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Sustainable Markets Initiative

Wood-based Solutions and Alternatives

BRIEFING MATERIAL (SUSTAINABLE MARKETS INITIATIVE)

LSEG

Summary

- Forests play a critical role in Earth's ecosystem and are an important carbon sink.
- Sustainable forest management is therefore crucial for keeping this valuable resource viable in the long run.
- It is increasingly recognised that wood is a highly versatile material.
- Novel production and conversion technologies have expanded its applications beyond traditional uses.
- Wood-based materials can now be used as a replacement for many carbon-intensive commodities.

Background

- **Forests cover around 30% of Earth's land area,** about 8% of Earth's total surface.
  - 93% are natural forests, 7% are planted forests.[1]
- **Forests play a critical role in Earth's ecosystem,** in a number of ways.
  - **Forests are the second-largest carbon sink (the oceans are the largest), absorbing 25% to 30% of global CO_2 emissions.**[2]
    - Forests capture CO_2 from the atmosphere. Photosynthesis converts the captured CO_2 into living biomass (tree trunks, roots, branches, and leaves) and, generally, releases oxygen.
    - Moreover, forests also store carbon through leaf litter, woody debris, and roots being absorbed into the soil.
    - A likely order of magnitude of the carbon stored in the world's forests is 500 billion tonnes: this compares with an estimated 850 billion tonnes in the atmosphere today.[3]
  - **Forests also regulate the world's temperatures and fresh water flows.**
    - Forests contribute to atmospheric moisture and rainfall patterns over land through 'evapotranspiration', i.e., evaporation from soil and plant surfaces, and transpiration of water by plants. Around 40% of rainfall over land originates from evapotranspiration.
    - Forests also influence local temperatures, providing a cooling effect through transpiration and shade.
  - **Furthermore, forests host some 80% of all terrestrial species of animals, plants, and insects.**
- **Forests play a significant economic role,** supporting the livelihoods of around 1.6 billion people – one-fifth of the world's population, and more than that of any one country on earth.[4]

Sustainable forest management

Given the importance of forests to the planet, **sustainable management is essential** to ensure society's demands do not compromise the resource.

- Sustainable forest management offers a holistic approach, to ensure that forest activities deliver social, environmental, and economic benefits; balance competing needs; and maintain and enhance forest functions now and in the future.[5]
- Sustainable forest management is based on the **three pillars of sustainability:**
  - It creates outcomes that are:
    - **Socially just;**
    - **Ecologically sound; and**
    - **Economically viable.**[6]
- **Sustainable forest management is crucial for climate change mitigation.**
  - According to the IPCC:
    "In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit." [7]

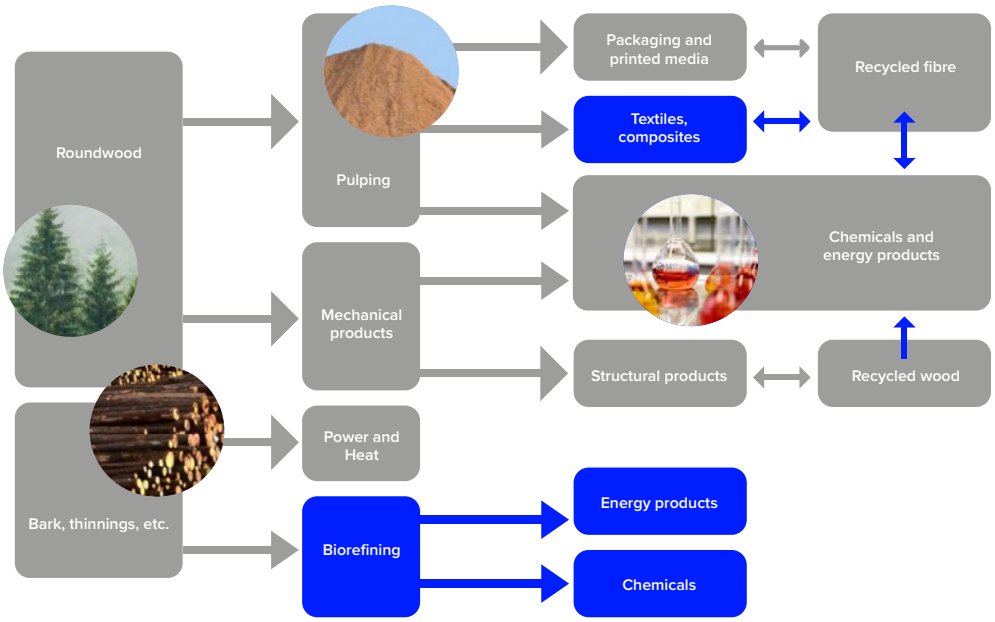
- **Forest certification** is a way to prove sustainable forest management and to connect the consumer with the sustainable origins of their products.
  - **Progress has been made**. Since 2000, the proportion of the world's forests certified to be managed sustainably has grown from 1% to 13%.[8]
  - In fact, in managed forests across Europe, there are five trees planted for every one that is harvested.[9]

