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Review Article

GLOBAL DEFORESTATION IN FOCUS: UNCOVERING THE SCALE AND FORCES BEHIND DEFORESTATION

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ABSTRACT

Global deforestation is accelerating at an unprecedented scale, driven by interconnected economic, political, and environmental forces that threaten biodiversity, climate stability, and human well-being. This article synthesizes global datasets and recent evidence to assess the magnitude, spatial distribution, and structural drivers of contemporary forest loss, with particular emphasis on tropical regions. It addresses three core research questions: (i) What is the current scale and geographic concentration of global deforestation and permanent tree-cover loss? (ii) How do agricultural expansion, mining, climate-driven wildfires, and armed conflict interact to intensify forest degradation? (iii) How do global consumption patterns, financial systems, and governance failures – including the symbolic contradictions of U.N. climate summits hosted in major fossil-fuel-exporting and high-emission countries such as the United Arab Emirates, Azerbaijan, and Egypt – externalize deforestation pressures onto vulnerable regions? The analysis shows that permanent land-use change, extractive industries, and conflict-related governance breakdowns dominate forest loss dynamics, whereas climate change amplifies fire-driven destruction, exposing a widening credibility gap in global climate governance and the urgent need for enforceable, equity-centered forest protection strategies.

Keywords: Tree-cover loss, Permanent land-use change, Tropical deforestation, Armed conflicts, Biodiversity decline, Agricultural expansion, Climate-driven wildfires, Mining-related loss, Wildfires.

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INTRODUCTION

Biodiversity loss has become one of the most urgent sustainability challenges of the twenty-first century. Although scientists estimate that Earth may host between 100 million and 1 trillion species (Mikołajczak, 2022), only about 2 million have been formally described, underscoring how little is understood about the biological systems upon which human well-being depends (Ritchie, 2022). The World Wide Fund for Nature's Living Planet Report shows that nearly three-quarters of global wildlife populations have disappeared in just five decades, a level of ecological decline that now disrupts ecosystem integrity, food systems, and economic stability worldwide (Gill & Briggs, 2024).

Today, roughly five million hectares of forest are destroyed each year, with 95% of this loss occurring in tropical regions (Ritchie, 2022). Socioeconomic pressures – from population growth and rising GDP per capita to disruptive shocks such as the COVID-19 pandemic and the 2008 financial crisis – continue to shape where and how quickly forests disappear. Research shows that population size, economic development, colonial history, geographic conditions, and existing forest cover all influence deforestation differently in countries with large versus limited forest resources (Prochazka *et al.*, 2023). Meanwhile, industrial activities such as logging, mining, and large-scale agriculture keep pushing deeper into forest landscapes, driven by soaring global demand for beef, palm oil, timber, soy, and paper, and accelerating destruction at an unprecedented scale.

A Nature study shows that wealthy nations – including the United States, the United Kingdom, Japan, China, Germany, and France – outsource their demand for commodities in ways that trigger 15 times more biodiversity loss abroad than within their own borders. This global imbalance becomes clear when looking at consumption patterns: for example, demand in the U.S. and the U.K. alone is linked to 13% of all forest loss occurring outside their territories (Wiebe & Wilcove, 2025). The same pattern holds for mining. Just six countries – many of them geographically distant from the extraction sites – are responsible for over half of the world's mining-related deforestation. One striking case is the European Union, whose imports drive 85% of its total deforestation footprint in other regions, well beyond the continent's own borders (Kramer *et al.*, 2025).

Alarmingly, Global Canopy reports that in 2024, 150 of the world's largest financial institutions directed nearly $9 trillion into sectors directly linked to deforestation (Thomson *et al.*, 2025a). Its latest review of the 500 most influential real-economy companies reveals that nine forest-risk commodities – beef, leather, soy, palm oil, timber, pulp and paper, cocoa, coffee, and rubber – collectively account for more than two-thirds of all forest loss worldwide (Thomson *et al.*, 2025b). Political deadlock has further intensified the global forest crisis. For example, the European Union's Deforestation Regulation (EUDR), designed to hold supply chains accountable for forest loss, has faced repeated delays since its approval in April 2023. These setbacks are driven by pushback from the U.S., major commodity-producing countries, farmer protests, the ongoing war in Ukraine, and opposition from a right-wing majority in the European Parliament (Abnett, 2024; Bounds & Hancock, 2025).

Forest decline and its multidimensional impacts on people and planet

Forests – home to more than 80% of the world's threatened species – remain central to global sustainability because they support food security, economic stability, and the livelihoods of more than 1.6 billion people, including nearly 70 million Indigenous peoples (Neumann *et al.*, 2025). Yet more than one-eighth of global greenhouse gas emissions now arises from deforestation and forest degradation, linking ecosystem collapse directly to climate instability (Grantham Research Institute, 2023).

Deforestation amplifies environmental stress by increasing pollution, disrupting water and carbon cycles, and accelerating climate change. These cascading pressures trigger inflammation and oxidative stress, elevating the risk of hypertension, cardiovascular disease, and other non-communicable diseases. Research in Nature indicates that deforestation-driven erosion and rising chemical pollution contaminate soil, air, and water, intensifying exposure pathways responsible for an estimated 5.5 million pollution-linked cardiovascular deaths worldwide in 2019 (Münzel *et al.*, 2025). Another *Nature* study shows that tropical deforestation contributes to dangerous local warming, resulting in over 28,000 heat-related deaths annually and exposing hundreds of millions – particularly in Southeast Asia, Africa, and the Americas – to increasing heat stress and sharply reduced safe working hours (Reddington *et al.*, 2025).

A global meta-analysis found that greater exposure to forests and green spaces is associated with lower risks of asthma, lung cancer, and chronic obstructive pulmonary disease mortality, with protective effects influenced by age and proximity to greenery (Tang *et al.*, 2023). Country-level analyses across 230 nations also reveal that larger forested areas are significantly linked to lower prevalence of mental health disorders (Bolton *et al.*, 2022). Table 1 reflects key health impacts linked to deforestation across different regions.

The World Health Organization estimates that the current global deforestation trend drains roughly $10 trillion from the global economy each year, driven by mounting healthcare costs and crop losses as pollinators disappear (World Health Organization, 2025). The World Bank adds an equally sobering projection: ongoing deforestation could shave $2.7 trillion off global GDP annually, with low- and lower-middle-income nations facing the steepest fallout – potentially more than a 10% GDP drop by 2030 (Johnson *et al.*, 2021).

Deforestation threatens the livelihoods, food security, and cultural identity of local and Indigenous communities by depleting clean water, fertile soil, and climate stability. While it may offer short-term profits, the long-term economic costs – from lost ecosystem services to land degradation and higher disaster risks – far outweigh any immediate gains (Dénes, 2024). Each year, tens of thousands of animal species disappear, while human-generated mercury emissions further pollute the atmosphere. Forest loss disrupts rainfall patterns, accelerates soil erosion, and intensifies floods and droughts. Indigenous communities are displaced, livelihoods are undermined, and the risk of zoonotic disease spillover increases (Nantale *et al.*, 2025). Among rural populations, deforestation exacerbates poverty, deepens social inequalities, and weakens community resilience, highlighting the urgent need for effective conservation and community empowerment measures (Santelices-Moya, 2024). Businesses also face supply chain disruptions, litigation risks, and reputational damage, while financial institutions contend with elevated credit, market, and liquidity risks from nature-related losses. Collectively, these impacts threaten macroeconomic stability through reduced productivity, inflationary pressures, and increased financial system vulnerability (Almeida *et al.*, 2024). Altogether, deforestation poses severe environmental, health, social, and economic risks that demand urgent action.

Historical and contemporary dynamics of human-driven deforestation

Human-driven deforestation – rooted in land clearing for crops and livestock since as early as 10,000 BC – has become one of the planet's most enduring and damaging environmental legacies (University of Cambridge, 2012). Half of the world's forests disappeared between 8000 BCE and 1900, yet the remaining half vanished in only the last century, underscoring an escalating sustainability crisis (Ritchie, 2021). Before the twentieth century, temperate regions such as Europe, Russia, China, North America, and Australia absorbed most of this pressure, driven by rising demand for food, fuel, and timber (Houghton, 2023).

Between 1800 and 1914, global forest loss surged, not primarily because populations were expanding, but because Europe's intensifying appetite for commodities and raw materials reshaped land use across continents (Tucker & Richards, 1983). This market-driven transformation depleted ecosystems, destabilized natural capital, and forced rural communities – especially in non-Western regions – to depend on increasingly volatile global supply chains. Over the past 300 years, an astonishing 1.5 billion hectares of forest – an area roughly 1½ times the size of the United States – have been cleared, highlighting a central sustainability dilemma: economic growth has been achieved at the expense of ecological stability, long-term resilience, and the biodiversity upon which human well-being ultimately depends (Ritchie, 2021).

