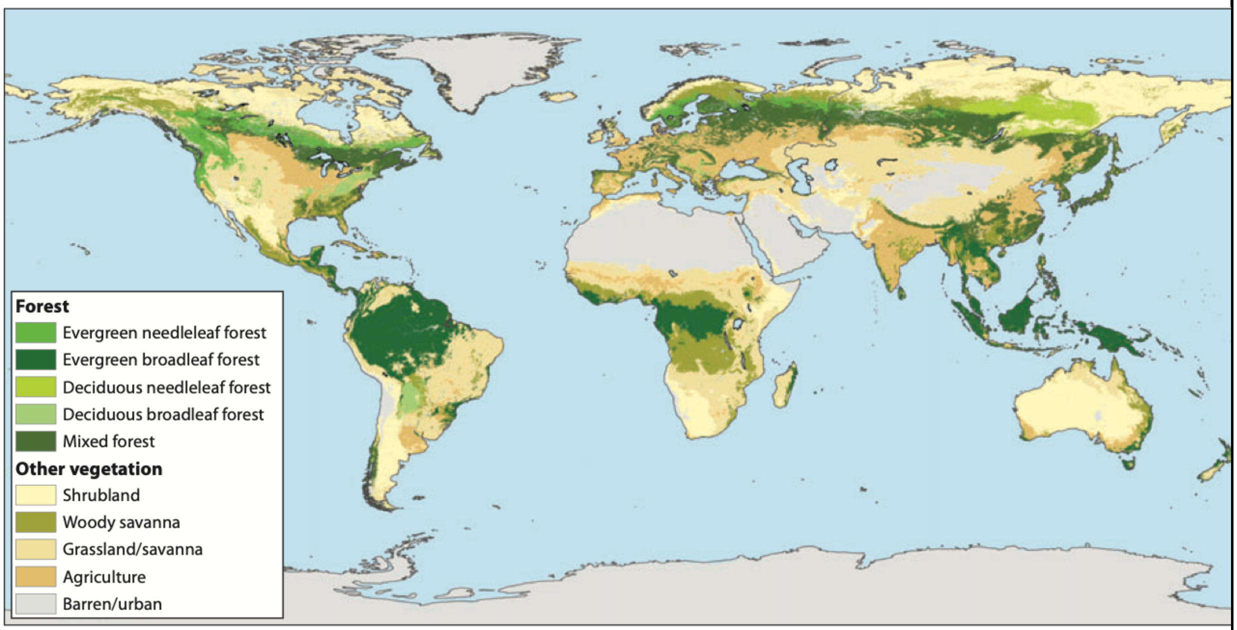
In summary, this paper aims to contribute to the growing evidence base on economic and financial ramifications of deforestation and land-use change. By doing so, it seeks to inform and influence policy decisions that will help safeguard forest ecosystems and ensure economic stability in the face of environmental challenges.

1. The critical role of forest ecosystems

Forests are complex ecosystems comprising various biotic (living) and abiotic (non-living) components interacting in intricate ways. From an ecological perspective, forests play critical roles in providing habitat and resources for numerous species and supporting various ecosystem services such as water capture and filtration; soil conservation; hazard protection from storms and floods; climate, surface temperature, and hydrological cycle regulation; provision of natural resources; and preservation of biodiversity intactness and air quality, all of which are essential for human well-being and economic growth.

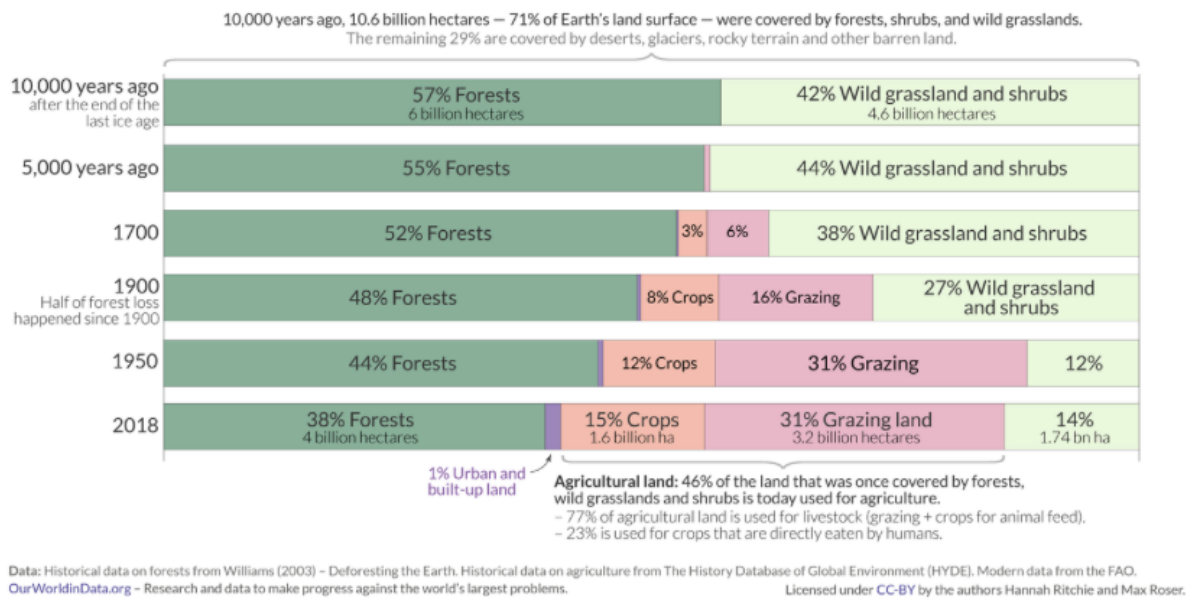
Currently, forests cover approximately 4 billion hectares or 31% of the Earth’s total land area (FAO, 2020). In terms of the distribution of forests around the world, 15% of forests are situated in Asia , 21% in South America, 16% in Africa, 19% in North and Central America, 5% in Europe (including the Russian Federation), and 5% in Oceania (FAO 2020). However, over half of the world's forests are in just five countries (Russia, Brazil, Canada, the USA, and China), and 66% of forests are in ten countries (FAO, 2020). Globally, 5% of forests are plantations generally used for commercial purposes (Pan et al, 2013).

Figure 1: Distribution of forests globally



Source: 2011 global forest cover map, based on MODIS satellite data at 500-m resolution and on IGBP-DIS (The International Geosphere-Biosphere Programme Data and Information System) land-cover classifications, from Pan et al, 2013

Figure 2: Forest coverage and land use changes overtime



Source: Ritchie, 2021

Over the course of history, natural and human disturbances have significantly impacted global forests (See Figure 2). It is estimated that over 60% of the world's forests are recovering from past disturbances, and 3% are affected annually by logging, fire, pests, or weather (FAO 2006). Over the past 20 years, the global primary forest loss has been 3.5 million hectares per year on average (World Resource Institute, 2024). Expansion of agricultural lands is responsible for 80% of deforestation, especially in the 1980s and 1990s (**Gibbs et al. 2007,** Houghton 2007). The loss of forests also leads to the loss of important ecosystems provided by the forests.

Forests are vital components of the Earth's ecosystem, providing a wide array of services that are crucial for the well-being of both the environment and human societies. These ecosystem services encompass a range of regulatory, provisioning, and supporting functions that sustain life and promote economic and social stability. Forests play vital roles in filtering water, providing buffers against natural hazards like storms and floods, regulating the hydrological cycle and global temperatures, and sequestering carbon dioxide, thereby mitigating climate change. Forests also play a key role in significantly improving air quality. Meanwhile, the biodiversity within forests ensures the resilience of ecosystems, supports species diversity, and aids in disease regulation. Furthermore, forests provide valuable resources such as timber and bioenergy. These functions and their relevance to a functioning society and economy are outlined below.

- **Water capture and filtration**: Forests have an important effect on water conservation, purifying water and maintaining water quality (Sun et al, 2023). Forests act as natural filters, trapping sediments and pollutants, thereby protecting downstream water bodies from contamination. Moreover, when rainwater falls on forested landscapes, it passes through the vegetation and the forest floor, where it is naturally filtered and purified. The roots of trees and plants absorb excess nutrients and pollutants, preventing them from contaminating water bodies. Because of this, upstream tree cover is associated with a lower prevalence of diarrheal disease in children downstream, as shown in Malawi (Johnson et al., 2013). Additionally, forests play an important role in regulating water temperature, preventing excessive heating and maintaining suitable conditions for aquatic life. *Policy: Ellison et al. (2017) offer an important call to action for policymakers to consider forests' role in maintaining groundwater recharge.*

- **Soil conservation:** Soil quality determines agricultural productivity. Healthy soil makes water uptake available, reduces erosion, and enhances biological activity, and is a vital component for agricultural productivity. This has been well documented over time. In western Kenya, land use change, namely converting forests to permanent agriculture, resulted in progressive soil degradation, or the loss of productivity of land, which threatens agricultural sustainability (Nyberg et al., 2012). This happens through deteriorated soil structure (which leads to erosion) and a reduction in soil organic carbon. In Nigeria, deforestation affected soil's ability to receive and transmit water, and increased bulk density of soil – which limits microbial activity root penetration (Lal, 1996). Similarly, in Bangladesh, deforestation was shown to significantly impair soil's biological, physical, and chemical properties (Sirajul Haque et al., 2014). Forests prevent soil erosion through their dense root systems and canopy cover, which stabilise soil and reduce the impact of raindrops on the earth. Additionally, the presence of fallen leaves on the ground, slope stabilisation, nutrient cycling, and water absorption further contribute to soil stability and erosion prevention, and in turn, flood prevention. When forests are cleared, soil erosion happens at landscape scales, which can dramatically increase the pace of sediments moving into river systems, exceeding natural levels of sedimentation (Reusser et al, 2015). Floods in the northern Andes of Colombia for example, have been linked to severe soil erosion and high sedimentation of the Magdalena river catchment from decades of forest clearance (Restrepo et al, 2015). This region in Colombia is where the majority of the country's population live and where more than 80% of GDP is generated. Scenarios of extreme riverine flooding have been explored in a climate stress test of the Colombian banking system, with potentially substantial impacts on the macroeconomy and financial sector (Reinders et al, 2021).

- **Hazard protection from storms and floods:** Forests help regions respond to storms and extreme rainfall – they moderate variations in discharge by allowing soil to absorb water. Nainar et al. (2018) conducted a study of the physical properties of catchments, finding that forested areas have the most buffered storm response. Several studies have found a strong relationship between deforestation or land-use change and flooding and landslide events (Sunbrad et al (2016); Bradshaw et al. (2007); Agarwal et al. (2023); Bhattacharjee and Behera (2018); Robalino et al. (2023)). Looking particularly at deforestation for urbanisation purposes, Nirupama and Simonovic (2007) show how previously forested areas face elevated risks of floods. Chauhan et al (2023) reviews environmental changes in the Himalayas, which is home to around 50,000 glaciers and faces extreme threats from shrinking glaciers and land use change, leading to cascading hazards such as glacier outburst floods and frequent droughts and floods. The Himalayan region is the source of the ten largest rivers in Asia (including the Indus, which flows through Tibet, India and Pakistan; the Ganges, which flows through India and Bangladesh; the Brahmaputra which flows through Tibet, Bhutan and Bangladesh; the Mekong, which flows through Tibet, China, Burma, Laos and Cambodia; and the Yellow and Yangtze rivers which flows through Tibet and China), providing ecosystem services to at least 1.9 billion people (Sharma et al, 2019). Besides the warming of the Himalayas and glacial melt, land use change is major cause of soil degradation, such as the destruction of forests and shrubland for fuel wood or commercial timber and mining, causing devastating impacts not just on local people but on those living in downstream river basins (Chauhan et al, 2023; IPCC, 2021; Wester et al, 2019).