- **Increasing the inherent value of forests through expanding markets for wood products** is also important.
  - With approximately half of deforestation occurring for agricultural expansion – of which livestock (mainly cattle) pasture accounts for about half – there is a need for appropriate (financial) incentives and/or regulation to discourage this behaviour (for more, see the latter part of this brief).
  - In general, the returns earned from agricultural activities are currently greater than those obtained by leaving the forests intact or using them for timber production.

Forest materials as a replacement for carbon-intensive commodities

There is increasing recognition that wood-based alternatives to carbon-intensive materials such as plastics, steel, and concrete could be used for every-day objects (Figure 1).

Figure 1: New and existing wood-based products



Source: *TEM_oppaat_2_2017_Wood_based_Bioeconomy_Solving_Global_challange_29052017web.pdf (valtioneuvosto.fi)

- The true potential of new added-value wood-based products and their applications lies in:
  - **Innovative use** of the unique properties of wood and its components, in combination with
  - **Novel production and conversion technologies,** product design, and the Internet of Things (IoT).
- Encouraging sustainable management and use of this renewable source would **contribute to mitigating climate change,** rather than exacerbating the problem.
- **Cellulose,**[10] an important structural component of the primary cell wall of green plants, **has been dubbed as the future 'super material'.**[11]
- **Nanocellulose,** the smallest fibrous structure in wood fibres, possesses unique strength and surface properties that have a vast application potential.
  - Nanocellulose is already used, for example, to improve the properties of paper products.
    - It has high potential in various other applications, including biocomposites, packaging, filtering, hygiene, medical applications, electronics, and construction.
  - Novel additive processing technologies, such as 3D printing, allow the creation of cellulose-based structures designed for purpose.
- Unsurprisingly, many of the wood-based innovations and novel products come from Finland, a country where 86% of land is covered by forests.

Construction/architecture

There is a growing recognition that **timber can provide a sustainable alternative to concrete and steel.**

- **The climate economic rationale is clear.**
  - The construction and operation of buildings accounts for some 40% of the world's energy consumption, and approximately **one-third of greenhouse gas (GHG) emissions.**
  - Whereas the production of concrete, cement, and steel emits a huge amount of carbon, and these are some of the harder-to-abate sectors, **trees instead absorb carbon throughout their lifetime.**
  - If trees are harvested at the right time (i.e., once they have matured and cannot absorb much more carbon), the lifespan of trees could be prolonged by 100-200 years if the buildings are designed with longevity in mind.
  - A cubic metre of timber building material can store approximately a tonne of carbon within the building fabric.[12]
- Wood is nature's most versatile building material, and **modern engineering methods have expanded its application beyond traditional uses.**
- The rise of **engineered wood,** also called **mass timber,** has enabled ground-breaking advances in the use of timber in construction.
  - Mass wood includes a range of derivative wood products, manufactured by binding or fixing the strands, particles, fibres, or veneers of wood together with adhesives, or other methods of fixation, to form composite material.[13]
  - Cross-laminated timber (CLT), a precision-engineered building material, is a common type of mass wood. It is produced by gluing strips of laminated wood together at 90-degree angles, before being compressed at great pressure into huge beams or panels.[14]

- **Costs of engineered wood have been coming down significantly** through economies of scale, spurring the wider use of mass timber in construction.
  - The cost of cross-laminated timber, for example, has fallen so much in recent years that it is now comparable with that of traditional building materials.
- **Building regulations and shifting attitudes** towards the engineered materials have also helped the advance of timber in large-scale construction projects.