The scale and pace of tropical forest loss underscore a critical sustainability challenge. According to data from the University of Maryland's Global Analysis and Discovery (GLAD) Laboratory, published on the World Resources Institute (WRI)'s Global Forest Watch platform, approximately 6.7 million hectares of tropical primary forests were lost in 2024 – a more than 150% increase over the past two decades, marking a 20-year peak in forest destruction. To put this in perspective, the area lost is roughly equivalent to the size of Panama

Table 1: Deforestation and Its health consequences: evidence from recent case studies

Study place	Investigation details	Deforestation-related health outcomes	References
Indonesia	Effect of forest loss on child health and education	Higher malaria incidence; greater risk of academic delay	Kishida *et al.*, 2025
Southeast Asia	Link between deforestation, environmental change, and the Nipah virus	Human-driven land use (deforestation, agriculture, urbanization) promotes NiV transmission	Bhowmik *et al.*, 2025; Branda *et al.*, 2025; Singh *et al.*, 2025
Nigeria	Two approaches to quantify deforestation's impact on children	Increased risk of cough, diarrhea, and malaria via soil pH, organic carbon, and cation levels	Di Maria, 2025
Peruvian Amazon	Spatial durbin model analysis of deforestation and malaria	Loss of 1000 ha of forest linked to 69 additional malaria cases	Aguirre *et al.*, 2025
Brazil	Spatiotemporal analysis of visceral leishmaniasis (VL) and deforestation (2001–2023)	Deforestation significantly raises VL incidence, especially in areas of intense land-use change	Filho *et al.*, 2025
	Deforestation and COVID-19 in Indigenous populations	Strong link between deforestation and COVID-19 spread before vaccination	Laudares *et al.*, 2025
The Democratic Republic of the Congo	Human–animal–environment risk factors for Monkeypox (mpox)	Forest cover changes, via deforestation or conservation, alter the mpox transmission risk	Lu *et al.*, 2025
Mexican Municipalities	Deforestation's impact on infant health	Higher likelihood of low birth weight and low Apgar scores	Garcia-Vara *et al.*, 2025

and nearly twice the size of Belgium or Taiwan, and represents almost double the forest loss recorded the previous year (Goldman *et al.*, 2025; Bourgoin *et al.*, 2025).

Brazil bore the brunt of forest loss, shedding an area comparable in size to Belgium or the U.S. state of Massachusetts, primarily due to extensive wildfires (Andreoni & Villegas, 2025). Meanwhile, Bolivia experienced a staggering 200% increase in primary forest loss, exceeding the size of Montenegro and driven largely by fire rather than the agricultural expansion that dominated previous years (Czaplicki Cabezas, 2023). Climate change, unsustainable land use, and unusually dry conditions linked to El Niño are fueling a self-reinforcing cycle in the Amazon, where increasing forest vulnerability amplifies both the frequency and intensity of wildfires, further weakening the ecosystem and accelerating long-term degradation (Bourgoin *et al.*, 2025).

The Democratic Republic of the Congo (DRC)'s vast forests – forming part of the Congo Basin, the world's second-largest rainforest – cover two-thirds of the country and support more than half of its largely rural population, who depend on them for food, fuel, and income, often at significant environmental cost (World Bank, 2024). The country offers a distinct lens for understanding ecological change, as severe fragmentation from mining, rapid urban expansion, and recurring conflict creates a real-time setting to study tipping points, conflict-driven regrowth, and the ways instability reshapes landscapes (Useni Sikuzani & Bogaert, 2025). In 2024, the DRC's primary forests shrank by an area roughly the size of Delaware, marking a 150% increase in loss driven by a combination of armed conflict and widespread wildfires (Thomas, 2025).

In Indonesia, deforestation intensified at lower elevations and along coastal areas between 1950 and 2017 due to the rapid expansion of plantations – except in Java and Bali, where most forest loss occurred earlier – and although protected areas slowed this trajectory, they still experienced edge-related degradation as plantations advanced (Santoro *et al.*, 2023). In 2024, Indonesia had lost forest cover comparable in size to Luxembourg or even the Greater Tokyo area, with nearly half of these losses lacking a clearly identifiable cause (Parker *et al.*, 2024; Jong, 2025).

Global drivers of accelerating deforestation and tree-cover loss

Biodiversity now confronts one of the most profound sustainability threats of the modern era: the rapid and relentless loss of forests. With the global population now surpassing 8 billion, pressure on the world's forests is escalating at an unprecedented rate. Rapid urbanization and industrial expansion are driving large-scale deforestation, as expanding cities, roads, and infrastructure encroach upon previously intact forested landscapes. Research indicates that the growing demand for land and forest-derived resources intensifies both legal and illegal logging, leaving remaining forest fragments ecologically isolated, highly vulnerable, and poorly connected (Leite, 2024). Concurrently, industrial activities – including logging, mining, and large-scale agriculture – continue to clear vast tracts of forest, while the surging global appetite for commodities such as beef, soy, palm oil, and paper compounds this loss, accelerating ecosystem degradation worldwide (FAO & UNEP, 2020).

Permanent land-use change: A major driver of global forest loss

Between 2001 and 2024, over a third of global tree-cover loss – 168 million hectares, an area larger than Mongolia – was likely driven by permanent land-use change, according to the WRI using Global Forest Watch data (Fig. 1). The impact is even more pronounced in tropical primary rainforests, where more than 60% of forest loss – 50.7 million hectares, roughly the size of Thailand – can be attributed to permanent land-use conversion (Sims *et al.*, 2025).

DATA SOURCE AND METHODOLOGY

Data sources and study design

The study adopts a mixed-methods design that integrates quantitative analysis of large-scale environmental datasets with qualitative

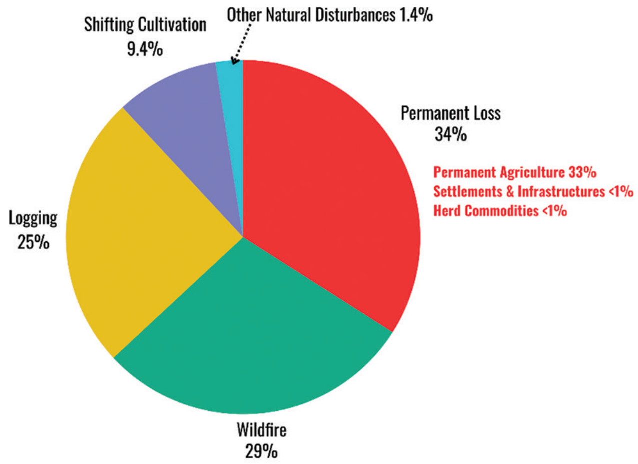

Fig. 1: The pie chart shows an estimated 515 million hectares of global tree-cover loss between 2001 and 2024, with 34% deemed permanent. The World Resources Institute and Google DeepMind dataset, based on nearly 7000 samples and available through Global Forest Watch, uses a neural-network model with 90.5% accuracy to identify forest-loss drivers. Regional patterns indicate that logging dominates in Europe, permanent agriculture in the tropics, and wildfires in Russia, North America, Asia, and Oceania (Figure generated by Canva Illustrator)

synthesis of peer-reviewed scholarship and authoritative institutional reports. Quantitative data were drawn from well-established and publicly accessible sources, including Global Forest Watch, devised by the University of Maryland's GLAD laboratory, the WRI, Food and Agriculture Organization of the United Nations (FAO) remote-sensing assessments, World Bank databases, and reports produced by the World Health Organization and the World Wildlife Fund (WWF). These sources were selected for their methodological transparency, global coverage, and frequent use in high-impact environmental research. Together, they provide a robust empirical foundation for examining patterns and drivers of deforestation across spatial and temporal scales.

Quantitative analytical framework

The quantitative component employed descriptive statistics, trend analyses, and spatial comparisons to assess tree-cover loss, permanent land-use conversion, wildfire impacts, mining-related deforestation, and conflict-associated forest degradation across regions and time periods. Where appropriate, reported outputs from advanced modelling approaches – such as neural-network classifications and spatial regression analyses presented in the cited literature – were interpreted to identify dominant drivers and recurring patterns. Priority was given to recently published peer-reviewed studies indexed in established databases, including PubMed, Embase, Scopus, Web of Science, and the Cochrane Central Register, as well as leading journals published by Elsevier, Springer, Wiley Online Library, and Wolters Kluwer. This approach ensured analytical consistency while grounding the assessment in current scientific evidence.