- **Regulating the hydrological cycle:** Forests are important drivers of rainfall. Trees absorb water from the soil through their roots and release it into the atmosphere through a process called transpiration, which contributes to the formation of clouds and precipitation, thereby influencing rainfall patterns and water availability in a region. Precipitation patterns change with changes to forest cover (Malhi et al, 2007). This relationship is highly dependent on geography: for example, deforestation of Mexico's cloud forests led to more rainfall, as well as more volatile fluctuations of water reserves (drier dry seasons, propensity to floods) (Muñoz-Villers et al. (2015); Lozano Trejo et al. (2020)).

- **Regulating global temperatures:** Forests are also important regulators of local and global temperatures. At the local level, tropical and temperate forests particularly reduce Earth's surface temperature, due to forests' shade and evaporation functions. In fact, temperatures in ecosystems with non-functional or no vegetation are similar to asphalt surface, whereas dense, bushy or tree vegetation displayed balanced temperature dynamics (Hesslerová et al., 2013). Furthermore, similar effects can be observed at the regional and global scales (rather than the purely redistributive effects of local cooling). Due to the emission of organic compounds, forests contribute to low-level formation of clouds and increase reflection of sunlight into space, which results in global cooling effects (Ban-Weiss et al., 2011).

- **Regulating the carbon cycle:** Forests play an important role in removing carbon dioxide from the atmosphere – an important link in the climate-nature nexus. Globally, forests absorb a third of anthropogenic carbon emissions, making it the second largest source of carbon sink (the ocean being the first). However, forests are both a sink and source of carbon emissions. Trees absorb carbon dioxide when it is growing or standing, and emit carbon dioxide when they decay, get cleared or degraded. Therefore, global deforestation constitutes a net source of carbon emissions, which are large and persistent (Yude Pan et al., 2021). Land use change, mainly in the form of deforestation accounts for 12 - 20% of greenhouse gas emissions (Palmer et al, 2023). A carbon mapping approach applied to Perú found that a significant amount of carbon stocks was at imminent risk of emitting carbon as a result of deforestation activities (Asner et al. 2014)– which could apply to all growing tropical nations. Moreover, carbon emissions from deforestation, particularly in Mexico, are likely underestimated as organic soil carbon stocks are not considered in estimations thus far, resulting in the value of Mexican temperate forests being underappreciated (Santini et al., 2019). Importantly, the loss of forests and the resulting release of carbon emissions is projected to have a negative impact on GDP (Johnson et al. 2021).

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- **Provisions (timber, bioenergy):** In addition to the negative effects through other ecosystem services, natural degradation itself impacts the ability of ecosystems to directly provide valuable resources and materials, such as timber. Johnson et al. (2021) estimated the effects of a loss of provision services provided by ecosystems focussing on pollination, provision of timber, and marine fisheries. This study indicated that land use change affects existing high-quality habitats of pollinators, which results in crop yield reductions of neighbouring agricultural land (although this may be offset by higher productivity of increases in agricultural land). Moreover, natural resources also play a fundamental part in the forestry (timber) and fisheries sectors, which are dependent on the balance of delicate ecosystems for its materials. Another important output provided by ecosystems is bioenergy, For example, forests provide biomass for bioenergy generation, which is important for both energy needs and for meeting climate goals, particularly when used in substitution of fossil fuels (Yu et al. 2021).

- **Habitat, species and biodiversity intactness:** Intact ecosystems play a fundamental role in maintaining an equilibrium among a diversity of species. Furthermore, the greater the diversity of species and ecosystems within an environment, the higher the resilience of ecosystems to withstand and recover from shocks such as invasive species or elevated temperatures. When degraded, these ecosystems may not regulate disease organisms or their vectors. Deforestation is often accompanied by increased human contact with the natural ecosystem, which facilitates zoonotic transmission of diseases (IPBES, 2018). This has important implications for human health: in Central and West Africa, Ebola virus disease outbreaks are preceded by forest loss in the previous 2 years, likely as zoonotic transmission would be more probable due to human incursions and the increased density of potential reservoirs of the virus in fragmented forests (Olivero et al., 2017). This is substantiated by Gibb et al. (2020) that show how sites under substantial human use have a much higher proportion of known wildlife hosts of human-shared pathogens and parasites compared to undisturbed habitats. In Brazil, MacDonald and Mordecai (2019) find a strong feedback loop between malaria and deforestation. In fact, deforestation can worsen malaria by increasing forest edge habitat which promotes mosquito breeding habitats and survival, leading to higher human biting rates. These effects are strongest at early stages of deforestation.

- **Regulating plant diseases:** In addition to human health, ecosystem equilibria regulate non-human diseases. Land use change, urbanisation, and forest fragmentation increase the risk of new emerging diseases in plants and animals in peripheral human-dominated areas. For example, agriculture-forest interfaces contribute to plant disease epidemics through spillover from wild to domesticated plants (Guégan et al. 2023). Research also finds a negative relationship between plant species richness and diversity with virus infection prevalence, suggesting natural populations with higher biodiversity are better able to regulate viruses (Susi and Laine, 2021).

- **Air quality:** Forest ecosystems play a crucial role in improving air quality through direct and indirect mechanisms. Firstly, and directly, trees in forests filter pollutants from the air, similarly to how they purify water. They reduce gaseous air pollutants and remove particulate matter, which helps prevent human mortality and acute respiratory symptoms (Nowak et al., 2014). In Mexico, research shows that peri-urban forests, such as the national park between Mexico City and Puebla, significantly reduce the annual concentration of air pollutants (Baumgardner et al., 2012).

  Secondly, and indirectly, protecting forests reduces the risk of wildfires, which also benefits air quality. Land use changes increase wildfire risks by altering forest structures, making fragmented landscapes more susceptible to frequent and larger fires (Alencar et al., 2015). This is particularly significant in tropical regions, where fires are not part of the natural cycle. Both wildfires and conversion fires produce substantial particulate matter, adversely impacting air quality and public health, consequently leading to pressures on public finances. The forest fires in Southeast Asia in 1997 were estimated to cost $9-11 billion, including healthcare expenses. Deforestation in Brazil's Amazon rainforest since 2012 has increased fire occurrences in the dry season by 39%, potentially resulting in 3,400 additional deaths (Butt et al., 2021). In Equatorial Asia, the 2015 forest fires exposed 69 million people to unhealthy air quality, possibly leading to 11,880 excess mortalities, primarily due to fires with anthropogenic ignitions, occurring in deforested land and degraded peatlands, exacerbated by extraordinary drought conditions.

2. Macroeconomic and macro-financial impacts of deforestation and land-use change

Deforestation and land-use change can lead to macroeconomic and macro-financial impacts, affecting workers, households, firms, financial institutions, and the overall economy. For workers and households, the loss of forests can lead to reduced labour productivity, food security, and negative health impacts. Households reliant on forest resources for income and sustenance face significant economic instability. For firms, especially in the agriculture and forestry sectors, deforestation can initially boost short-term profits but often leads to long-term resource depletion, higher operational costs, and reputational risks. Financial institutions encounter increased credit risks as environmental degradation undermines the viability of investments, leading to potential defaults on loans, particularly in agriculture-dependent regions. The broader economy suffers as ecosystem services—such as carbon sequestration, water regulation, and biodiversity—deteriorate, exacerbating climate change impacts and increasing the frequency of natural disasters, which strain public finances and disrupt economic stability. Collectively, these factors contribute to a cycle of economic vulnerability, reduced productivity, and increased financial instability, underscoring the critical need for sustainable land-use policies.

3.1 Impacts to Workers and Households

Land use change can significantly impact the economic well-being of households at the individual level, manifesting through various channels such as disease outbreaks and compromised air quality, which directly affect health and productivity.

By disrupting ecosystem equilibriums and increasing human exposure to wildlife, deforestation can lead to more frequent **disease outbreaks**. For example, MacDonald and Mordecai (2019) identified a feedback loop between malaria incidence and forest clearing in the Brazilian Amazon. Firstly, forest loss within a given municipality was found to increase malaria incidence, particularly in interior regions where forest cover is higher. On the other hand, malaria itself was found to decrease land clearing rates, as it affects working days and economic activity. Sachs and Malaney (2002) explored the different channels through which infectious diseases may impact economic activity through multiple channels. In addition to premature mortality and medical costs, malaria hampers economic activity through school absenteeism, disproportionately high fertility rates and population growth, reduced savings and investment rates, as well as limited economic relations (such as migration, trade, or investment flows) with non-malarious regions and counterparts.

Forests also play a key role in maintaining **air quality**. Deforestation directly and indirectly increases the risk of forest fires, which are significant sources of air pollution. Nowak et al. (2014) estimated the human health effects of removal of air pollution by trees and forests in the United States in 2010, reaching a figure of USD 6.8 billion (range of USD 1.5 – 13 billion). Naturally, this is in addition to the massive impact on mortality of the particulate matter emitted by forest fires. Jayachandran (2009) looked at the effect of Indonesia's 1997 wildfires, which affected foetal, infant, and child mortality. By using literature references for valuation of statistical life, early-life mortality costs were estimated at above USD 15 million, which excludes health costs among survivors. Wang et al. (2021) estimated the healthcare-effects cost of the 2018 California wildfires at USD 32.2 billion due to increased mortality, medical expenses, and work time lost.

Deforestation also impacts healthcare outcomes through the loss of **temperature regulation**, and particularly reducing resilience to heat waves. Alves de Oliveira et al. (2021) explore how large-scale deforestation increases the risk of exposure to extreme heat caused by climate change. Vulnerable regions will particularly suffer from physiologically intolerable heat levels, which affect workability, mortality associated with cardiovascular diseases, psychological outcomes, and kidney diseases. Parsons et al. (2021) focus on the productivity effects, showing how tropical deforestation is associated with local warming, which also significantly affects outdoor working conditions. According to the researchers, recent tropical deforestation may have resulted in a total loss of 0.5 billion potential safe work hours per year (0.5 hours per day for 2.8 million workers). Masuda et al. (2021), through a field experiment in Indonesia, demonstrate that worker productivity was 8.22% lower in deforested areas, where temperatures were higher. The authors show that the productivity gap is explained by behavioural adaptations, such as more frequent work breaks.

3.2 Impacts to Firms and Production Processes

In addition to its effects on households, deforestation poses significant challenges to firm activity, impacting both physical ecosystem services and introducing transition risks that can disrupt supply chains and operational sustainability.

Physical risks

Land use change, particularly deforestation, profoundly affects rainfall patterns, which in turn impacts a region's ability to sustain various economic practices such as agriculture and hydropower generation. The relationship between land use and hydrological services is critical for firms relying on these resources. Aylward (2005) provides a comprehensive overview of how deforestation diminishes economic welfare due to changes in water quality and quantity. Increased sediment levels can clog irrigation systems and reduce the efficiency of hydropower facilities, while runoff from deforested areas can carry nutrients and chemicals into water bodies, affecting water quality and increasing treatment costs for industries dependent on clean water. Additionally, deforestation can decrease the water storage capacity of a region, impacting both irrigation and hydropower generation.