Examples

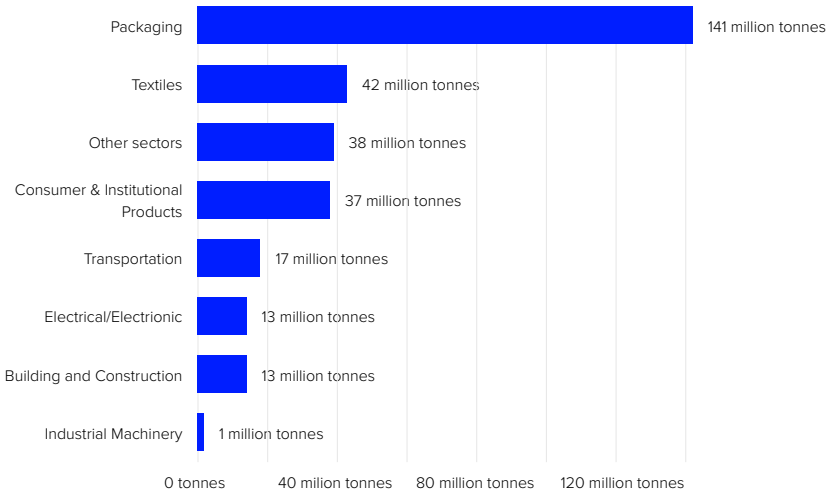
- There have already been **a number of record-breaking feats in high-rise timber construction,** sometimes dubbed **"plyscrapers"**.[15]
  - The world's tallest timber building, the Mjøstårnet tower in Norway, completed in 2018, is 280-feet high. This 18-story structure was made possible by advances in engineered wood (notably CLT) manufacture.
  - A 238-foot wooden apartment block is being planned in Milwaukee, Wisconsin. The developers of this apartment complex claim that its use of timber represents the equivalent of taking 2,100 cars off the road.
  - In London, the British firm PLP Architecture has created proposals for three wooden skyscrapers, including a 984-foot-tall tower in the heart of the city.

Packaging

Plastic is the most common packaging material today.

- Yet the **negative environmental impacts** of plastic production, use, and disposal are well-known. Plastics have a particularly **carbon-intense life cycles:**[16]
  - The overwhelming proportion of plastic resins comes from petroleum, which requires extraction and distillation. Then the resins are formed into products and transported to market.
  - All of these processes emit GHGs, either directly or via the energy required to accomplish them.
  - The carbon footprint of plastics continues even after disposal. Dumping, incinerating, recycling (only 6% of all plastic products!), and composting (for certain plastics) all release CO_2.
  - The global demand for plastics, it has been projected, stands to increase by some 22% over the coming five years.
  - On their current trajectory, emissions from plastics stand to reach 17% of the global carbon budget by 2050.[17]
- **Plastic production waste is a major global problem, and packaging is the biggest culprit,** generating the most plastic waste of any sector (Figure 2).

Figure 2: Plastic waste generation by industrial sector, 2015



Source: https://www.weforum.org/agenda/2020/12/sustainable-packaging-reduce-plastic-waste/

- To overcome the plastic waste problem, it is essential that **alternative packaging solutions** be found.
- **Wood and wood-based fibres,** such as nanocellulose, **offer innovative and practical alternatives.**
  - Wood-based products are already replacing plastics in almost every industry, but need to be deployed at a bigger scale to achieve the required reduction in plastic waste.
- **New materials and technologies can enhance the already-in-use wood-based products' properties.**
  - Dispersion coating for cardboard production, for example, will provide barrier properties that will reduce fossil plastics in food service end use applications, especially in paper cups, and will also make the products fully renewable.[18]

Examples

- The Finnish company Paptic has created a renewable, reusable, and recyclable alternative to plastic bags based on wood-fibre.
  - Unlike traditional paper bags, which are mostly unfit for repeat usage, Paptic's licenced technology has enabled them to create a product with increased strength and durability.[19]
- The Finnish company Woodly, a cleantech company produces a **novel type of carbon-neutral, wood-based plastic** made from cellulose extracted from sustainably-managed and certified forests.[20]

Textiles

- To a large extent, **modern textiles are made from cotton and oil-based materials.**
  - The problem with cotton is that considerable amounts of water, chemicals, and energy are needed for the cultivation of the plants. In addition, the land used for the cultivation of cotton plants could be used to grow food crops.
  - The production of oil-based materials is carbon intensive and environmentally damaging, so the textile industry is striving to reduce its reliance on the former.
- The global textile industry has been in desperate need for sustainable innovation.
- It is estimated that the **fashion industry is responsible for 10% of global GHG emissions** – more than international flights and maritime shipping combined.[21]
- **New bioproducts,** such as **wood-based textile fibres,** provide novel possibilities for the eco-friendly fashion industry globally.
  - In short, this process involves transforming wood into fibre and weaving it into yarn.[22]
  - Unlike traditional cotton production, for example, this process consumes relatively low levels of water and energy.
  - **Viscose, acetate, lyocell, and other forest fibres** now make up about 6% of global textile production, but their importance is likely to grow.[23]

Examples

- Finnish company Spinnova converts wood pulp directly into textile fibre, with zero waste and 99% less water usage than that used in cotton production.[24]
  - Its products can also be recycled as easily as paper can.
- Likewise, Finnish design icon Marimekko is working on solutions to incorporate wood-based fibres in its production to deliver more sustainable fashion.[25]

Chemicals

The chemical industry is a major consumer of energy, and hence a major source of GHG emissions.