Qualitative synthesis and validation

The qualitative component consisted of a structured narrative review of high-impact academic articles, policy documents, and credible investigative reports. This review was used to contextualize the quantitative findings, examine underlying political-economic drivers, and assess associated social, health, and governance implications of deforestation. Cross-referencing and triangulation across multiple data sources were employed to enhance the validity and reliability of the interpretations. In addition, recent media reports were selectively incorporated to capture emerging trends and developments in contexts where peer-reviewed evidence remains limited, while maintaining a cautious and critical approach to their use.

LITERATURE REVIEW

Agricultural and industrial drivers of global deforestation

Over the past three decades, crop and cattle production have become dominant drivers of global deforestation, progressively reshaping landscapes across tropical and subtropical regions. Between 2000 and 2018, FAO's global Remote Sensing Survey found that agriculture – particularly livestock grazing – accounted for nearly 88% of forest loss, a sharp escalation compared to earlier estimates (FAO, 2021).

Palm oil cultivation, livestock grazing, and the production of beef and animal feed now account for more than 40% of global deforestation (Morris & Hurd, 2025), with cattle pasture alone eliminating over 45 million hectares between 2001 and 2015 and soy cultivation for animal feed clearing an additional 8 million hectares – together an expanse slightly larger than Spain and just under the size of Texas (Eurogroup for Animals, 2021).

In South America, for instance, a region producing a quarter of the world's beef, cattle production surged 70% between 1990 and 2020, whereas 90 million hectares of degraded pasture continue to drive deforestation (Costa *et al.*, 2025). Overall, agricultural expansion – including both crop and livestock production – was responsible for 80–86% of global deforestation between 2001 and 2022 (FAO & UNEP, 2020; West *et al.*, 2025), and from 1990 to 2020, global forests declined by 7.1%, with agricultural expansion and population growth identified as the primary forces behind this loss (Farrokhi *et al.*, 2025).

Accelerating forest loss driven by climate and human-caused wildfires

Although the role of fire in forest loss has been quantified at regional and global scales using diverse satellite sensors, these estimates remain inherently uncertain. Beyond naturally occurring wildfires, humans frequently use fire as a low-cost tool for land management and agricultural conversion, intensifying its ecological impact. Between 2001 and 2024, fires were responsible for approximately 150 million hectares of tree-cover loss – roughly the size of Mongolia or 4 times that of California – accounting for nearly 29% of global deforestation, with the remaining 71% driven by other human and natural factors (Global Forest Watch Live Data) (Fig. 2). Alarmingly, this trend is accelerating: the annual global area of fire-induced forest disturbance in 2023–2024 was 2.2 times higher than the 2002–2022 average and 3 times higher within tropical regions. At the continental level, North America saw the most pronounced escalation, with fire-related forest disturbance increasing 3.7-fold over the past two decades, followed by Latin America at 3.4-fold and Africa at 2.4-fold (Potapov *et al.*, 2025).

Climate change is dramatically amplifying wildfire risks, making fires 25–35 times more likely in some regions than they would be in a cooler world (Kelley *et al.*, 2025). According to data from the University of Maryland's GLAD laboratory, about 74.9 million hectares of forest – an area roughly the size of France, or nearly 1½ times that of Germany – were burned across 2023 and 2024 (Potapov *et al.*, 2025). Kelley *et al.* (2025) further report that at least 3.7 million square kilometers of land, an expanse larger than India, went up in flames between March 2024 and February 2025 alone. Nearly half of this destruction was driven by wildfires (Tabuchi, 2025).

While wildfires can occur naturally in some ecosystems, in tropical forests they are predominantly human-induced, often set deliberately to clear land for agriculture and frequently spreading uncontrollably into adjacent woodlands (Tabuchi, 2025). Estimates suggest that at least half of global forest loss stems from a combination of natural and human-driven fire processes, including wildfires and intentional burning associated with land grabbing, commodity-driven deforestation, and shifting cultivation (van Wees *et al.*, 2021; Tyukavina *et al.*, 2022). In Indonesia, for instance, approximately 60% of forests burned between 2015 and 2016 were subsequently converted into palm oil plantations, underscoring the direct link between fire use and land ownership change (Purnomo *et al.*, 2019). Similarly, across parts of Africa, landowners frequently set fires on or near their properties, destroying forested areas to expand pastureland, further accelerating deforestation and landscape degradation (Coppola, 2020).

During severe fire years such as 2016 and 2024, more than a quarter of all fire-related forest loss occurred in tropical regions (Potapov *et al.*, 2025). Tropical primary forests were particularly hard hit, with fires accounting for nearly half (49.5%) of their total loss in 2024, nearly 4 times the 13.3% recorded in 2023 (Climate Adaptation Platform, 2025), representing an 80% increase in loss year-over-year (Fig. 3). Analyses from the University of Maryland further show that the world was losing forest cover at a rate equivalent to 11 football fields every minute in 2022 (McGrath & Poynting, 2023), a pace that surged to 18 football fields per minute by 2024 (Goldman *et al.*, 2025).

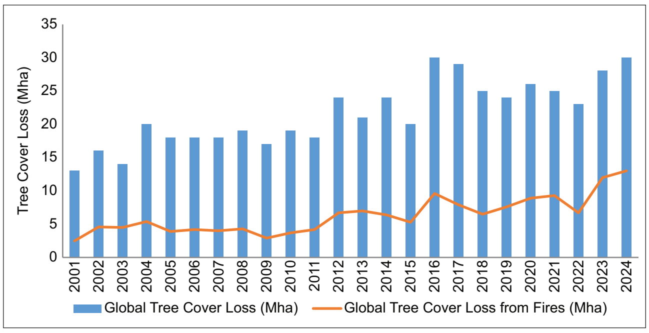

Fig. 2: The annual global loss of tree cover caused by wildfires (Source: Global Forest Watch). The graph shows that, alongside rising deforestation worldwide, wildfires are becoming an increasingly significant driver of forest loss, accounting for 45% of tree-cover loss in 2024. Analysis indicates that the global area affected by fire-induced forest disturbances in 2023–2024 was 2.2 times higher than the 2002–2022 average, highlighting a sharp upward trend in wildfire-driven deforestation

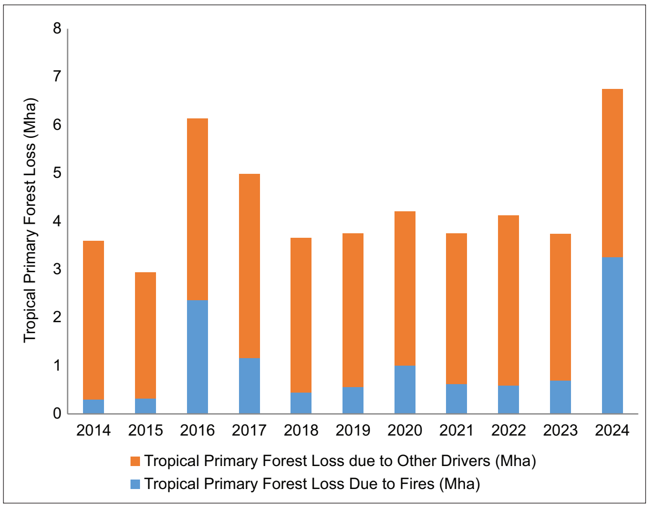

Fig. 3: The global trend in tropical primary forest cover loss over the past decade (Source: University of Maryland's GLAD Laboratory). The data highlight that tropical primary forests were particularly affected in 2016 and 2024, with fire-related losses in 2024 nearly quadrupling compared to the previous year, accounting for almost half of all tropical primary forest loss worldwide

Mining expansion and the global forest crisis

Miners worldwide are locked in a fierce race for mineral wealth, forgetting that the true treasures lie in the lush greenery of nature – nurturing biodiversity for centuries and sustaining human life itself. While global leaders proclaim their devotion to saving the planet, their actions tell another story: In the name of progress, they pursue relentless excavation, mining the world's poorest lands as if they belong to another planet (UNCTAD, 2015; Vidal, 2015; Lee & Kim, 2022; Gonzales-Zuniga *et al.*, 2024; Mathiesen, 2024; Center for Responsible Investment, 2025). According to authors from the World Wildlife Fund (WWF), mining – currently the fourth-largest driver of deforestation – has a far-reaching impact, affecting up to one-third of the world's forest ecosystems when indirect effects are considered. Mining activities have accelerated alarmingly, with more than one-third of all mining-related deforestation over the past 20 years occurring in just the last 5 years, and this upward trend is expected to continue (Kramer *et al.*, 2025). An abstract presented at the EGU General Assembly 2025 reported that 236,028 mining areas worldwide were associated with 9,765 km^2 of deforestation – roughly the size of Puerto Rico – between 2001 and 2023, with about half linked to undocumented mining operations (Zhang *et al.*, 2025).