These changes disrupt downstream hydropower and irrigation facilities, reduce benefits from fisheries, tourism, and flood regulation, and elevate water treatment costs. Wu et al. (2021) showed how forests affected the output of farming activities downstream, with deforestation being particularly detrimental in years of excess or insufficient rainfall, resulting in more volatility. Arellano Gonzales (2023) explores how crops are sensitive to changes in precipitation and temperature, with relevant repercussions for agricultural productivity. Colesanti Senni and Jagow (2023) further highlight that reduced water availability significantly impacts hydroelectricity generation in the US and Europe, underlining the global implications for energy-dependent industries. An illustrative study by Pérez-Rubio et al. (2021) shows that landholders recognize the economic value of water availability and soil erosion control. Their willingness to accept restoration projects underscores the economic importance of these ecosystem services for maintaining and enhancing productivity.

Forest fires, which are sometimes set deliberately as a strategy to clear land, can significantly disrupt productive economic activity by causing widespread damage that extends far beyond the immediate area of the fire. The disruption of supply chains and production capacity leads to substantial indirect losses. For instance, in the 2018 California fires, indirect losses accounted for 59% (USD 88.6 billion) of the total estimated wildfire damages. This highlights the extensive economic ripple effects caused by such events. Furthermore, Borgschulte et al. (2022) demonstrated the impact of wildfire smoke on the labour market, revealing how it leads to decreased quarterly earnings. The smoke from wildfires reduces air quality, which in turn affects worker health and productivity. This not only increases absenteeism but also diminishes overall workforce efficiency. Consequently, businesses face heightened operational costs and reduced output, exacerbating the financial strain caused by direct fire damage.

Land use change, particularly through deforestation and the use of fire to clear land, creates environments that facilitate the spread of invasive species, significantly impacting firms' productivity and revenue. In agriculture, invasive plant species can overrun croplands, reducing yields and increasing weed management costs, while invasive insect species can damage crops and decrease productivity. Forestry operations suffer from invasive pests and diseases that harm valuable tree species, raising operational costs and reducing profitability. This phenomenon is evident in the spread of the emerald ash borer, which has led to substantial economic losses in the North American timber industry (Susi & Laine, 2020). Additionally, Guégan et al. (2020) examines how land use change facilitates the spread of vector-borne diseases by creating ideal conditions for invasive species to thrive, which can significantly affect ecosystems, human health, and business costs. The proliferation of these invasive species disrupts local biodiversity and impacts agricultural productivity, forestry, and fisheries, leading to increased management costs and reduced profitability for businesses operating in these sectors. The economic impacts of invasive species extend beyond direct production costs, as firms may face reduced revenue due to decreased product quality and marketability. Crops damaged by invasive pests may not meet market standards, and the loss of valuable tree species can reduce the availability of high-quality timber (Chort & Öktem, 2023).

Transition and litigation risks

In addition to the physical risks covered so far, deforestation practices also expose economic actors to transition risks, i.e., a misalignment between their economic activity and actions related to restoration or conservation of nature. Firstly, given a global policy paradigm that recognises the importance of preserving forests and biodiversity, economic activities which significantly contribute to natural degradation are expected to face increasing limitations. In this section, we also include litigation risks, as corporate and financial law duties may stem from companies depending on and negatively impacting ecosystems. Moreover, transition risks may also materialise in the shape of evolutions in market and investor sentiment, consumer preferences, or technological advances that yield certain activities obsolete.

i. **Policy and Legal Risks**: In a context of worsening biodiversity conditions and climate change, policy response is expected to decisively target deforestation. One key example is the upholding of deforestation-free value chains. For example, the European Union recently enacted regulation on deforestation-free products, which since June 2023 requires companies to ensure that key commodities (such as soy, beef, palm oil, wood, etc) are produced without contributing to deforestation or forest degradation. The EUDR will also be reviewed by June 2025 on "the role of financial institutions in preventing financial flows that contribute directly or indirectly to deforestation and forest degradation and assess the need to provide for any specific obligations for financial institutions in Union legal acts in that regard, taking into account any relevant existing horizontal and sectoral legislation." The UK and the US have recently adopted similar measures, through the Forest Risk Commodities regulations and the FOREST Act, respectively. The EU has also implemented the Carbon Border Adjustment Mechanism (CBAM), which attempts to capture the carbon emissions resulting from a good's production process. This mechanism is in its transitional phase and therefore only applicable to specific industrial goods and fossil fuels. On the other hand, the US implemented bans on palm oil imports from two Malaysian companies in 2020, due to concerns of human rights violations. Because of this, both companies suffered financial and reputation consequences, with key clients reducing exposure to those companies and stock prices falling. Policy pressure may also originate from domestic institutions. In Brazil, the Central Bank has already implemented regulations requiring financial institutions to report on environmental risks and incorporate them in risk management frameworks. The Brazilian Central Bank has also introduced regulation with restrictions to the provision of rural credit, requiring due diligence processes to ensure financing does not contribute to deforestation. In Indonesia, a permanent moratorium on conversion of land for palm plantation and logging activities has been issued in 2019, which has severely impacted the performance of these sectors. Additionally, the presence of invasive species often leads to increased regulatory scrutiny and compliance costs, as governments impose stricter management practices to control their spread (Guégan et al., 2020).

These policy risks are often realised through litigation initiatives, which can result in relevant financial consequences in the shape of fines or stranded assets. As deforestation becomes a more salient issue, these newly created policies are rapidly being upheld in court – often empowered by technological developments in satellites and traceability. Following an initial wave of climate justice initiatives targeting governments' climate change commitments, civil society has turned its attention to corporate actors responsible for sizable greenhouse gas emissions. In fact, following the Urgenda decision against the Dutch government, a group of NGOs filed a complaint against Royal Dutch Shell in 2019, alleging hazardous negligence in failing to reduce its contributions to climate change. Although Shell has appealed the decision, the 2021 initial ruling determined that Shell should take action to limit the volume of its emissions by 45% relative to 2019 levels, both from own operations and from the use of the fossil fuels it produces. Cases have also been brought by public entities, such as the city of New York, the State of California, and certain municipalities in California which sued oil and gas giants (Exxon, Shell, Chevron, and others) for misleading the public regarding the role of fossil fuels in planet-warming.

These have served as inspiration for biodiversity-focused initiatives. A collective of political parties presented a case to the Brazilian Supreme Court based on the failure of the Federal Union to adopt measures concerning both the Climate Fund and the Amazon Fund. With significant political repercussions, the Supreme Court ruled that the federal government had failed its duty to activate and fulfil these funds, ultimately exacerbating trends of deforestation and climate change. In the Lhaka Honhat Association v. Argentina case, the Inter-American Court of Human Rights ruled that Argentina breached its obligation to respect Indigenous groups' rights. These include the right to a healthy environment, food, water, and cultural identity, with reparation measures including the recovery of forest resources (Tiger, 2015). In 2018, Pakistan members of civil society filed a petition against Government Departments for failing to implement policies to protect forests in Punjab. In court, the Government was found to have neglected its duties in applying existing laws, and was consequently ordered to reforest recent urban settlements, improve reporting on forested areas, as well as better enforce national forestry legislation.

In addition to public authorities, private entities have also been targeted by biodiversity-linked litigation. For example, a group of Brazilian and Colombian indigenous people and environmental NGOs brought a case against the French supermarket chain Casino concerning the alleged sale of Amazon deforestation-linked deforestation. According to them, this constitutes a failure of their due diligence obligation under France's duty of vigilance law. A similar lawsuit targeted the French bank BNP Paribas, which is accused of insufficient due diligence before providing services to firms allegedly responsible for deforestation, land-grabbing, and forced labour. In addition to NGO-led cases, evolving legislative toolboxes have also allowed national authorities to file environmental class-actions against companies and private persons. In Brazil, the Federal Environmental Agency (IBAMA) sued a steel company and its managing partner for the firm's long standing use of illegally sourced coal, which promoted an illegal deforestation scheme. Similarly, the Amazon taskforce within the Public Prosecutor's office sued a Brazilian farmer for causing the deforestation of 2.500 hectares in the Amazon, ordering the removal of cattle from farms and seeking compensation for monetary damages. As early as 2009, the Indonesian government sued two mining firms for damages linked to illegal mining, including the clearing of protected forests. In 2014, the defendants were found liable by the Supreme Court to compensate for the GHG emissions from destroyed forests, as well as restoration costs.

ii. Market Risks: The increased importance of land use changes present risks to the business model of companies, which may find increasing operational difficulties. For example, the implementation of stricter procurement policies of palm oil buyers has forced non-sustainable growers out of the market. In order to meet commitments such as No Deforestation, No Peat, No Exploitation (NDPE), firms often demand certifications such as the International Sustainability and Carbon Certification or the Roundtable on Sustainable Palm Oil Certification, which has significantly reshaped the palm oil market and constrains the action deforestation-inducing firms (Yeong Sheng et al., 2021). More broadly, voluntary sustainability standards have become relevant conditions for market access, affecting in particular the cocoa, palm oil, soybean, and timber industries (Larrea et al., 2021). Similarly, the adoption of the Principles for Responsible Investment (PRI) showcases the willingness of investors and financial institutions to reduce their exposure to deforestation-inducing practices. Ultimately, this may result in an increase in the financing costs of non-compliant firms, facing higher interest rates in order to cover the additional risks (Van Gelder et al., 2017). Changing customer behaviour; Uncertainty in market signals; Increased cost of raw materials. To look into Daniel Beunza

iii. Reputational Risks: Changes in consumer and investor perceptions are also significant sources of financial risks for companies. As the impact of deforestation becomes more salient, worst-performing firms may face challenges related to decreased demand by consumers and lower appetite from investors. These risks may apply both to companies contributing to deforestation or the financial institutions financing them. In their brief on the Indonesian palm oil sector, Van Gelder et al. (2017) highlight how market surveys show relevant portions of the consumer base willing to shift to other products based on sustainability concerns. NGOs often play a role in these decisions, with organisations such as Forests & Finance or Responsibank enabling cross-bank comparisons based on sustainability impacts. In the Amazon, there was significant pressure by NGOs in uncovering the link between the soybean and cattle industries and deforestation (Greenpeace International (2006, 2009)). Since then, these companies have had to adapt their practices in order to maintain or improve their reputation, for example by designing Brazil's Soy Moratorium (H. K. Gibbs et al., 2015).
Shifts in consumer preferences; Stigmatisation of sector; Increased stakeholder concern or negative stakeholder feedback.

iv. Technology Risks: Recognising the criticality of reducing our environmental footprint has also motivated serious efforts in developing enabling technology. As such, successful technological developments could allow economies to satisfy their needs without resorting to operational models that cause deforestation. For example, the known impact of cattle raising on forests is fuelling innovation in the food industry that can lead to disruptive transformations in the sector. Although clearly beneficial for the environment, and therefore actively pursued at a societal level, these breakthroughs could negatively impact the bottom line of companies relying on these practices.

3.3 Impacts to Physical Capital, Damages, and Valuation Losses

Due to their importance in the biophysical system, forests and land use change affect our resilience to natural disasters and extreme weather events. These events often destroy or damage physical capital, such as housing stocks or public infrastructure, which represents a significant reduction in total wealth.