- It is responsible for approximately **7% of global GHG emissions** (around 20% of industrial GHG emissions).[26]
- **Biochemicals have the potential to open new horizons.**
  - They are often listed as offering particular scope for radical product innovations.
    - One such area is as an alternative to numerous oil-based chemicals.
- **Biochemicals represent new and interesting territory for the forest industry.**
  - The sector is actively investigating new technologies for separating wood-based biomass into its constituent components.
    - These can then be processed into finished products or used as raw materials in the chemical, food, and medical sectors.
- It has been suggested that 60 to 70 chemical components can be made from wood-based biomass and used in the production of a wide range of products. These include:
  - **Paints, solvents, epoxy, resins, polyurethane insulation elements, and transparent films.**[27]

- **Lignin**,[28] to take on example, **is a valuable wood-based resource for novel bio-based products.**
  - Around 60 million tons of lignin is extracted annually from wood as a by-product of the pulping industry.
  - Wood lignin has a high potential for added-value applications:
    - Examples include concrete, adhesives, and other chemicals, in addition to its current energy use.

Examples

- The Nordic company, Stora Enso, recently began extracting lignin on an industrial scale with a view to using it as a replacement for fossil material-based glues.[29]

Energy

The energy sector, broadly defined, is by far the biggest polluter.

- **Electricity and heat production** account for 25% of global GHG emissions, and transport for 14%.
- **Biomass and biofuels** (admittedly not only wood-based products) are **already well-known energy sources,** but there is significant scope to increase scale and range of applications.
- Biomass-based energy is still the largest source of renewable energy worldwide. Yet, its use has significant environmental impacts:
  - Household uses of biomass account for nearly 60% of black carbon emissions globally.
  - 'Black carbon', or soot, is a significant contributor to global warming because of its high absorption of solar radiation and its effects on cloud formation, regional circulation, and rainfall patterns.
- **Liquid biofuels** potentially offer a (partial) solution for decarbonising transport. Once again, there are 'issues' to be considered:
  - Biofuels emit CO_2 when burned.
  - To be produced at scale they would make heavy demands on land use e.g., to meet current demand for aviation with plant-based biofuels, arable land approximately the size of Australia would be required.

Examples

- NASA has determined that a mixture of 50% aviation/biofuel mix can cut air pollution caused by air traffic by 50–70%.

Biomedical

The scope for wood-based solutions extend even as far as the medical sector.

- **Biofibrils**, which are also referred to as micro- and nano-fibrillated cellulose, have recently been developed into an exciting commercial application. This biomedical solution **can be used in cell cultivation and wound treatment products.**

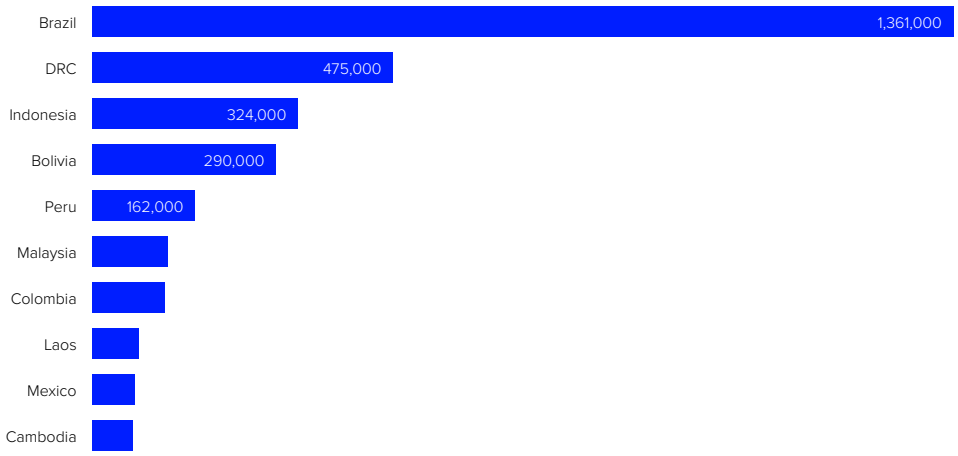
Examples

- Biomedical company UPM has developed a gel (called GrowDex®) that is highly biocompatible with human cells and tissues. It provides a 3D culture to analyse how cancer cells are reacting to medical treatment.[30]

Forests and climate change: deforestation

- Just as forests play a key role in climate change mitigation and adaptation, so does **deforestation exacerbate climate change.**
  - When forests are cleared or burned, whether for agricultural use, infrastructure, or urbanisation, the net flow of carbon from the atmosphere into the forest stops, both in the present and for what would have been the entire future lifetime of the trees.
  - Deforestation also releases carbon that has accumulated, both in the trees themselves and in the forest soil.
  - The speed of carbon release depends on how the forest is cleared, and what the wood is used for.
- **About 12% of global greenhouse gas (GHG) emissions are estimated to derive from deforestation.**[31]
  - If deforestation were a country, it would rank third (behind the US and China) in CO_2-equivalent emissions! [32]
- **Deforestation is occurring on a massive scale** (Fig 1).
  - 32% of the world's forest area has been destroyed.
  - An area the size of a football pitch of primary rainforest – particularly important for climate change mitigation – was lost every 6 seconds in 2019.[33]
  - Brazil single-handedly accounted for over a third of all loss of humid tropical primary forests worldwide. Clear-cut deforestation for agriculture and other new land uses has rapidly increased in the Brazilian Amazon over the past year.