Since 2001, global mining activity has expanded by more than 50%, fueled by surging demand for gold, coal, lithium, cobalt, and other industrial minerals (Kirsanov & Saaya, 2024). This rapid growth has intensified pressure on forests in every region – from the Congo Basin to the boreal woodlands of Russia. Between 2001 and 2020 alone, mining caused the permanent loss of nearly 1.4 million hectares of tree cover, an area roughly the size of Montenegro (Stanimirova *et al.*, 2024). A separate global analysis found that mining activities contributed to the loss of 16,785.90 km^2 of forest between 2000 and 2019, exceeding the land area of Hawaii (Ranjan & Gorai, 2024).

By 2022, countries such as Russia, China, Australia, the United States, and Indonesia together accounted for nearly half of global mining land use. Between 2000 and 2019, mining caused more than 9000 km^2 of forest loss worldwide, including 1374 km^2 in Brazil and 1272 km^2 in Indonesia, placing these countries among the world's top hotspots (Giljum *et al.*, 2025). Overall, just 11 countries – including Indonesia, Brazil, Russia, the U.S., and Canada – are responsible for more than 85% of global mining-related deforestation (Fig. 4).

The timeline is especially stark in the tropics. Although tropical regions host <30% of the world's mining sites, they account for a disproportionate 62% of all mining-related forest loss (Stanimirova *et al.*, 2024; Kramer *et al.*, 2025). This imbalance is visible on the ground: open-pit gold mines in the Amazon can strip thousands of hectares of rainforest within a decade, while expanding coal operations in Indonesia routinely flatten forested mountain ranges in just a few years.

A WWF study shows that gold and coal extraction alone contributed over 71% of all mining-linked deforestation from 2001 to 2019. Indonesia stands out as the global epicenter of mining-driven forest loss. With about 370,000 ha of tree cover cleared, mostly for coal extraction, the country accounts for more than one-fifth of all deforestation tied to mining worldwide (Kramer *et al.*, 2025). This pressure has intensified as nickel mining – essential for lithium-ion batteries – expanded more than 700% between 2000 and 2020 to meet global demand for electric vehicles (Ranjan & Gorai, 2024; Giljum *et al.*, 2025).

In Sub-Saharan Africa, mining activities led to forest loss around mine sites over 2000–2020, roughly equivalent to the size of Jamaica or nearly the state of Connecticut, representing a 47.5% higher loss than comparable non-mining areas. Annual deforestation rates increased 2.6-fold following the establishment of mines. Beyond direct clearing, associated infrastructure and secondary land-use changes further drive off-site forest disruption (Ahmed *et al.*, 2025). Ghana's forests shrank by 5.9% between 2018 and 2023, whereas illegal gold mining surged by an extraordinary 1917.6%, with the fastest expansion occurring from

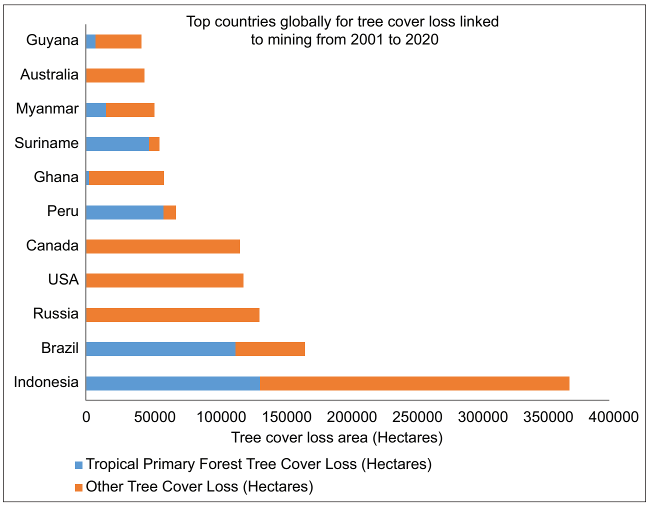

Fig. 4: Top countries globally for tree cover loss linked to mining (Source: World Resources Institute). Between 2001 and 2019, Indonesia and Brazil together lost a combined area of forest roughly equivalent to the size of Brunei or the island of Bali, representing more than one-quarter of all mining-related forest loss worldwide

2022 to 2023, driving severe ecological decline. Mined areas showed drastic losses in plant diversity, vegetation structure, and carbon storage (Abugre *et al.*, 2025).

In South America, mining has become a major driver of deforestation. In Peru, gold extraction alone has resulted in 139,169 ha of forest loss between 1984 and mid-2025, with Madre de Dios suffering the most severe impacts, despite temporary declines following Operation Mercury in 2019, according to the Monitoring of the Andean Amazon Project (MAAP) and its Peruvian partner, Conservación Amazónica (Taylor, 2025). Mining-linked deforestation is now spreading across the country, affecting Huánuco, Pasco, Ucayali, Amazonas, Cajamarca, and Loreto, where nearly 1000 dredges have enabled rapid forest clearing in Indigenous territories and protected areas (Taylor, 2025). In Suriname, mining has expanded rapidly since the mid-2000s, causing 421.3 km^2 of forest loss between 1997 and 2019, with 85% attributed to artisanal mining (Quash *et al.*, 2024) and driving a fourfold increase in deforestation on Saamaka lands after the 2007 Inter-American Commission on Human Rights ruling (Ebus, 2024). These activities have resulted in severe forest fragmentation, sharp declines in vegetation greenness, and reduced carbon-sequestration capacity across the Amazon. Spikes in gold prices – following the 2008 boom and the COVID-19 pandemic – have further accelerated deforestation and pushed mining into previously intact forest areas (Quash *et al.*, 2024).

Colonial legacies in Brazil and the DRC have shaped resource-driven economies where mining and infrastructure are major drivers of forest loss. In the DRC, Belgium's mining regime evolved into a post-independence system dominated by foreign companies, with artisanal and industrial mining causing deforestation up to 28 times greater than the land directly cleared (Dabees, 2025). Home to 107 million hectares of rainforest, the DRC shows a strong pattern of indirect forest loss: Artisanal mining in eastern regions directly cleared only 6.6% of 924,502 ha between 2002 and 2018, yet indirectly spurred additional deforestation though agriculture (6.8% of 752,077 ha) and settlements (23.9% of 23,299 ha) around mining sites (Ladewig *et al.*, 2024). Mining affects forests both directly, through pits and tailings, and indirectly, through infrastructure and supply chains, driving land cover change, biodiversity loss, and water stress. In Brazil, Portugal's colonial legacy of plantations and mineral exports laid the foundation for modern agribusiness and mining, which have cleared vast Amazonian tracts, displaced Indigenous communities, and fueled fires (Dabees, 2025).

Indirect deforestation linked to mining can be up to 40 times larger than direct loss (Giljum *et al.*, 2025), with Brazil ranking second globally in mining-related forest loss at roughly 170,000 ha cleared between 2001 and 2020, largely from small-scale, informal gold mining that opens roads, pollutes rivers, and fragments remote Amazonian forests (Kramer *et al.*, 2025).

Mining, the pursuit of natural resources, and armed conflict are intertwined challenges worldwide. In conflict-affected Myanmar, a handful of mining sites in the eastern region bordering China exported rare earths more than twice between 2021 and 2023. Since then, mining has expanded rapidly, now spanning an area roughly the size of Singapore. In Kachin State, where mining is most concentrated, approximately 32,720 ha of subtropical and moist forests across Chipwi, Momauk, and Bhamo – regions experiencing both mining activity and clashes between the Myanmar junta and the Kachin Independence Army – were lost between 2018 and 2024 (Meehan *et al.*, 2025).

Armed conflicts and post-war drivers of forest loss

Armed conflicts are a major yet often overlooked driver of unsustainable forest loss, undermining ecological stability and long-term human well-being. They frequently spark sharp surges in deforestation – particularly in protected areas – through weakened environmental governance, civilian survival strategies, and prolonged military occupation (Weir *et al.*, 2025). During the Vietnam War, millions of acres were defoliated with Agent Orange, destroying tree cover and critical food sources for local populations (Institute of Medicine, 1994). In Gaza and the West Bank, the targeted felling of olive trees has devastated livelihoods while heightening social and political vulnerabilities (Burke & Taha, 2025). Syria lost roughly one-fifth of its forests during the civil war (2010–2019) due to direct impacts such as fires from shelling, displaced populations relying on wood for fuel, and indirect pressures including poverty and weakened governance (Daiyoub *et al.*, 2023). Across Sub-Saharan Africa, protected areas such as Virunga, Gorongosa, and several reserves in Liberia have experienced partial deforestation linked to armed conflicts (Johnson & Bongers, 2024).