Forests affect a region's vulnerability to **floods –** both in terms of frequency and severity. Bradshaw et al. (2007) show how lack of forest cover is correlated with the economic damages caused by floods, similarly to Bhattacharjee and Behera (2018) and Agarwal et al. (2023). Brookhuis and Hein (2016) leverage flooding and economic damages data in Trinidad to estimate the monetary benefit of this flood risk regulation service. Similarly, forests also regulate **landslide risks**. Tankha et al. (2018) define a methodology for calculating the economic value of this service, quantifying the implicit damage risks from land use change.

Although deforestation is not independently responsible for **forest fires**, its contribution to their frequency and intensity also entails larger economic damage risks. In the Pacific states of the U.S., Wang & Lewis (2024) showed how wildfires reduce the economic value of timberland. So far, more frequent wildfires (mainly caused by climate change) have reduced timberland values by 8.78%, with most of the effect coming from changes in expectations (rather than direct burning on specific properties). Looking at the 2018 California wildfires, Wang et al. (2021) estimate total costs at USD 148.5 billion, of which capital losses represented USD 27.7 billion. These damages ultimately impact either productive capital, such as commercial, industrial, or public assets, which represent 83% of the capital damages, or household property (17%).

<u>3.4 (Aggregated) Macroeconomic Impacts</u>

Focusing on the macroeconomic impact of **wildfires**, Meier et al. (2023) leverage panel data on employment and GDP growth to estimate that Southern Europe economies lose 1.3-2.1 billion euros per average wildfire season. As wildfires become the norm in the changing climate, these costs are likely to recur year after year. While the effect on employment is heterogeneous across sectors, with tourism-related activities being the most affected, the researchers identify the aggregate negative effect on regional GDP growth rate to be 0.11%-0.18%.

Forest loss also has an impact on water purification and maintaining **water quality**. Desbureaux et al. (2019) explore the relationship between river pollution and downstream economic growth at a global scale and find that water quality degradation reduces growth by 1.4% and 2.5% in downstream regions, with even stronger effects in low and middle-income countries. El Khanji et al. (2016) study the relationship between economic growth and both water scarcity and quality in a panel of 177 countries concluding that while water pollution has immediate positive impacts on GDP per capita, it negatively affects the five-year growth rate. In fact, there seems to be a clear limit to the extent that economies can benefit from pollution-generating activities. Moreover, water scarcity and economic growth are found to have a U-curve relationship, with water utilisation initially benefitting growth but eventually becoming a constraining factor. Here, the role of forests cannot be overstated – forests play both an important role in regulating the water cycle through evapotranspiration, but also in maintaining water quality.

<u>Price pressures:</u> Parker (2018) shows how natural disasters (including floods, storms, and droughts) affect inflation. In general, developing countries normally see inflation rise following a natural event. Moreover, this effect is broken down in short-term increases in food prices and negative impact (deflation) in housing and other sub-indices. The inflationary effect of droughts is generally longer-lasting than that of storms and floods. Naturally, this has further implications for the exchange rate and capital account. Arellano Gonzalez et al. (2023) show precisely how heat waves create

pressures on price indexes, mainly on fruit and vegetables, and with geographical heterogeneity across Mexico.

Economic damages caused by natural disasters: Natural disasters severely affect the output of developing and low-income countries (Cavallo et al. (2021); Noy (2009)). Strobl (2012) looks particularly at the highly localised effects on economic output, following the passage of hurricane destruction in specific areas. Mohan (2017) and Spencer and Polachek (2015) looked at how natural events were disruptive enough to cause significant decreases in exports and, therefore, on GDP.

Bauer and Wing (2016) estimate the costs of pollinator shocks, which particularly affect crop sectors but eventually impact the world economic output.

Looking explicitly at the effects of land use changes from a cost-benefit standpoint, Lykke (2015) conducts an extensive CBA comparing intact Amazonian forests and agricultural land, highlighting several ecosystem services of forests, such as timber production, water recycling, or fire control. While actual estimates depend on assumed discount rates, the author places the economic value at around USD 18,000/hectare, which would mean that Present calculations conclude that optimally used agricultural land yields more economic value than forested land. However, as forested areas shrink, the total value of standing rainforest will exceed that of agricultural land.

In Australia, Cross et al. (2022) quantified the trade-off between conserving wet forests in the Central Highlands of Victoria and continued logging. Focusing on the benefits of carbon sequestration and tourism activity, and comparing them to the revenues from logging activity, their findings indicate that ending deforestation for the 2022-2030 period would yield a net benefit of $59 million in present value terms.

In Nicaragua, a preliminary report by the World Bank (2018) analysed the cost of environmental degradation to society, including the cost of deforestation. Here, estimations of different ecosystem services provided by forests (including carbon removal and storage, watershed protection, and non-timber forest products) are brought together to place the annual cost of deforestation in the country at USD 162 million, or 1.2% of the 2016 GDP.

3.5 Transition to Financial System

In this section, the implications of forest loss on various actors within the economy was explored. In this examination, it became evident that it poses significant macroeconomic and financial challenges by disrupting the intricate balance between ecosystems and economic activities. Households bear the brunt through lost productivity, job losses in forest-dependent sectors, and deteriorating health outcomes due to increased air pollution and reduced natural resources. Firms face physical risks from increased natural disasters and resource scarcities, alongside transition risks associated with shifting regulations and market preferences. These disruptions cascade through the economy, leading to increased volatility, higher insurance costs, and strained public finances. The cumulative impact can transmit into financial system, manifesting in asset devaluation, credit market instability, and heightened systemic risks that threaten financial stability and economic resilience. Notwithstanding, there may also be direct effects to the financial system, for example through reputational risks.

i. Nature-Climate Nexus

Climate-related risks that central banks, financial supervisors and financial institutions are concerned about, such as floods, droughts, storms and landslides that lead to loss of labour productivity and asset destruction do not occur in a vacuum. Ultimately, it is the degradation of nature such as forest loss or ocean heating that precedes these events. As we have seen in Section 1, forest loss results in the loss of functioning of ecosystem services such as carbon storage, water and temperature regulation, and soil maintenance. Without these services, the impacts of climate change are exacerbated, increasing the frequency and severity of climate-related risks. This underscores the interconnectedness of natural ecosystem health and economic stability, highlighting the importance emphasises the necessity of integrated policy approaches.

The role of forests in regulating the carbon cycle is a good example of the importance of considering both climate and nature simultaneously, rather than in isolation or as separate issues. Physical risks are one of the main axes of the climate-nature nexus, in addition to providing adaptation opportunities and both transition risks and opportunities. On one hand, forest loss exacerbates the effects of climate change, as it is a major source of carbon emissions, deprives territories from climate regulation services, and reduces resilience to natural disasters. On the other hand, global temperature changes can irreversibly affect ecosystems' natural equilibrium, while extreme weather events further contribute to the destruction of forests and biodiversity (Finance for Biodiversity Initiative, 2021).

Reinders et al. (2021) conducted a flood risk assessment revealing that 6.5% of the total loan exposures of Colombian banks are in municipalities at high risk of flooding. They also demonstrated that severe flood scenarios could lead to declines in capital adequacy, with impacts on the capital adequacy ratio is further influenced by exacerbating factors such as stronger climate change effects, a concurrent recession, and the flood's severity. The authors also identified that certain banks are substantially more vulnerable to flood hazards due to high exposures in rural areas or to sovereign debt. Finally, they noted that severe natural disasters, such as floods, could lead to the downgrade of sovereign debt, with significant implications for the financial system

Aguilar-Gomez et al. (2023) explore the link between heat waves and credit delinquency in Mexico, showing that extreme heat events affects credit default and credit use. The authors find particularly strong effects on SMEs and agriculture. In regions with a sufficiently, large proportion of agricultural workers, extreme heat also affects non-agricultural sectors.

Calice et al. (2021) look more directly at the consequences of biodiversity loss for the financial sector. They show that 46% of the total corporate loan portfolio of Brazilian banks (20% of total credit portfolio) is to corporates operating sectors highly or very highly dependent on ecosystem services, with particular dependence on climate regulation, ground water, and surface water. The authors estimate that GDP losses associated with ecosystem services collapse could translate into a long-term increase in corporate NPLs of 9 percentage points. A similar analysis was conducted for the Dutch financial sector (Toor et al. (2020) and Malaysia (World Bank and BNM (2022)).

There is an unpublished NGFS-INSPIRE Study Group Input Paper by Martínez-Jaramillo, S. and Montañez-Enríquez, R. (2021): the Dependencies and impact of the Mexican banking sector on ecosystem services.

ii. Global and Local Effects

At this point, it is useful to explicitly consider the different geographical scales at which forests play important roles, and how their loss leads to varying impacts at different scales. The ecosystem services that they provide are not confined to specific localities where they exist, and the impacts from the loss of forests can reverberate across society and economies near and far. The role of forest ecosystems in regulating temperature, the hydrological cycle and carbon emissions are critical at regional and global scales. This climate-nature nexus means that, on one hand, the risks from forest loss in the context of climate change are often considered as a global concern, as both its causes and effects are geographically diffuse. In fact, local emissions do not directly result, at least in a traceable way, in specific changes to a region's climate. This disconnection structurally alters the incentives for action, and helps explain the decades of delay in the implementation of substantial climate initiatives – even though this global problem necessarily manifests in locally-relevant effects to communities, such as health impacts, crop yields, or natural disaster damages (Baldos et al., 2023).

On the other hand, many impacts from biodiversity and nature loss are intrinsically local and so too, are the resulting risks. The majority of the physical risks covered above, such as soil conservation, hazard protection, and provisions, derive from the material influence of trees in their surroundings, which has a very strong local element to it. This dynamic has important consequences for the way policymakers regard nature-related risks, particularly when there is already a tendency to treat them identically to climate risks. The highly localised effects of biodiversity loss mean that megadiverse countries face a stronger imperative to protect their forests, if they want to conserve the ecosystem services that they provide to their economy. However, these countries are also often economically constrained and are pursuing growth development pathways that run counter to conservation goals. The absence of such policies to protect their forests will, however, likely impact these countries first and foremost, with important consequences on their production systems. Moreover, the local specificity of these risks also has relevant intra-national implications. Forest loss directly denies key ecosystem services to forested regions, hurting their economy, and exposing them to disproportionate risks. In fact, even if their economic impact may seem manageable at the national scale, the materialisation of these risks often results in very severe, concentrated impacts to specific regions and economic sectors, which further complicates their absorption by the national economy. In this sense, megadiverse developing economies have to grapple not only with domestic developmental trade-offs, but also with severe social-environmental impacts from the loss of forests, while contending in the arena of global trade.