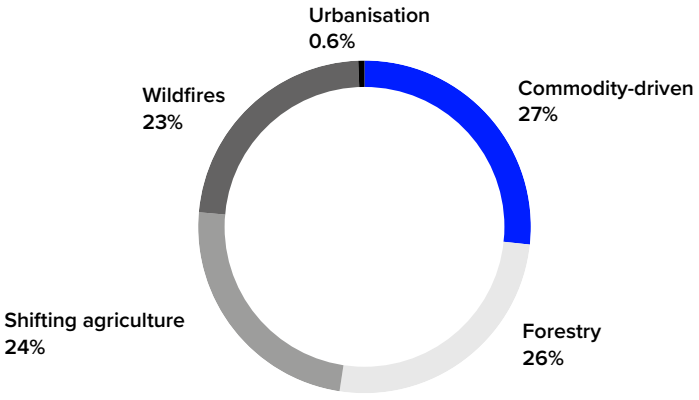
Figure 1: Top 10 tropical countries by primary forest loss in 2019 (hectares)



Source: Global Forest Watch
Full link: https://blog.globalforestwatch.org/data-and-research/global-tree-cover-loss-data-2019/

- **Deforestation is driven by a number of activities.**
  - Between 2001 and 2015 gross tree cover loss globally was caused primarily by (Fig 2):[34]
    - **Commodity-driven deforestation**, e.g. palm oil, soy, beef, minerals, and oil and gas production. These areas are unlikely to be reforested.
    - **Forestry**. Loss within managed forests. Most of these area are likely to be regrown.
    - **Shifting agriculture**, i.e. clearance and burning of forests for short-term cultivation of crops. These forests may or may not grow back.[35]
    - **Wildfires**. Forests are likely to regenerate.
    - **Urbanisation**. This loss is almost always permanent.