Cross-border and internal conflicts, combined with complex tensions over land use and distribution, have driven multidimensional deforestation in India. Since 2001, the five Northeast states – Assam, Mizoram, Nagaland, Manipur, and Meghalaya – have collectively lost more than 1.44 million hectares of forest, roughly twice the size of Luxembourg, far exceeding the national average (PTI, 2025). Much of this loss stems from complex ethnic conflicts and border disputes: Assam–Nagaland tensions rooted in colonial-era demarcations push communities to rely on forests (Lahkar *et al.*, 2018; Nath & Dhanaraju, 2025), while violent ethno-religious conflicts in Assam's Bodoland forests drive rebel control, illegal logging, and displacement (Dutta, 2020; Brahmachari, 2019). In Manipur, deforestation is linked to land use conflicts, illegal migration from Myanmar, and poppy cultivation (Bhattacherjee, 2023). Jhum cultivation, mining, and quarrying are key drivers of deforestation in Mizoram and Meghalaya (Dhar *et al.*, 2023; Karuppusamy *et al.*, 2021), fueling competition over forested land among tribal groups, settlers, and commercial actors, while refugee influxes in Mizoram and Manipur further drive clearing for settlements and subsistence agriculture, albeit with limited data available.

Armed conflicts can drive deforestation both within the country and across its borders. From 1990 to 2020, Myanmar lost over 11 million hectares of forest cover in three major waves driven by conflict dynamics, post-Cold War geopolitics, and cross-border resource extraction (Aye, 2023; Kyaw *et al.*, 2024). In Tanintharyi, military offensives, ceasefires, and Thai-backed logging and infrastructure projects fueled timber extraction and oil palm concessions; in Kayin, counterinsurgency, road building, and later ceasefire-enabled investments drove cycles of displacement and forest clearing; and in Kachin, ceasefires, shifting alliances, and China's commercial engagement spurred logging, agribusiness, and mining (Woods *et al.*, 2021). Armed groups and cronies exploited these territories, creating uneven deforestation patterns. Following the 2017 Rohingya refugee influx in Bangladesh, 2300–7000 ha of forest around Cox's Bazar were lost, with daily tree losses equal to three football fields, further straining resources (FAO, 2020; FAO, 2022; Karin *et al.*, 2020; Ullah *et al.*, 2025). Dependence on forests for fuelwood, low education, and insecure livelihoods reinforced a cycle where conflict and deforestation mutually intensified. In addition, from 2021 to 2024, an overwhelming 96% of Myanmar's tree cover loss occurred within natural forests, amounting to roughly 1.2 million hectares, according to Global Forest Watch's dynamic data.

Armed conflicts, when intertwined with illicit crop production used to fund warfare, have dramatically accelerated deforestation, yielding severe ecological and social consequences. In Myanmar's Shan State, ongoing conflicts drove the expansion of opium poppy cultivation, making the country the world's largest opium producer at 1080 metric tons in 2023, while simultaneously triggering widespread deforestation, water scarcity, soil erosion, and heightened landslide risks (UN-SDG, 2024). In the Lao People's Democratic Republic, nearly 44% of poppy plots were located within 10 km of protected areas, including 11% inside official reserves, and roughly half of recently deforested lands had been cleared within 3 years to make way for opium cultivation (UNODC, 2023).

Between 2000 and 2015 in Colombia, deforestation closely mirrored conflict intensity and proximity to illegal coca plantations, particularly in ecologically rich regions such as Tumaco, Catatumbo, San Lucas, La Macarena, and the Sierra Nevada. While armed conflict and coca cultivation each exerted independent pressures on forests, their combined impact was smaller than that of other drivers. Following the peace accord, areas with weak governance saw renewed forest loss tied to localized conflicts (Negret *et al.*, 2019). Across Central America, narcotics-driven deforestation – commonly termed "narco-deforestation" – transformed millions of acres of tropical forest into agricultural land for money laundering, accounting for up to 30% of annual forest loss in Nicaragua, Honduras, and Guatemala. Alarmingly, 30–60% of this deforestation occurred within protected, biodiversity-rich areas, highlighting the acute environmental threat posed by conflict-linked illicit agriculture (Taylor, 2017).

While some armed conflicts can temporarily shield ecosystems by limiting human activity, these benefits are usually short-lived and often offset by deforestation and land-use changes elsewhere, as seen in Ukraine's disrupted agriculture (Weir *et al.*, 2025). In just 2 years of war with Russia, Ukraine lost nearly 600 square miles of forest – roughly twice the size of New York City – demonstrating how rapidly conflict can accelerate ecosystem loss (Yale E360, 2025). As natural gas supplies tightened and prices surged, households and industries across Europe increasingly turned to fuelwood and biomass for energy (Hutt, 2022; Prins, 2022; Kaczyński & Wiezik, 2022; Pikulicka-Wilczewska, 2022; Carter, 2024). Simultaneously, some governments loosened logging restrictions or fast-tracked timber auctions to stabilize energy markets, adding further pressure on already stressed forests. Rising energy costs, combined with European Union (EU) bioenergy subsidies, have driven households to burn wood even in protected areas (Reynolds, 2022). At the same time, the conflict has spurred a surge in global food prices, prompting cropland expansion – including in Europe's fallow lands and in countries such as the United States, Brazil, China, and India – threatening biodiversity worldwide, especially in tropical regions (Chai *et al.*, 2024).

Critically, deforestation often accelerates after conflicts due to reconstruction efforts, weak governance, and renewed commercial logging. For example, annual forest loss in Nepal, Sri Lanka, Ivory Coast, and Peru rose by 68% in the 5 years following conflicts – far surpassing the global average of 7.2% – primarily driven by illegal logging and agricultural expansion (Grima & Singh, 2019). Yet, incorporating local communities' perceptions into peacebuilding initiatives can play a crucial role in guiding forest conservation amid post-conflict land-use changes. In Colombia's post-conflict Antioquia region, for instance, community views on peacebuilding and reconciliation significantly shaped deforestation patterns, with areas holding pessimistic perceptions experiencing a 22.09% lower annual deforestation rate compared to neutral areas (Gutiérrez-Zapata *et al.*, 2025).

In Colombia, however, armed conflict, stalled peacebuilding, and deforestation are deeply intertwined. Municipalities most affected by violence have experienced the highest forest loss, with coca-growing areas facing up to triple the deforestation rates of non-priority zones during 2016–2019 (Natalia *et al.*, 2025). Weak state presence and delayed implementation of the 2016 Peace Agreement have allowed armed groups and illicit economies to expand, perpetuating both violence and forest destruction rather than delivering anticipated stability. National deforestation surged 35% in 2024, rising from 793 km^2 – a 23-year low – to 1070 km^2, with conflict-affected Amazonian regions accounting for nearly 60% of losses (Griffin, 2025). Governance erosion in hotspots such as Tinigua and Sierra de la Macarena enabled large-scale clearing, land grabbing, and illegal operations, contributing one-quarter of the country's 2024 deforestation. Post-accord power vacuums continue to shape forest dynamics, from the 2017 surge after the Revolutionary Armed Forces of Colombia peace deal to medium-scale clearing of 2,700 ha in Chiribiquete National Park and Yarí–Yaguará II Reserve in 2024–2025 (MAAP, 2025).

A climate summit and the Amazon: Exposing the gap between climate rhetoric and environmental reality

The COP30 conference underscored a profound sustainability crisis, triggering global backlash for delivering little more than symbolic progress. While wealthy nations pledged to triple adaptation finance by 2035, they simultaneously obstructed essential measures to phase out fossil fuels, curb deforestation, and regulate critical minerals (Harvey *et al.*, 2025) – decisions that directly undermine long-term environmental and social sustainability. Belém, a region in Pará already burdened by chronic deforestation, illegal gold mining, threatened Indigenous territories, and mercury-polluted waterways (World Bank, 2023; Tapajós & de Castro, 2023; Basta, 2023; Piccinini, 2024; Speetjens, 2025), became an emblem of this contradiction. The conference's operations in Belém – marked by excessive spending, exclusionary planning, and large-scale infrastructure demands, including the felling of 100,000 Amazon trees to accommodate delegates (Melore, 2025; Forster, 2025) – exposed a stark misalignment between stated sustainability goals and actual practices, further eroding trust in global climate governance.

Yet this is no isolated incident. Tree felling has become a global scourge, ravaging livelihoods, development projects, and even war-torn lands. While nature nourishes the Amazon with Sulfur-rich dust carried more than 6000 km from the distant Sahara (NASA, 2015), humanity continues to strip it of life. Between 2000 and 2018, the rainforest lost an area larger than Spain (The Brussels Times, 2020), and over the past four decades' deforestation has consumed land equal to the combined size of Germany and France (BBC News/UN, 2024) – driven by cattle ranching, soy cultivation, logging, mining, and unchecked expansion, leaving its biodiversity increasingly fragile. Further, the UN FAO report indicates that Brazil lost an average of 2.9 million hectares of forest annually from 2015 to 2025 (FAO, 2025) (Fig. 5).