Nonetheless, the need to balance these trade-offs remains a necessary task for megadiverse countries not only for their own national interests, but also because there are relevant physical risks of forest loss that manifest at a much broader scale, with regional and global effects. For example, climate-related risks are much more diffused, as illustrated by Butt et al. (2023) finding that, in addition to local temperature effects, Amazon deforestation has caused regional warming within a range of up to 100 km. The effect of forest loss on precipitation also has an important global dimension. Werth and Avissar (2002) look precisely at the local and global elements of Amazon deforestation, finding that it decreases precipitation in remote areas such as Central America, the Gulf of Mexico, and the Indian Ocean, in addition to its effects in the Amazon itself. Devaraju et al. (2015) also examine the remote effects of deforestation in precipitation patterns, linking it to an increase in precipitation in Southern Hemisphere monsoon regions, and a precipitation reduction in Northern Hemisphere monsoon regions. A similar global dimension of forest ecosystem services is observed in their regulation of the carbon cycle, which translates to globally relevant emissions of greenhouse gases, and the conservation of intact habitats and regulation of disease propagation, whose effects can quickly extend beyond the local area in which deforestation takes place. These regional and global dimensions necessitate countries to have a ‘commons’ approach, which places responsibilities to act not only on the countries where forests remain, but also on countries that rely on resources, goods and financial accumulation from extractive activities that put pressure on those forested lands. The next section aims to discuss these pressures that drive the ongoing destruction of forests, showing how the drivers of deforestation and land-use change also have a global and local dimension that necessitates critical policy responses from economies with supply chain dependencies and impacts on forested regions.

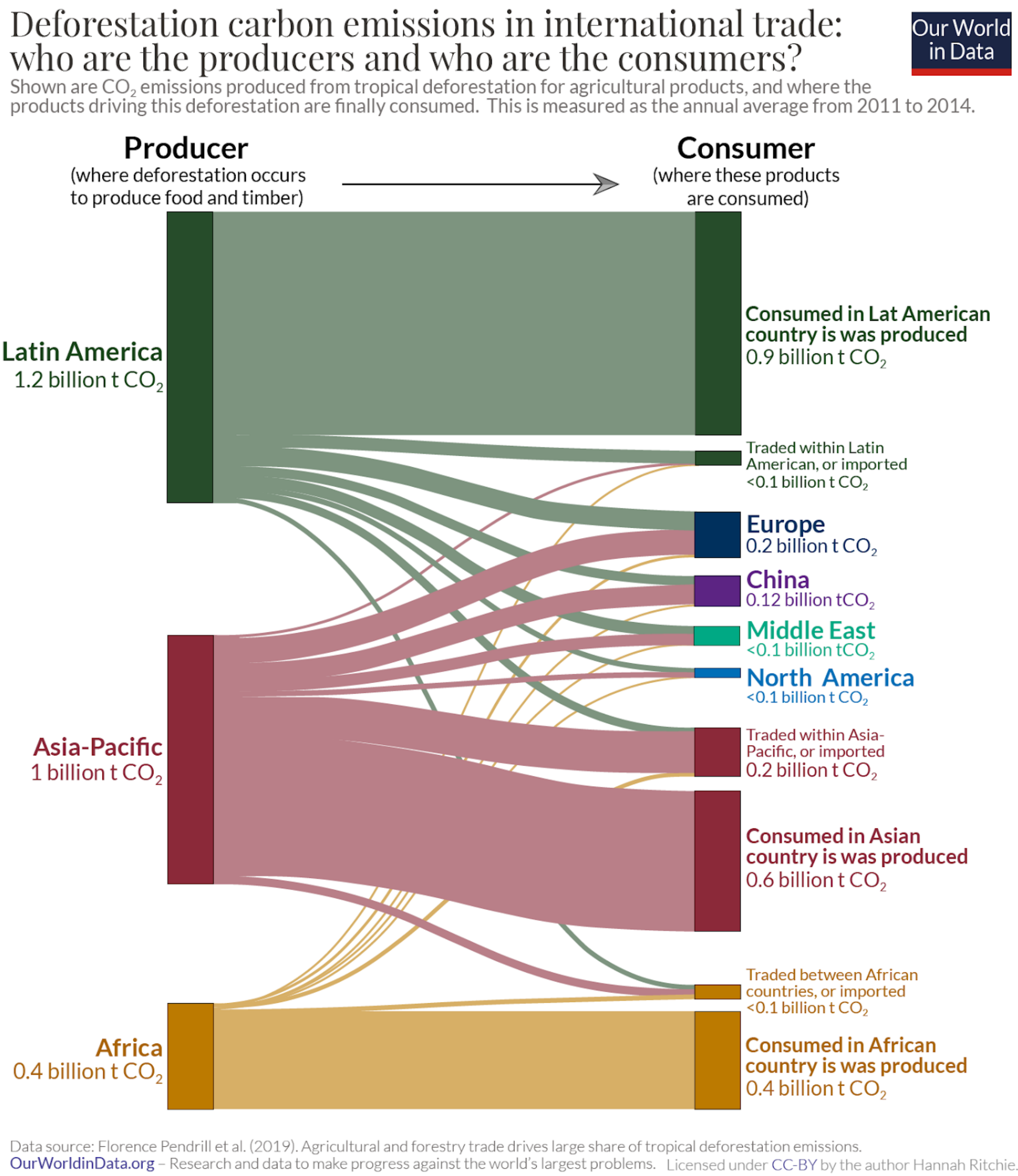
4. Economic pressures on forests

4.1 International demand

Growing demand for resources globally and the dependence of economies on extractive activities are fundamental drivers of deforestation and land-use change. Demand for food, fuel and consumer products are increasing within the context of a largely extractive global economy that fuels unsustainable levels of agricultural expansion, urbanisation, and natural resource and mineral extraction. This growing demand is tied to high and rising consumption patterns (IPBES, 2018). For example, the global forestry product industry, valued at US$250 billion annually, is heavily influenced by the consumption patterns of wealthy nations, which can lead to significant forest loss, particularly in regions where enforcement of logging regulations is weak (Antonarakis et al, 2022). Such a global economic context, with international trade and growing commodity markets supported by the accompanying economic and financial structures and institutions, puts relentless pressure on forests, and unless addressed, will continue to be a dominant driver of deforestation in tropical regions (IPCC, 2021; Dempsey et al, 2024). Tackling deforestation and land degradation thus requires systemic change in the macroeconomy (IPBES, 2018), at both global and national levels.

These economic pressures from rising consumption demand drives forest loss and land degradation, through various ways, one of which is **large-scale land acquisitions**. These acquisitions have surged in recent decades, particularly in countries of the Global South, driven by the growing global demand for food, fuel, and fiber. According to Davis et al. (2020), foreign land investments account for 76% of all acquired land area in these regions, highlighting the significant role of international actors in this process (ibid.). These investments are often aimed at securing access to natural resources or agricultural commodities, such as palm oil, timber, and wood fiber, which are in high demand in both domestic and international markets. This particular study utilised a comprehensive database of over 82,000 land deals across 15 countries in Latin America, sub-Saharan Africa, and Southeast Asia, revealing that these acquisitions frequently target areas with high forest cover, leading to elevated rates of deforestation.

Beyond direct large scale land acquisitions, another way that of economic pressure translates into forest loss is through international trade, with **embodied deforestation in imported products**. Many developed countries, despite obtaining net forest gains domestically, have increased the deforestation embodied in their imports, threatening mainly tropical forests. In fact, consumption patterns of G7 countries drive an average loss of 3.9 trees per person per year, and that the deforestation embodied in international trade are in biodiversity hotspots such as in Southeast Asia, Madagascar, Liberia, Central America and the Amazon rainforest (Hoang and Kanemoto, 2021). Crucially, only a handful of countries contribute a large part to the import and consumption of embodied deforestation, with China, India, Russia, and the US being individual countries accounting for the most imported deforestation (Pendrill et al, 2019). These findings highlight that deforestation (and therefore biodiversity loss) is being displaced through international trade, with countries that experience net forest gains offsetting such progress through the import of commodities that cause deforestation elsewhere - mainly in tropical regions. However, instead of tackling the source of economic pressures, it is countries facing these deforestation pressures that are expected to manage the issue.



4.2 Domestic pressures: trade-off between environmental conservation and economic growth.

Meanwhile, as international trade and external demands on land are increasing, domestic economic pressures are also rising in countries home to forest biomes. Throughout human history, forests have been cleared in order to obtain resources (namely, wood) and to create suitable spaces for agriculture, pastures, and urbanisation. Therefore, socio-economic pressures, such as demographic growth, urban expansion, and agricultural production, have always played a role in society's relationship with forests. Countries with large forest biomes often face difficult choices when balancing the need for economic development and the preservation of their natural resources. This tension is especially pronounced in developing nations, where poverty alleviation and economic progress are pressing priorities.

One of the primary domestic pressures leading to deforestation is the expansion of **agricultural activities.** As populations grow and urbanisation increases, the demand for arable land and food production rises, prompting the conversion of forested areas into farmland or pastures. This is particularly evident in countries like Brazil - where the clearing of the Amazon rainforest for cattle ranching and soybean cultivation has been a major contributor to deforestation - and Indonesia - where the clearing of rainforest is primarily driven by expansion of palm oil plantations. The economic incentives provided by the global demand for agricultural commodities often outweigh the perceived benefits of forest conservation, leading governments to prioritise short-term economic gains over long-term environmental sustainability. Similar arguments can be made about clearing land for the purpose of mining metals, which has become even more lucrative in the transition to a net zero future, coupled with legislations to limit the creation of new mines in developed countries due to the industry's significant environmental impacts. The expansion of mining operations and the extraction of natural resources, driven by domestic economic interests, also contribute to the degradation of forest landscapes.

Normally, understanding forest degradation requires looking at a number of interacting processes acting in tandem, rather than a single direct factor. While the most relevant direct cause of deforestation in the tropics is conversion for agriculture or pastures, this process tends to interact with **infrastructure expansion**, such as road building, which creates easy access to previously intact ecosystems. Infrastructure development exerts significant pressure on forest ecosystems. As new transportation networks are built to facilitate economic growth and connect remote areas, they inadvertently open up previously inaccessible forests to logging activities, illegal settlements, and further deforestation.

Box 1: Drivers of Deforestation in the Amazon Rainforest

The Amazon rainforest, one of the world's most biodiverse and ecologically significant ecosystems, is facing severe threats from deforestation driven by various human activities. This case study examines the primary drivers contributing to the alarming rate of forest loss in the Amazon region.

Agricultural expansion, particularly for cattle ranching and soybean cultivation, has been the leading driver of deforestation in the Amazon. 80% of deforested areas in the Brazilian Amazon are now used for cattle ranching (Berenguer et al, 2021), . The demand for beef and other livestock products, both domestically and internationally, has fuelled the conversion of vast swaths of primary forests into pastures. Furthermore, the expansion of soybean cropland and palm oil plantations has also contributed significantly to deforestation in the region. These large-scale monoculture operations often involve the clearing of forests to make way for agricultural land, leading to habitat loss and biodiversity decline.

Infrastructure development, particularly road construction, has been a significant indirect driver of deforestation in the Amazon. The construction of roads not only directly impacts forests through clearing but also facilitates further deforestation by increasing land values, attracting new settlements, and enabling access to previously inaccessible areas. A prime example of this phenomenon is the Trans-Amazonian highway. Constructed in the 1970s, the highway was intended to promote economic development and integrate the Amazon region with the rest of Brazil. However, this highway has significantly accelerated deforestation in the region, contributing to habitat loss and biodiversity decline, as it provided access to vast areas of the rainforest, leading to increased logging, agricultural expansion, and settlement.

Moreover, other infrastructure projects, such as hydropower dams, railways, waterways, and urbanization centers, exacerbate deforestation pressures by fragmenting habitats, displacing local communities, and creating new demands for land and resources.