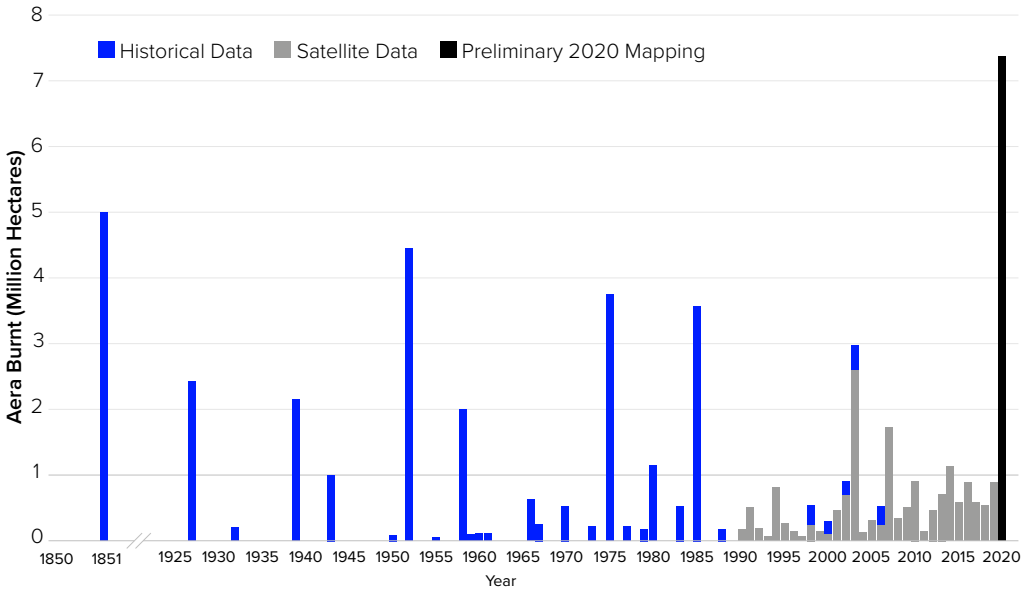
Figure 2: Drivers of global forest loss



Source: Curtis, P. et al (2018),

- **The drivers of deforestation differ greatly by region.** [See Appendix for more details.]
- **Deforestation's impact on the climate also depends on the type of forest.**
  - Peatlands, for example, cover only about 3% of global land area, but store some 20-25% of all soil carbon.
  - Likewise, mangrove forests are a particularly important natural carbon sink.
- **Forest loss and degradation reduce evapotranspiration, with implications for rainfall** thousands of kilometres downwind.
  - Climate models suggest that large-scale deforestation may reduce rainfall in some regions by as much as 30%. This can lead to feedback effects including slower forest growth, drought, die-off, and fires.
- **Tropical forests are particularly important for climate change mitigation**, accounting for, on average, about 70% of the gross carbon sink in the world's forests. In recent years, however, this carbon absorption impact is close to being diminished by the negative impacts from deforestation.
  - The tropics lost 12m hectares of tree cover in 2019, the third-highest annual primary forest loss since record-keeping began in 2001.
    - Nearly one-third of that loss, 3.8 million hectares, occurred within tropical primary forests, areas especially important for biodiversity and carbon storage.[36]
    - Primary forest loss in 2019 represented the loss of an estimated 1.8 Gt of CO_2 absorptive capacity, equivalent to the annual emissions of 400 million cars, nearly one-third of the world total.
  - Nearly 17% of forest cover in the Amazon has been destroyed since 1970.
    - In Brazil, 20% of the Amazon rainforest, especially in the south-eastern part, has become an emitter of GHGs instead of being a carbon sink.[37]
    - If the present rate of forest loss continues, and 20% to 25% of the forest is lost, scientists warn that the region will get pushed into a state of savannah, releasing billions of tonnes of GHG emissions, leading to increased droughts, and huge losses in agricultural production.[38]
- **A significant share of deforestation for agriculture is illegal**, particularly in Brazil and Indonesia.[39]
  - In the Amazon, at least 90% of deforestation for agriculture is reckoned to have been illegal.
  - In Indonesia, at least 80% of deforestation for commercial agriculture – mostly palm oil – and timber plantations is considered to have been illegal.
- **Natural disturbances to forests stand to be exacerbated by climate change.**
  - Climate change has the potential to increase both the frequency and the intensity of fires, droughts, storms, snow and ice, insect infestation, and disease.
  - Many of these disturbances may come to exceed forest ecological resilience, and result in permanently altered forests or shifts to non-forest ecosystems.
  - In California, 14 of the 20 largest wildfires on record have occurred over the past 15 years, and on average fires now burn more than twice the area that they did in the 1980s and 1990s.
- **Forest fires release significant quantities of GHGs into the atmosphere.**
  - "Forests don't make headlines; forest fires do."
  - Australia's devastating bushfire season is likely to have released 830m tonnes of CO_2, far more than the country's annual GHG emissions. Historical and satellite data suggest that 50% more forest land burned in 2020 than in any previous year dating back to 1850.

Figure 3: Annual area burnt by bushfires in Australian temperate forests



Source: Department of Industry, Science, Energy and Resources
Full link: https://www.theguardian.com/australia-news/2020/apr/21/summers-bushfires-released-more-carbon-dioxide-than-australia-does-in-a-year

- Likewise, total carbon emissions from fires in the Amazon area in 2019 were equivalent to more than 80% of Brazil's 2018 GHG emissions.[40]

- **Deforestation is also a major cause of biodiversity loss.**
  - Some 80% of all terrestrial species of animals, plants, and insects live in the forests.
- **Biodiversity loss is damaging ability to combat pandemics.**
  - Deforestation has been linked to nearly one-third of outbreaks including Ebola, and the Zika and Nipah viruses.
  - Deforestation drives wild animals out of their natural habitats and closer to human populations, increasing the likelihood of spread of' zoonotic' diseases – from animals to humans.
  - More broadly, climate change is altering and accelerating the transmission patterns of infectious diseases including Zika, malaria, and dengue fever, and causing human displacement.
  - Movements of large groups to new locations, often under poor conditions, increase displaced populations' vulnerability to biological threats such as measles, malaria, diarrheal diseases, and acute respiratory infections.
- **Data gaps and inconsistencies are vast**
  - Countries collectively reported net land-use emissions of the order of 0.25 Gt carbon annually.
  - However the latest IPCC report estimates net emissions (mostly due to deforestation) over the period 2000 to 2009 at around 1 Gt of carbon per year – more than 4x higher.