There are numerous consequences to this level of environmental disruption. For instance, the World Bank warns that continued Amazon deforestation – including the clearing of transition zones such as the Cerrado savanna and the Pantanal wetlands – could saddle Brazil with $317 billion in annual economic losses, a figure that is 7 times greater than the combined profits from agriculture, logging, and mining (Hanusch, 2023). A study published in nature further found that in the Brazilian Amazon, the destruction of just 1 square kilometer of forest resulted in an additional 27 malaria cases (Chaves *et al.*, 2018). Moreover, beyond the obvious indirect health benefits of preserving the forest, another Nature study reported that reduced hospitalization costs for local Brazilians could amount to nearly $6 million in annual savings (Damm *et al.*, 2024).

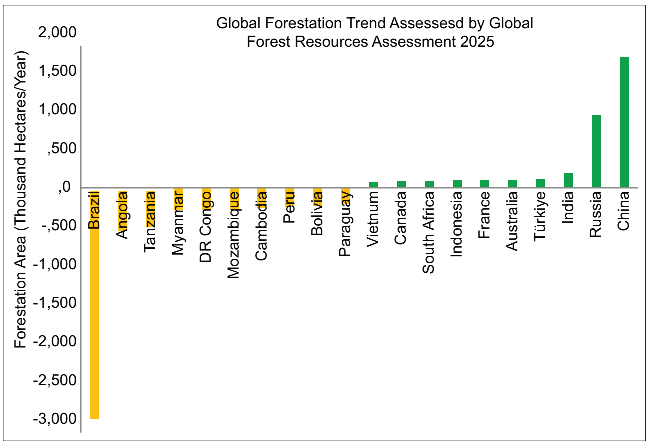

Fig. 5: Top 10 countries gaining and losing forest area (Source: Global Forest Resources Assessment 2025). The figure highlights a sharp contrast in global forest trends: Countries such as China and Russia show significant net gains through large-scale afforestation, whereas others – especially Brazil – continue to experience steep losses

DISCUSSION AND RESULTS

The analysis indicates that global deforestation is not solely driven by local land-use decisions but reflects broader structural influences, including global demand, financial incentives, governance constraints, and geopolitical instability. The synthesized evidence shows that deforestation and permanent tree-cover loss remain highly concentrated in tropical regions, with both scale and intensity continuing to increase rather than stabilize. Estimates from Global Forest Watch and the University of Maryland's GLAD laboratory indicate that roughly 515 million hectares of tree cover were lost globally between 2001 and 2024, with nearly one-third attributable to permanent land-use change rather than short-term disturbance. A substantial proportion of this loss occurred in tropical primary forests, which accounted for more than 60% of permanent conversion, suggesting that highly biodiverse and carbon-rich forest ecosystems are being permanently transformed (Sims *et al.*, 2025; Potapov *et al.*, 2025). Spatial patterns further reveal that the greatest losses are concentrated in the Amazon Basin, the Congo Basin, and Southeast Asia, reinforcing the conclusion that modern deforestation is increasingly focused in regions with limited capacity to absorb or offset its environmental, social, and economic consequences.

Addressing the first research question, the results show that modern deforestation is no longer a widely dispersed global issue but is increasingly concentrated in particular regions and primarily driven by permanent land-use changes. Countries such as Brazil, the DRC, Indonesia, and Bolivia together account for a significant portion of recent tropical forest loss, with 2024 recording the highest levels of primary forest destruction seen in the past 20 years (Goldman *et al.*, 2025; Bourgoin *et al.*, 2025). The scale of this loss highlights a clear disconnect between international pledges to halt deforestation by 2030 and the actual trajectories observed on the ground. Overall, the evidence points to an expanding gap between declared policy goals and the capacity for implementation, especially in forest-rich low- and middle-income nations.

In relation to the second research question, the results demonstrate significant interactions among agricultural expansion, mining activities, climate-driven wildfires, and armed conflict, which together contribute to reinforcing patterns of forest loss. Agricultural expansion remains the primary driver, accounting for approximately 80–90% of global deforestation, largely associated with cattle grazing, soy production, and oil-palm cultivation (FAO, 2021; West *et al.*, 2025). These pressures are further intensified by climate change, which increases the frequency and severity of drought conditions and heightens wildfire risk. Fire-related tree-cover loss reached historically high levels in 2023–2024, with wildfires accounting for nearly half of tropical primary forest loss in 2024 – almost 4 times the proportion recorded in 2023 (Climate Adaptation Platform, 2025).

Mining constitutes a comparatively smaller yet increasingly significant driver of global deforestation, particularly when indirect effects are taken into account. Although direct mining-related forest loss since 2001 is estimated to cover an area comparable to Puerto Rico, associated indirect impacts – including road construction, settlement expansion, and secondary land-use change – may increase the affected area by as much as fortyfold (Kramer *et al.*, 2025; Giljum *et al.*, 2025). The findings indicate that tropical regions, despite hosting a smaller share of global mining sites, account for nearly two-thirds of mining-related forest loss, reflecting a marked spatial imbalance in environmental impacts. Growing demand for transition minerals such as cobalt, lithium, and nickel further complicates these dynamics, suggesting that climate mitigation pathways could unintentionally intensify deforestation pressures in the absence of robust governance and regulatory safeguards.

Armed conflict functions as a significant cross-cutting factor that amplifies forest degradation across multiple regions. Evidence from Myanmar, the DRC, Colombia, and parts of South Asia indicates that conflict is associated with weakened environmental governance, population displacement, and increased dependence on forest resources for subsistence and informal economic activities (Daiyoub *et al.*, 2023; Weir *et al.*, 2025). Post-conflict contexts appear particularly susceptible, as deforestation rates often increase during reconstruction phases due to expanded logging, agricultural conversion, and infrastructure development (Ladewig *et al.*, 2024). Together, these patterns suggest that deforestation should be examined not only as an environmental outcome but also as a structural indicator of governance capacity and political stability.

The third research question highlights the role of global consumption patterns, financial systems, and governance failures in externalizing deforestation pressures onto vulnerable regions. Consumption-based analyses indicate that high-income economies generate biodiversity loss abroad at rates approximately 15 times higher than within their own borders, largely through imports of forest-risk commodities (Wiebe & Wilcove, 2025). The European Union alone is estimated to externalize nearly 85% of its deforestation footprint, whereas a small group of wealthy nations accounts for more than half of mining-related forest loss globally (Kramer *et al.*, 2025). These patterns reflect structural imbalances in global trade and finance rather than isolated national policy failures.

Financial flows further reinforce these dynamics. In 2024, major global financial institutions channeled nearly USD 9 trillion into sectors associated with deforestation risk, despite widespread public commitments to sustainability (Thomson *et al.*, 2025a; Thomson *et al.*, 2025b). Delays in implementing regulatory frameworks – most notably the European Union Deforestation Regulation – have weakened supply-chain accountability and signaled limited political willingness to confront powerful commercial interests (Abnett, 2024; Bounds & Hancock, 2025). The results indicate that voluntary corporate pledges remain insufficient without enforceable legal and financial consequences.

Within this context, the selection of recent host countries for United Nations climate conferences has drawn scholarly attention to the alignment between summit objectives and national policy environments. COP27 in Egypt, COP28 in the United Arab Emirates, and COP29 in Azerbaijan generated discussion regarding the influence of fossil-fuel sectors, governance conditions, and the pace of progress on deforestation-related commitments (Lee & Kim, 2022; Mathiesen, 2024). Several analysts suggest that repeated hosting of climate summits in countries with high greenhouse-gas emissions and significant hydrocarbon dependence may shape perceptions of the effectiveness and credibility of global climate governance frameworks (Mills, 2025; Timilsina & Sebsibie, 2024).

At COP27 in Egypt, negotiations on key climate mechanisms, including the establishment of the “loss and damage” framework, took place within a complex political and environmental context that influenced stakeholder participation and negotiation dynamics (Aziz, 2022; Maslin *et al.*, 2022). At COP28, the appointment of Sultan Al-Jaber, Chief Executive Officer of the United Arab Emirates’ state-owned oil company ADNOC, as conference president prompted discussion among researchers and civil society groups regarding governance safeguards and institutional independence (University of the Built Environment, 2023). COP29 in Baku, Azerbaijan, similarly attracted attention concerning governance capacity, human rights considerations, and the country’s continued reliance on fossil-fuel production, alongside reports of restrictions affecting some observers and critics (Townend *et al.*, 2024). At COP30 in Belém, Brazil, infrastructure development associated with hosting the summit reportedly involved the clearance of an approximately eight-mile stretch of Amazon forest to accommodate event-related facilities (The Times, 2025). Although some fact-checking assessments have questioned the scale or attribution of these impacts, media coverage and public responses nonetheless contributed to renewed scrutiny of leadership and implementation within global climate governance processes.