Mining activities for minerals, oil, and gas resources have also contributed to deforestation in the Amazon. These activities involve direct forest clearing, environmental pollution, and increased human activity in previously preserved areas. Sonter et al. (2017) found that mining contributed to 9% of Amazon forest loss between 2005 and 2015, with most of the impact occurring beyond the mining lease boundaries due to urban expansion and infrastructure development.

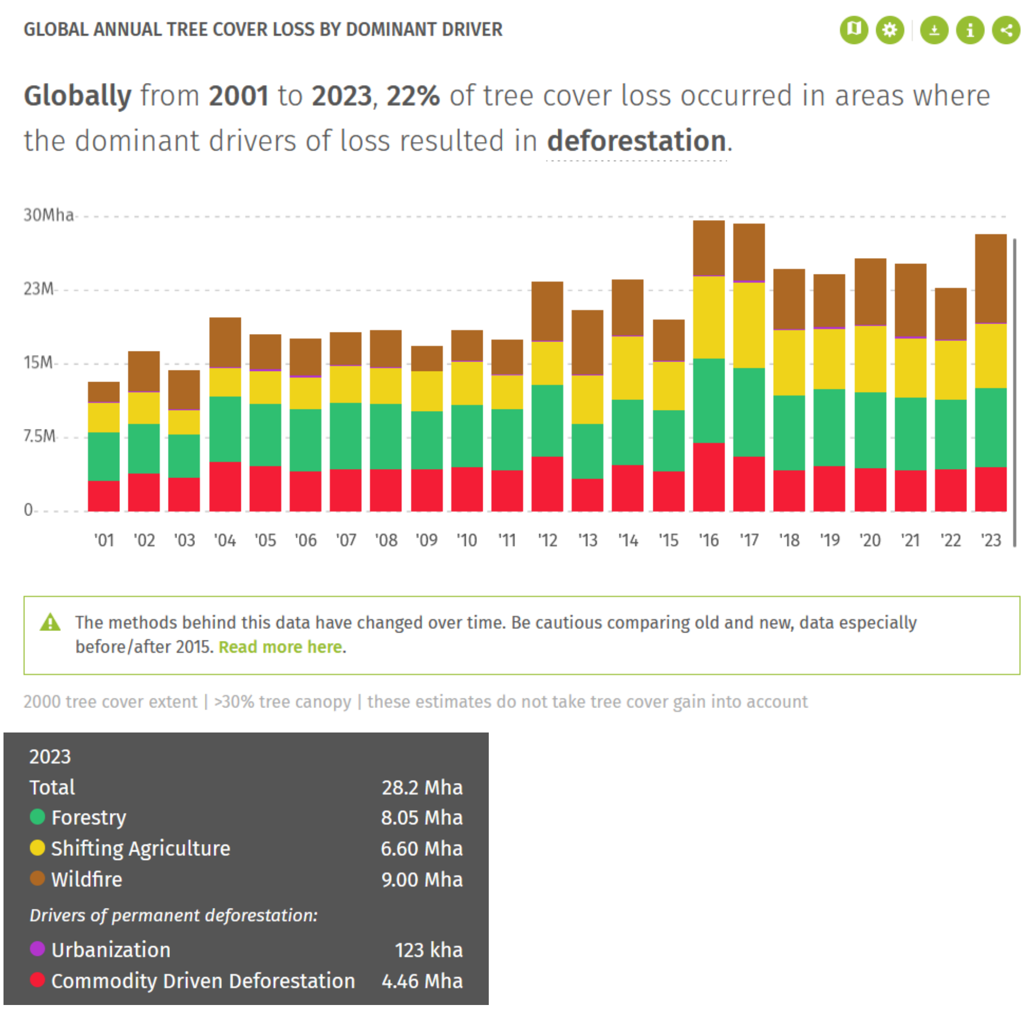
Lapola et al. (2023) also identified demand for timber, agricultural expansion, credit provision, and road and settlement development as the main underlying drivers of forest degradation in the Amazon. These drivers interact with proximate causes of deforestation, such as extreme droughts, fires, timber extraction, and edge effects, which directly impact forest ecosystems.

It is crucial to recognise the complex interplay between these drivers and their cumulative impact on the Amazon rainforest. Addressing deforestation requires a comprehensive approach that considers the economic, social, and environmental factors contributing to this pressing issue.

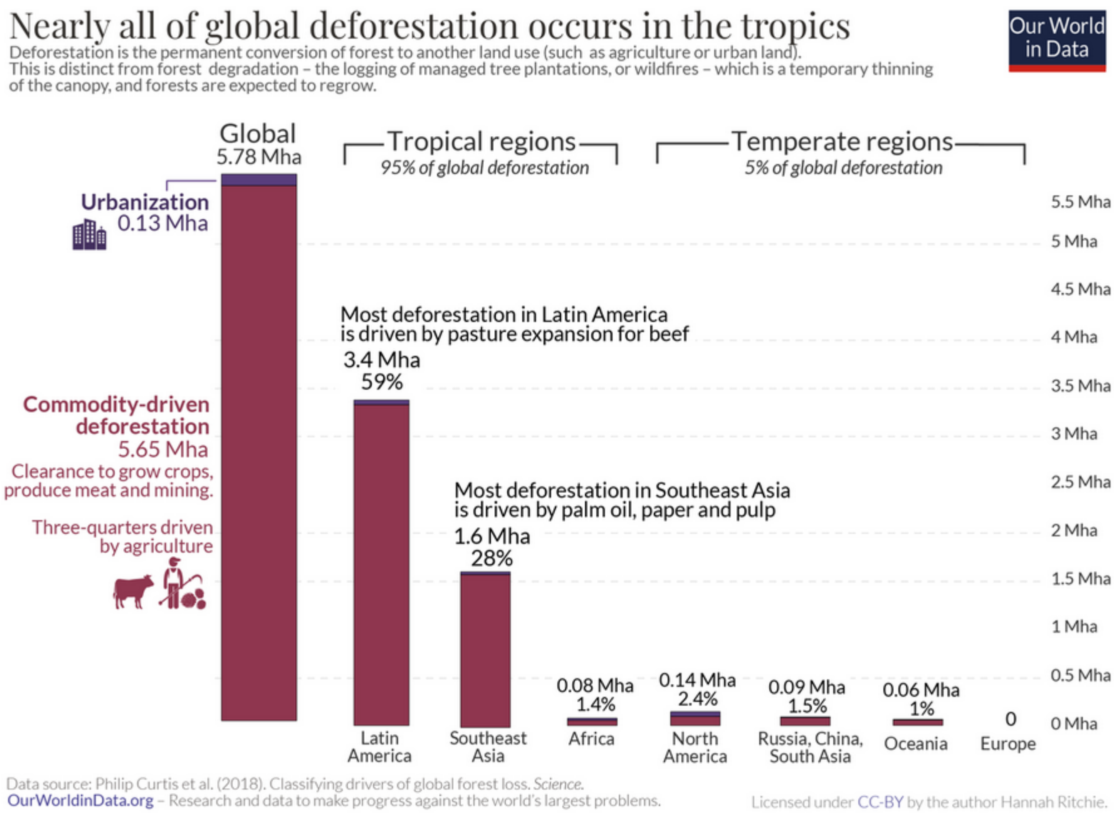
Both agriculture and logging activities occur at a wide range of scales, from small subsistence farming to large commercial operations. It is important to note that these domestic pressures are often intertwined with global market forces and international trade dynamics. The demand for agricultural commodities, timber, and other forest products from developed nations creates strong economic incentives for deforestation in countries rich in forest resources. This external demand, coupled with domestic economic priorities, can lead to unsustainable exploitation of forests, as governments seek to capitalise on their natural resources to generate revenue and promote economic growth.

Addressing the trade-off between environmental conservation and economic growth requires a delicate balance and a long-term perspective. Governments must recognise the value of ecosystem services provided by forests, such as carbon sequestration, biodiversity preservation, and climate regulation, and incorporate these considerations into their economic policies.

These findings underline how the responsibility for deforestation pressures is heavily concentrated in a number of economic activities, namely agriculture, timber harvesting, and mining. The outsized influence of these industries means that effective policies for managing forest risks must first and foremost address their impact. Simultaneously, the current operational model of these industries depends on the large-scale destruction of forest ecosystems, which exposes them significantly to transition risks from future forest protection initiatives. However, the scale of these industries' impact is linked to the use of these resources in the supply chain of a wide range of products, including the automobile, textile, chemical and personal care sectors, and most challengingly, in low carbon technology. As such, a fair share of pressures on forests must also be attributed to these activities, which ultimately trickles down to demand for forest land.



Source: [Global Forest Watch]()



5. Governance amplifiers

Deforestation rarely occurs in a vacuum of governance - there is often a legal and political process by which it is enabled or deterred. Despite decades of targets, little has been achieved in arresting the increase of forest loss and current policy trends of quantitative target setting has been questioned in terms of its effectiveness in bringing about meaningful and transformative change in land use governance (McDermott, 2023). An important reason for this is that the economic pressures described in the section above act at multiple scales and form complex interactions with other drivers of deforestation and degradation such as poverty, insecure land tenure, weak forest sector governance and institutions, poor cross-sectoral coordination and illegal activity (IPCC, 2021). Unless these underlying drivers are addressed with a focus on equity, justice and inclusion, forest and land use governance would continue to be fraught by issues that enable and amplify the extraction of resources and forest loss.

Box 2: Defining deforestation and related terms

In the broadest sense, deforestation is the removal of forests or conversion of forested land to non-forested land. Some definitions specifically look at deforestation that is primarily driven by human activities (WRI, 2024 and IPBES, 2018) and others include non-human induced causes to track total extent of forest loss (e.g. FAO FRA). For deforestation caused by human activities, it can occur through the felling and clearing of trees for timber and wood products. It can also occur through a change in land-use, where forests are cleared for another purpose such as agriculture plantations, mining, infrastructure or urban development, construction of hydropower or water reservoirs. This process is often referred to as 'land-use change'. This term is sometimes used to imply a legal change in the land status, while the term 'forest conversion' is often used by non-state actors when there is a visible physical change in the structure and use of the land, whether or not there is a change in legal land status.

'Forest degradation' refers broadly to a decline in a forest ecosystem's health, intactness, quality and its ability to support local biodiversity and human populations through ecosystem services (including to sequester and store carbon). It can involve subtle, gradual or incremental changes to the forest structure, caused by human or natural disturbances. Persistent degradation can lead to less resilience against storms, fires, droughts, which increases the vulnerability of local populations to more frequent extreme weather events. Forest degradation is often a precursor to forest conversion or further deforestation (WRI, 2024).

5.1 Global governance; an absence of legal mechanisms and reliance on voluntary initiatives

In contrast to approaches taken towards issues such as climate change, desertification and biological diversity, there is a notable absence of an overarching global convention on forests. While the concept of a Global Forest Convention was proposed at the 1992 Rio Earth Summit, it was strongly opposed on the basis that forests are a sovereign's natural resource, and states have a right to use them in line with development objectives (Humphreys, 2005).

Since the 1992 Rio Summit, the first initiative which resembled a global framework for forest protection was the Aichi Biodiversity Targets, which set 20 ambitious goals adopted under the Convention on Biological Diversity (CBD) in 2010. These targets were designed to address the ongoing loss of biodiversity and to set a strategic framework for global biodiversity conservation efforts. Building on this, the New York Declaration on Forests constituted a voluntary and non-legally binding international declaration introduced during the United Nations Climate Summit held in New York in September 2014. The New York Declaration set a number of goals, including to halt global deforestation by 2030 and restore 350 million hectares of degraded forests and land by 2030.