Forests and climate mitigation

- The importance of forests in Earth's ecosystem, and in mitigating climate change, indicates that **the utmost should be done to stop deforestation and forest degradation.**
  - This would have the single most important impact on climate change via forestry-related activities.
- **Other forest-related climate change mitigation options include:**
  - Promoting sustainable forest management.
  - Increasing the area of forests through reforestation, afforestation, and forest landscape restoration. There are a number of initiatives:
    - The UNSPF Global Forest Goals and Sustainable Development Goals (SDGs) call for a 3% increase in forest cover globally.
    - More recently, the World Economic Forum launched a global initiative to grow, restore, and conserve 1 trillion trees around the world.[41]
    - The UK, for example, has also pledged to plant 30m trees per year.[42]
    - Progress towards these pledges, however, has been slow globally. The planting rate in England, for example, would need to increase tenfold to hit the government's target.[43]
  - Promoting the expansion of natural forests instead of planting monoculture tree plantations.
  - Increasing the value of forests through expanding markets for wood products.
- With approximately half of deforestation occurring for agricultural expansion – of which livestock (mainly cattle) pasture accounts for about half – **there is a need for appropriate (financial) incentives and/or regulation** to discourage this behaviour.
  - In general, the returns earned from agricultural activities are currently greater than those obtained by leaving the forests intact or using them for timber production.
- **Reducing the reliance on wood as a source of energy.**
  - Biomass-based energy is still the largest source of renewable energy worldwide (although it is debatable if it truly is carbon-neutral).
  - Household uses of biomass account for nearly 60% of black carbon emissions globally.[44]
    - 'Black carbon', or soot, is a significant contributor to global warming because of its high absorption of solar radiation and its effects on cloud formation, regional circulation, and rainfall patterns.
    - The UK, for example, has banned the use of house coal or wet wood in wood burners from 2021.
- **Promoting deforestation-free supply chains.**
  - Illegal and unsustainable timber and goods are flooding global markets.
  - Stopping deforestation cannot and will not happen by voluntary action alone: however, pressure to 'do the right thing' could come via regulation, financing, or other measures.
  - In September 2019, asset managers and institutional investors representing $17.2 trillion in assets signed an open letter that called on companies to move faster on deforestation, threatening loss of access to markets.
    - Norway's $1 trillion sovereign wealth fund has divested from 33 firms because of deforestation risk arising from developing palm oil.
  - Action globally is however not yet on anything like a sufficient scale.
- **Carbon tax revenues could be used for conservation purposes.**
  - Colombia introduced a carbon tax of $5 per tonne on emitted carbon. Of the revenue raised, around 30% is allocated to various environmental causes.
- **Technology can help.**
  - The high spatial and temporal resolution of the latest Earth's satellite imagery opens up new possibilities in forest monitoring.[45]

Conclusions

- When implemented correctly, **trees are currently the most cost-effective and best technology for carbon removal and storage.**
  - Moreover, healthy forests provide a number of co-benefits, including improved air and water quality, wildlife habitat, and stabilisation of soils. They also provide opportunities for recreation, etc.
- **Not enough progress, however, is being made globally to stop deforestation.**
  - The New York Declaration on Forests (NYDF), signed in 2014, had ten ambitious goals, including halving deforestation by 2020, and stopping it by 2030.[46]
  - Global Forest Watch data however suggests that, since the NYDF was signed, annual global deforestation has increased by between 55% and 64%.[47]
- **The coronavirus pandemic may have further worsened the outlook for forestry.**
  - In the near term, forests may be affected by a lack of enforcement, resulting in more frequent illegal clearing and fires.
  - In the medium term, economic pressures and stimulus measures may result in greater forest loss, as countries attempt to stimulate their economies with extractive industries.[48]