Taken together, these findings support an interpretation of contemporary deforestation as a process of ecological externalization embedded within global political-economic systems. Forest-rich regions disproportionately absorb the environmental and health burdens associated with global consumption patterns, energy transitions, and geopolitical disruptions that are largely driven beyond their borders. The interaction of agricultural expansion, mining activities, climate-driven wildfires, and armed conflict generates reinforcing dynamics that accelerate forest loss, particularly in tropical ecosystems. In the absence of binding international mechanisms that effectively align trade, financial flows, and climate policy with forest conservation objectives, current deforestation trajectories are likely to persist.

FOREST PRESERVATION AND THE PREVENTION OF DEFORESTATION: SCHOLARLY RECOMMENDATIONS

Systems-based governance for structural deforestation control

A systems-theoretical framework is essential to address deforestation as an interconnected outcome of land-use change, global consumption, finance, conflict, and climate stress rather than isolated national failures (Fig. 6). Future strategies should embed forest governance within macroeconomic planning frameworks to ensure policy coherence between economic development objectives and environmental sustainability goals (Sateriano *et al.*, 2025). Such integration is critical for aligning forest policies with climate-mitigation pathways (Bergkvist *et al.*, 2024; Sevillano *et al.*, 2025) and for regulating trade systems through targeted policy instruments and market-oriented mechanisms that guarantee forest products placed on markets are legally harvested and sustainably produced (Datta *et al.*, 2025; Assembe-Mvondo, 2014; Hoogstra, 2012). At the same time, strengthening institutional and decentralized governance arrangements for economic valuation and spatial planning is necessary to support evidence-based policy decisions (Nguyen *et al.*, 2020; Weiland & Dedeurwaerdere, 2010; Wright *et al.*, 2016), thereby internalizing deforestation risks within policy and market systems rather than shifting them to forest-rich regions. Countries driving large-scale forest loss should adopt whole-of-government coordination mechanisms linking agriculture, mining, energy, and climate portfolios, ensuring that forest protection targets are binding across sectors rather than confined to environmental or forest ministries alone.

Aligning climate mitigation pathways with forest integrity

Aligning climate mitigation pathways with forest integrity requires integrated planning that harmonizes human and natural systems while

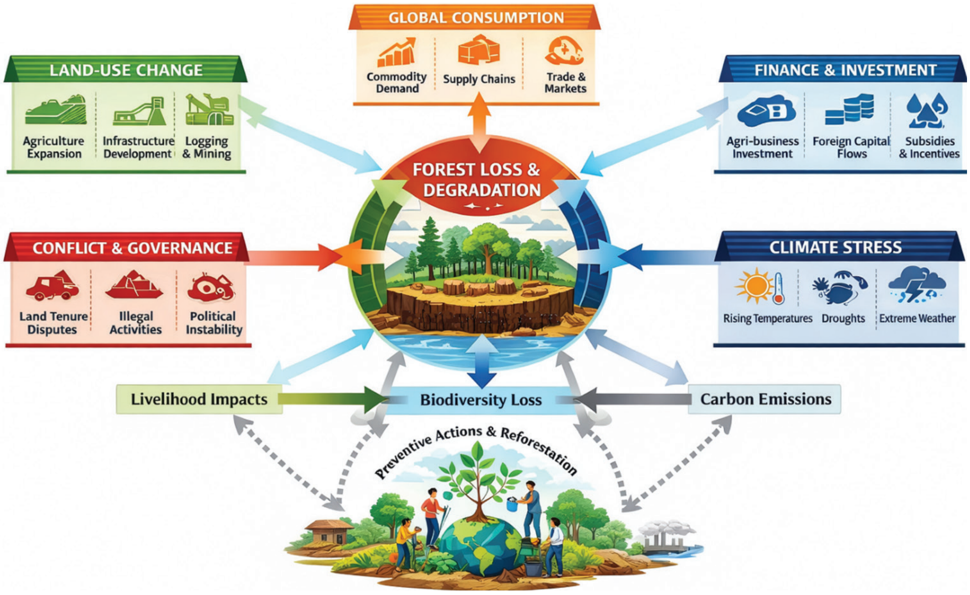

Fig. 6: Forest governance as a systemic lever against deforestation. The figure illustrates deforestation as an emergent outcome of interacting subsystems, including land use, global demand, finance, governance, and climate pressures. Integrating forest governance into macroeconomic planning coordinates development, climate, and trade objectives while internalizing deforestation risks across policies and markets

promoting resilient, energy-efficient forest operations (Tampekis *et al.*, 2024). Climate-smart forestry operationalizes this goal by combining management, protection, and restoration across landscapes to deliver carbon, biodiversity, and social co-benefits (Cooper & MacFarlane, 2023). When guided by forward-looking policies, rising timber demand can increase harvests while expanding long-term carbon stocks through afforestation, productivity gains, and investment incentives (Daigneault *et al.*, 2022). Complementary instruments, including forest carbon taxes, can reduce emissions from industrial logging while financing climate-smart transitions (Talberth *and* Carlson, 2025).

Because primary forests retain far higher ecological integrity than human-modified systems, mitigation strategies must prioritize identifying and protecting high-integrity areas within an ecosystem integrity framework (Rogers *et al.*, 2022). Global targets to protect 30% of forests by 2030 and 50% by 2050 are essential to safeguard biodiversity, carbon storage, and hydrological functions (Law *et al.*, 2022). Forests should be treated as irreplaceable carbon and water systems – not merely offsets – within national development and climate strategies coordinated across sectors and governance levels (Hurlbert *et al.*, 2019). Halting deforestation alone could cut global emissions by roughly 4 gigatons/year, underscoring its centrality to net-zero pathways (UNEP, 2024).

Existing mechanisms provide a foundation for scaling results-based forest mitigation. Reducing emissions from deforestation and forest degradation in developing countries (REDD+) now covers more than 90% of tropical forests and over 75% of forests in developing countries under the United Nations Framework Convention on Climate Change, whereas new approaches such as the Reversing Deforestation Mechanism link verified net removals to predictable payments (Assunção *et al.*, 2025). By combining carbon markets, policy instruments, and jurisdictional mechanisms, these frameworks align economic development with ecological integrity. Bilateral offtake agreements can further stabilize finance and complement jurisdictional REDD+ and Tropical Forest Forever Facility by rewarding verified outcomes at scale.

Forest protection should be elevated to a primary mitigation action on par with decarbonization, as conserving high-carbon forests avoids large emissions and sustains sequestration comparable to many energy-sector measures (Mackey *et al.*, 2020). Public investment in forests significantly boosts net sequestration and supports national climate targets, confirming forests as a scalable mitigation lever (Favero *et al.*, 2025; Enríquez-de-Salamanca, 2022). As countries expand renewables and critical-mineral extraction, strong deforestation safeguards are essential to prevent shifting environmental costs onto tropical forests, where mining pressures are growing (IEA, 2021). Evidence shows that restricting mining in protected areas could reduce over 60% of forest threats, while improved inventories reveal mining-related deforestation to be 2–3 times higher than previously estimated – making forest safeguards indispensable to credible clean-energy transitions (Sun *et al.*, 2024; Zhang *et al.*, 2025) (Fig. 7).

Enforceable supply-chain accountability and trade reform

Enforcing supply-chain accountability is vital for global forest preservation, as opaque reporting and inconsistent corporate commitments continue to undermine deforestation reduction. Standardized data, public disclosure, and robust due diligence legislation are essential for creating deforestation-free supply chains and holding companies accountable (Thomson, 2021). Voluntary corporate pledges have proven insufficient, highlighting the need for importing countries to adopt mandatory traceability, customs-level verification, and financial penalties for non-compliance (Berning & Sotirov, 2023). State-led regulations such as the EUDR exemplify this shift from voluntary to enforceable standards, institutionalizing zero-deforestation requirements for forest-risk commodities. Yet their effectiveness depends on regulatory design, enforcement, and market actors' responses, particularly in opaque supply chains influenced by rising trade volumes and shifting power toward countries such as China, which weakened prior initiatives such as the EU Forest Law Enforcement, Governance and Trade Action Plan (Partzsch *et al.*, 2023). Implementation gaps in regions such as the DRC and Indonesia, coupled with reliance on private-sector enforcement, further underscore the need for stronger public sanctioning and dynamic monitoring.