More recently, the 2022 Kunming-Montreal Global Biodiversity Framework was adopted in December 2022, which expanded upon the Aichi Biodiversity Targets of the CBD. One of its various objectives is to commit the global protection of at least 30% of the planet's land and oceans by 2030, which would imply substantial efforts to combat deforestation. Further, the Glasgow Declaration on Forests and Land Use, introduced in November 2021 at COP26, made a similar attempt at convening global action on forests. Constituting a voluntary commitment to end and reverse deforestation and land degradation by 2030, the Declaration has over 100 signatories, representing 75% of global trade of forest-risk commodities and 85% of global forest cover. Alongside the declaration, 12 countries have pledged $12 billion as part of the Global Forest Finance Pledge, channelling public finance to support the protection, restoration and sustainable management of forests. However, current investments in forest conservation are vastly inadequate compared to the scale of the problem.

Furthermore, private sector investments in sectors contributing to deforestation continue to outpace conservation efforts, with financial institutions holding significant active financing in deforestation-risk sectors (Forest Declaration).

Several issues persist with this global context of forest governance. Most importantly is the absence of enforcement mechanisms due to their non-legally binding nature. Voluntary initiatives are rarely translated into domestic legislation and regulations. Given that none of the mechanisms are legally binding, there is no standardised and agreed-upon definitions, nor an alignment of monitoring processes, tracking mechanisms, accountability measures, and implementation strategies.

At the base of this is an inconsistency across forest definitions, where a range of terms and proxies are used to depict diverse conditions and changes within forests. In the absence of a global convention, efforts to standardise these terms and definitions are chiefly led by the Food and Agriculture Organization (FAO) through initiatives like the Global Forest Resources Assessment. These standardised terms serve as reference points in the execution of various international environmental agreements and goals including the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the Sustainable Development Goals (SDGs), particularly concerning land and forest-related matters. The following table highlights key terms and definitions sourced from the FAO, alongside other frequently referenced terms in this context.

Term	Definition and explanatory notes	Reference
Forest	“Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use” i. Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 meters in situ. ii. Includes areas with young trees that have not yet reached but which are expected to reach a canopy cover of 10 percent and tree height of 5 meters. It also includes areas that are temporarily unstocked due to clear-cutting as part of a forest management practice or natural disasters, and which are expected to be regenerated within 5 years. Local conditions may, in exceptional cases, justify that a longer time frame is used. iii. Includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific environmental, scientific, historical, cultural or spiritual interest. iv. Includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 hectares and width of more than 20 meters.	FAO 2025 FRA working paper

	v.Includes abandoned shifting cultivation land with a regeneration of trees that have, or are expected to reach, a canopy cover of 10 percent and tree height of 5 meters. i.Includes areas with mangroves in tidal zones, regardless whether this area is classified as land area or not. i.Includes rubber-wood, cork oak and Christmas tree plantations. i.Includes areas with bamboo and palms provided that land use, height and canopy cover criteria are met. x.Includes areas outside the legally designated forest land which meet the definition of "forest". x.Excludes tree stands in agricultural production systems, such as fruit tree plantations, oil palm plantations, olive orchards and agroforestry systems when crops are grown under tree cover. Note: Some agroforestry systems such as the "Taungya" system where crops are grown only during the first years of the forest rotation should be classified as forest	
Forest	"Forest is a minimum area of land of 0.05-1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10-30% with trees with the potential to reach a minimum height of 2-5 metres at maturity in situ"	UNFCCC
Forest	"Forest is a land area of more than 0.5 ha, with a tree canopy cover of more than 10%, which is not primarily under agricultural or other specific non-forest land use. In the case of young forests or regions where tree growth is climatically suppressed, the trees should be capable of reaching a height of 5 m in situ, and of meeting the canopy cover requirement."	CBD, 2006
Naturally regenerating forest	Forest predominantly composed of trees established through natural regeneration. It includes: i.Forests for which it is not possible to distinguish whether planted or naturally regenerated. i.Forests with a mix of naturally regenerated native tree species and planted/seeded trees, and where the naturally regenerated trees are expected to constitute the major part of the growing stock at stand maturity. i.Includes coppice from trees originally established through natural regeneration. v.It includes naturally regenerated trees of introduced species.	FAO, 2025

High Conservation Value Forests (HCVFs)	A high conservation value approach to forests places emphasis on biological, ecological, social or cultural values of outstanding significance or critical importance. HCVF possess one or more of the following: HCV1: Forest areas containing globally, regionally or nationally significant concentrations of biodiversity values (e.g. endemism, endangered species, refugia). HCV2: Forest areas containing globally, regionally or nationally significant large landscape level forests, contained within, or containing the management unit, where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance. HCV3: Forest areas that are in or contain rare, threatened or endangered ecosystems. HCV4: Forest areas that provide basic services of nature in critical situations (e.g.watershed protection, erosion control). HCV5: Forest areas fundamental to meeting basic needs of local communities (e.g.subsistence, health). HCV6: Forest areas critical to local communities' traditional cultural identity (areas of cultural, ecological, economic or religious significance identified in cooperation with such local communities).	FSC and HCV Network, 2014
Planted forest	Forest predominantly composed of trees established through planting and/or deliberate seeding. i. Predominantly in this context means that the planted/seeded trees are expected to constitute more than 50% of the growing stock at maturity. i. Includes coppice from trees that were originally planted or seeded.	FAO, 2025

Plantation forest	Planted forest that is intensively managed and meet all the following criteria at planting and seed maturity: one or two species, even age class, and regular spacing. i.Specifically includes: short rotation plantation for wood, fibre, and energy. i.Specifically excludes: forest planted for protection or ecosystem restoration. i.Specifically excludes: forest established through planting or seeding which at stand maturity resembles or will resemble naturally regenerating forest	FAO, 2025
Primary forest	Naturally regenerated forest of native species, where there are no clearly visible indicators of human activities and the ecological processes are not significantly disturbed. I.Includes both pristine and managed forests that meet the definition. Management practices in primary forests should imply minimum human intervention and aim for the long-term conservation of native vegetation and wildlife habitat. I.Includes forests where Indigenous Peoples and local communities engage in traditional forest stewardship and management/use activities that meet the definition. I.Includes forests with visible impacts of natural disturbances (such as storms, snow, drought, wildfire or insects, pests and diseases outbreaks) V.Excludes forests where hunting, poaching, trapping, or gathering have caused significant native species loss or disturbance to ecological processes. V.Some key characteristics of primary forests: i. they show natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure, and natural regeneration processes; ii. the area is large enough and retains a degree of connectivity such that its natural ecological processes are maintained; and iii. there has been no known significant human intervention, or the last significant human intervention was long enough ago to have allowed natural ecosystem elements (including species diversity) and functions to have become re-established.	FAO FRA, 2025

Primary forest	A primary forest is a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age. It excludes the intentional clearing of forest by any means (including fire) to alter or manage them for human use – referred to as "direct human disturbance". It does include forests that are used inconsequentially by indigenous and local communities living traditional lifestyles relevant for the conservation and sustainable use of biological diversity.	Convention on Biological Diversity, 2006
Primary forest	"Primary forests are naturally regenerated forests of native tree species, including mangroves and peat forests, whose structure and dynamics are dominated by ecological and evolutionary processes, including natural disturbance regimes, and where if there has been significant prior human intervention it was long enough ago to have enabled an ecologically mature forest ecosystem to be naturally re-established. Many primary forests are also home to Indigenous Peoples and local communities and are the basis of their identity, culture, belief system, traditional knowledge, and livelihoods; a forest that meets the definition above would not be excluded due to the presence of these communities. As used here, primary forest is a broad term which encompasses related terms including: stable forest, intact forest,old-growth, frontier, long-untouched and virgin forest and is consistent with the ways 'primary forests' are defined by other authorities such as the CBD and the United Nations Food and Agriculture Organization (FAO)".	IUCN, 2020
Secondary forests	"A secondary forest is a forest that has been logged and has recovered naturally or artificially. Not all secondary forests provide the same value to sustaining biological diversity, or goods and services, as did primary forest in the same location."	CBD, 2006
Intact forest landscapes	"A seamless mosaic of forests and associated natural treeless ecosystems that exhibit no remotely detected signs of human activity or habitat fragmentation and are large enough to maintain all native biological diversity, including viable populations of wide-ranging species." IFLs include	Potapov et al, 2008

	large fragments of primary forests with a minimum extent of 500 km2.	
Old growth forest	“Old growth forest stands are stands in primary or secondary forests that have developed the structures and species normally associated with old primary forest of that type and have sufficiently accumulated to act as a forest ecosystem distinct from any younger age class.”	CBD, 2006
Deforestation	The conversion of forest to other land use independently whether human-induced or not. I.Includes permanent reduction of the tree canopy cover below the minimum 10 percent threshold. I.Includes areas of forest converted to agriculture, pasture, water reservoirs, mining and urban areas. I.The term specifically excludes areas where the trees have been removed as a result of harvesting or logging, and where the forest is expected to regenerate naturally or with the aid of silvicultural measures. /.The term also includes areas where, for example, the impact of disturbance, over-utilization or changing environmental conditions affects the forest to an extent that it cannot sustain a canopy cover above the 10 percent threshold.	FAO FRA 2025

Source: Mackey et.al, 2021 and FAO Forest Resources Assessment working paper 2025

The terms above reflect different states and changes to a forest, which has implications on their ecological characteristics. However, these terms are not necessarily used in national forest governance frameworks, which adopt classification systems that best suit their administrative processes. Some countries do not distinguish between primary forests, which have a broad diversity of species, with plantation forests that are managed and typically have one or two specific tree species (Agarwal et al, 2023 and FAO, 2018). States may also permit concessions for managed logging within areas of intact forest landscapes, which over time may be further degraded, encroached upon and lead to more deforestation outside of the concession areas, but this may not be reflected as such in statistical accounts.

In practice, national categories of land-use differ, and countries use a variety of sources with inconsistent definitions to report and communicate Land-use and Land-use Change and Forestry (LULUCF) activities to the UNFCCC, including agriculture census data, forest inventories and remote sensing data (IPCC, 2003). Even under UNFCCC methodologies, states are not compelled to harmonise their domestic definitions and categorisations of forest management with international environmental agreements. This results in a multitude of operational definitions of forests and deforestation across jurisdictions and policy frameworks, posing challenges to global initiatives aimed at tracking and halting deforestation (Fernandez-Montes de Oca et al., 2021). For example, none of the CBD Aichi Biodiversity Targets were fully met, in part due to a lack of common mechanisms for monitoring and reporting towards the targets of reducing biodiversity loss by the end of 2020 (CBD, 2020, Maxwell et al, 2020).