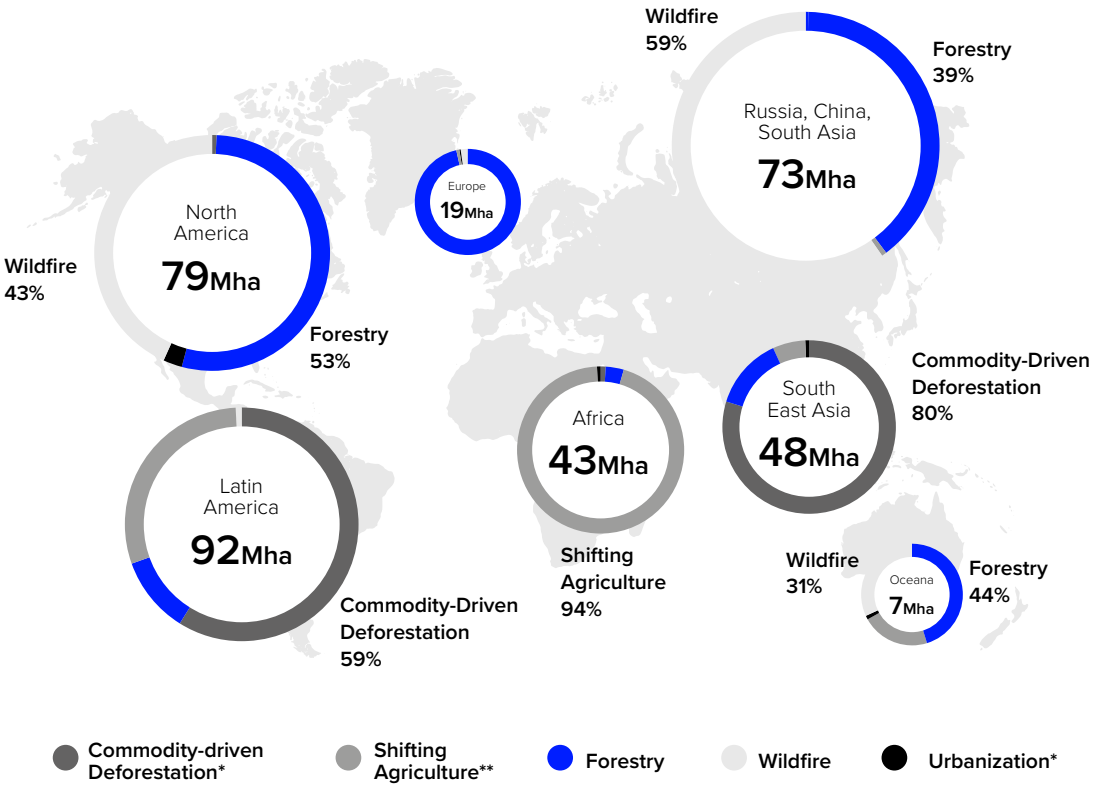
Useful sources

Global Forest Watch: https://www.globalforestwatch.org/

World Economic Forum: https://www.weforum.org/agenda/archive/forestry/

Carbon Brief: https://www.carbonbrief.org/category/science/nature/plants-forests

Appendix



*Permanent deforestation
**May or may not lead to permanent deforestation

Note: Numbers reported as of March 3,2020
Source: Global Forest Watch

[1] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/forest-cover

[2] https://www.un.org/esa/forests/wp-content/uploads/2019/03/UNFF14-BkgdStudy-SDG13-March2019.pdf

[3] Woods Hole Research Centre: http://whrc.org/

[4] https://www.weforum.org/agenda/2020/01/we-can-save-our-forests-collective-action/

[5] Sustainable forest management has been defined as: "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems." For more, see https://www.pefc.org/what-we-do/our-approach/what-is-sustainable-forest-management

[6] Ibid.

[7] https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/

[8] https://cdn.pefc.org/pefc.org/media/2020-10/8100ff13-f45a-48b5-82cb-ecf4afb89cf9/695986ad-4a75-5b1f-9461-f9dcdb780ef3.pdf

[9] What is Mass Timber Construction? - A&DS Materials Library. https://materials.ads.org.uk/what-is-mass-timber-construction/

[10] For more, see https://www.bbc.co.uk/bitesize/topics/znyycdm/articles/z2d2gdm

[11] https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/79985/TEM_oppaat_2_2017_Wood_based_Bioeconomy_Solving_Global_challange_29052017web.pdf?sequence=1

[12] https://www.mainewoodlandowners.org/articles/carbon-in-wood-products-translated-to-plain-english#:~:text=A%20cubic%20meter%20of%20wood%20is%20roughly%20equivalent,the%20Copenhagen%20Climate%-20Conference%20was%20held%20in%202009.

[13] The panels vary in size but can range upwards of 64 by 8 feet (19.5 by 2.4 m) and in the case of cross-laminated timber (CLT) can be of any thickness from a few inches to 16 inches or more. For more, see https://materials.ads.org.uk/what-is-mass-timber-construction/

[14] For more, see https://www.homebuilding.co.uk/advice/cross-laminated-timber

[15] https://edition.cnn.com/style/article/wooden-skyscraper-revolution-timber/index.html

[16] https://www.sciencedaily.com/releases/2019/04/190415144004.htm

[17] Ibid.

[18] https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/79985/TEM_oppaat_2_2017_Wood_based_Bioeconomy_Solving_Global_challange_29052017web.pdf?sequence=1

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[28] Lignin is a complex organic polymer deposited in the cell walls of many plants, making them rigid and woody. For more, see https://www.sciencedirect.com/topics/materials-science/lignin

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[33] https://blog.globalforestwatch.org/data-and-research/global-tree-cover-loss-data-2019/

[34] Philip G. Curtis et al (2018), 'Classifying drivers of global forest loss', available at: https://science.sciencemag.org/content/361/6407/1108.full

[35] Shifting cultivation is an agricultural system in which plots of land are cultivated temporarily, then abandoned and allowed to revert to their natural vegetation while the cultivator moves on to another plot.

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