Sustainable outcomes in commodities such as soy and coffee require more than legislation. Adaptive performance management, context-sensitive monitoring, and end-to-end traceability – including block-chain-enabled timber marking, transport documentation, and restoration obligations – enhance transparency, curb illegal logging, and strengthen accountability through tamper-proof records linking procurement, insurance, and reforestation (Alexander *et al.*, 2024;

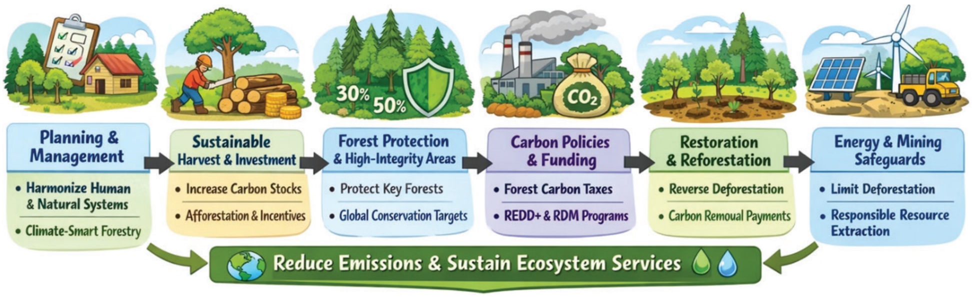

Fig. 7: Forest protection as a core climate mitigation pathway. The figure illustrates how aligning climate mitigation pathways with forest integrity prioritizes halting deforestation and protecting high-carbon, high-integrity forests as primary mitigation actions alongside decarbonization. It highlights integrated planning, policy instruments, and restoration mechanisms that conserve forest carbon stocks while supporting biodiversity and sustainable development

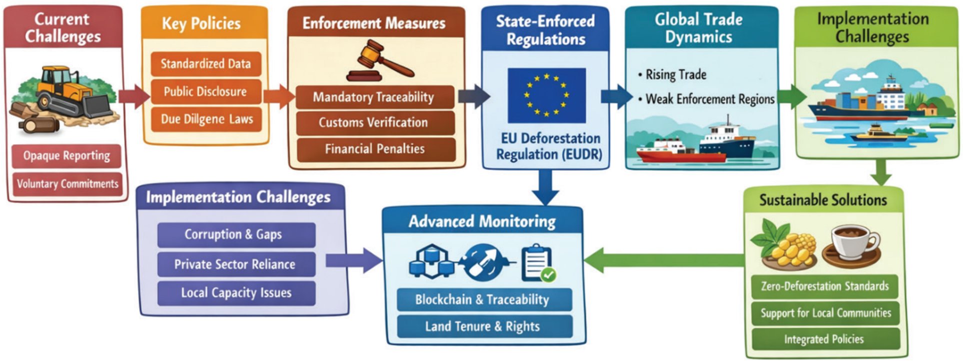

Fig. 8: Strengthening supply-chain accountability to protect forests. The flowchart illustrates key strategies for reducing deforestation through enforceable supply-chain reforms. It highlights policy measures, enforcement mechanisms, advanced monitoring, and sustainable solutions that collectively ensure transparent, zero-deforestation supply chains

Mechik & von Hauff, 2021) (Fig. 8). Brazil's soy sector demonstrates that focusing solely on deforestation, without integrating land tenure and human rights, limits effectiveness, emphasizing the importance of empowering grassroots actors and harmonizing local development with transnational policies (Schilling-Vacaflor & Gustafsson, 2024).

Linking historical and projected forest loss to commodity supply chains ensures accountability across actors and regions, while coordinating forest and non-forest policies – agriculture, urban planning, and environmental protection – strengthens enforcement and safeguards ecosystem services (Lathuillière *et al.*, 2025; Min *et al.*, 2024). Aligning forest laws with trade regulations integrates conservation into development goals, while EU Trade and Sustainable Development chapters reinforce accountability and provide technical support to partner countries (Garcia, 2025). Corporate supply chains often face opacity and unequal market power, highlighting the need for zero-deforestation sourcing and nature-positive business models (Panwar *et al.*, 2023).

Ultimately, effective forest protection requires coordinated action among investors, companies, policymakers, and data providers, backed by mandatory reporting, dynamic monitoring, and international collaboration. Integrating regulatory enforcement with adaptive management aligns financial and corporate behavior with national and global conservation targets while addressing human rights risks (Gustafsson *et al.*, 2023; UNEP Finance Initiative, 2025a). By institutionalizing enforceable standards, strengthening supply-chain oversight, and linking trade reforms to environmental accountability, global forest preservation can move beyond voluntary commitments to measurable, sustainable outcomes.

Financial system realignment and risk internalization

Global forest preservation increasingly depends on realigning financial systems to internalize deforestation and biodiversity risks. Evidence suggests that deliberate sequencing of government, REDD+, and supply chain interventions, supported by early state incentives, creates an enabling environment for private and transnational actors, enhancing cost-effectiveness and scalability (Furumo & Lambin, 2021). Biodiversity loss now poses distinct financial risks capable of undermining firm value, credit quality, and systemic stability, necessitating integration into market pricing and capital allocation (Lucey *et al.*, 2025). Case studies from Brazil and Indonesia highlight that international climate finance alone is insufficient, as domestic priorities and sovereignty concerns often outweigh external influence, emphasizing the need to align funding with national development goals and foster reciprocal cooperation (von Lüpke *et al.*, 2025). Engaging financial institutions through regulatory incentives and green banking frameworks can redirect capital toward sustainable forest management, supporting regenerative practices, community-based conservation, and legal timber trade (Harris, 2024; Hermawan & Khoirunisa, 2023).

Political and sectoral dynamics, however, continue to dilute sustainable forest finance ambitions, as observed in EU policy struggles, underscoring the need for transparent, science-based mechanisms that link biodiversity conservation to financially viable forest management (Begemann *et al.*, 2025). Future protection hinges on restructuring incentives that currently favor deforestation, requiring risk-based models where financial institutions treat forest-loss exposure as material and integrate it into credit, insurance, and investment decisions (UNEP Finance Initiative, 2025b). Leveraging high-integrity REDD+, targeted forest finance, and nature-based solutions can close the $216 billion annual forest finance gap projected by 2030, potentially tripling private investment from $7.5 billion in 2023. Strengthening legal and governance frameworks across supply chains, particularly in high-risk timber markets such as Vietnam–Africa trade, ensures verified sourcing while internalizing ecological and financial risks (Pham *et al.*, 2025). Together, coordinated financial realignment, risk internalization, and policy integration offer a pathway to sustainable, global forest preservation. Public and private finance should be redirected toward forest-positive land use, restoration, and climate-resilient livelihoods, while capital flows to high-risk sectors are constrained through disclosure mandates and enforceable exclusion policies.

Conflict-sensitive and post-conflict forest governance

Both armed conflict and post-war reconstruction are critical accelerators of forest loss. Future recommendations must embed forest protection within peacebuilding and recovery frameworks, recognizing forests as both ecological assets and governance indicators. Conflict-affected countries require targeted international support to restore land tenure systems, prevent opportunistic land grabbing, and integrate community-based forest management into reconstruction efforts, thereby reducing the post-conflict deforestation surge documented across multiple regions.

CONCLUSION

This study synthesizes recent global evidence to examine the scale, spatial concentration, and interacting drivers of deforestation and permanent tree-cover loss, addressing the three core research questions outlined at the outset. The findings indicate that contemporary deforestation remains heavily concentrated in tropical regions and is increasingly characterized by permanent land-use conversion rather than temporary disturbance. Agricultural expansion continues to dominate as the primary driver, while mining activities, climate-driven wildfires, and armed conflict interact in ways that intensify forest degradation and reduce ecosystem resilience. These pressures are further amplified by global consumption patterns and financial systems that externalize environmental costs to forest-rich, lower-income regions.

The analysis also highlights persistent governance gaps that limit the effectiveness of existing policy commitments and regulatory frameworks. In particular, the location and context of recent international climate summits underscore broader challenges in aligning global climate governance with measurable reductions in deforestation. Taken together, the evidence suggests that forest loss should be understood as a systemic outcome of interconnected economic, political, and environmental processes rather than isolated local failures. Addressing these dynamics will require coordinated action across supply chains, finance, and land-use planning.

Future efforts should prioritize enforceable deforestation-free trade measures, stronger financial disclosure and accountability mechanisms, integration of forest protection into climate adaptation and mitigation strategies, and targeted support for governance capacity in high-risk regions. Continued investment in transparent data systems and interdisciplinary research will also be essential to monitor progress and inform more effective forest conservation and restoration policies.

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AI support was used solely to improve the clarity and flow of the text, rendering it in smooth American English while preserving all original observations, data, and sources.

DATA AVAILABILITY STATEMENT

The data used in this study were sourced from the Global Forest Watch Dashboard, devised by the GLAD laboratory at the University of Maryland. These data are publicly available at: https://www.globalforestwatch.org/dashboards/global

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DECLARATION OF PATIENT CONSENT

N/A.

AUTHOR CONTRIBUTION

Abdul Kader Mohiuddin is the sole author.

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