While there is an absence of coordination among states, there has been increasing private sector pledges and initiatives to align with the voluntary forest declarations and the recent Global Biodiversity Framework. Firms have made individual organisational-level zero deforestation pledges, primarily through No Deforestation, Peat and Exploitation (NDPE) commitments, and signed up to initiatives like the Task Force on Nature-related Financial Disclosures and various others to fund conservation, which often combine private sector and state intentions through private-public partnerships. Nonetheless, there remain challenges regarding the scope and effectiveness of financial pledges. Notably, Irvine-Broque and Dempsey (2023) highlight instances where pledged funds for forest conservation and nature-based solutions (NBS) have gone unaccounted for and financial disclosure under the TNFD being the primary method of governance. Additionally, economic pressures, such as foreign countries or investments engaging in land grabs for securing food or extracting fossil fuels, remain unaddressed without coordinated legal safeguards. Crucially, the issue of equity is also overlooked, which underscores the failure of target setting to adequately address key concerns (McDermott 2014).

Past biodiversity targets, notably the Aichi Biodiversity Targets, have evidently not been successful in reversing the accelerating rate of biodiversity loss. The 2019 IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) Global Assessment demonstrated that only four out of the twenty Aichi targets had "good progress" and trends in loss of biodiversity and ecosystem services would undermine progress on 80% of the Sustainable Development Goals (IPBES, 2019, Dempsey et al, 2021). Among the various reasons, failing to adequately address the underlying causes of forest and biodiversity loss such as unsustainable consumption, debt and tax injustice and harmful subsidies (IPBES, 2019; Dempsey et al, 2021 & 2024).

4.2 Trade and supply-chain governance

Intro paragraph (to expand/improve): Countries importing forest-risk products tend to mitigate this risk by ensuring legality, promoting certification and applying importer's duties. However, each of these solutions do not have the aim of preventing deforestation, and do not address the root cause of deforestation.

i. Ensuring legality

Given the predominance of international trade in driving deforestation, countries have sought to enact policies or legislation that aims to avoid importing products linked to deforestation abroad. Historically, these trade-based policies focused on the issue of legality, with the aim to curb illegal deforestation. Buying countries (or blocs, in the context of the EU) legislate to prohibit importing products that violate laws of the country of origin and require declarations of legality and proof of due diligence in ensuring their legal origin. This is also premised on respecting state sovereignty and ensuring that products imported are legal by host country definitions (EU timber regulation, FLEGT VPAs). The emphasis is on legal forest production, giving much authority to pre-existing institutional and power structures to control access to and use of resources.

Brief case studies: Ghana and Cameroon with EU FLEGT VPAs https://www-sciencedirect-com.gate3.library.lse.ac.uk/science/article/pii/S0962629824000143?via%3Dihub
Problems: Risks concentrating powers in the hands of the state (be it at federal or more local levels), interacting with political patronage and elite capture. This is complicated by issues of land tenure, whether or not clear and strong legal regimes exist in those countries, and enforcement on the ground. Doesn't tackle equity and structural issues. And promotes legal deforestation.

ii. Promoting certification

Market-led initiatives have emerged to track and verify the source of commodities and determine whether they are produced more sustainably. FSC is one key example of a certification scheme which began in 1993 to spur demand for wood-based products that met standards of sustainable forest management. Standards were set at global and national levels and audited by third party verifiers. A standardised system of tracking and auditing aimed at global transparency for consumers and buyers. Similar standards and certification schemes now exist for palm oil (e.g. RSPO), cocoa (e.g. Rainforest Alliance), and rubber, among others certifications.

This is problematic for smallholders, issues of market access and cost of certifications. Also has tenure issues and quality of audits. Doesn't tackle equity and structural issues. Leakage issues - mixing sources.

iii. Importer's duties

Also premised on the concept of state sovereignty, but recognises both legal and illegal deforestation. The only example so far is the European Union Deforestation Regulation (EUDR), which is innovative in this respect. The regulations aim to guarantee that the products that EU citizens consume do not contribute to deforestation or forest degradation worldwide. This regulation covers seven commodities (i.e., cattle, cocoa, coffee, oil palm, rubber, soya, and wood), as well as many derived products listed in the annex to the regulation (for example,e.g., meat products, leather, chocolate, coffee, palm nuts, palm oil derivatives, glycerol, natural rubber products, soybeans, soy-bean flour and oil, fuel wood, wood products, pulp and paper, and printed books). This regulation came into force for most products (excluding. timber) beginning June 2023, and has significant implications to EMDE countries whose economies rely on EU imports of their products. The EUDR defines deforestation more narrowly as conversion of forests for agricultural purposes, owing to the scope and purpose of the regulations to tackle deforestation driven by the EU's demand for agricultural commodities, but it does also acknowledge other dynamic processes with destructive impacts to forest cover in its definition of 'forest degradation': "including the conversion of primary forests or naturally regenerating forests into plantation forests into other wooded land; or primary forests into planted forests," with the intention to review and update this definition based on scientific evidence and developing perspectives globally around the scope of the definition.

Problems: implementation yet to play out given it's still early days but the process of policy roll out and review should be attentive towards issues of 'leakage', that it may disadvantage small scale farmers from producing countries whose livelihoods are dependent on demand from foreign markets, uncertainties about sources of data needed from suppliers to prove whether concessions are legitimate, the risk that countries are lobbying against being put on the 'high risk' list, reorienting status quo agriculture policies towards other kinds of commodities that could have the same demand on land e.g. mining for minerals. Other big importers may not follow suit to legislate as the EU did, thus shifting the destination of products linked to deforestation elsewhere.

5.3 Domestic governance

Just as there are domestic economic pressures on forests, there are also domestic governance issues that amplify forest loss. States predominantly view forested lands as resources or sources of alternative land use for revenue generation - with the exception of protected area designations. Countries therefore have complex and often ambiguous legal regimes to govern land use change. They use policy instruments and legal regimes that are fit for developmental purposes, not for conservation. They may have decentralised systems of land governance which devolve authority to states or regional levels to grant permits or approve development projects in forested lands (case for Brazil, Indonesia, Malaysia etc), with ambiguous lines of authority and coordination problems among different actors in government. Land tenure laws, concession granting and permit processes, land is seen, and governed for state income (link to lesser known but equally important local drivers of deforestation - critical minerals, shrimp farming and plantation forests). The IPCC's 6th Assessment report summarises key factors that contribute to increasing forest loss in tropical regions in the context of environmental law and implementation:

- Weak forest sector governance and institutions, conflicting policies beyond the forest sector, corruption and illegality;
- Poor implementation and enforcement of environmental laws owing primarily to a lack of political will;
- Conflicting legal instruments, lack of clarity in implementation, monitoring and evaluation, poorly defined and fragmented responsibilities across multiple agencies;
- Lack of sanctions, transparency and accountability; and
- Open-ended decision-making exacerbating political asymmetries

So, in this context, political will, elite capture, political patronage, no transparency in land concession permits, procedures, no accountability, poor enforcement of regulations, inadequate legal protections of forests, conflicting policies across sectors, no human rights protection for the indigenous groups.

6. Challenges of policy making on nature risks / areas for further work

In order to effectively tackle the threat of nature-based risks, decision makers must recognise and address specific challenges of this policy area.

Coordination at the Local and Global scales

Firstly, we have covered several dimensions in which biodiversity risks apply differently to different local contexts. While biodiversity trends such as deforestation necessarily have a global element to it, namely through its interaction with global climate changes, they firstly and above all affect the local reality in which it takes place. This means that megadiverse countries, mostly located in the Southern Hemisphere, stand to lose the most from further forest loss. Simultaneously, these same forest-rich territories are often low- or middle-income countries where developmental trade-offs are more acute, so that the economic activities contributing to deforestation are often key for raising incomes. Moreover, in addition to domestic pressures on growth, structural imbalances in the international financial system effectively coerce poorer countries to prioritise environment-damaging activities, such as resource extraction (Dempsey et al., 2024).

Conversely, wealthier countries are not able to directly define global deforestation trends through the administration of their territory. However, they often play a critical role in contributing to forest loss globally through their economic influence, consumption demand, and international financial systems that promote deforestation/nature loss (Dempsey et al, 2024). Nevertheless, these countries are still impacted by the negative global effects of deforestation, in addition to potentially having other reasons not to support deforestation activities. In this regard, Northern Hemisphere countries have increasingly focused on regulating their impact on forest loss through consumption and production, imposing stricter requirements on the supply chain due diligence (for example, through the EU Deforestation Regulation or the US Forest Act).

The highly heterogeneous sovereignty over forest resources and different degrees of freedom to define economic policy affect each country's ability to contribute to forest protection. As such, these dynamics clarify the need for international agreements to foster bespoke policy solutions, rather than universal approaches, which would prove unfair and unrealistic. As a matter of fact, this calls for locally adaptive solutions fits more broadly into the trade-off identified in NGFS (2023b), according to which decision makers must find a way to effectively balance the need for locally relevant actions with a level of global integration that sufficiently recognises the aggregate repercussions of local deforestation events.

<u>Nature complexity: interconnections, synergies, and trade-offs</u>

The extreme complexity of the biophysical system further complicates conservation efforts. In order to effectively act on environmental degradation, public authorities need to have a precise picture of how natural processes occur. However, and although research in this sector is bridging existing gaps, there are several areas in which scenarios remain approximative, due to the sheer complexity of the underlying physical dynamics they seek to model.

Firstly, the interconnectivity of ecosystem services underscores the necessity of integrated policy approaches, as policy actors need to account for how changes in a specific environmental dimension interacts with and affects other dimensions. By understanding and valuing the complex interactions within ecosystems, financial and economic policymakers can develop more effective strategies to manage environmental risk and halt nature loss. A particularly important example of this is forests' role in regulating the carbon cycle, which calls on policymakers to consider both climate and nature simultaneously, rather than in isolation, as separate issues or consequentially (climate first, then nature), which tend to be the approach taken by the financial sector.

Moreover, biophysical processes often behave non-linearly, which introduces an important degree of uncertainty in decision-making. In fact, while it is relatively clear when certain actions are detrimental to the environment, it is often challenging to comprehensively account for the full extent of these effects. Often, natural equilibria exhibit "tipping points", meaning that changes may initially be marginal, but severe impacts take place in abrupt and irreversible ways. In order to avoid these, a broader perspective on the consequences of natural degradation is needed, incorporating medium- and long-term impacts at the system-level.

The irreversibility of tipping points is particularly worrisome in face of another key aspect of natural risks, which is the inexistence of substitutes for natural capital. Indeed, the traditional conception of natural risks treats these simply as potential costs, which implicitly assumes that, if they materialise, economic activity could be resumed but in a less efficient, more costly way. However, the natural world provides a number of underlying services that cannot be compensated for – they are simply not substitutable. In fact, these risks are existential for certain economic activities, such as the availability of arable land for agriculture. As a result, policymakers must account for the different levels of "substitutability" of natural capital, which varies considerably across ecosystem services and the economic sectors benefiting from them. Critically, economic cost estimates must be complemented by a "substitutability" assessment in order to understand whether environmental degradation simply results in more expensive production processes or an actual and irreversible loss of activity, as these may have ripple effects (namely, through supply chains) and goes beyond the strictly economic sphere (for example, on food security).

Finally, and as a result of these complexities, decision makers also face the critical challenge of defining the relevant metrics to adopt when setting objectives and tracking progress. The intricacy of the natural world cannot be reduced into a simple measurement in the same way that carbon emissions capture climate change risks. Due to the need to rely on multiple variables, methodological approaches and objectives vary across countries and across time. This complicates the task of designing and enforcing policy objectives at the national level, as their measurement is not straightforward, as well as that of coordinating internationally against threats on biodiversity.

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